PROTON
THE LEADER IN ON SITE GAS GENERATION.

High Performance, Low Cost Hydrogen Generation from Renewable Energy

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Organization: Proton Energy Systems

Date: May 16, 2012

Project ID #PD071

Overview

Timeline

- Project Start: Oct 2009
- Project End: December 2013
- Percent complete: 60%

Budget

- Total project funding
  - DOE share: $3,396,826
  - Cost share: $849,206
- Funding Received in FY11:$903K
- Planned Funding for FY12: $625K

Partners

- Entegris, Inc. (Industry)
- Penn State (Academic)
- Oak Ridge (National Lab)

Barriers

- Barriers addressed

  G: Capital Cost

  H: System Efficiency

  J: Renewable Electricity Generation Integration

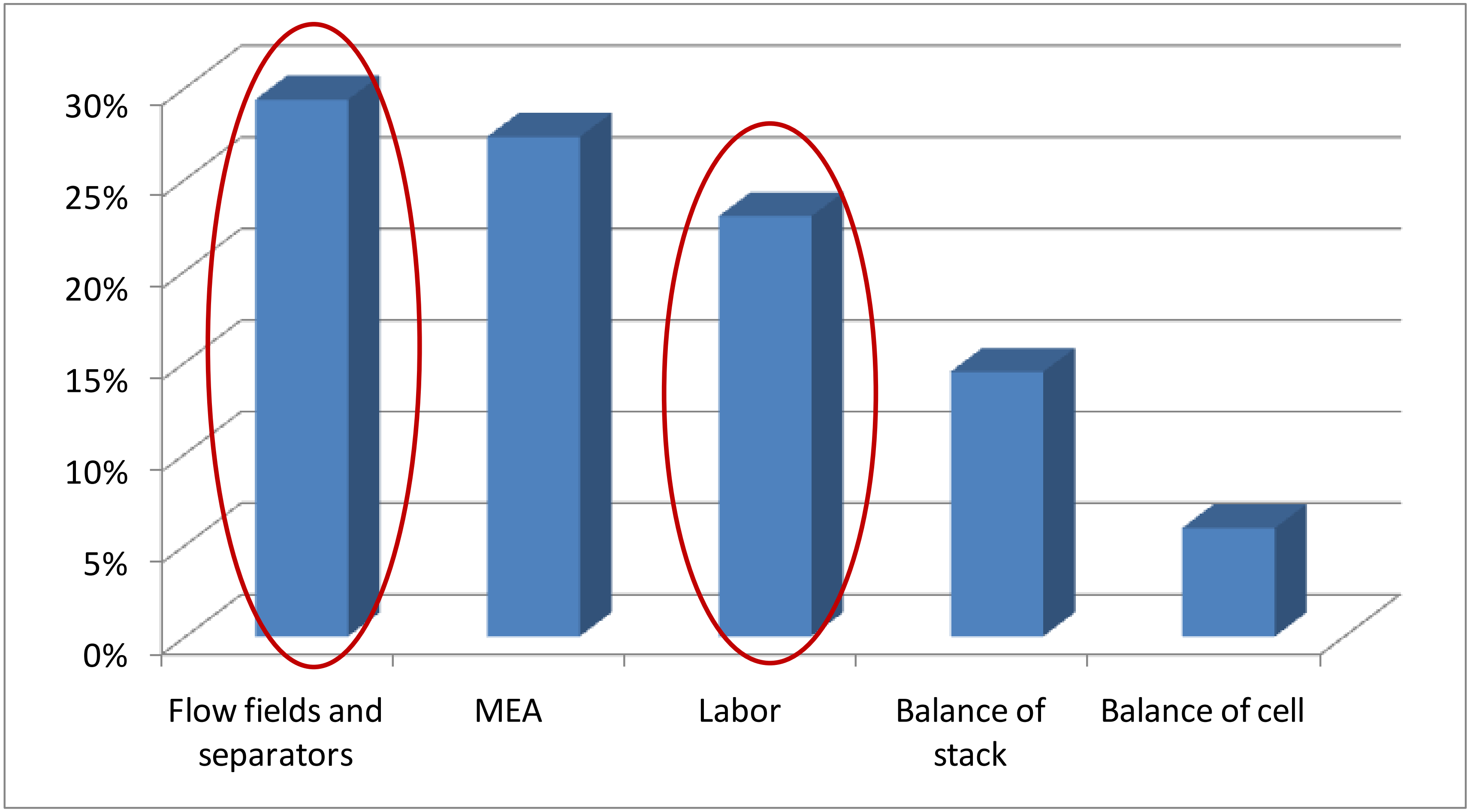
Table 3.1.4. Technical Targets: Distributed Water Electrolysis Hydrogen Production [a, b, c]

Characteristics	Units	2003 Status	2006 Status [c]	2012 Target	2017 Target
Hydrogen Cost	$/gge	5.15	4.80	3.70	<3.00
Electrolyzer Capital Cost [d]	$/gge $/kW	N/A N/A	1.20 665	0.70 400	0.30 125
Electrolyzer Energy Efficiency [f]	% (LHV)	N/A	62	69	74

Table 3.1.4 Source:
DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development, and Demonstration Plan, Updated April 2009

Relevance

- Project addresses high impact areas of flow field cost and labor reduction



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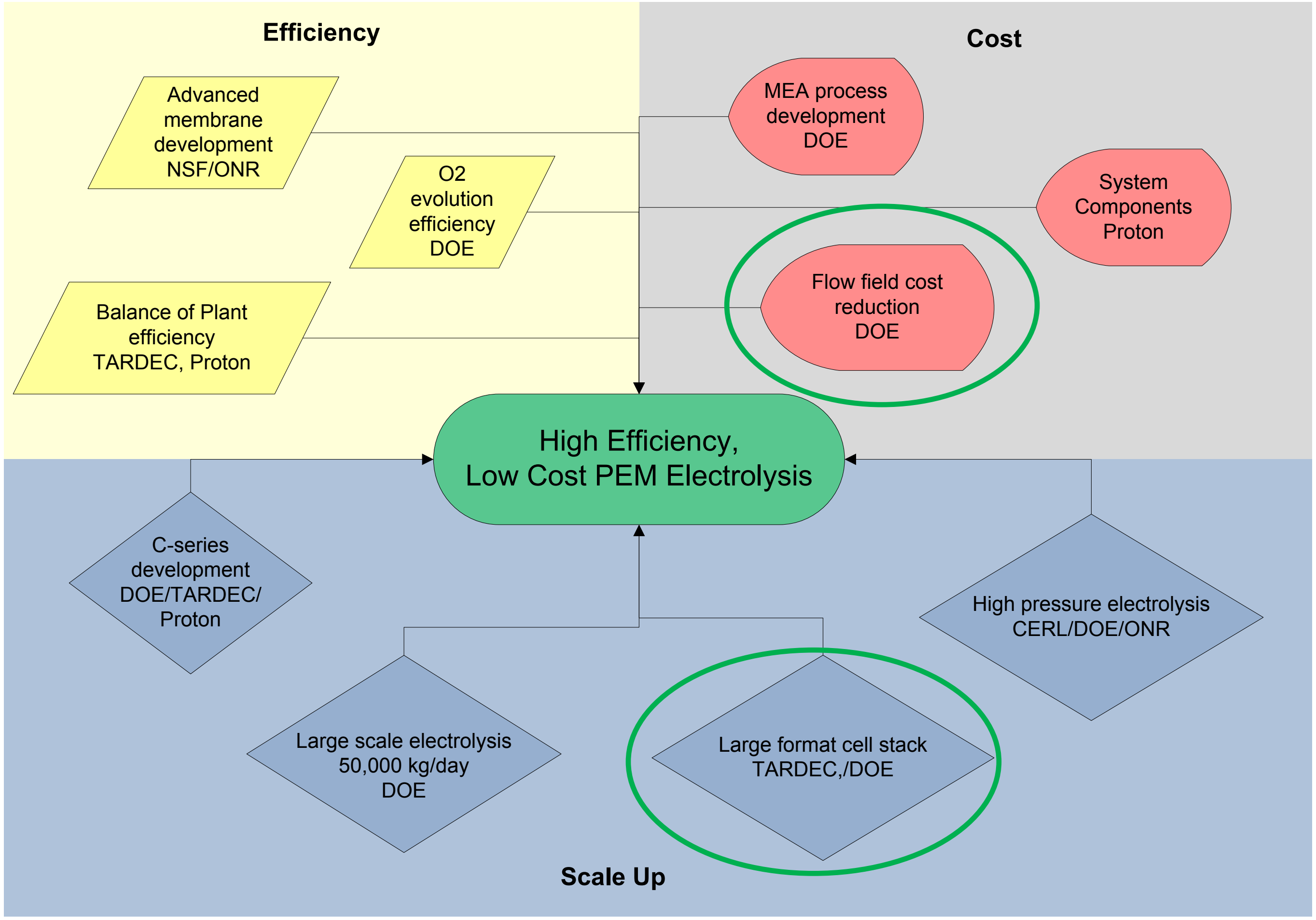
Relevance

