Manufacturing Fuel Cell Manhattan Project

Low Temperature PEM Fuel Cell Manufacturing Needs

Presented by
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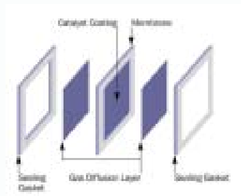
Manufacturing Fuel Cell Project – Phase 1

- **Cost drivers were identified for the following:**
  - **MEA**



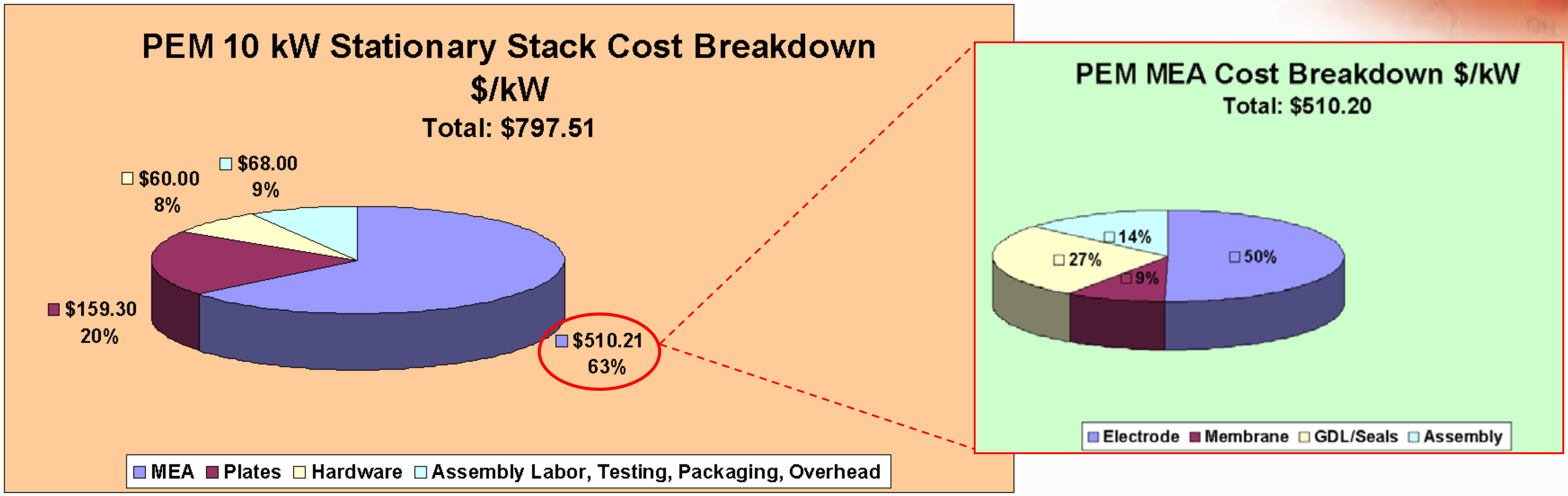
  - **Plates**

  - **Balance of Plant (BOP)**
  - **Fuel Processing**

Note that this presentation will be MEA centric as this is the working group I represent…

