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PEM Stack Manufacturing: Industry Status

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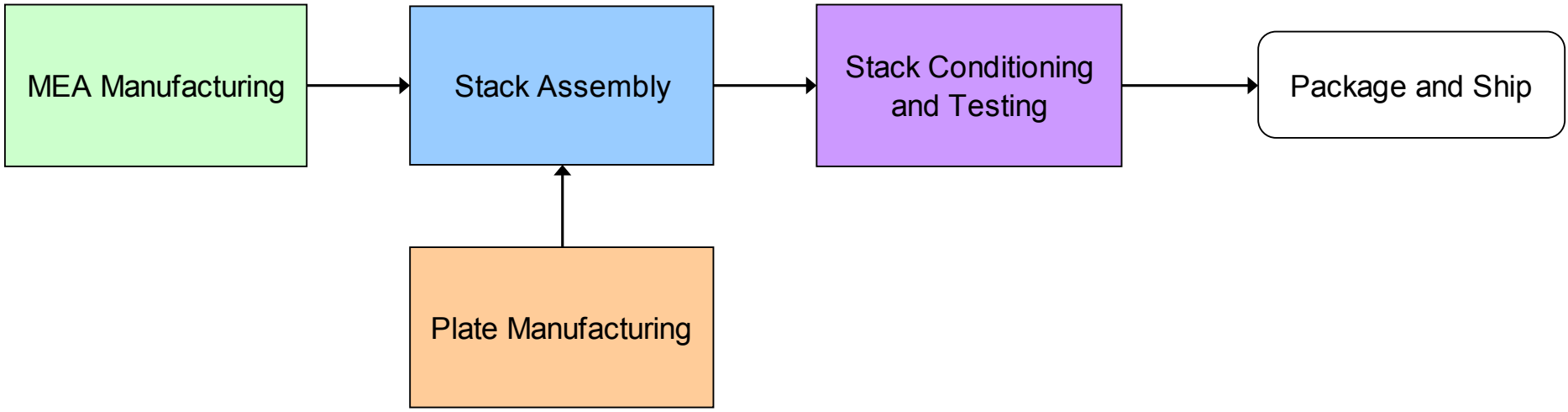
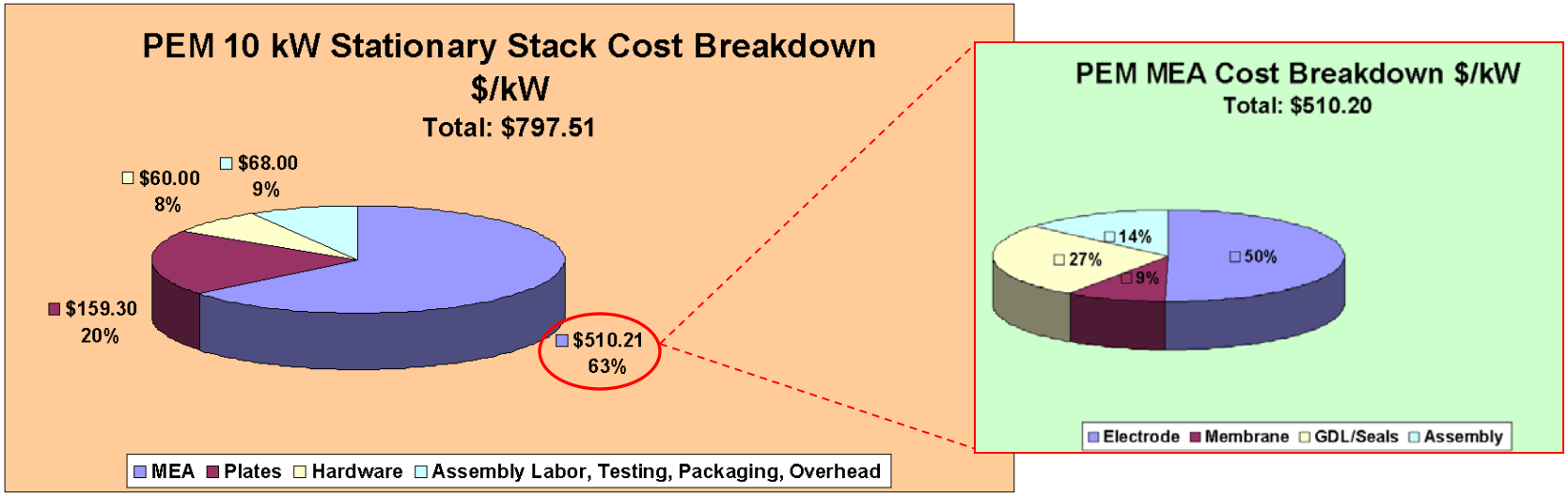
Overview of PEM Stack Manufacturing



For each of the four main processes, the following will be provided:

1. A brief history of where we have been;
2. Where we are today;
3. Where we would like to transition to;
4. Gaps and proposals.

