Manufacturing Issues in Bipolar Plate Production

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Manufacturing Issues in Bipolar Plate Production

Plate material/forming process interaction
Operational effects of dimensional variation

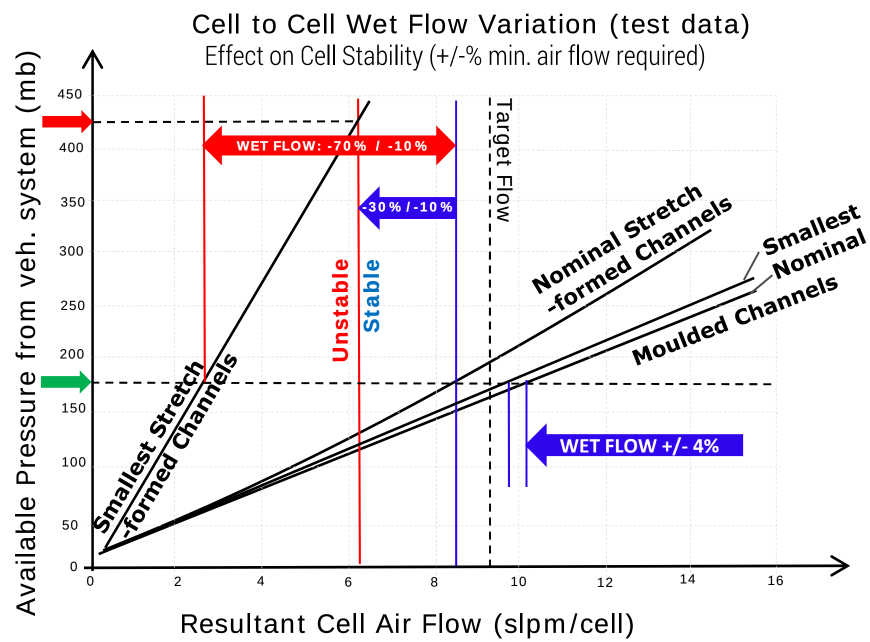
Stretch-formed flowfields (elastic and plastic forming)

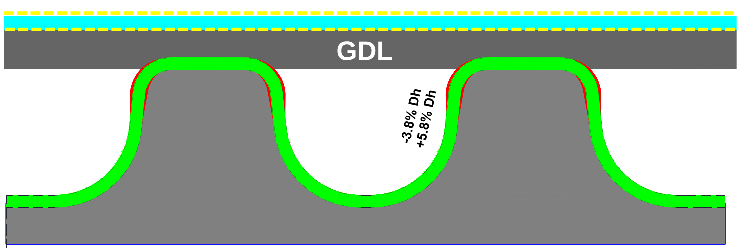
- Target flowfield geometries (based on loss optimization) are not achievable
- Manufacturable parts are at the sensitivity limit under dry conditions
- Unstable under wet flow conditions (requires increased P and dP)
- Alternative flowfield architectures are recommended to achieve feasibility

Moulded or Embossed flowfields (plastic forming only)

- Target geometries (based on loss optimization) are achievable
- Insensitive when dry and stable under and wet operating conditions
- Alternative flowfield architectures may enable process cost savings

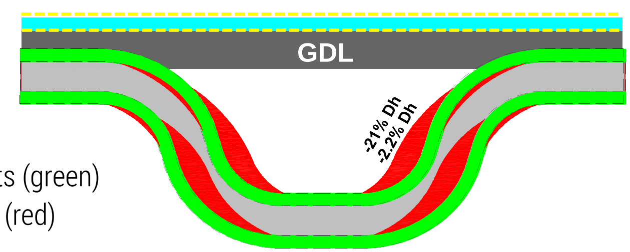
(eg. robust to cavity-cavity variations, input material property variations)





Moulded or embossed plate cross section

Tolerance specification limits (green)
Measured dimensional data (red)