Identifying MEA Cost Drivers

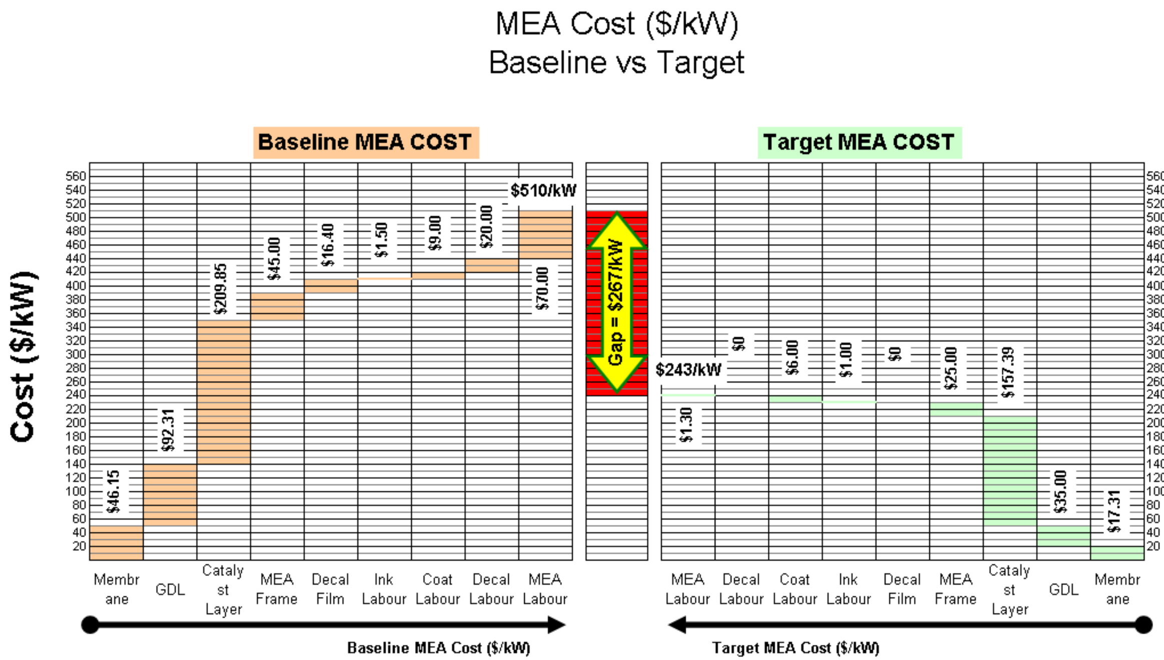
➢ MEA Cost Drivers Identified:



- The MEA was readily identified as the major cost driver in a 10 kW stationary stack.
- The precious metal catalyst electrode is the major cost driver for the MEA.

Thus, focus cost reduction efforts on MEA manufacturing methods.

Identify gaps in MEA manufacturing technology: How much better can we do?



	Material Cost	Yield	Total Cost	Cost Gap	Total Cost	Yield	Material Cost	
Membrane	$27.69	60%	$46.15	$28.84	$17.31	80%	$13.85	Membrane
GDL	$55.39	60%	$92.31	$57.31	$35.00	80%	$28.00	GDL
Catalyst Layer	$125.91	60%	$209.85	$52.46	$157.39	80%	$125.91	Catalyst Layer
MEA Frame	$45.00	100%	$45.00	$20.00	$25.00	100%	$25.00	MEA Frame
Decal Transfer Film	$12.30	75%	$16.40	$16.40	$0.00		$0.00	Decal Transfer Film
Ink Mixing Labour			$1.50	$0.50	$1.00			Ink Mixing Labour
Coating Labour			$9.00	$3.00	$6.00			Coating Labour
Decal Transfer Labour			$20.00	$20.00	$0.00			Decal Transfer Labour
MEA Assembly Labour			$70.00	$68.70	$1.30			MEA Assembly Labour
		Total:	$510.21	$267.21	$243.00	Total		

Note: Cost reductions realized from both material price reduction and manufacturing yield improvements.

Identifying Plate Cost Drivers

Key Manufacturing Needs Identified for Bi-Polar Plates

- Development of alternative graphite resins for LTPEM to facilitate easier molding;
- Improved understanding, testing and evaluation of critical design parameters;
- Development of low cost metallic plates using more conventional manufacturing processes that would lower cost;
- For HTPEM it is critical to reduce multiple heat treatments for cost reduction
- For HTPEM find a method to employ air cooling process to replace high water pressure /steam mixture

Identifying BOP Cost Drivers

Key Cost Drivers BOP

- Manufacturing of low-cost, high-efficiency heat exchangers
- Liquid metering pumps for sub kilowatt reformed based FC generators
- Best practices for manufacturing anode gas movement devices
- Manufacturing improvements for fuel cell humidification systems
- Specification analysis for fuel cell power systems
- Liquid flow meter for sub-kilowatt reformer based FC generators