- Supports Proton overall roadmap for cost effective renewable hydrogen production



Relevance

- Strong success in commercialization lends confidence to investment impact

2000: S-Series
1-2 kg/day
13 bar

2006: HPEM
0.5 kg/day
138 bar

2009: Outdoor HPEM
2 kg/day
165 bar

2011: C-Series
65 kg/day, 30 bar

Steady History of Product Introduction and Improvement

1999: GC
300-600 mL/min
13 bar

2003: H-Series
4-12 kg/day
30 bar

2006: StableFlow® Hydrogen Control System

2010: Lab Line

Relevance
Project Objectives

- Improve electrolyzer cell stack manufacturability
  - Consolidation of components
  - Incorporation of alternative materials
- Reduce cost in electrode fabrication
  - Reduction in precious metal content
  - Alternative catalyst application methods
- Part of Proton R&D portfolio for cost reduction, scale up, and efficiency improvements

Top Level Approach

- Task 1.0: Catalyst Optimization
  - Control catalyst loading
  - Improve application
- Task 2.1: Computational Cell Model
  - Develop full model
  - Flex parameters, observe impact on performance
- Task 2.2: Implement New, Lower Cost Cell Design
  - Design and verify parts
  - Production release
- Task 2.3*: Prototype Concepts
  - Test material compatibility
  - Fabricate test parts
- Task 2.4*: Composite Bipolar Plates
  - Demonstrate functionality
- Task 3.0*: Low Cost Manufacturing
  - Laminate concepts
  - Alternate processes
- Task 4.0*: Operational Testing and Stack Scale Up
- Task 5.0: Manufacturing Development
- Task 6.0: Manufacturing Qualification
- Task 7.0*: H2A Cost Analysis**
  - Input design parameters
  - Assess impact of changes

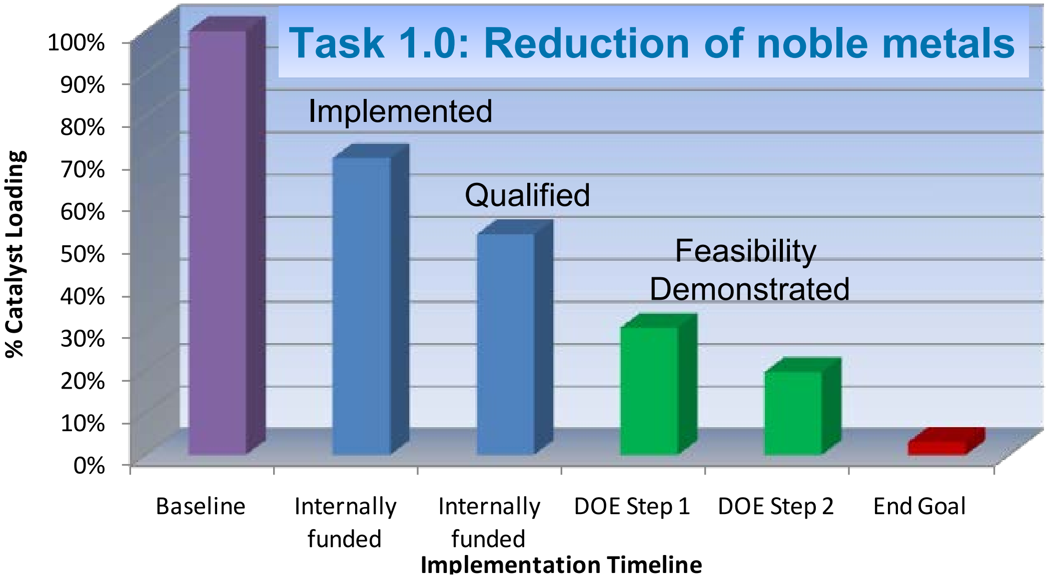
***blue = current review year activities**

