Fuel Cell Bipolar Plate Technology Development for Heavy Duty Applications

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General Motors, LLC

DOE project award # DE-EE0009616

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DOE Hydrogen Program

2022 Annual Merit Review and Peer Evaluation Meeting

AMR Project ID: FC348

Project Goal

- Develop a bipolar plate (BPP) manufacturing solution to achieve DOE 2030 BPP cost, performance, and durability targets for heavy duty applications through fundamental investigation in Budget Period 1 (by improving low cost ferritic stainless steel formability, high speed laser welding quality and conductive coating durability).
- Demonstrate the developed technology in Budget Period 1-through technology integration of small size plate manufacturing and stack testing in Budget Period 2.

Overview

TimeLine

- Project Start Date: 01/01/2022
- Project End Date: 03/31/2025
- Duration: 39 months

Budget

- Total Project Budget: $ 2,772,042
- Federal Share: $ 1,998,642
- Participant Share (27.9%): $ 773,400
- Total DOE Funds Spent*: $0

*nothing billed to DOE as of 03/31/2022

Partners

- General Motors, LLC (Project Lead)
- Penn State University (PSU)
- Northern Illinois University (NIU)

Relevance

The project objective is to develop a Bipolar Plate (BPP) manufacturing technology to meet DOE 2030 BPP cost, performance, and durability target for heavy duty applications

Plate Characteristics	Units	2030 DOE Targets	2030 Project Targets
Cost	$/kWnet	5	4.5
Durability	hrs	25000	25000
Plate Weight	kg/kWnet	<0.18	0.18
Plate H2 Permeation Coefficient	std $cm^3/(sec\ cm^2\ Pa)$ @80°C, 3 atm, 10% RH	<2x10-6	<2x10-6
Corrosion Anode	$\mu A/cm^2$	<1 and no active peak	<1 and no active peak
Corrosion Cathode	$\mu A/cm^2$	<1	0.05
Electrical Conductivity	S/cm	>100	>100
Area Specific Resistance	ohm cm^2	<0.01	<0.01
Flexural Strength	Mpa	>400	>400
Forming Elongation	%	40	>40

Approach

Fundamental Technology Development

- ➢ Develop stamping technology to achieve formability >40% equivalent elongation (EE) for low cost ferritic stainless steel
  - – Explore multistage, thermal and high strain rate forming effect for formability enhancement
- ➢ Develop low cost post-stamping coating technologies to meet 25000 hours durability and high conductivity
  - – Deposition chemistry and process development and optimization
- ➢ Develop high speed BPP laser welding technology to meet 100,000 units/year through-put with less than 2% scrap rate
  - – Investigation of defect formation mechanisms and develop defect prevention and minimization technologies

Technology Integration

- ➢ Integrate fundamental development results into design, manufacturing, and testing process of a small BPP (50cm^2 active area) to demonstrate the feasibility and scalability to achieve 2030 BPP DOE target.