Manufacturing Fuel Cell Project – Phase 2

Objectives Phase 2 – March 2011

Manufacturing Roadmap

- Projects to resolve the gaps
- Schedule a strategy for effective investment
  - Sequence Projects
  - Prioritize Projects
  - Projects that can benefit all
- Manufacturing Fuel Cell Publication: Oct. 2011

Manufacturing Fuel Cell Project – Phase 2

- **Assumptions for project selections:**

  - **Cost savings based on 5000 units per year**
  - **Each unit standardized at 10 kW**
  - **Cost savings realised in 3 years or less**
  - **No "early R&D" or unproven technology**
  - **Cost savings standardized in $/kW**

Addressing Gaps: MEA Projects

- **Manufacturing cost trade-off analysis**
- **Reduce Pt loading to 0.15 g/m^2**
- **Develop patch coating**
- **Direct coated layers on membranes**
- **Develop paper GDL for HTPEM**
- **Develop continuous mixing process**
- **Improve ink mixing process**
- **Direct coating catalyst layers on GDL**
- **Process development for migration from discrete to continuous**
- **Develop X-Y gradients from H_2-rich inlets to H_2-depleted outlets**

Details of each on the following slides …

Addressing Gaps: MEA Projects

➢ Manufacturing cost trade-off analysis

- Using physics and designed experiments, develop transfer functions relating critical product, raw material and process parameters to process and product performance;
- Determine critical product parameters and assign validated measurable tolerances;
- Develop the necessary measurement tools;
- Develop non-contact, non-destructive, in-process inspection and characterization techniques;
- Facilitate company-to-company information and knowledge exchange to reduce development times;

Manufacturing operates by delivering on requirements. By measuring and controlling the correct requirements (i.e. those validated to performance) with the widest possible design tolerances, improved yields and lower material costs can be realized.

Addressing Gaps: MEA Projects

➢ Reduce Pt loading to 0.15 g/m^2

- Platinum cost is the current principal cost driver for MEA that cannot be reduced with volume because platinum spot pricing is uncontrollable and generally high and increasing.

- This project will develop a robust manufacturing process that produces anode and cathode electrodes with a Pt total loading $\leq$ 0.15 mg/cm^2.

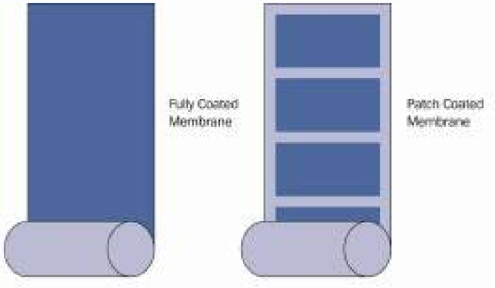
- The electrodes will be created with commercially available materials using a robust process and high volume commercially available manufacturing equipment.

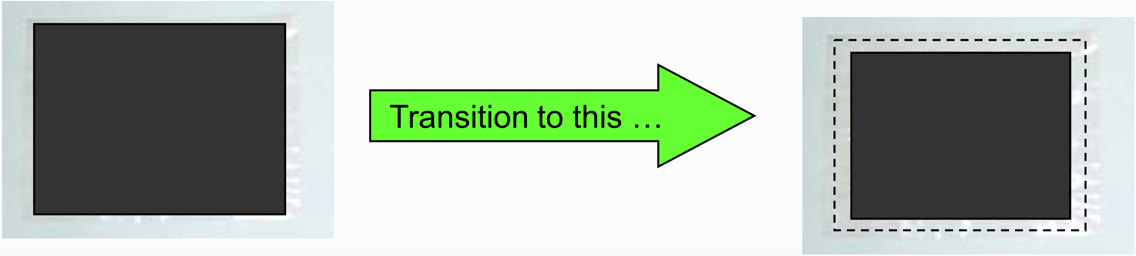
- Quality assurance measuring equipment will also be developed.