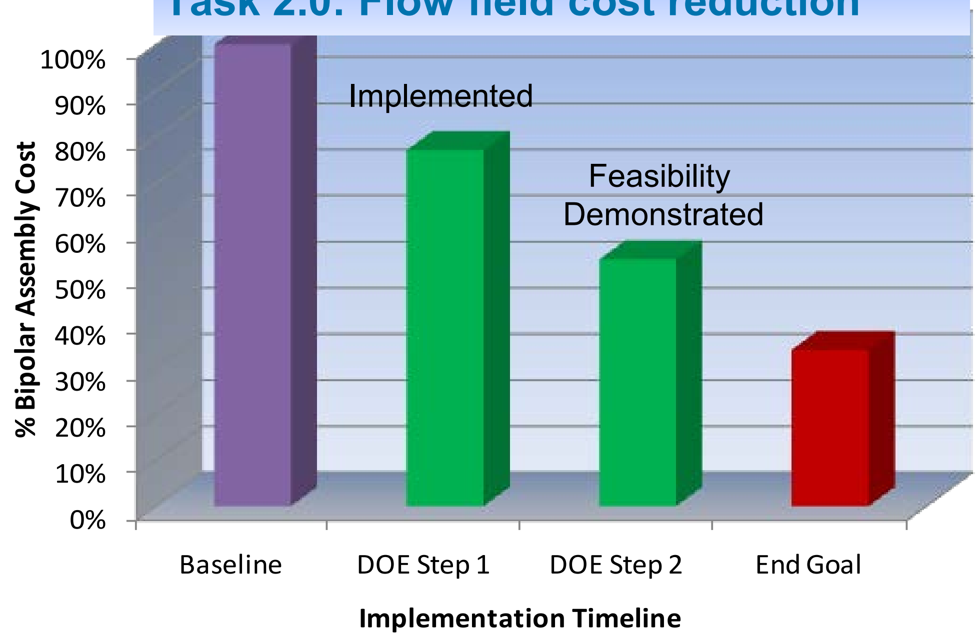
**** Uses H2A version 2.1.1**

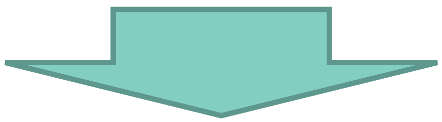
Progress on Milestones

Task Number	Project Milestones	Task Completion Date	
		Original Planned	Percent Complete
1	Catalyst Optimization	03/31/10	100%
2.2	Improved Flowfield Implementation	05/30/10	100%
2.1	Electrolyzer Cell Model	01/30/11	100%
2.3	Next Generation Flowfield Prototypes	05/30/10	100%
2.4	Metal-Composite Laminate Plate Fabrication	12/31/10	100%
3.1	Metal-Composite Plate Development	12/30/11	100%
3.2	All-Metal Laminate Plate Development	12/30/11	100%
3.3	Hydrogen Resistant Coating Development	12/30/11	80%
4.1	Sample Operational Tests	12/31/11	100%
4.2	Post Operational Testing Analysis	03/30/12	30%
4.3	Stack Scale Up	09/30/12	10%
5	Bipolar Plate Manufacturing Development	06/30/13	0%
6	Bipolar Plate Manufacturing Qualification	09/30/13	0%
7	H2A Cost Model Analysis	09/30/13	60%
8	Project Management	09/30/13	60%

Technical Accomplishments: AMR 2011 Review

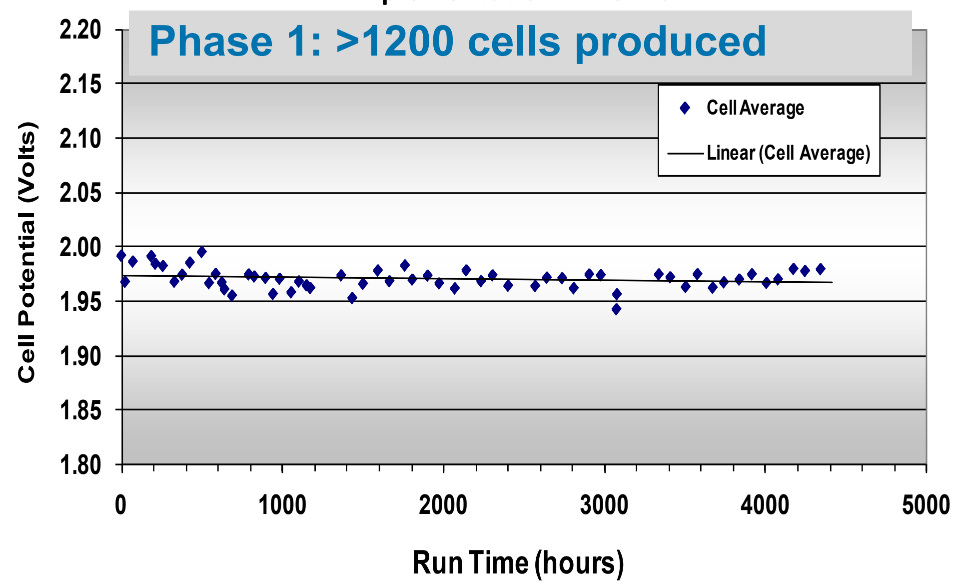






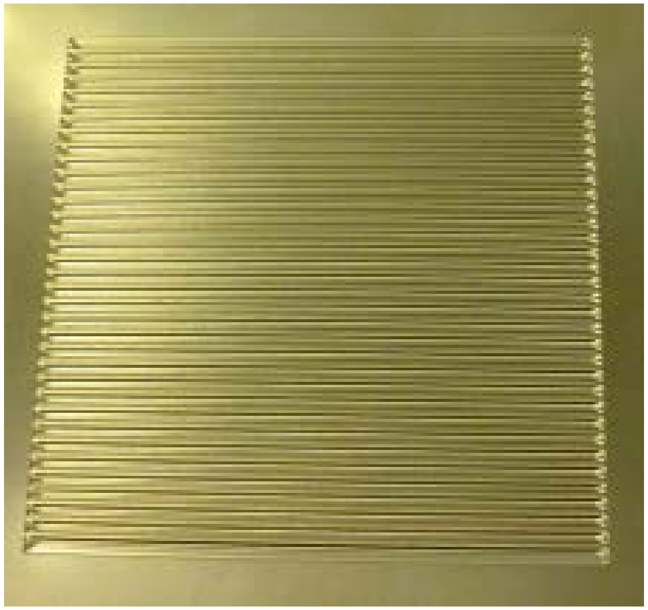
Continuing under Phase 2 SBIR (PD090)

- Phase 2A: Manufacturing development to move Qualified/Step 1 advancements to production
- Phase 2B: Demonstrate End Goal feasibility and optimize OER efficiency

