Electrolyzer Manufacturing Progress and Challenges

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DOE Manufacturing Workshop 8/12/11

Outline

- Proton Commercialization Status: PEM Electrolysis
- Current Manufacturing Limitations: Stack
  - Cost Breakdown
  - Approaches
- Current Manufacturing Limitations: System
  - Cost Breakdown
  - Approaches
- Potential Impact
- Summary and Conclusions

Proton Energy → Proton Onsite

- World leader in Proton Exchange Membrane (PEM) electrolyzer technology
- Founded in 1996 – changed name from Proton Onsite in April 2011 to reflect product expansion.
- ISO 9001:2008 registered
- Over 1,500 systems operating in 62 different countries.

Headquarters in Wallingford, CT

ANAB ACCREDITED

Certified to ISO 9001:2008

TÜVRheinland®
Precisely Right.

Cell Stacks

Complete Systems

Turnkey Solutions

Military Applications

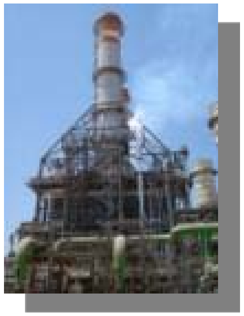
Capabilities

- Complete product development, manufacturing & testing
- Containerization and hydrogen storage solutions
- Turnkey product installation and integration
- World-wide sales and service
- Broad understanding of PEM Electrolysis systems and markets

Proton Production Floor

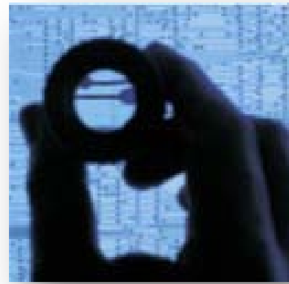
Markets and Products

Power Plants



Heat Treating

Semiconductors



Laboratories

Government

2000:
S-Series
1-2 kg/day

2006:
HPEM

2009:
Outdoor
HPEM

2011: C-Series, 65

Steady History of Product Introduction

1999: GC
300-600
mL/min

2003:
H-Series
4-12 kg/day

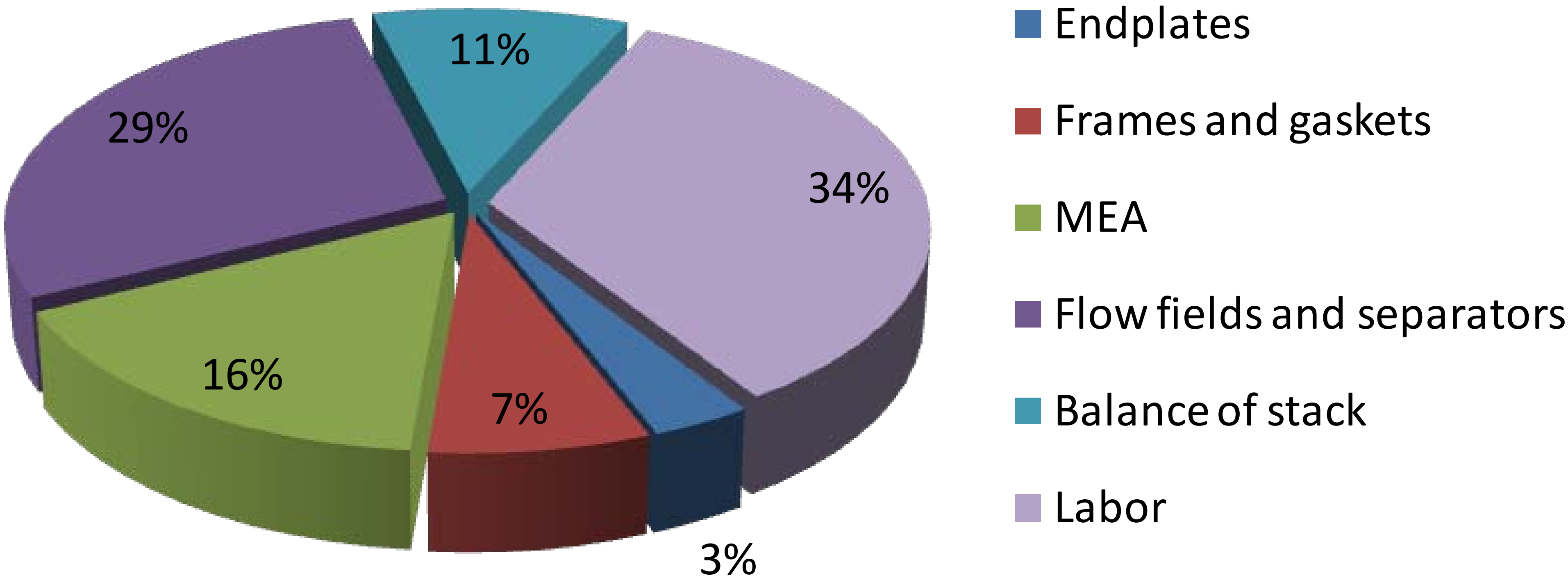
2006:
StableFlow
Hydrogen
Control
System