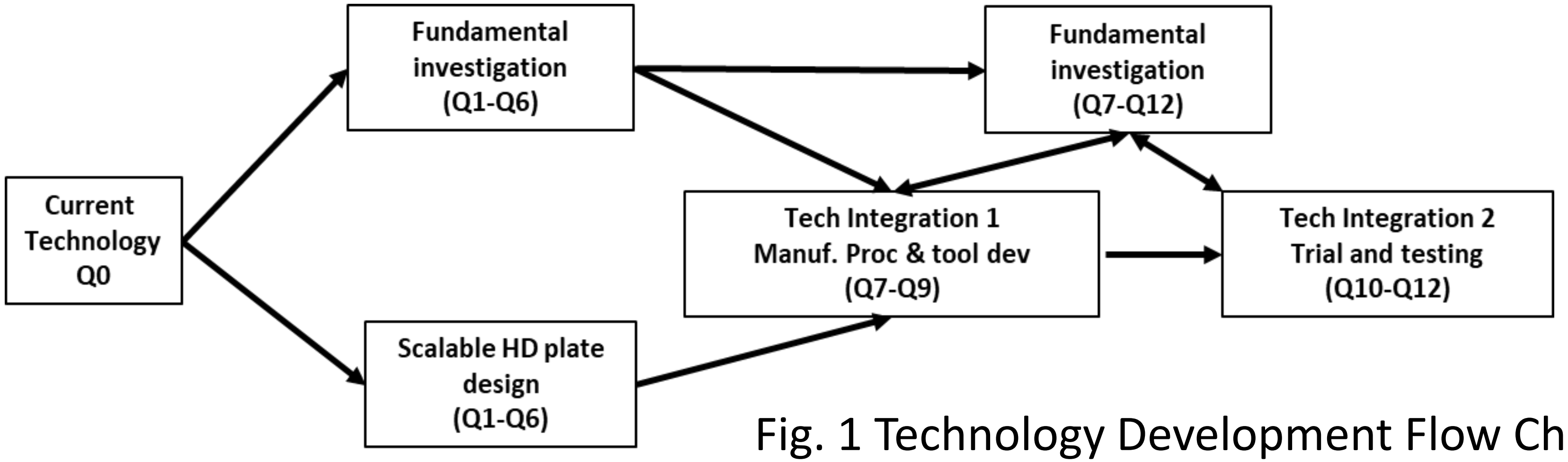


Fig. 1 Technology Development Flow Chart

Approach (Continued)

Budget period one milestones and Go/No Go Criteria (BP1)					
Quarter /Month	**Task Number**	**Task or Subtask**	**Milestone Type**	**Milestone Number**	**Milestone Description & Verification***
Q1/M3	1.1	Material (matl) formability (fm) characterization (chara)	Technical	M1.1	Demo matl preparation (NIU/GM)
Q2/M6	3.1	Evaluate high speed welding defects	Technical	M3.1	Identify weld defects and root causes (PSU)
Q3/M9	3.2	Modeling defect formation mechanism	Technical	M3.2	Establish capability for defect simulation (PSU)
Q4/M12	1.1	Matl fm chara	Technical	M1.1	Matl failure strain vs tool radii (NIU/GM)
Q5/M15	2.1, 2.3	PVD, ALD coating process dev	Technical	M2.1,2.3	Optimized CR, ICR, EC data (GM)
Q6/M18	1.2	HD channel fm enhancement	Technical	M1.2	Demo RT /HT fm improvement (NIU/GM)
Q6/M18	4.1	HD test plate dev &design	Technical	M4.1	Complete HD test plate design (GM)
Q6/M18	**Budget Period 1**	Key BPP technology fundamental development for DOE 2030 target	Go/No-Go Decision Point	MA1	FSS coupon stamping EE >33%; flat coated sheet ICR<0.014 ohm.cm^2, EC>100S/cm^2, CR< 1 uA/cm^2, iron elution (pH3, 70hr, 80C, 0V) <0.40 ug/cm^2

Accomplishments and Progress

- This is a new award with a start date of 1/1/2022 and project is just ramping up.
- Progress
  - Developed ferritic stainless-steel (FSS) required specifications (elongation, strength, max C-contents, surface quality and inclusions) for the project with supplier
  - Down-selected candidate FSS grades. The quoting process is complete. PO for FSS is ready to go
  - Coating team is negotiating with suppliers for coating development plan
  - PSU is designing weld test fixture and updating CFD UMAT for laser weld simulations
  - NIU is fine-tuning test procedures and design tool for thin sheet characterization and formability test
  - The team has started conversations with national labs to seek for potential support opportunities from them