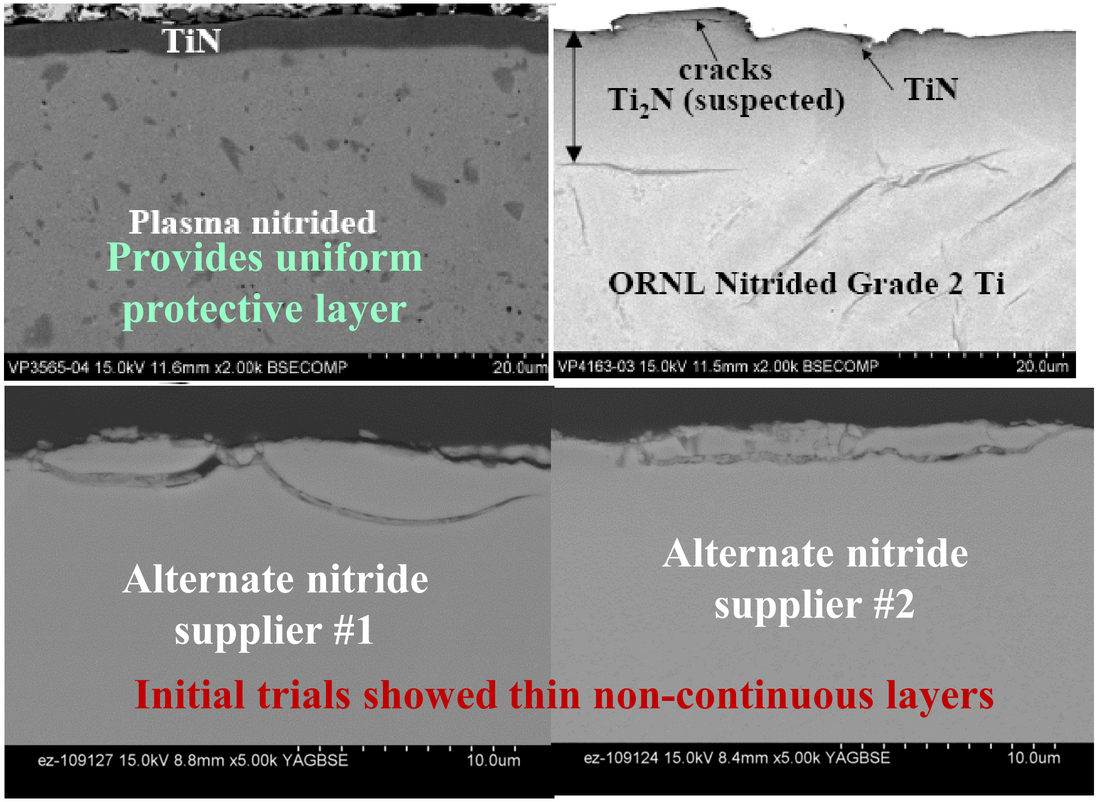


Technical Accomplishments: Subtask 2.4 Alternative Coatings

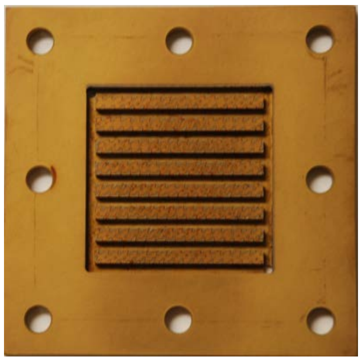
- Surveyed commercial suppliers and prototyped parts
  - Thermal nitride yields Ti_2N vs. TiN, need to confirm stability
  - Provided feedback to alternate suppliers for retest



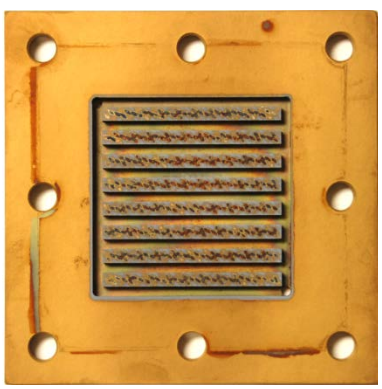
Conceptual part made with new manufacturing process/plasma nitride

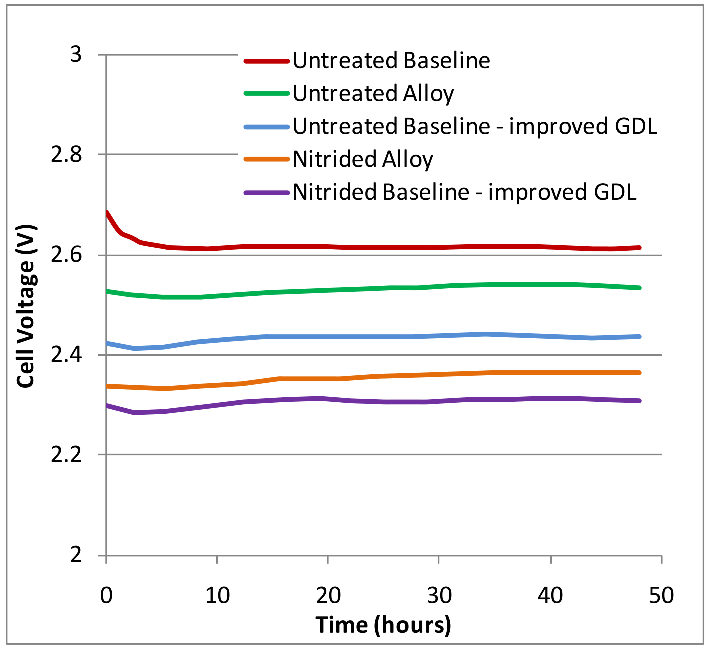


Technical Accomplishments: ORNL Nitride Studies



500 hr. test



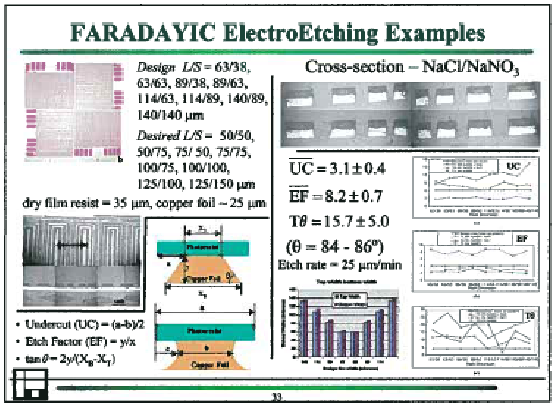


50 hour screening test

- Thermal nitride shows some discoloration
- Continuing to investigate stability
- Alloy improved vs. Grade 2
- Nitriding significantly lowers part stress vs. existing process

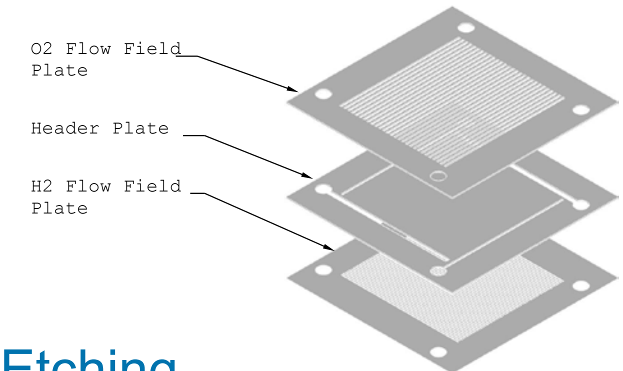
Technical Accomplishments
Task 3: Alternative Concepts

- Created a list of 27 possible configurations including:



