



"Manufacturing Readiness Levels to Assess the Status of PEM Fuel Cell Stack and System Manufacturing for the Back-up Power and Materials Handling Equipment Emerging Markets", # 240



**2009 Fuel Cell Seminar
& Exhibition**

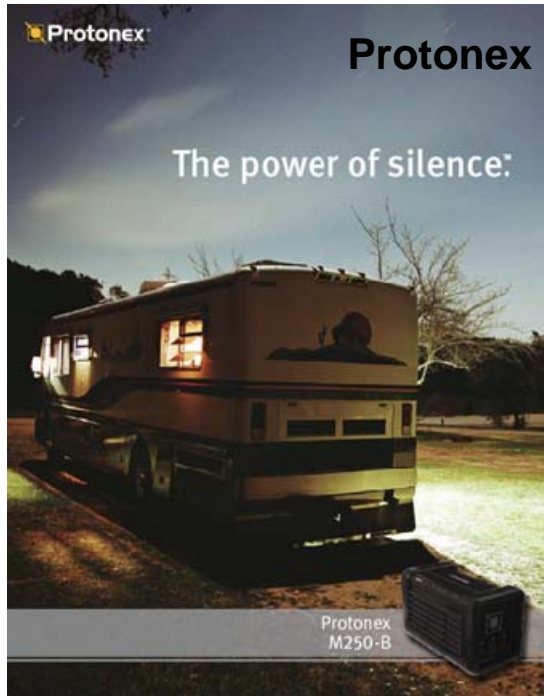
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Outline

- Motivation for the study
 - DOE Market Transformation
 - Methodology
 - Participant Companies
 - Emerging Markets
- Manufacturing Readiness Levels (MRLs)
 - Purpose
 - Creating DOE MRLs for fuel cells
 - Risk elements
- Manufacturing Readiness Assessment (MRA)
 - Results for stacks & systems
 - Conclusions
 - Key barriers
 - Recommendations

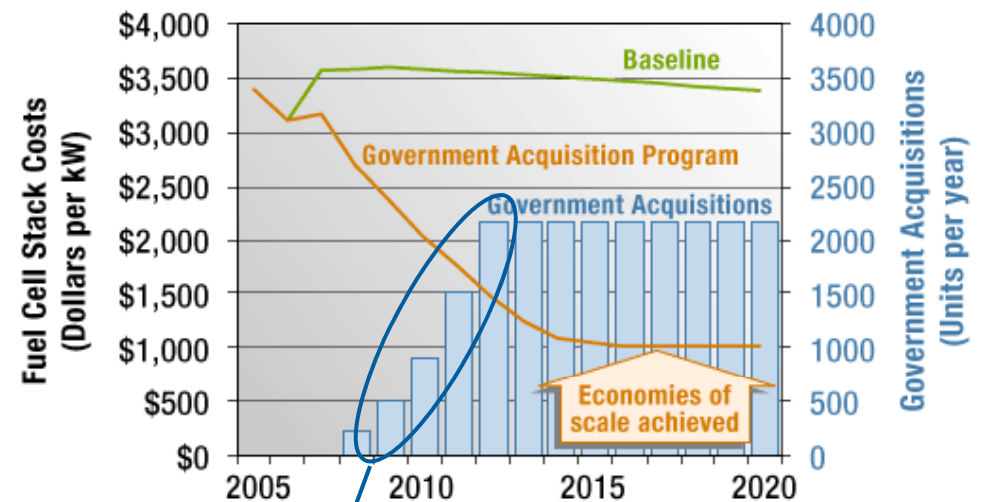
MRA Participants



Market Transformation

- Assist Federal Agencies in using hydrogen and fuel cells to meet requirements of:
 - EPACK 2005 Sec. 782 and 783
 - Executive Order 13423
- Increase volume of fuel cell purchases to achieve economies of scale
- Support national infrastructure and domestic supplier base development
- Improve user confidence in fuel cell reliability by collecting operations data