Addressing Gaps: MEA Projects

➢ Develop patch coating

- Develop robust methods of continuously coating segments or patterns on a moving web as a means of increasing precious metal utilization for designs using framed MEAs





Addressing Gaps: MEA Projects

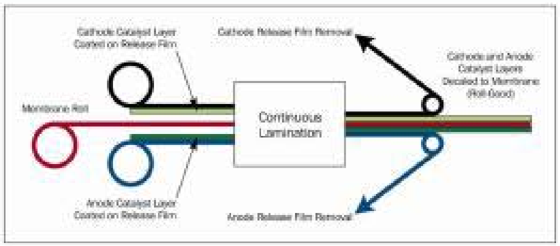
➢ Develop direct coated layers on membranes

- Direct coating is an enabling manufacturing technique delivering the following benefits and cost reductions:
  - Reduced labor;
  - Reduced yield loss potential;
  - Reduced capital cost during scale-up;
  - Reduced residence time of precious metal catalyst in the plant;
  - Increased precious metal catalyst utilization and membrane utilization (decal transfer processes necessitate coating wider catalyst layers to address alignment tolerance stack up and membrane shrinkage issues at lamination);
  - Elimination of release film costs (which may not be a trivial consumable cost);
  - For ultra-low precious metal loadings, all the precious metal is coated onto the membrane (decal transfer processes can leave residues on the release film which, at ultra-low loadings, can become significant);
  - Elimination of web handling issues inherent in handling webs that are close to their reflow temperatures;

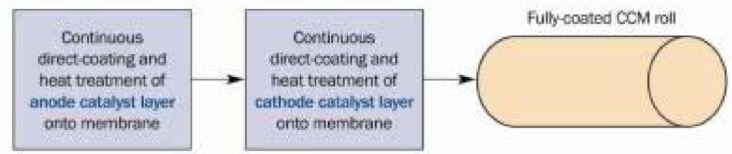
Addressing Gaps: MEA Projects

- **Develop direct coated layers on membranes**

Migrate from decal transfer methods ….. To ….. Direct coating methods



Transition to this …



Addressing Gaps: MEA Projects

➢ Develop paper GDL for HTPEM

- In the case of GDEs made for the high-temperature PEM, the GDL has historically been a carbon fabric. If a paper design could be used instead of the fabric there would be a cost savings.
- A significant effort would be required to develop a paper design that would meet the requirements of this type of system.

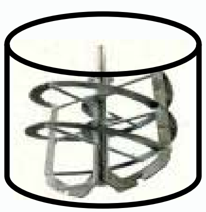
Addressing Gaps: MEA Projects

➢ Develop continuous mixing processes

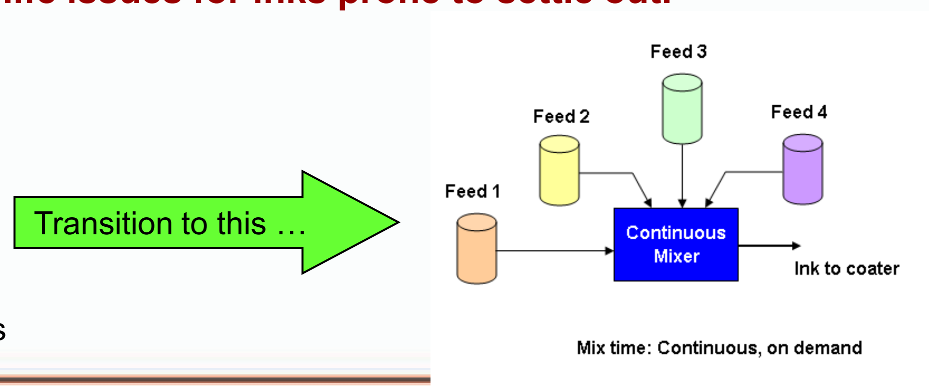
- Migrate from batch mixing to continuous mixing;
- Develop in-line measurement methods for ink rheology.

Benefits:

- Reduced mix times and labor;
- Reduced skin losses = improved Pt utilization;
- Simplified material handling;
- Elimination of shelf life issues for inks prone to settle out.



Mix time = 4 to 6 hours



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Addressing Gaps: MEA Projects

➢ Improve ink mixing process

- For batch mixing processes, minimize skin losses in mixing vessels by maximizing batch sizes and using batch-overs;
- For batch mixing processes, blend batches to present a single rheology to the coating process;
- To minimize skin losses, minimize hopper volumes at coating, or eliminate hoppers altogether by continuous mixing and direct dispensing into coating dies;
- Minimize line lengths and line diameters;
- Maximize ink batch sizes to enable maximum length of coating campaigns.