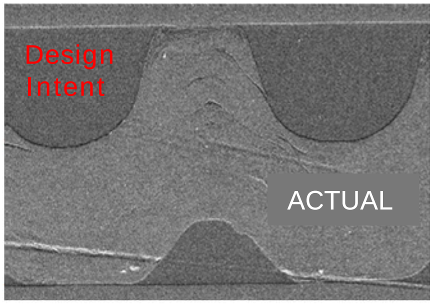


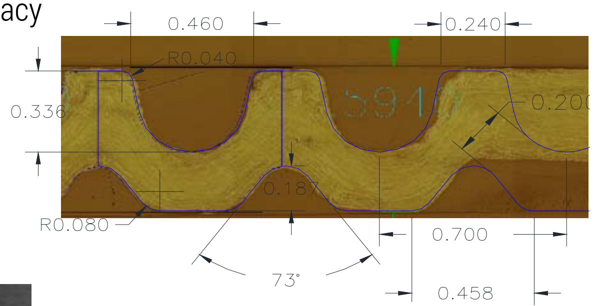
Stretch-formed plate cross section

Manufacturing Issues in Bipolar Plate Production

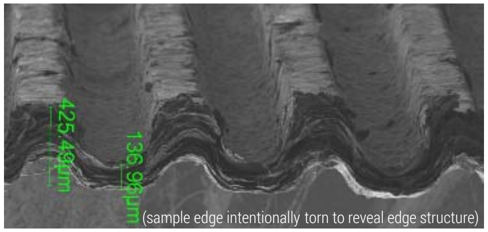
Expanded graphite / Resin composite bipolar plates

- Observed material and forming influences on part quality
  - Feature definition is sufficient to meet design requirements (radii, depth, draft, thickness).
  - Mechanical properties are sufficient, but refined material models are needed to optimise forming of the finished composite for specific applications.
  - Thermal conductivity is high (>300W/m.K) due to continuously conductive phase
  - Surface energy – requirement for low contact angle requires development of manufacturing and/or material/design solutions.
  - Further roller embossing process development is needed to achieve required precision, accuracy
  - Contact resistance is the largest component of electrical loss for all plate options. Post-processing has not been required to activate this material surface.
  - Roller embossing can achieve densities of >1.8g/cm^3 with low levels of elastic recovery
  - <5% resin is required also limiting shrinkage on cure to very low levels
  - Material savings and forming enhancements may be possible by addition of low cost fillers.





Reference cathode plate target and actual profiles.
+/- 15 µm profile tolerance target

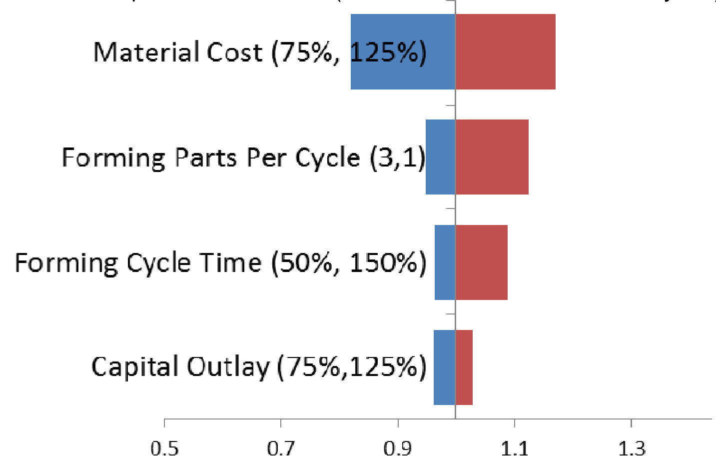


(sample edge intentionally torn to reveal edge structure)

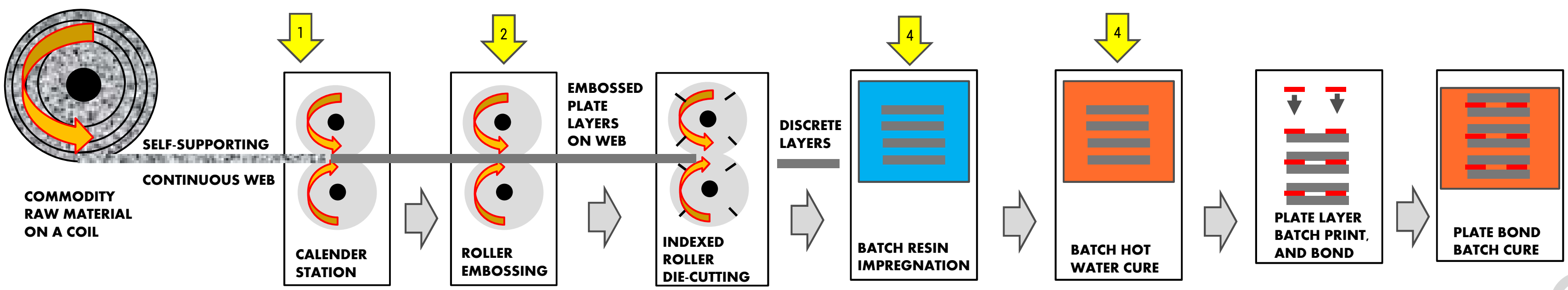
Expanded graphite / resin composite bipolar plates