Chemical/Electrochemical Etching

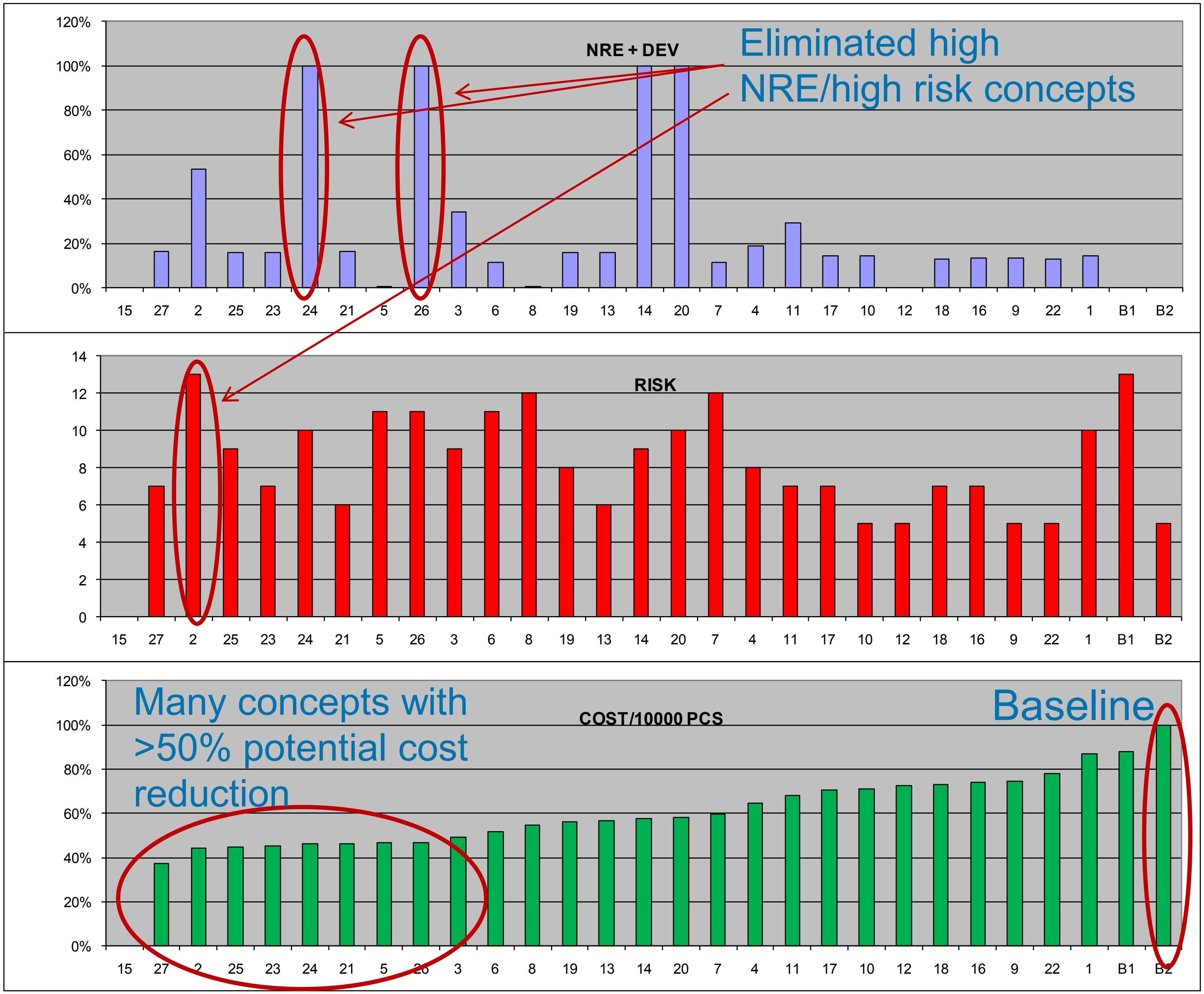
Diffusion bonding



Stamping

- Created a manufacturing decision matrix
  – Scored concepts on multiple criteria
  – Used the existing designs as cost baseline

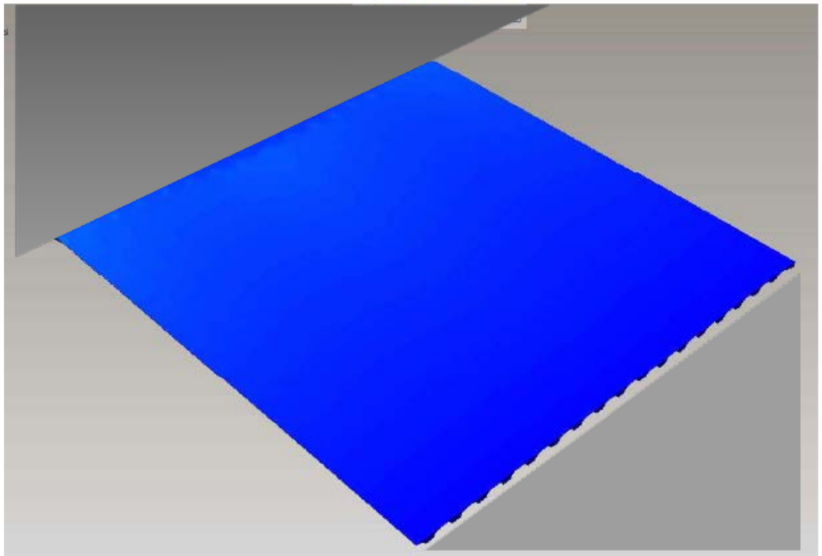
Results

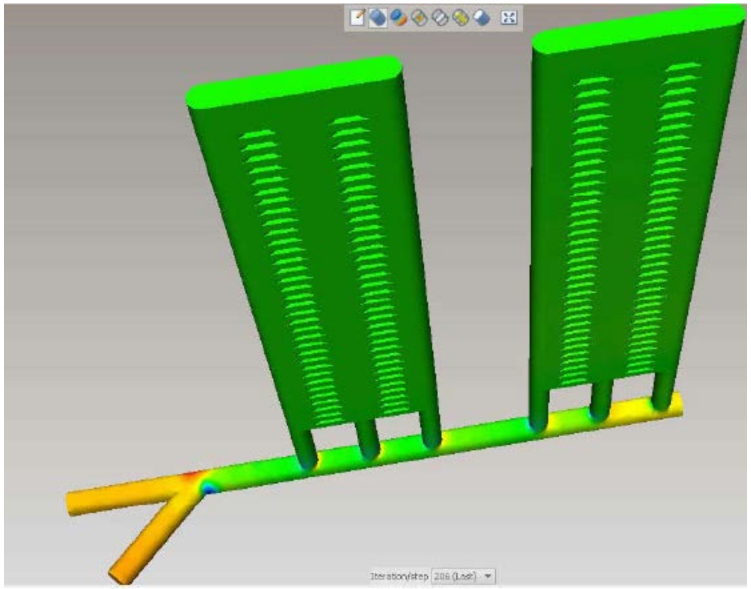


NRE + DEV
Eliminated high
NRE/high risk concepts
120%
100%
80%
60%
40%
20%
0%
15 27 2 25 23 24 21 5 26 3 6 8 19 13 14 20 7 4 11 17 10 12 18 16 9 22 1 B1 B2
RISK
14
12
10
8
6
4
2
0
15 27 2 25 23 24 21 5 26 3 6 8 19 13 14 20 7 4 11 17 10 12 18 16 9 22 1 B1 B2
COST/10000 PCS
Many concepts with
>50% potential cost
reduction
Baseline
120%
100%
80%
60%
40%
20%
0%
15 27 2 25 23 24 21 5 26 3 6 8 19 13 14 20 7 4 11 17 10 12 18 16 9 22 1 B1 B2

Design Approach for Selected Concept

- Performed FEA analysis on frames, manifolds, and flow field channels
  - No stress levels of concern noted
- Performed flow analysis at cell and stack level
  - Pressure drop in line with existing designs