Addressing Gaps: MEA Projects

➢ Direct coating Catalyst layers on GDL

- **For manufacturers that produce GDE's (i.e. coated catalyst layers on GDL's), there is a need to improve both the surface roughness of the GDL and the coating techniques used to apply catalyst.**

Addressing Gaps: MEA Projects

➢ Development of continuous processing

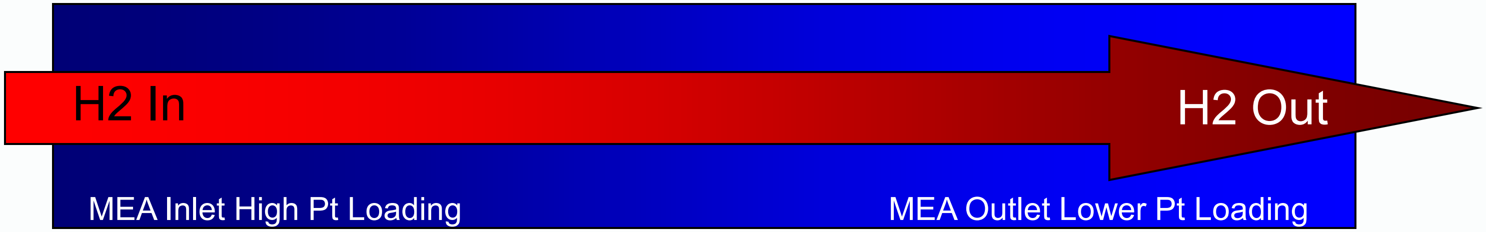
- For manufacturers using discrete methods of MEA manufacture, there is a need to develop continuous roll-to-roll methods.
- Development of in-line, real time quality control methods are needed.

Benefits:

- Improved productivity;
- Improved material yields due to reduced handling;
- Improved raw material utilisation;

Addressing Gaps: MEA Projects

➢ **Develop X-Y gradients from H2-rich inlets to H2-depleted outlets**



- Opportunities may exist to reduce overall Platinum loading by coating the MEA with a Platinum loading gradient: higher at the inlet and lower at the outlet.
- Producing MEA's with such Platinum loading gradients is not trivial and would need development effort.