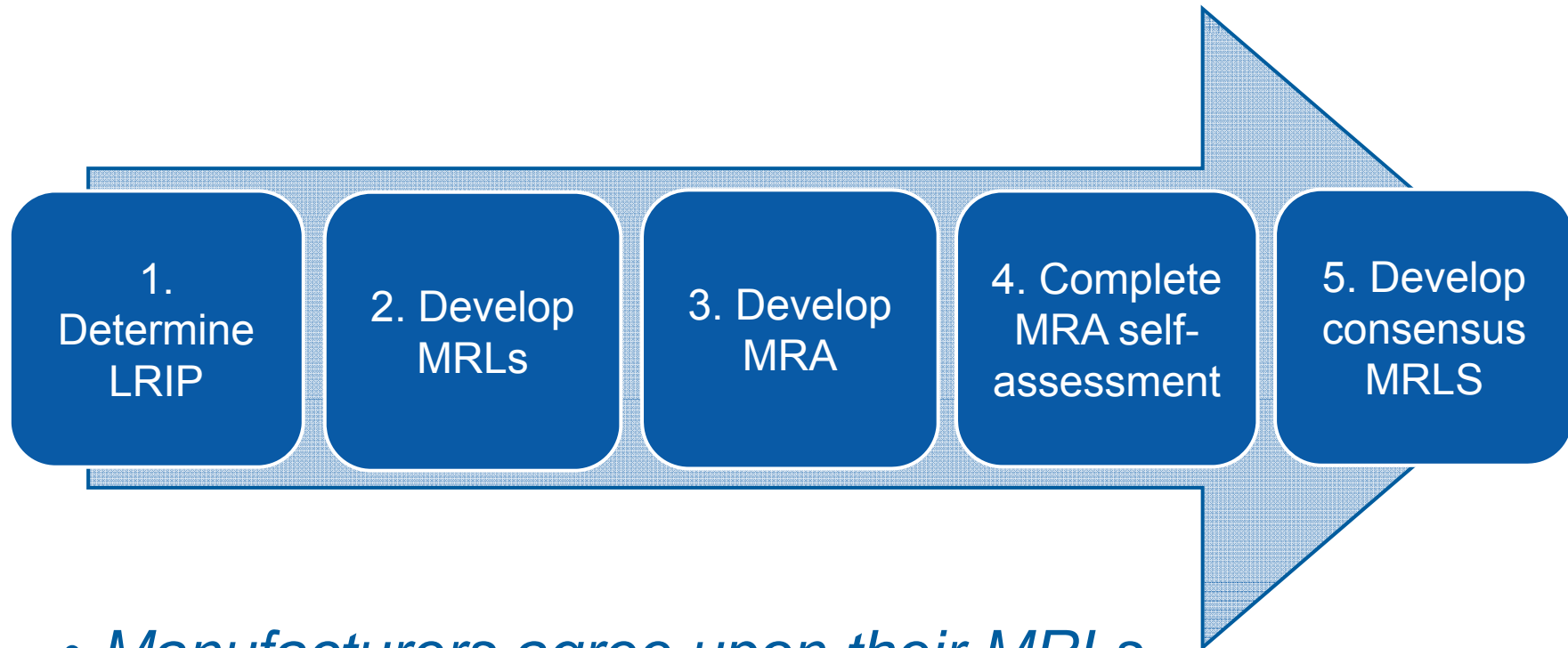
Estimated Impact of Government Acquisitions on Fuel Cell Stack Costs



Joseck, "System Analysis," DOE HFCIT Annual Merit Review, May 2009

What is the readiness of the industry to produce at these volumes?

Methodology



- *Manufacturers agree upon their MRLs*
- *MRL reporting in aggregate*
- *NREL provides independent assessment of manufacturing readiness*

Emerging Markets

Battelle Market Analysis (federal applications)

- Emergency Backup Power (FAA and others)
 - Immediate 75% replacement market penetration
 - Industry projected slower market penetration
 - ✓ 100 to 500 units in year one
 - ✓ **1000 units in year two – Low Rate Initial Production (LRIP)**
- Forklift Trucks (DLA and USPS)
 - Assumed 20% replacement market for all but Class 2 forklift trucks
 - **Low Rate Initial Production confirmed by industry: 1000 units per year**



Table 3: Battelle market analyses data for Emergency Backup Power and Forklift Trucks

Market	Market Size	Annual Replacement Market	Replacement Market for PEM Fuel Cells in Initial Years
Emergency Backup Power	19,900	2,265	1,699
Forklift Trucks*	755,967	108,606	~5,000
DLA & USPS Forklift Trucks	14,175	2,435	472