PEM Stack Manufacturing: Cost Overview



- 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.

Courtesy Manhattan Project for Fuel Cell Manufacturing

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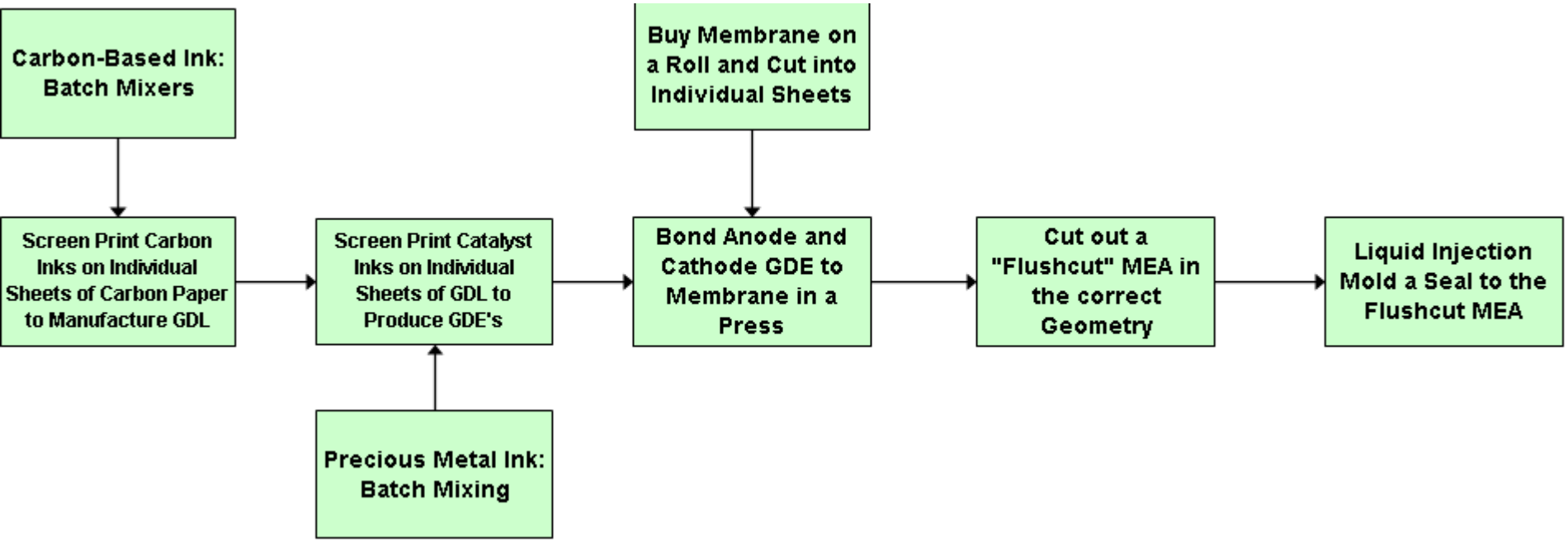
Discrete, sheet-by-sheet manufacturing:



- Very labor-intensive
- High touch processes result in handling yield losses
- Poor utilization of Catalyst from batch mixers and discrete sheet processing

MEA Manufacturing: Where we are today

Total Pt Loading Typically 0.5 mg/cm²

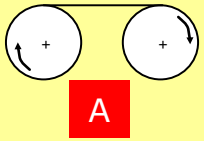
Understanding of critical design parameters and validated tolerance bands is ongoing thus tolerances are tight = strain on yields

Step 1
Coat Cathode Catalyst Layer Roll-to-Roll on Intermediate Release Film

Step 2
Coat Anode Catalyst Layer Roll-to-Roll on Intermediate Release Film

Step 3
Decal Transfer Cathode and Anode Catalyst Layers onto Membrane using Continuous Lamination Techniques

QC: Inline



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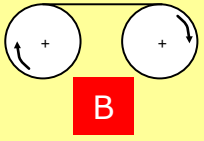
QC: Inline



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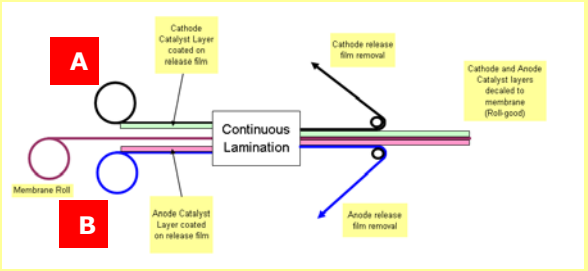