Collaborations

Partners	**Project roles**
General Motors, LLC (Primary recipient) Siguang Xu	▪ Project Lead. Project management and coordination ▪ Low-cost stainless steel stamping technology - Material sections and stamping coupon tests ▪ Coating development ▪ Technology Integrations
Penn State University (Sub-recipient) Prof. Jingjing Li	▪ High throughput faster laser welding technology development - Mechanism of high speed BPP laser welding defect formations - Numerical simulation and experimental test - Technology development for high-speed welding defect reduction - Laser welding in-situ x-ray imaging
Northern Illinois University (Sub-recipient) Prof. Jenn Terng Gau	▪ Low-cost stainless steel stamping technology - Thin material tensile properties characterizations - Thin material formability tests at different temperature, strain rate and forming sequences

Remaining Challenges and Barriers

Project timing

- Slight delays with subrecipient agreements will impact the start date of sub-recipient research work, although all sub-recipients have started their preliminary work within their limits.
- Stainless steel coil ordering has lead time of 12-16 weeks. The team is working with supplier to speed up the delivery time and will start testing with existing available materials for baseline data, equipment and fixture preparation.
- Budget Period 1 (BP1) deliverables may be delayed by three months. GM will closely monitor progress and work with DOE if no-cost extension is required.

Budget

- The unforeseen inflation will impact the cost for materials, tooling and services. The planned BP1 tests for coating and formability may have to be scaled back based on available budget (no changes to total budget).

Proposed Future Work

- **Remainder of FY2022**
  - Secure candidate FSS material coils for testing
  - Conduct low and high strain rate tensile tests
  - Conduct single channel draw depth and failure strains measurement
  - Multis-stage stamping numerical simulation
  - PVD and ALD coating interlayer thickness and material selection tests on flat sheets
  - Weld fixture design and fabrications and testing of weld parameter effect on defects
  - Establish numerical capability for weld effect analysis
- **FY2023**
  - Test effect of strain rate, temperature and forming sequence effect on formability
  - Verify numerical formability optimization results by multi-channel coupon tests
  - PVD and ALD interlayer and top layer coating optimization on flat sheets and channel coupons
  - Identify weld defect formation mechanism through simulation and tests
  - Complete integration plate design

Summary

- This is a new project with start date of 1/1/2022 and project is just ramping up. GM recently received the required agreement modification from DOE to finalize its agreement.
- Project technical kick-offs have been completed with sub-recipients. Discussions with potential suppliers have also been kicked off.
- Primary candidate FSS materials have been down selected for testing.
- Negotiation with suppliers for coating development is in progress. Test preparations at sub-recipients are under way.
- So far the project is 3 months behind schedule. The team will try to recover once the subrecipient agreements are complete.
- Due to the project late start and significant cost increase for material and services, some tests will be scaled back from original plan.

Technical Backup and Additional Information

Technology Transfer Activities

No activity to report

Welding Test Fixture Setup

- Machine: Laser Engineering Net Shape (LENS) in Direct Energy Deposition (DED)
- Use a rotating stage to create various high speed of laser welding. The goal of the welding speed is to achieve between 20 to 90 m/min.