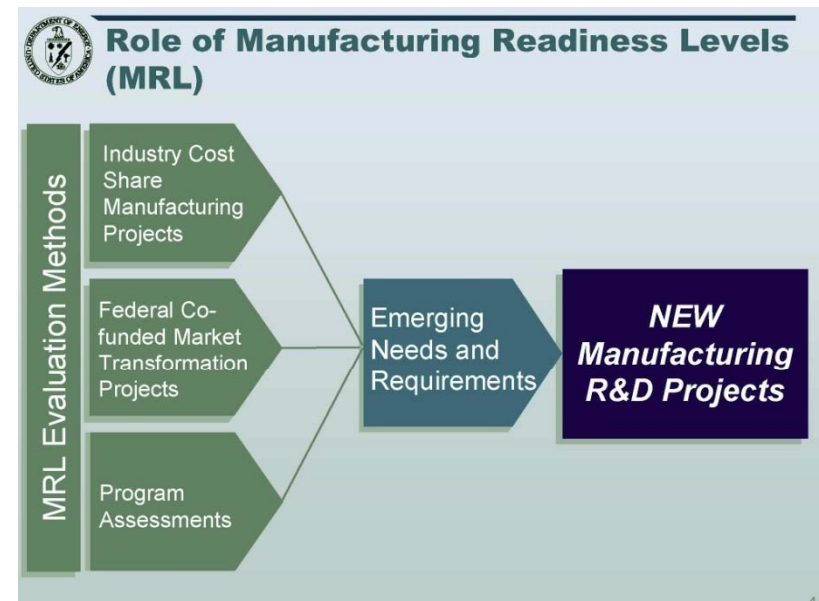
Mahadevan, K. et al, "Identification and Characterization of Near-term Direct Hydrogen Proton Exchange Membrane Fuel Cell Markets", Battelle, April 2007, DOE Contract No. DE-FC36-03GO13110
 Mahadevan, K. et al, "Market Opportunity Assessment of PEM Fuel Cells in Federal Markets," FCS&E, October 2007

MRLs

“Investment risk of developing manufacturing capability for hydrogen and fuel cell technologies is high.”

-U.S. Department of Energy HFCIT MYPP

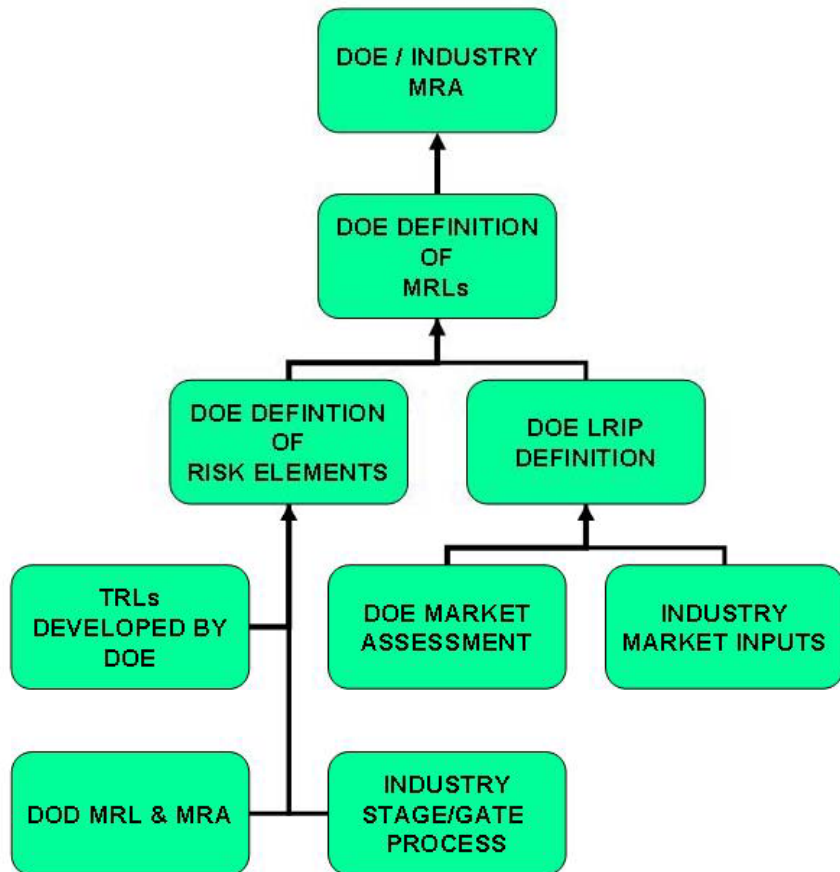
- A tool to address economic and institutional risks associated with scale-up of production
- The DOE MRLs gauge the progress of the PEM industry in its transition from R&D to commercialization
- MRLs can reinforce planning for DOE Manufacturing R&D and Market Transformation