2010:
Lab Line

Manufacturing Needs: Overview

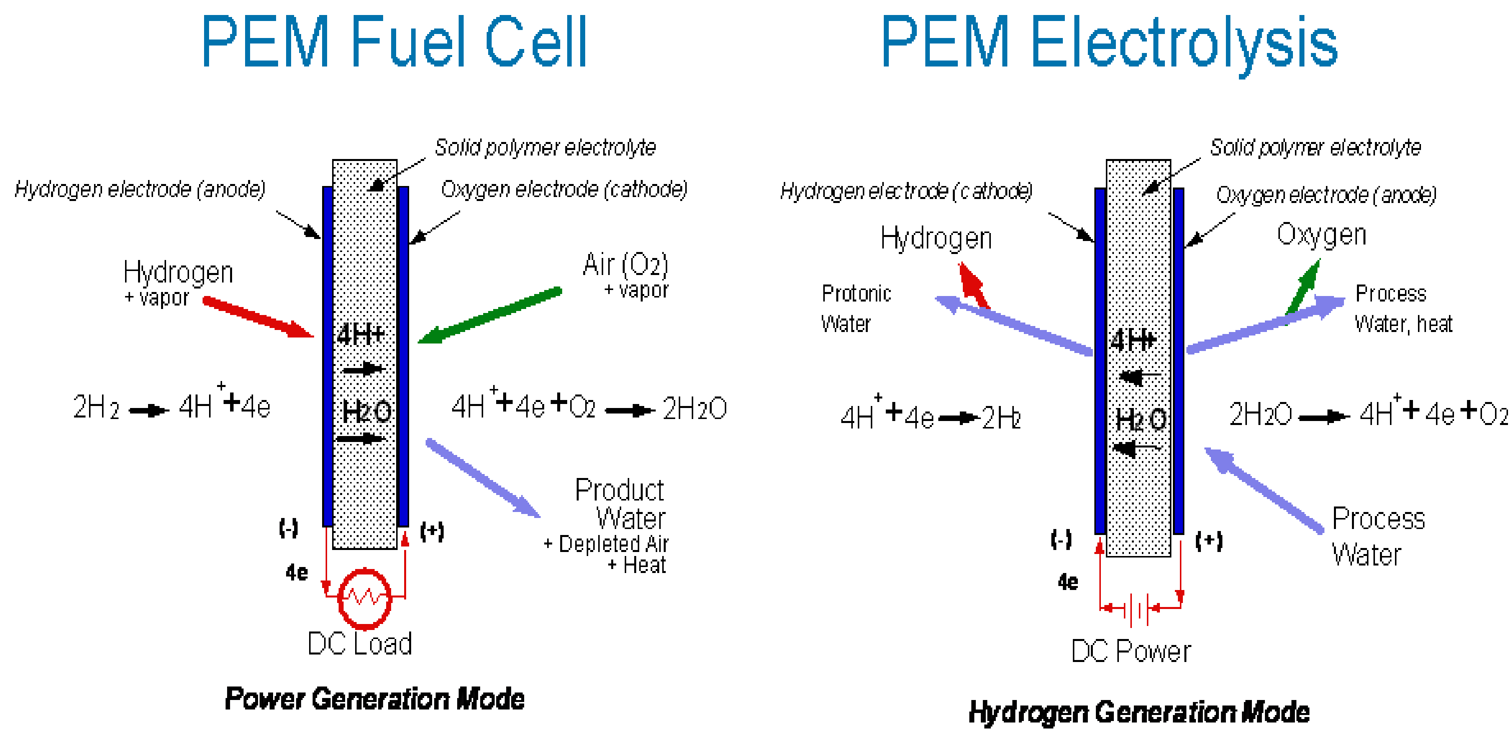
- Cost reduction areas defined for both stack and system
  – Over 50% decrease achievable
- Opportunities in material substitution, automation, and scale up
  – Collaborations established with key partners
- Roadmap developed for technology
  – Have shown cell scale feasibility
  – Need investment in manufacturing implementation