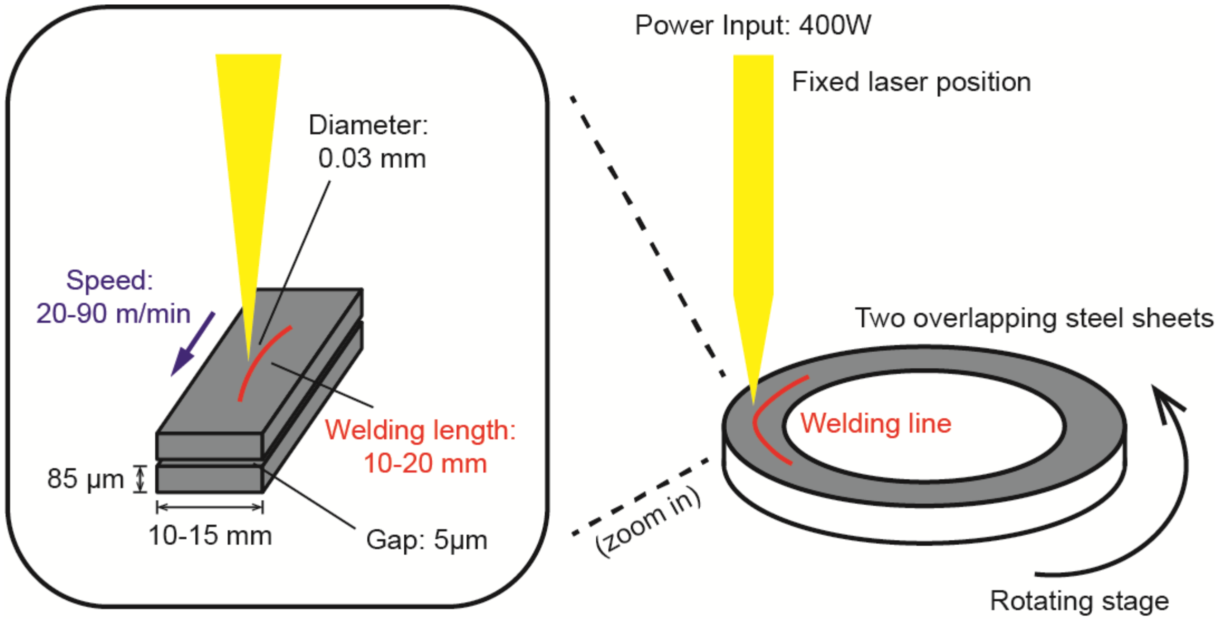


Fig. 2 Welding Test Fixture with Rotating Stage

Laser Weld Simulation Setup

- Simulation method: computational fluid dynamics
- Software: Flow-3D
- Input power: 400W (an initial value)
- Outer area:
  - Represents the steel plates
  - Size of cell: 0.0025 cm, Mesh blocks: 89600
  - Boundary condition: P for top surface, and W for the other surfaces
- Inner area:
  - Represents the laser welding path
  - Size of cell: 0.0005 cm, Mesh blocks: 2400000
  - Boundary condition: S for side surfaces, P for top surface, and W for bottom surface