Devlin, P., "Manufacturing R&D and Market Transformation", 2008 DOE Hydrogen Program Merit Review and Peer Evaluation Meeting, June 9, 2008

DOE MRL/MRA Approach

- MRL approach
 - DOD: Procurement
 - DOE: Grow the market
- DOE MRLs
 - Focus on near-term pre-automotive markets in determining LRIP
 - Specific to market
 - Market data from DOE and industry
 - Risk Elements
 - DOD formality
 - DOE fuel cell TRLs
- Manufacturing Readiness Assessment
 - Industry Self-assessment
 - NREL independent assessment



Manufacturing Readiness Levels

Table ES -1: Manufacturing Readiness Levels	
MRL - 1	Manufacturing Feasibility Assessed
MRL - 2	Manufacturing Concepts Defined
MRL - 3	Manufacturing Concepts Developed
MRL - 4	Laboratory Manufacturing Process Demonstration
MRL - 5	Manufacturing Process Development
MRL - 6	Critical Manufacturing Process Prototyped
MRL - 7	Prototype Manufacturing System LRIP is established here
MRL - 8	Manufacturing Process Maturity Demonstration
MRL - 9	Manufacturing Processes Proven FRP is demonstrated
MRL - 10	Full Rate Production demonstrated and lean production practices in place

Manufacturing Risk Elements

Risk Elements:

- Define nine areas of risk to be assessed across the entire manufacturing enterprise
- Are the same within each MRL, however
- Requirements become more advanced as manufacturing enterprise progresses along MRL scale

1	Technology & the Industrial Base
2	Design
3	Materials
4	Cost & Funding
5	Process Capability and Control
6	Quality Management
7	Manufacturing Personnel
8	Facilities
9	Manufacturing Planning, Scheduling, and Control

Manufacturing Risk Elements

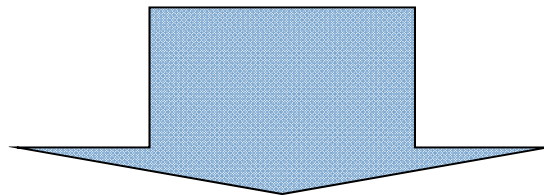
Example: Risk element 10 – Manufacturing, Scheduling, Planning, and Control