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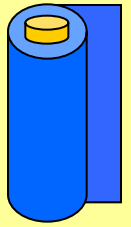
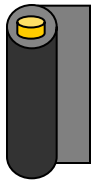
CCM Roll

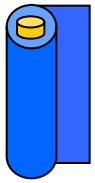


Anode GDL Roll



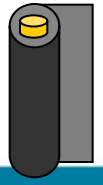
Manually Cut Net Shape

CCM Roll

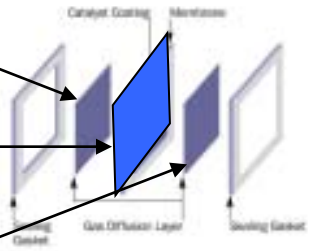


Manually Cut Net Shape

Cathode GDL Roll



Manually Cut Net Shape



Manually Assemble MEA

MEA Manufacturing: Where we want to go

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Reduce Pt Loading to 0.15 mg/cm² via Improved Catalyst Layer and GDL Design

Save $60/kW*

Improved Design Understanding = Wider Tolerances = Higher Yields

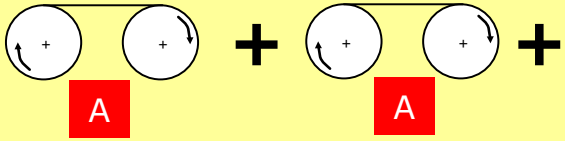
Step 1
Coat Cathode Catalyst Layer Roll-to-Roll **Directly on Membrane**

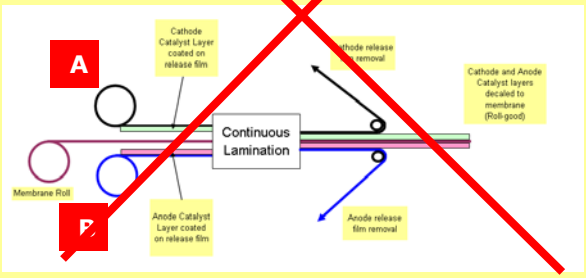
Step 2
Coat Anode Catalyst Layer Roll-to-Roll **Directly on Membrane**

Step 3
Decal Transfer Cathode and Anode Catalyst Layers onto Membrane using Continuous Lamination Techniques

Eliminate Decal Transfer

QC: Inline + QC: Inline +





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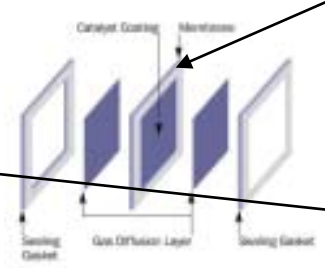
CCM Roll

Save $37/kW*

Anode GDL Roll → Manually Cut Net Shape

CCM Roll → Manually Cut Net Shape

Cathode GDL Roll → Manually Cut Net Shape



Develop Patch Coating Along with Inks that Support this New Approach

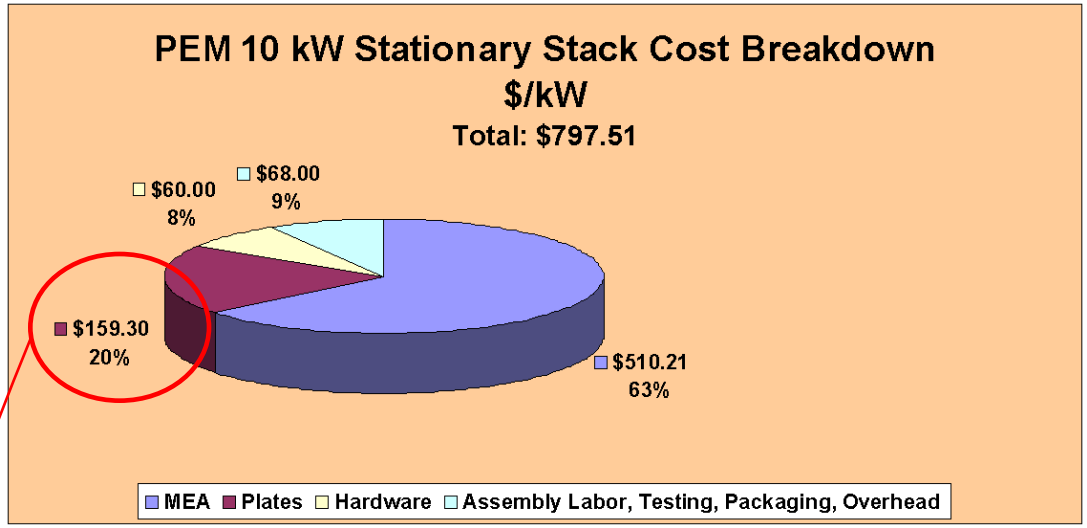
Save > $30/kW *

Automated MEA Assembly

Save $70/kW *

* Courtesy Manhattan Project for Fuel Cell Manufacturing

Plate Manufacturing: Where we are today



Two types of plates are in use:

1) Embossed, post-impregnated Grafoil (made in-house);

2) Compression molded (externally supplied).