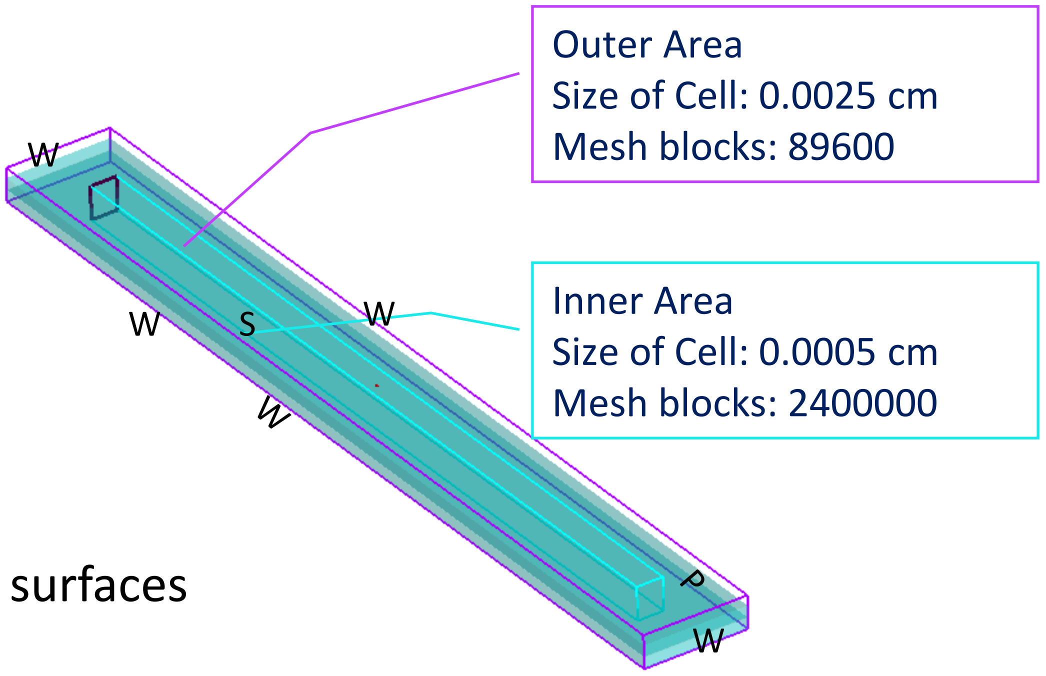
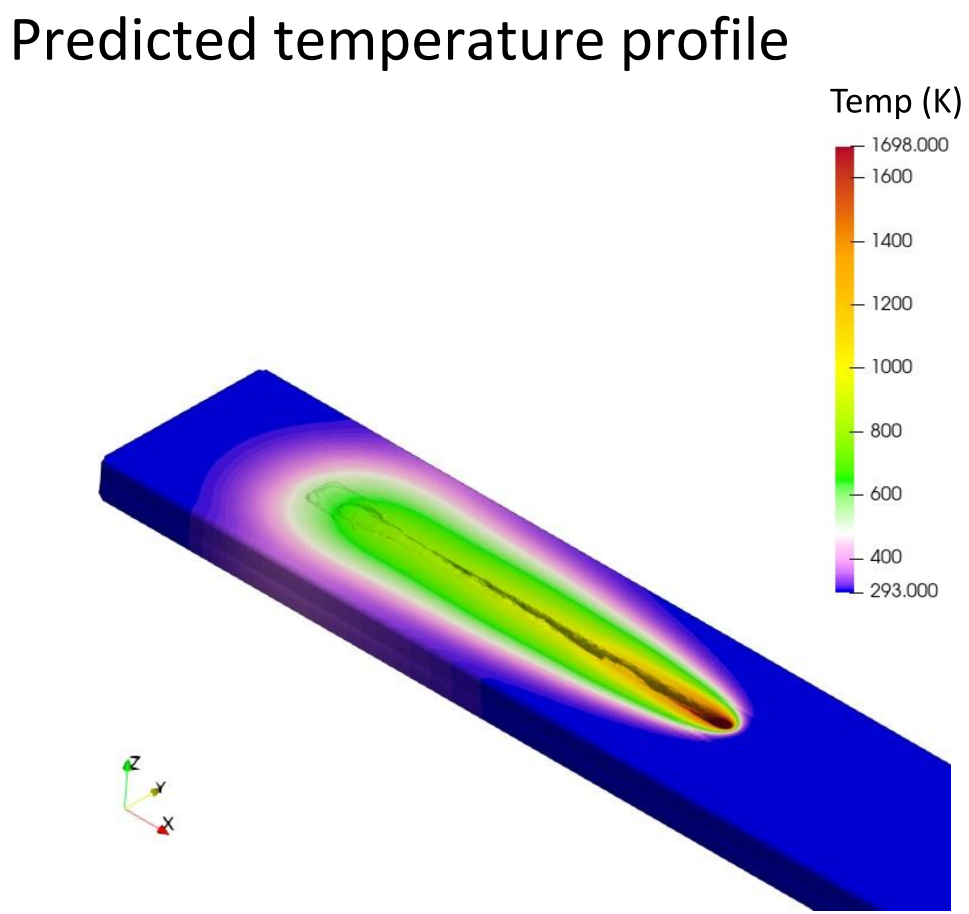


Fig. 3 Laser Welding Simulation Process Setup

Boundary condition:
- Symmetry (S): All fluxes into the boundary are zero, and there is no friction
- Wall (W): It was defined for walls and channel bed which act as virtual frictionless walls
- Pressure (P): Regular type of pressure boundary. Fluid can enter or leave the domain.