Addressing Gaps: BOP Projects

- Manufacturing of low-cost, high-efficiency heat exchangers
- Liquid metering pumps for sub kilowatt reformed based FC generators
- Best practices for manufacturing anode gas movement devices
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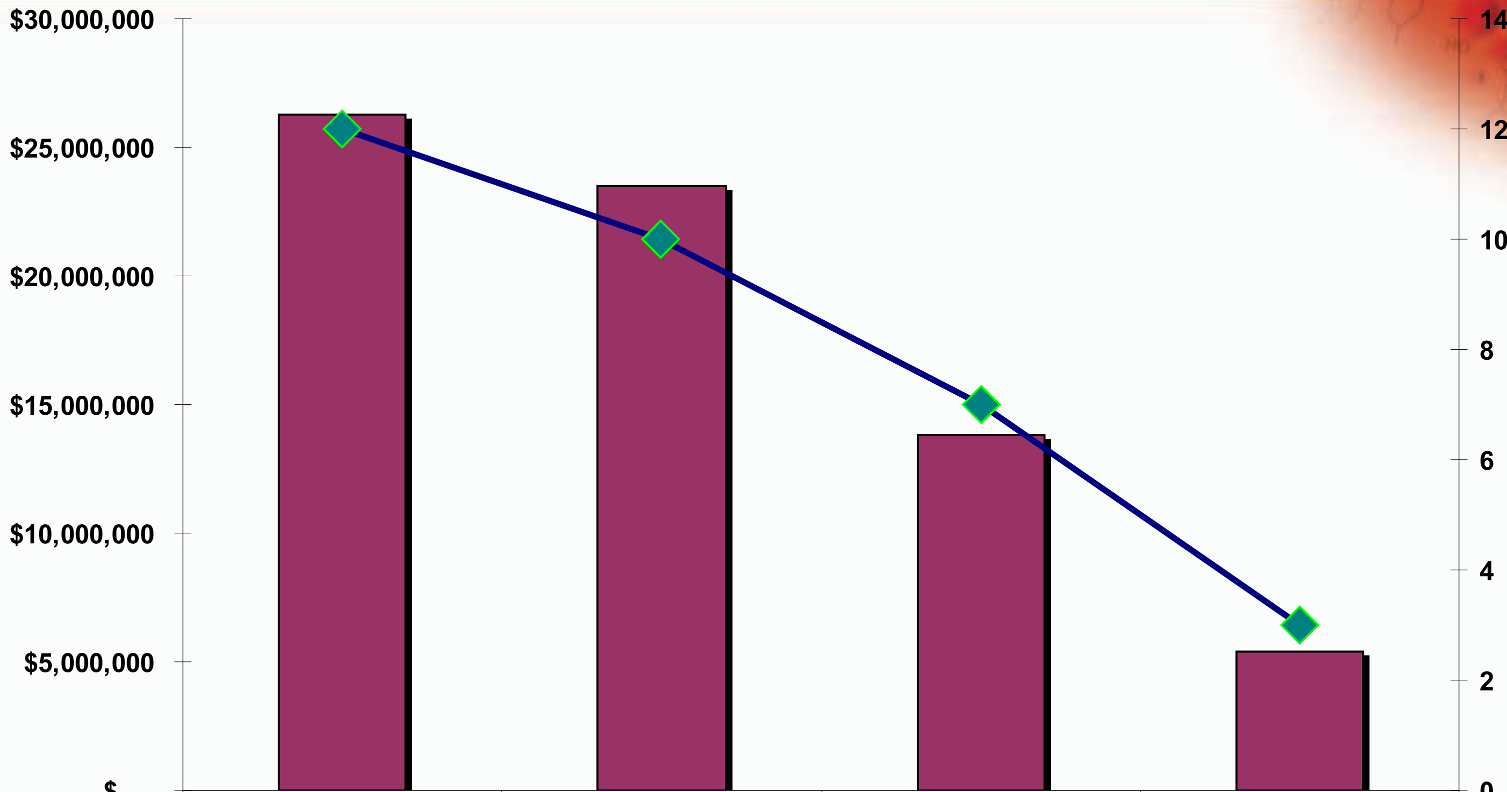
FC Area vs Costs by Projects



	Polymer	Ceramic	BOP	FP
Cost	$26,276,694	$23,456,956	$13,821,200	$5,375,185
Projects	12	10	7	3

Summary

- A structured roadmap has been developed outlining how fuel cell cost can be reduced substantially.
- On average, a 50% savings can be realized with current sustainable volumes of 5000 units a year leveraging the present technological infrastructure.
- Essentially, these savings are independent of full scale commercial production.

Conclusions

The conclusions of the project can be categorized into the following areas:

- ***The need to improve catalyst efficiency***

- As Catalyst is the primary cost driver, its efficient utilization must be optimized.

- ***A need to develop robust transfer functions***

- Establish validated correlations between product design characteristics and performance.
- Establish validated, tolerances.
- Establish robust correlations between these critical design characteristics versus raw material and process variables.

- ***For the Balance of Plant,* projects are needed to address following areas:**

- Greater efficiency in heat exchanges
- Optimized humidifiers
- Anode and cathode gas and air delivery systems
- Liquid metering pumps

Conclusions, continued

➢ ***More focus on transitioning to automation and reducing manual operations***

This operation cuts across a broad spectrum of projects, and is very process specific. Projects are needed to address:

- Automated testing of completed stacks – includes methods to reduce test times
- Automation of MEA assembly

➢ ***Fuel processing***

Processors improving the desulfurization of logistic fuels and fuel processors designed for use on desulfurized logistic and alternate fuels are a big step towards the acceptance of fuel cells for DoD applications. The two main projects revolve around:

- Fuel processors for desulfurization of logistic fuel
- Fuel processors for desulfurization logistic and alternate fuels