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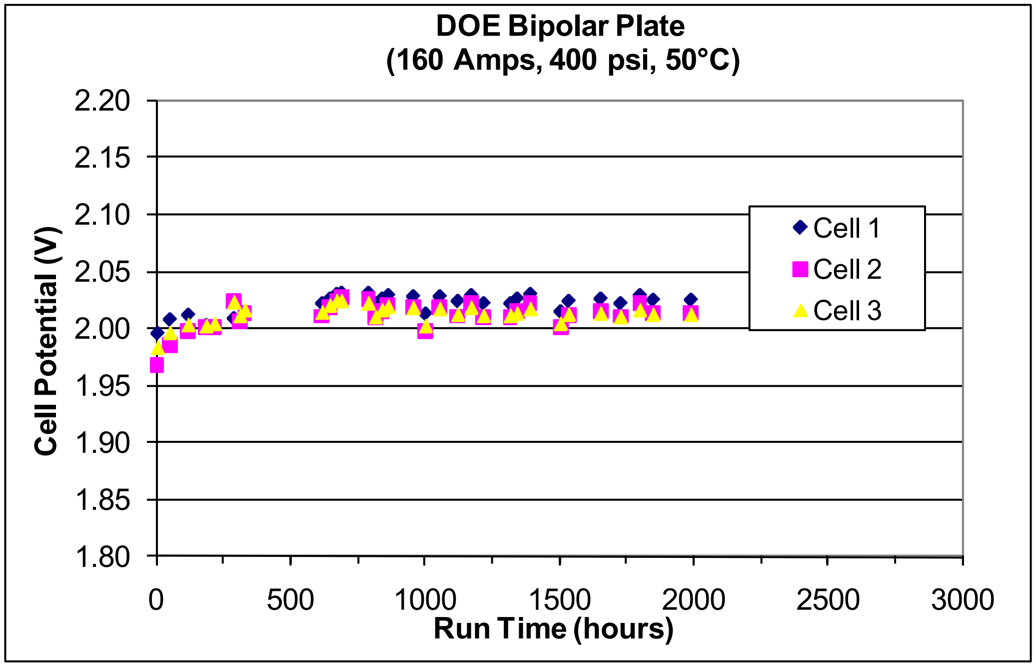
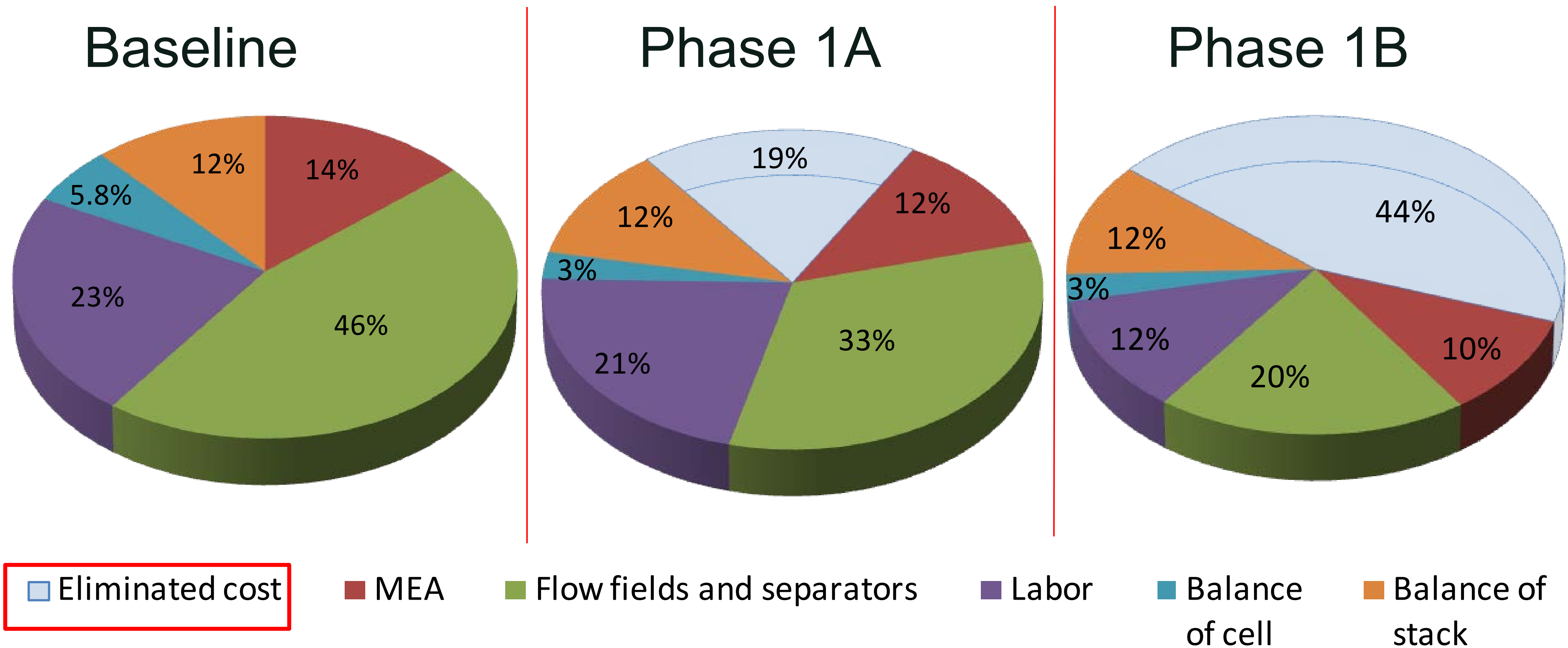
Technical Validation

- Prototype stack design demonstrated required proof pressure
- Stack operational in December for go/no go review, over 2000 hours as of March 2012



Cost Validation

- Combined labor and material advancements result in 19% production cell stack cost reduction
- Project additional step change in Phase 2



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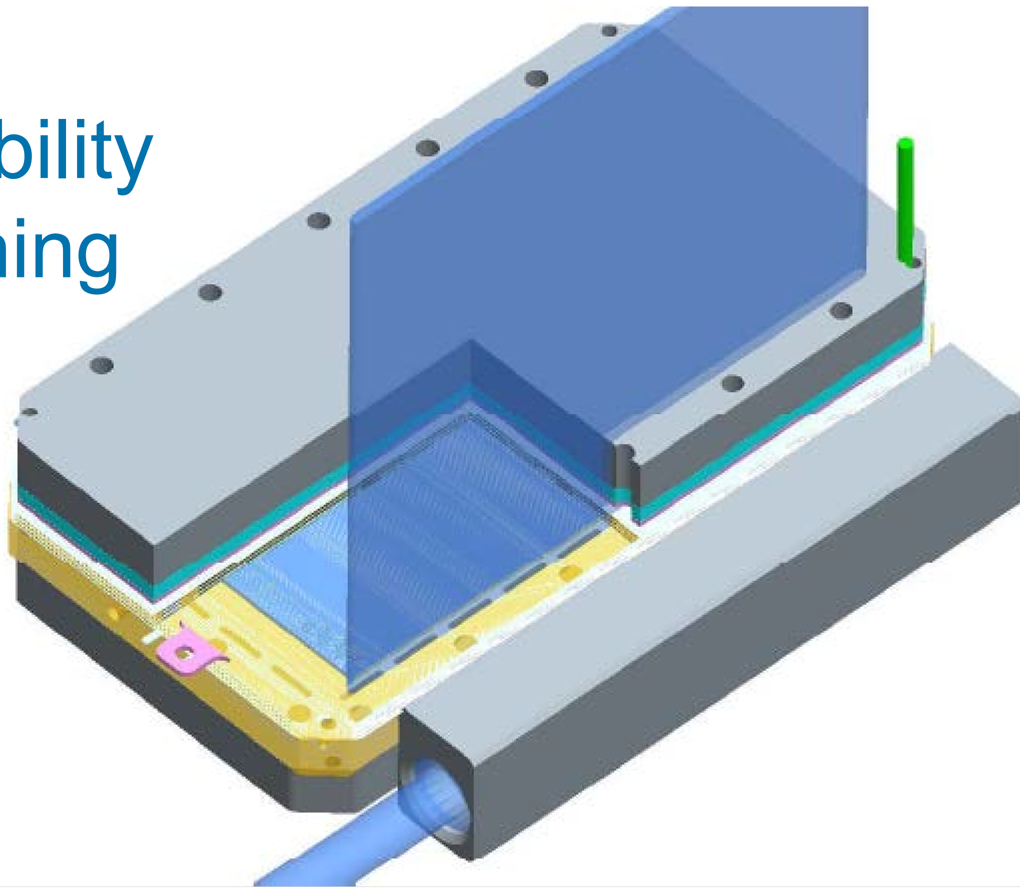
Initial scale up concept