Preliminary Simulation Results



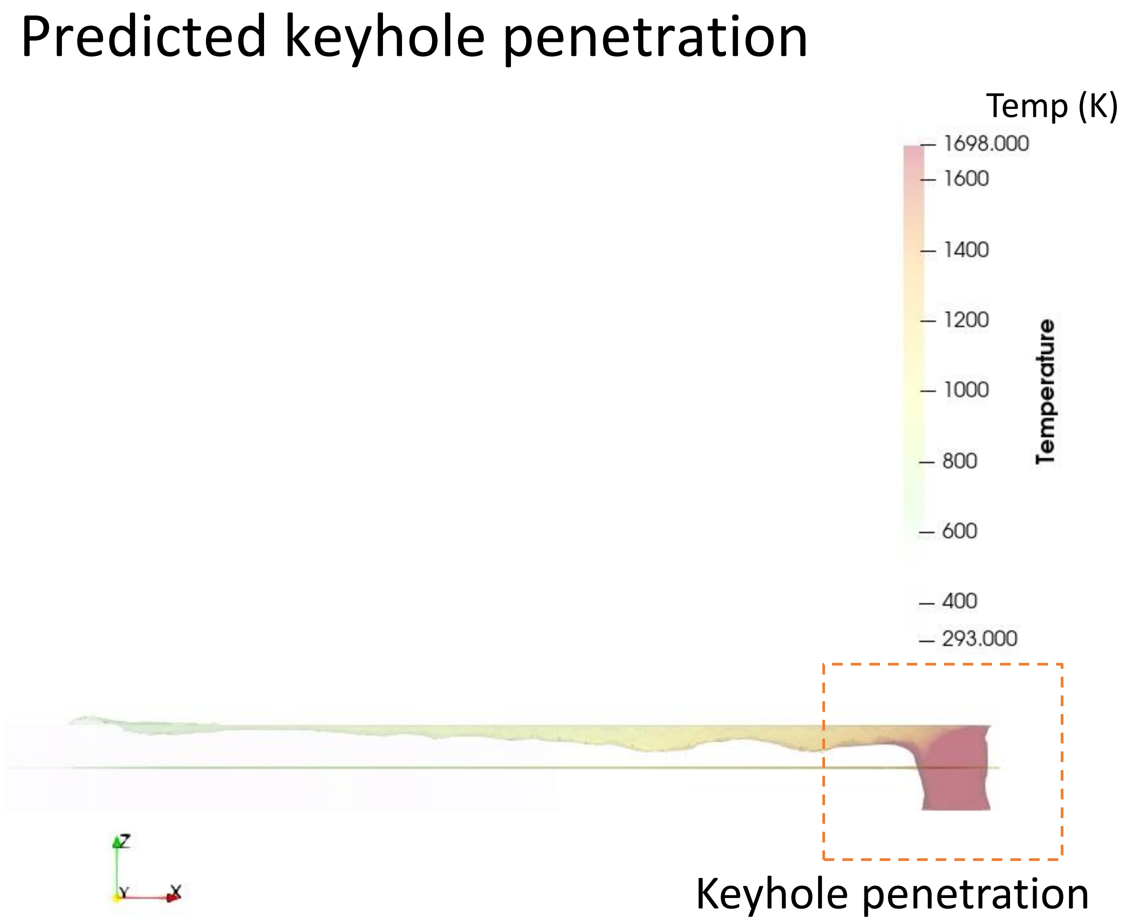


Fig. 4 Preliminary Simulation Results based on Setup in Fig.3

Background info for the project

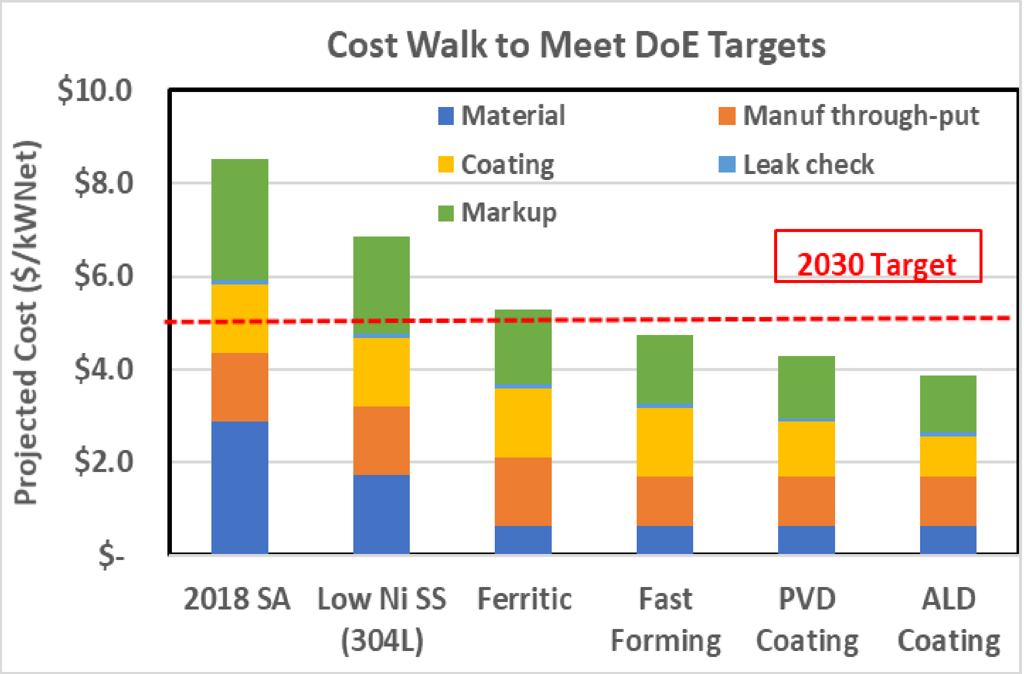


Fig. 5 BPP cost walk chart (Ref: Strategic Analysis cost model 2018)

Metric	Value	Units.
AA size	270.00	cm^2
AA Utilization	60.00%	