MRL – 4
Manufacturing control hierarchy is in place

MRL - 7
Production planning is complete; ready for LRIP

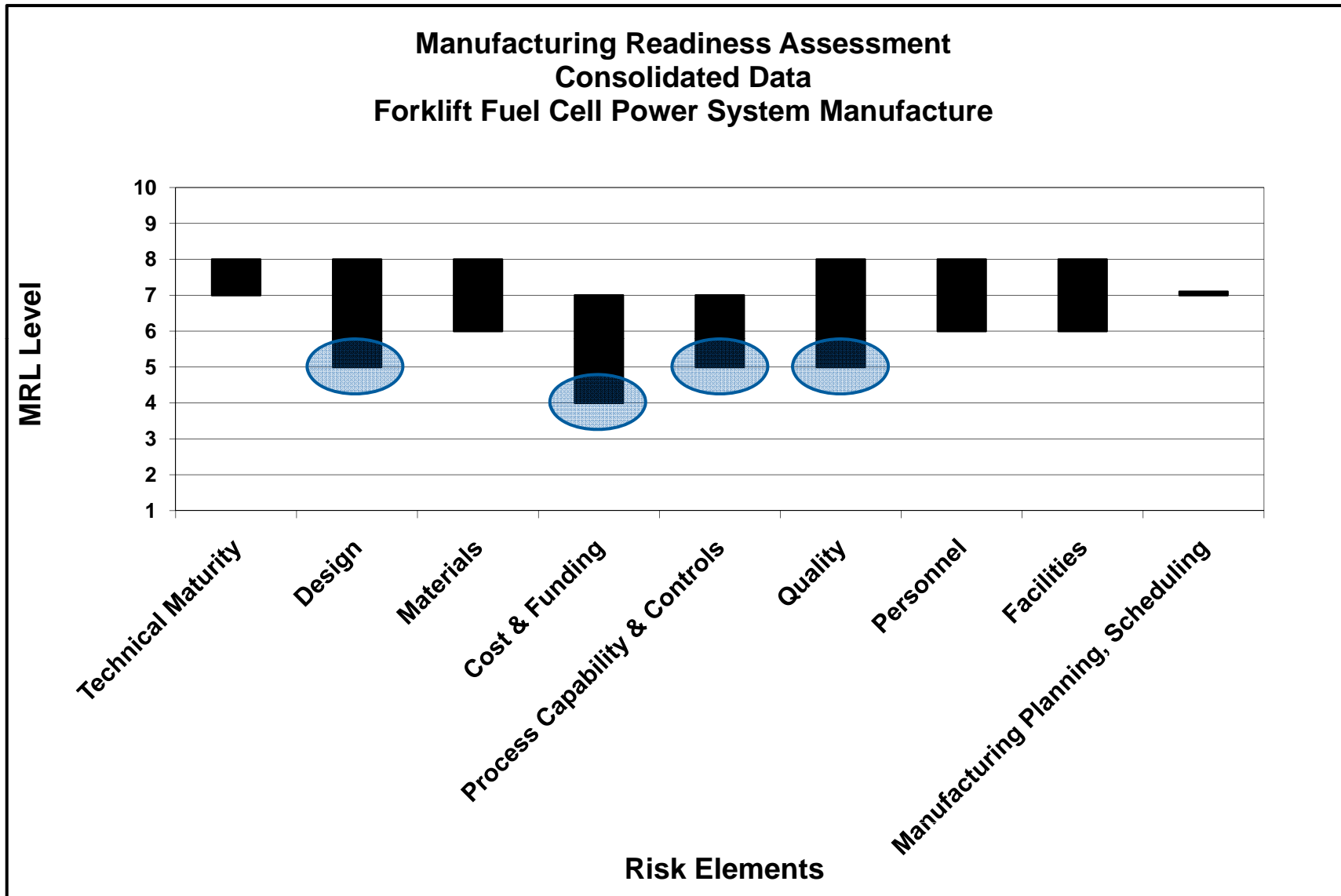
MRL- 9
FRP planning and control measures under development