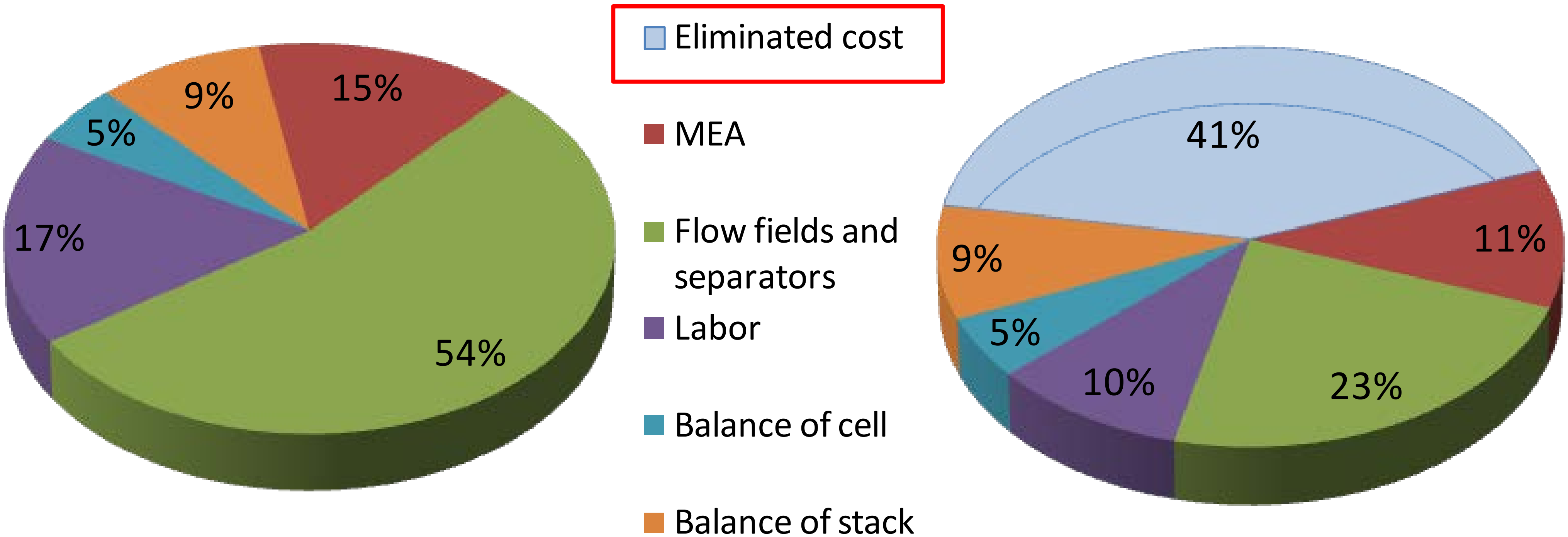
- MEA dimensions leverage existing fuel cell supplier base capability
- Plate designed for flexibility in length while maintaining uniform flow
- Performing FEA and CFD analyses



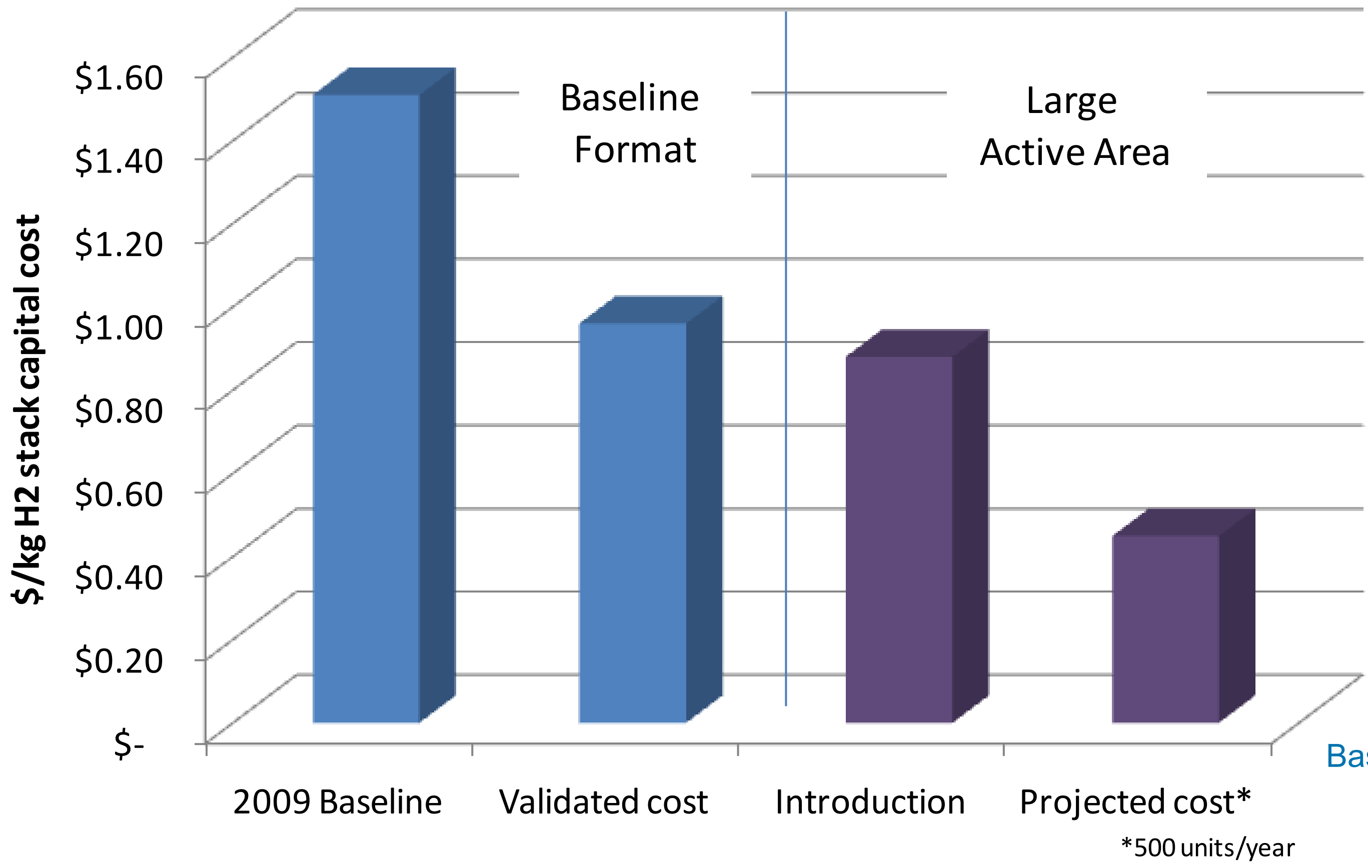
Large Format Cost Projections

Product Introduction

New design



H2A Impact: Cell Stack



Based on H2A model V2.1.1

- Large active area stack:
  - Reduced labor vs. 2009 baseline stack cost
  - Stack designed for minimization of scrap for major materials