Thickness	85.00	micron
Areal Wt.	0.07	g/cm^2
Cell Voltage	0.60	V
Current Density	2.50	A/cm^2 gross
Power Density	1.50	W/cm^2 gross
	1.20	W/cm^2 Net
Power / Cell	324.00	W
Plate Weight	59.67	g
Metric	0.18	kg/ kW

Table 1 Feasible path to achieve BPP mass target

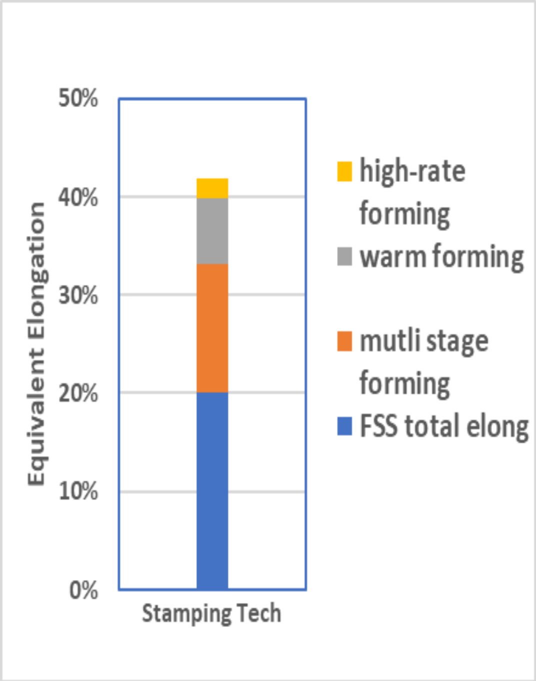


Fig. 6 BPP formability path