Cell Stack Cost Breakdown



- Highest cost areas: flow fields/separators, MEA, and labor

Comparison to PEM Fuel Cell Stack



- Similar materials of construction: PFSA membranes, noble metal catalysts
- Electrolysis membrane is fully hydrated, no RH cycling concerns
  - Have to withstand high pressure differential (200-2400 psi) and high sealing loads
- Stack materials have to withstand ~2 V potentials – particular concern for O_2 catalyst and flow fields
- Longer lifetime expectations (competing with gas cylinders)

Cell Stack Needs

- 50% reduction in bipolar assembly cost
  - Reduction of metal content in bipolar assembly
  - Reduction in bipolar assembly process time
- Increased part yield from suppliers
- Automation of MEA fabrication for electrolysis-specific MEAs
- Order of magnitude reduction in catalyst loading
- 30% reduction in membrane thickness
- Online quality control measurements

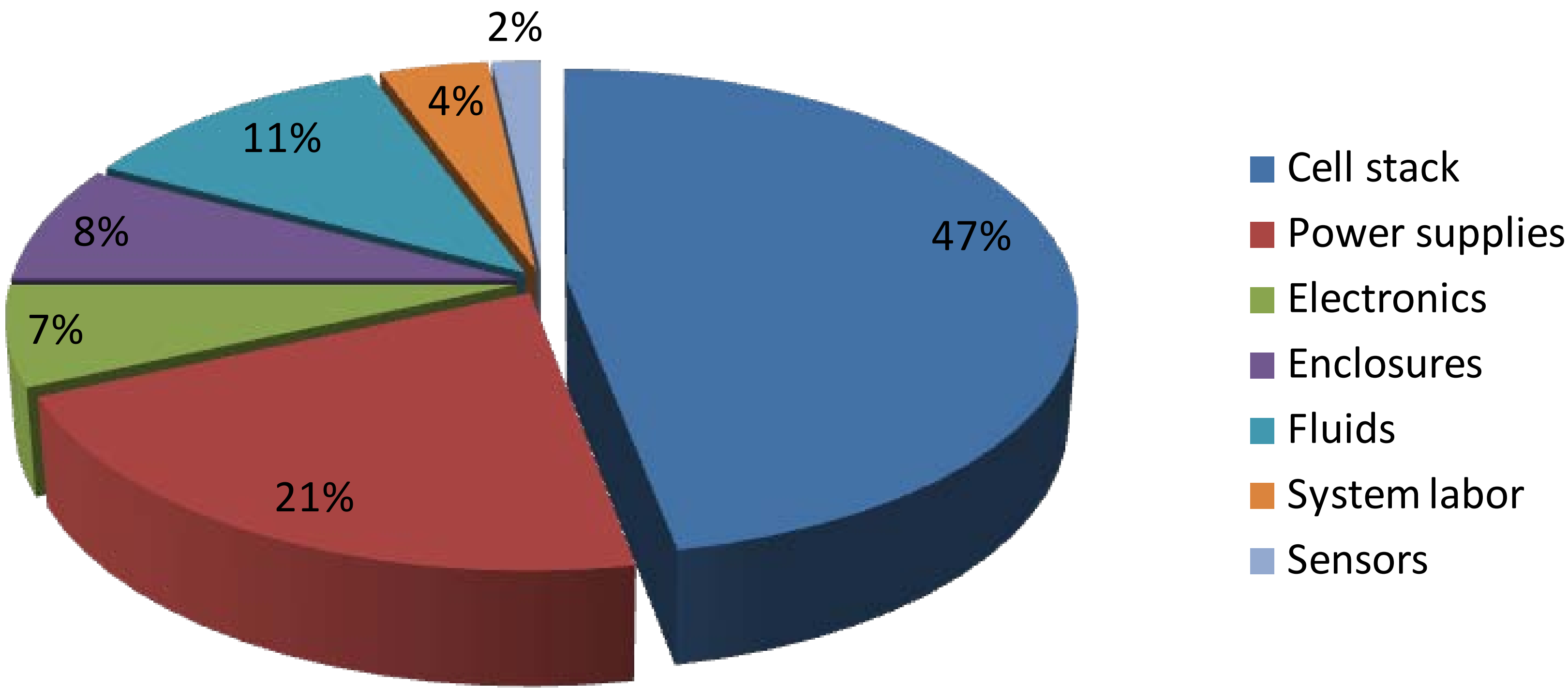
Manufacturing Goals: Examples

Part	Current	End Goal
MEA	Manual CCM process	Roll to roll coating
Flow Field	Multi-piece manual assembly	Single piece high speed manufacture
Gaskets	Single piece die cut	Roll stamping
Quality control	Individual part measurement	Inline measurement
Bipolar assembly	Metal plate	Laminate or composite