- Manufacturing issues and influences on cost
  1. Material cost reduction possible by further refinement of roller embossing pre-processing steps.
  2. Sensitivity to parallel processing could be exploited by side-by-side multi-cavity tooling for further cost reduction.
  3. Low sensitivity to cycle time due to low capital, footprint requirements
  4. Continuous impregnation and cure processes to replace batch steps are identified as feasible, and require further development to be realised.
  5. Process steps are proven, however immature. Supply chain is incomplete. Development of pilot scale capabilities within supply base is required to realise low costs.

Piece part cost drivers (650 cm^2 BiP, 20k vehicles/year)



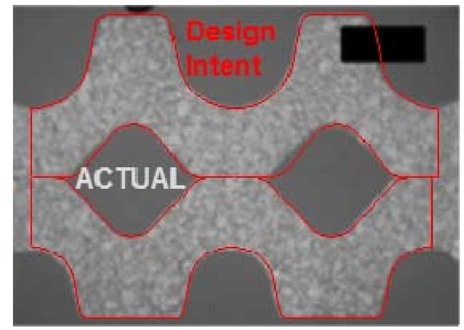
Cost multiplier, baseline process. 1.0x = €1.52 ($1.63) / BiP. assy. (AREC)

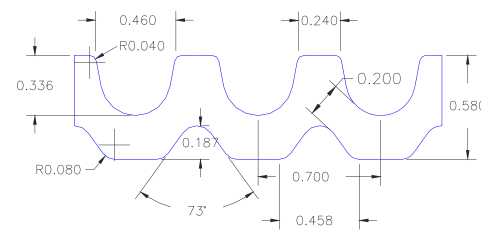


Manufacturing Issues in Bipolar Plate Production

Particulate graphite / resin composite bipolar plates

- Observed material and forming influences on part quality
  - Feature definition is sufficient to meet design requirements (radii, depth, draft, thickness).
  - Mechanical properties are sufficient, need to remain high in context of above improvements that may require reformulation.
  - Thermal conductivity is low for high current density application. Premixing resin and graphite disrupts the continuously conductive material phase. Improvement is needed, and may be possible by addition of highly conductive fillers for example.
  - Contact resistance is the largest component of electrical loss for all plate options. Low cost post-processing is now close to optimal by at least two methods.
  - Surface energy – requirement for low contact angle requires development of manufacturing and/or material/design solutions.
  - Resin cure speeds (press closed time) have improved and need continued development. Highly conductive fillers may facilitate cure time reduction.