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Key Manufacturing Needs Identified for Bi-Polar Plates*

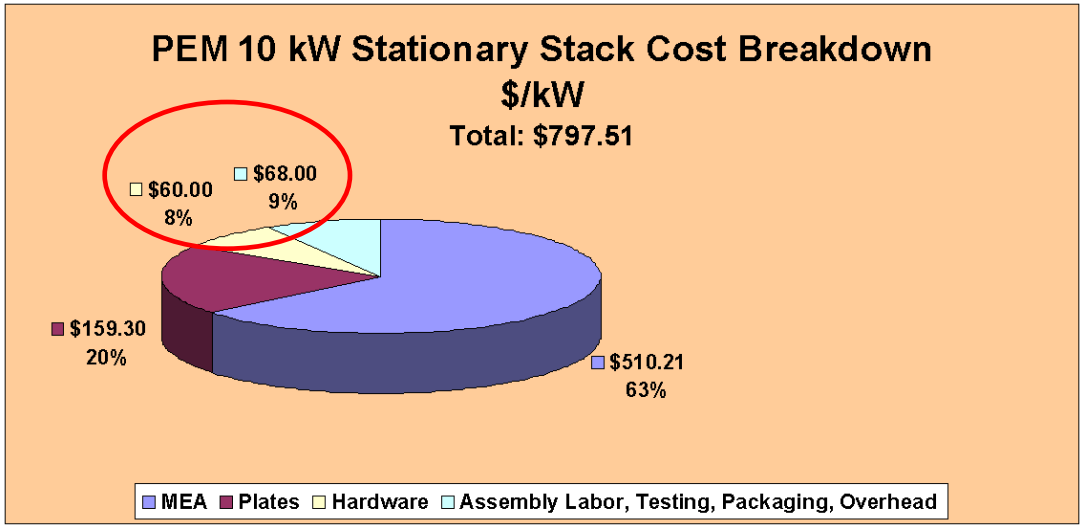
- Development of alternative graphite resins for LTPEM to facilitate easier molding;
- Improved understanding, testing and evaluation of critical design parameters;
- Development of low cost metallic plates using more conventional manufacturing processes that would lower cost;

- Experts in the field predict a 50% cost reduction is possible using embossed Grafoil
  - ➢ So, move from $159/kW to about $75/kW

- Effort would have to include both Manufacturing AND Design

* Courtesy Manhattan Project for Fuel Cell Manufacturing

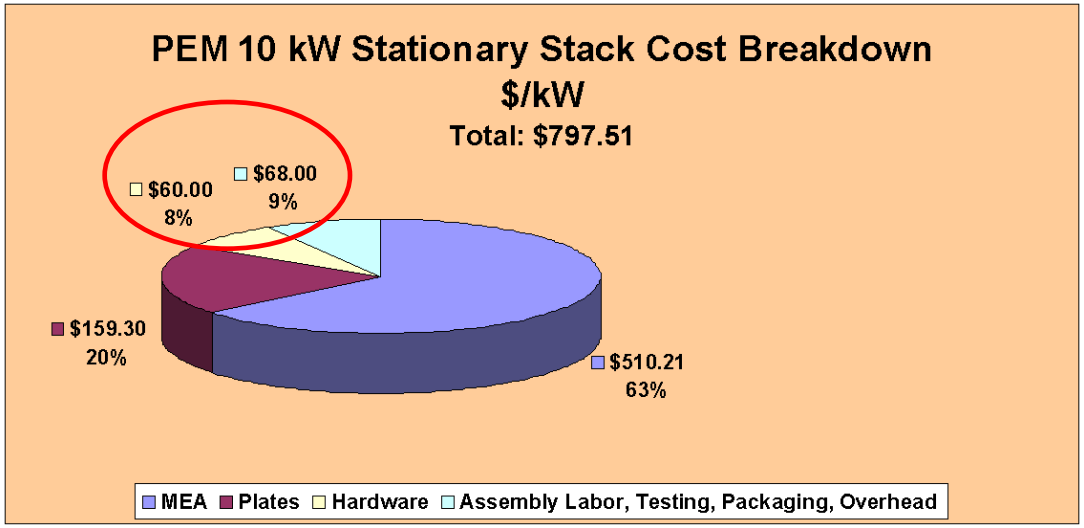
Stack Hardware and Stack Assembly: Where we are today



- Stack hardware costs are volume driven;
- Stack assembly is manual (about $10/kW*);
- Every stack is conditioned and tested (adds about $10/kW*).