Leveraging Fuel Cell Technology

- PEM electrolyzer cost reduction will follow the maturation of PEM fuel cells
- Materials of construction derived from the fuel cell supply chain
- Innovation needed to leverage existing fuel cell technology in electrolysis cell
  - Incremental funding over fuel cell investment
- Technical challenges are understood; will grow as fast as the markets emerge

C-series cost breakdown

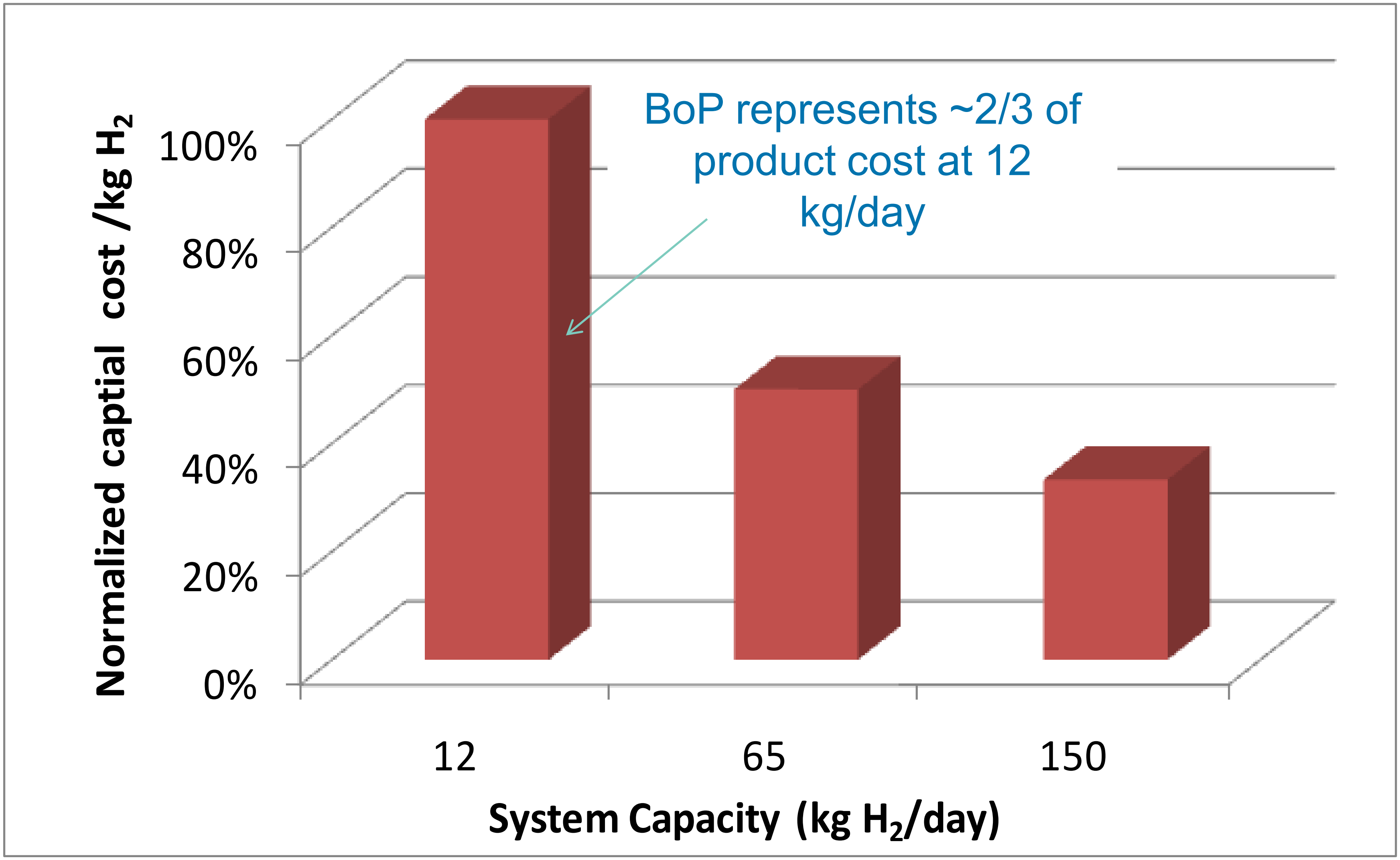


- Highest cost areas: cell stacks, power supplies/electronics, and assembly labor
- Cell stacks represent larger fraction of cost with scale up
- Enclosure and custom parts still much higher than typical “appliance”