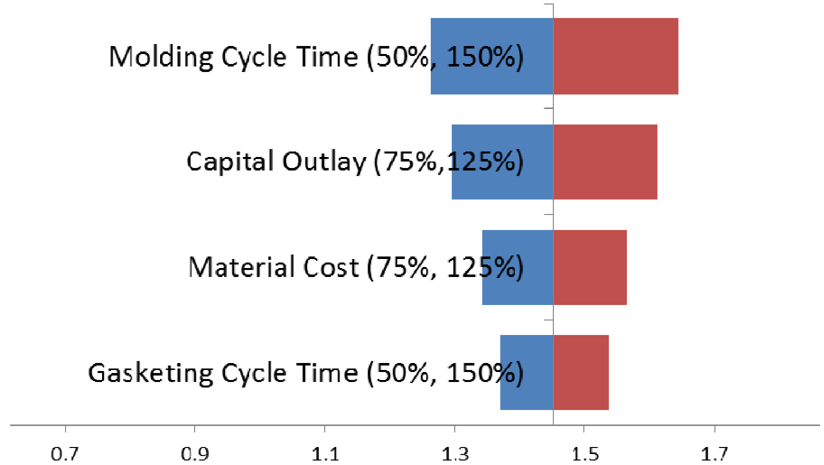


Reference Cathode Plate Target Profile +/- 15 μm profile tolerance target

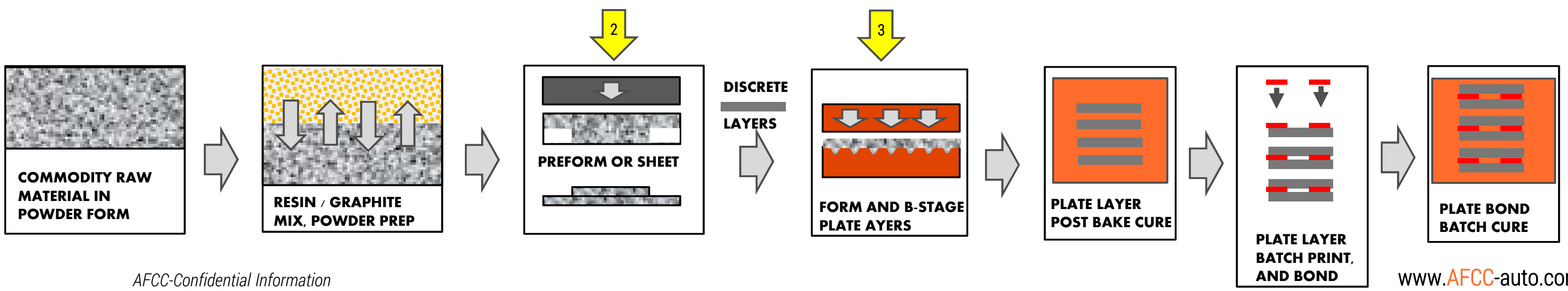
Particulate graphite / Resin Composite Bipolar Plates

- Manufacturing issues and influences on cost
  1. Very high sensitivity to cycle time due to high capital requirements *(Piece cost reduction does not scale with process volume)*
  2. Pre-impregnation and pre-forming processes require development or elimination
  3. Cure-in-press process imposes a fundamental cycle time limitation
  4. Supply chain is healthy, supplier choice exists, quality/cost trade offs can be made

Piece part cost drivers (650 cm² BiP, 20k vehicles/year)



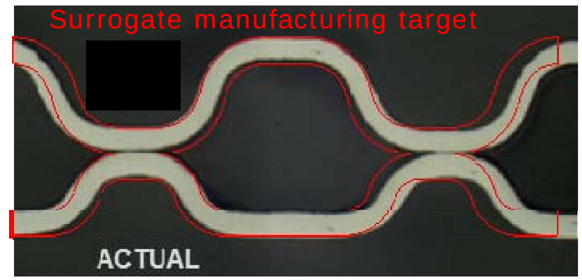
Cost multiplier, ref. baseline process. 1.45x = €2.21 ($2.36)) / BiP. assy. (AREC)

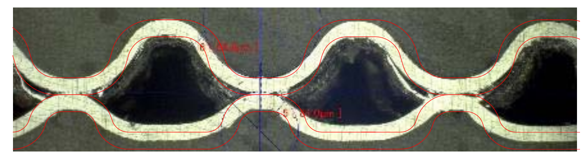


Manufacturing Issues in Bipolar Plate Production

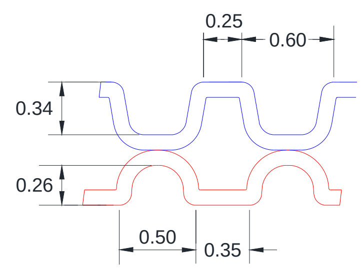
Stainless Steel Foil, Stretch Formed, Coated bipolar plate process

- Observed material and forming influences on part quality
  - Geometry targets based on optimized in-situ performance loss breakdown analysis cannot be met. Root causes of large corner radii, wider channels, wider landings are due to substrate properties and forming limitations.
  - Thermal conductivity is low (16 W/m.K), presenting a risk for high current density applications. Insulative substrate material limits part performance at high heat fluxes and at extremes of operation when conductive web cross sections are small.
  - Contact interface resistance is the largest component of electrical loss for all plate options. Contact resistance with GDL is low, competitive, and dependent on coating type.
  - Surface energy – requirement for low contact angle requires coating surface engineering solutions. Trade-offs with contact interface performance is anticipated.
  - Low overall thickness and material side feature dependency present significant fluid handling challenges for the cell designer, particularly at high current densities. Thicker plates would enable increased volumetric power density because they can be translated into plan area efficiency gains.
  - Very low coating costs are required to enable this technology.





Stretch-formed bipolar plate dimensional conformance. Examples taken from full sized bipolar plate samples.