MRL-10
Operating at FRP planning & control in place

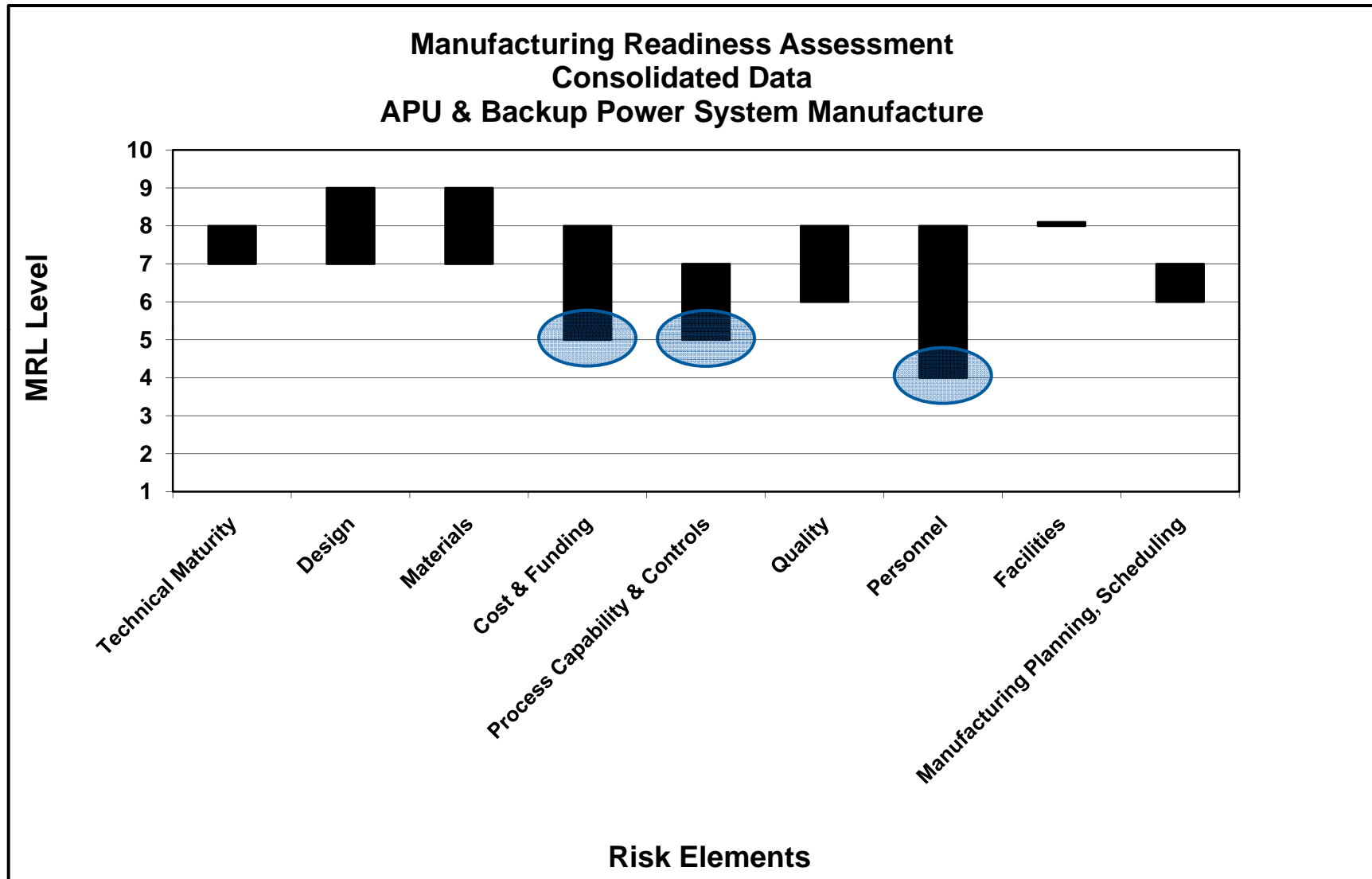


***Progression leads to MRA self-assessment
(questionnaire)***

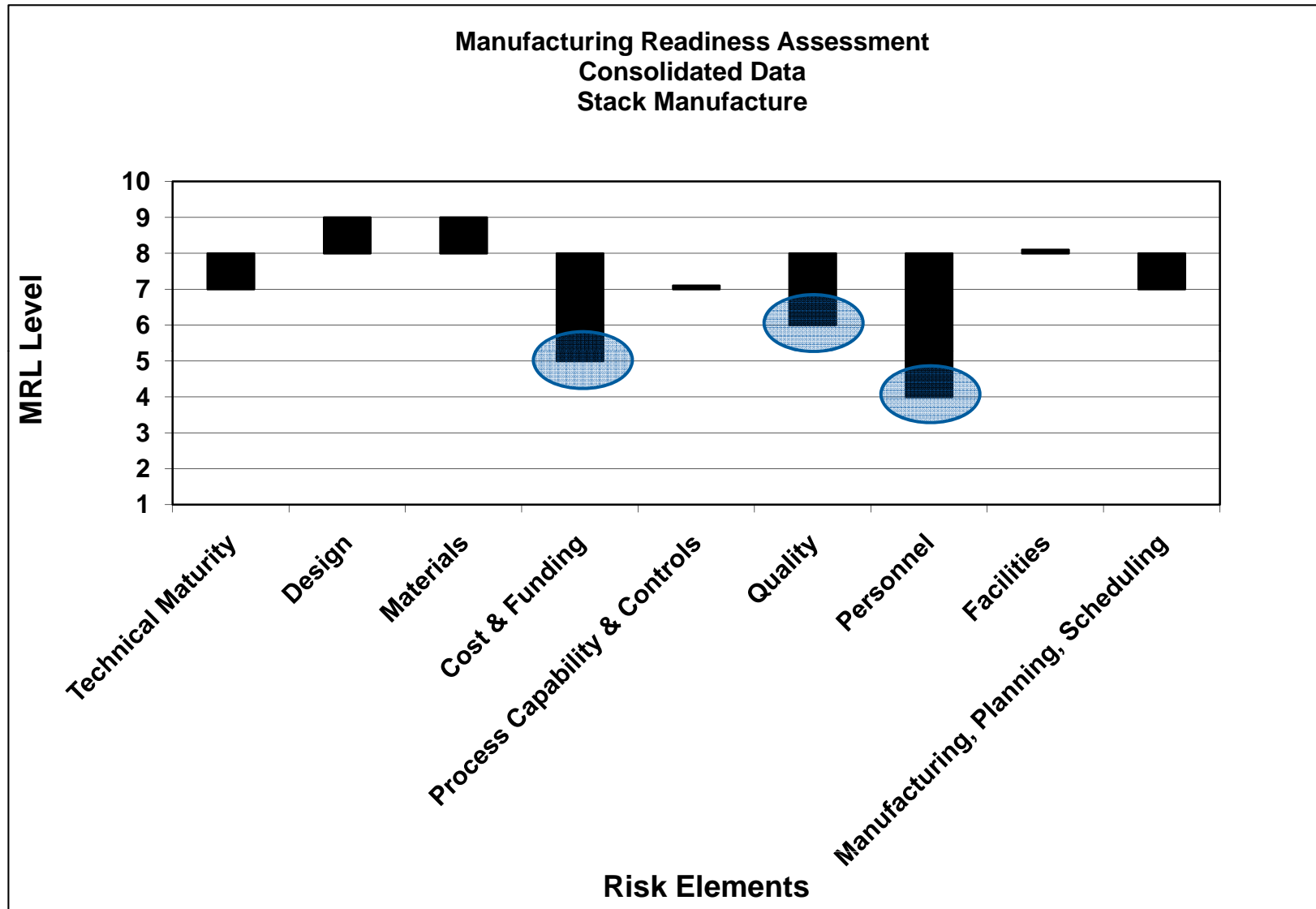
MRA Results: Forklifts



MRA Results: APU & Backup



MRA Results: Stacks



Conclusions

- Manufacturers are confident that their current manufacturing approaches can achieve LRIP
- For the forklift truck and back-up power & APU emerging markets, manufacturers are not currently producing at the 1000 unit LRIP
 - Current production levels are in the range of 200-300 units per year
- Manufacturing readiness for stacks is more advanced than for systems
- The risk elements with the lowest rankings are representative of the transition from prototype development to a stable, commercial design

Key Barriers to Achieving LRIP

- Testing and quality control was an issue mentioned by all four manufacturers.
 - Increased quality control in the assembly of stacks would advance automation
 - In-line quality control measurements are needed
 - Semi-automated and fully-automated stack and system assembly techniques need to be developed
- Stack and final system conditioning are too long and costly
 - Manufacturers recommended developing a suite of short term tests that would correlate with durability and reliability of the stack and system
- Balance of plant (BOP) subcomponent testing is a barrier
 - A better understanding of the quality variability of BOP components was clearly identified as an industry need
- Design-for-manufacturability is needed
 - *“Transition to full rate production will require a total redesign of manufacturing capability and facilities, and may require redesign of stack”*

Recommendations

- The following are recommended to address the Cost & Funding and Personnel risk elements:
 - **Market Transformation** programs that identify cost-competitive applications and support increased **market demand**
 - **R&D** support for programs to **lower the initial cost** of the fuel cell system
- The following are recommended to address the Quality risk element:
 - Support for programs to **establish quality control methodologies** for stack components
 - Support for programs to reduce the time and equipment required for **stack and system test and break-in**
- Further enhance the efficacy of the NREL analysis by completing MRAs with **additional manufacturers** supporting these emerging markets

Acknowledgement

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 - Sunita Satyapal, Nancy Garland, Terry Payne, and John Christensen
- Manufacturers: Hydrogenics Corp., Nuvera Fuel Cells, Plug Power Inc., Protonex Technology Corporation

<http://www.nrel.gov/hydrogen/pdfs/45406.pdf>