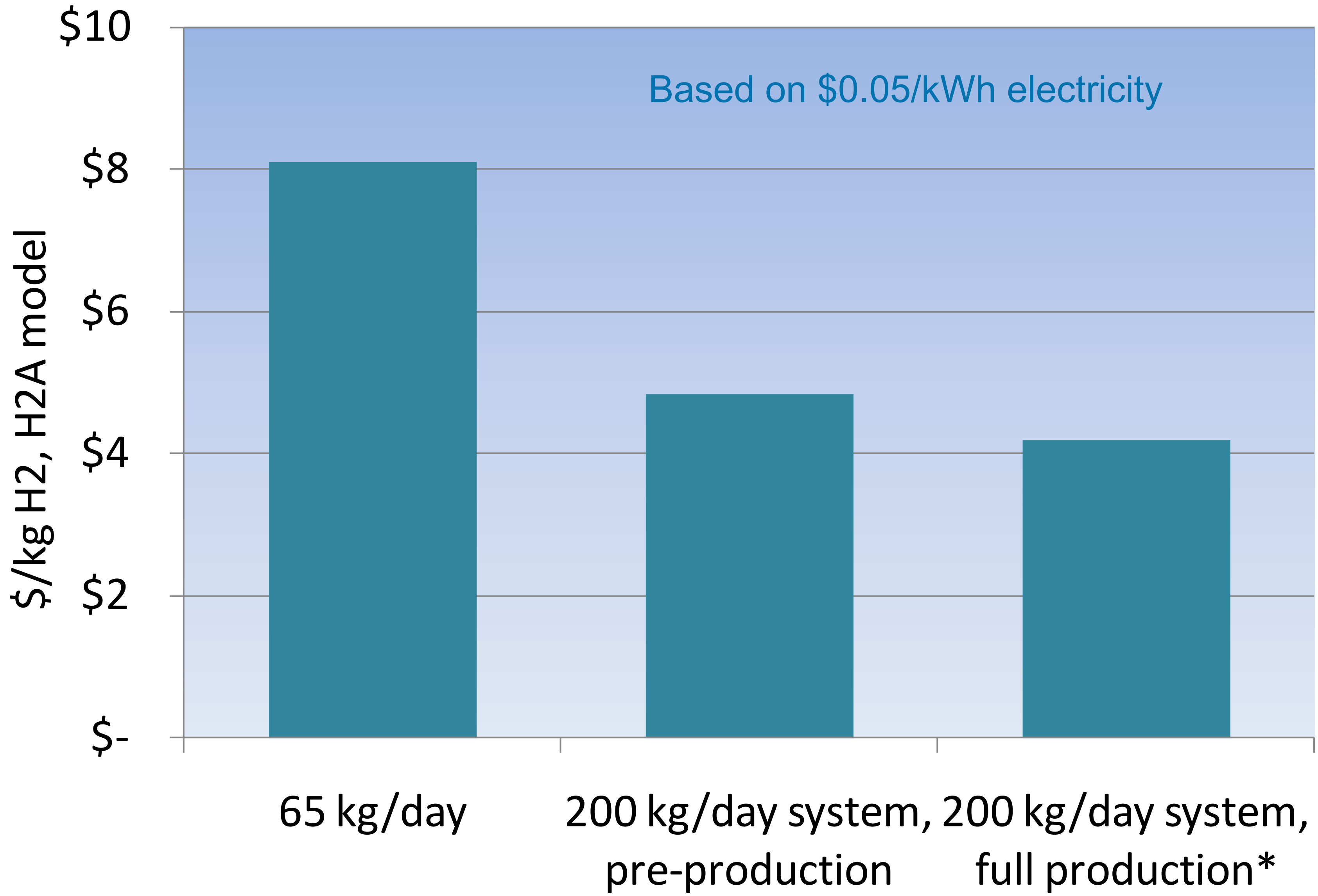
System Needs

- Utilization of off the shelf components
  - Electronics
  - Enclosures
- Investment in high speed tooling/molds
- Increased production volumes through strategic/subsidized deployment
- Investment in larger scale balance of plant
- Conversion to all DC input

Impact of Scale Up on Balance of Plant Cost



Resulting Hydrogen Cost Progression



*Assumes volumes of 500 units/year

Conclusions

- PEM electrolysis is at the tipping point for manufacturability
  - Sustainable business at current level
  - Can make huge impact with continued progress
- Labor component is still very high
  - Investment in volume manufacturing equipment needed
  - Need collaborative technology development with supply chain especially for cell stack cost reductions
- Larger systems are pathway to DOE targets