* Courtesy Manhattan Project for Fuel Cell Manufacturing

Stack Hardware, Stack Assembly, and Testing: Where we want to go



- Automation of stack assembly
  - Reduces cost from $10/kW to less than $2/kW

- Improved test conditioning/testing methods
  - Reduces cost from $10/kW to less than $2/kW

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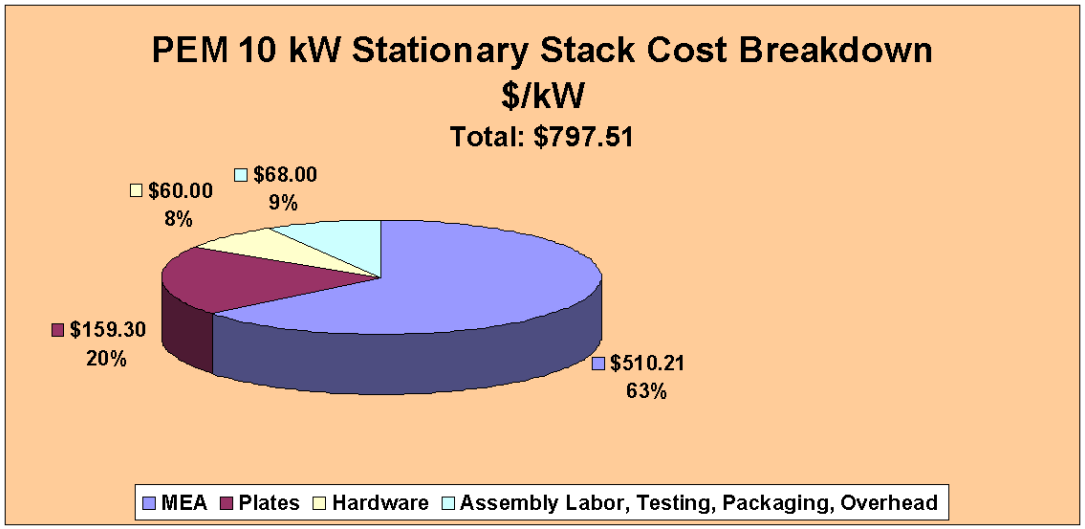
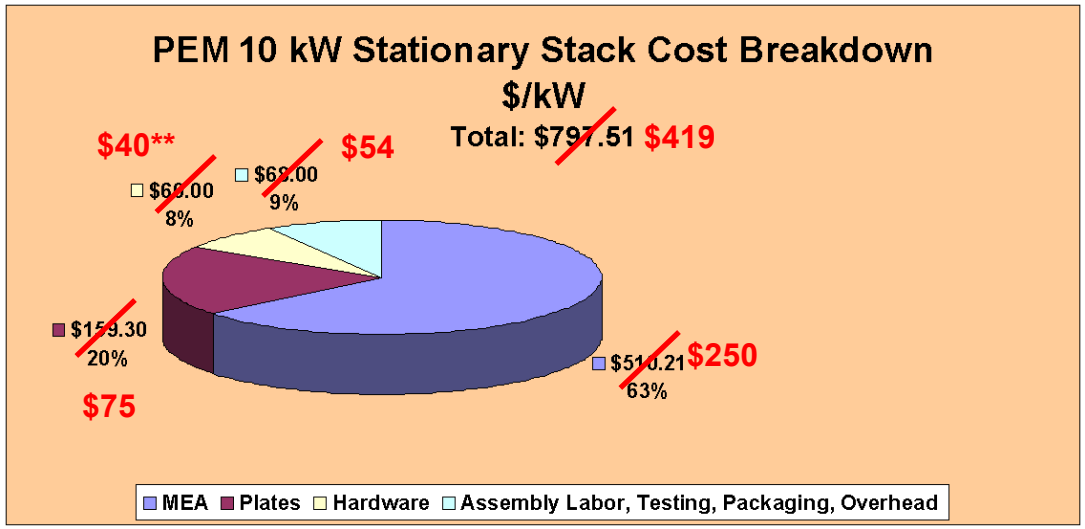
Today



What's Possible



** Estimate