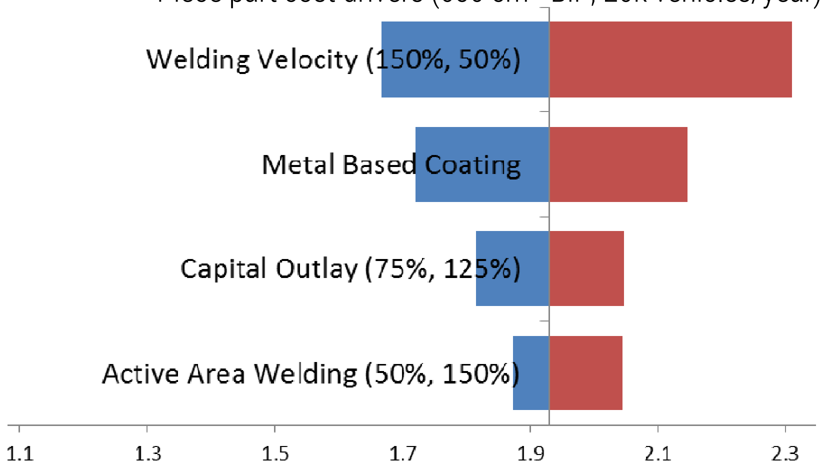


Reference Design intent
Target Profile
+/- 15 µm profile tolerance

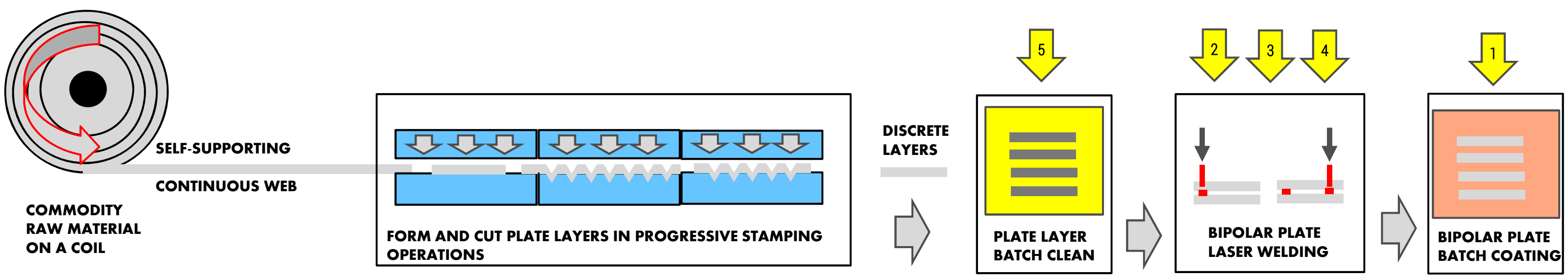
Stainless Steel Foil, Stretch Formed, Coated Bipolar Plates

- Manufacturing issues and influences on cost
  1. Highest risk is coating cost, neglected in this calculation due to lack of options. More development required.
  2. Baseline welding speed is second highest risk after coating cost.
  3. Laser welding is not demonstrated at high throughput in similarly complex parts. Significant design trade-offs exist between welding and part performance.
  4. Integration design trade-offs and challenges to reduce welding length are significant, neglected here.
  5. Cleaning process cost is dependent on capability of upstream and downstream steps, however low impact on cost

Piece part cost drivers (650 cm^2 BiP, 20k vehicles/year)



Cost multiplier, ref. baseline process. 1.95x = €2.96 ($3.17) / BiP. assy. (AREC)



Manufacturing Issues in Bipolar Plate Production

Summary of Remaining Development Gaps

- Stretch formed, metallic foils – recommendations:
  - Substrate materials that can be consistently formed to target profiles based on stack performance and operational stability
  - Durable substrate or very low cost coating to enable this technology path.
  - Alternative flowfield design to reduce electrical losses (wide channels, landings) and improve stability (dimensional conformance)
  - Demonstration of low cost, high speed welding or development of an alternative joining method
  - Material property improvements and/or increased flow domain thickness to tackle thermal distribution issues
  - Increased thickness to maintain reasonable flow domain depths for low flow resistances, with respect to system efficiency
  - Lower contact angle surfaces for wet-flow stability (may be relieved by alternative flowfields depending on concept)

- Compression moulded, particulate graphite composites - recommendations:
  - Improved material thermal conductivity (for cure time and operational benefits)
  - Press cycle time improvements (may come from above)

- Roller embossed, expanded graphite composites – recommendations:
  - Technology transfer from material and process developers to plate manufacturers
  - Process development to integrate impregnation and curing developments into a fully continuous process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