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Collaboration

- Partners
  - Entegris (Industry): Demonstrated alternative materials and coating techniques for reduced cost flowfields
  - Penn State (Academic): Developed a full computational model of a functioning electrolyzer cell
  - Oak Ridge National Laboratory: (Federal) Investigating advanced coating materials and deposition techniques

Future Work

- Task 2.4 Continued characterization of coating stability and part stress analysis/hydrogen uptake
- Task 4.0 Complete design scale up and prototyping
- Task 5.0 Manufacturing process development
- Task 6.0 Manufacturing qualification
- Task 7.0 Perform H2A analysis for end design

Manufacturing Development

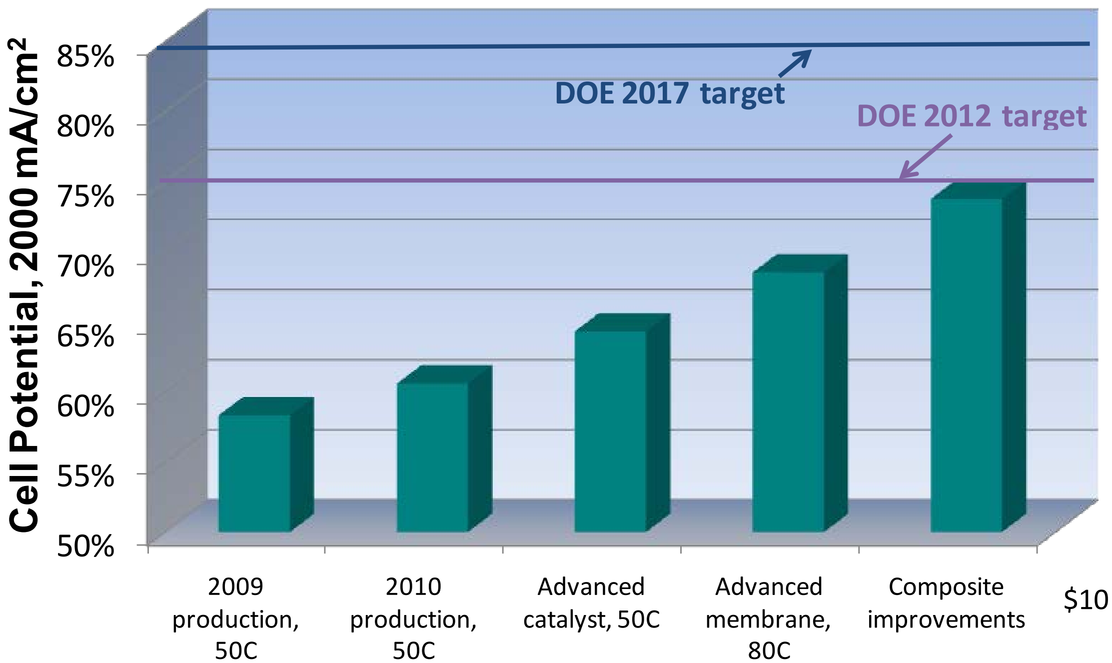
- End goal of program to scale up new flow field
- Utilize existing stack design and system capability
  - Testing infrastructure in place for 50 kg/day stack

Existing large format stack scaling to >50-cell design point

Overall 2011-12 Accomplishments: Electrolysis

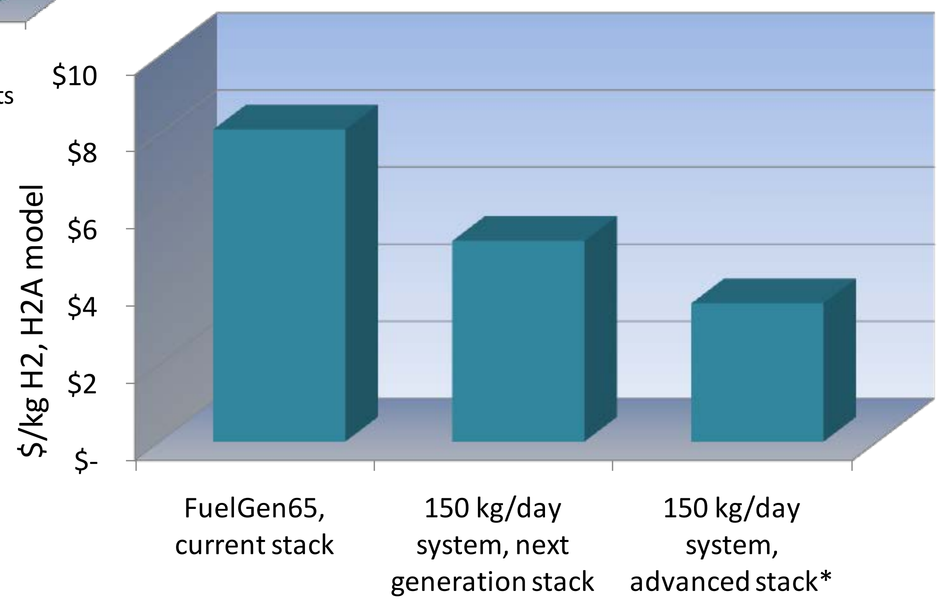
- Cost Reduction:
  - Validated stack cost reduced 40% vs. 2008
  - Feasibility demonstrated for >50% MEA cost reduction
- Efficiency:
  - Demonstrated 74% LHV efficiency (1.7 V per cell) at 2 A/cm^2
  - 77% LHV efficiency at 1 A/cm^2
- Scale Up:
  - Operational 5000 psi stack (direct electrochemical compression, differential)
  - Operational 50 kg/day stack
  - Low cost, large active area stack prototype
  - Large scale balance of plant concept complete

Efficiency and Cost Impact



LHV stack efficiency near 75%: Validated at 80°C, 30 bar

Overall portfolio demonstrates pathway to DOE hydrogen targets



*Assumes volumes of 500 units/year

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Summary

- Relevance: Cost savings at the electrolyzer cell level directly impacts hydrogen production costs
- Approach: Reduce cost of largest contributors first
- Technical Accomplishments:
  - Flowfield: Phase 1B design passed technical review, prototype on test; project 40% stack cost savings
- Collaborations:
  - Cell Model: Leveraging learnings for scale up
  - Entegris: Concepts show good durability, incorporated into design
  - ORNL: Providing detailed materials understanding for predictability of long term stability
- Proposed Future Work:
  - Scale up and manufacturing development

Team

- Blake Carter
- Luke Dalton
- Rachel Wax
- Andy Roemer
- Mike Niedzwiecki
- Tom Mancino (Entegris)
- Mike Brady (ORNL)
- Todd Toops (ORNL)