



power to change the world*



BALLARD®



Requirements & Status for Volume Fuel Cell Manufacturing

DOE Hydrogen Program, Washington, DC

July 13-14, 2005

Requirements for Manufactured Fuel Cells

- Customer Requirements: Commercial Plant Study
 - Volume: 250,000 fuel stacks per year
 - Cost: \$30/kw net



Requirements for Manufactured Fuel Cells

- Commercial Volume Manufacturing
 - Material Utilization: >85%
 - Controlled Environments (Humidity, temperature, dust)
 - Environmentally safe direct and indirect materials
 - Hydrogen safety
 - Make or Buy Decisions on non/proprietary unit cell components
 - Integrated strategic supply chain
 - Design for Manufacturing, Assembly, and Service

Requirements for Manufactured Fuel Cells

- Quality Control & Assurance
 - Accelerated tests and process parameters correlated to key product requirements (QFD)
 - From 100% Inspection to SQC Sampling to SPC
 - Measurement System Variability: <10% of signal
 - Error Proofing
 - Six Sigma capability on high cost and key performance related materials and processes (DMAIC & DFSS)
 - Configuration Control & Batch Traceability

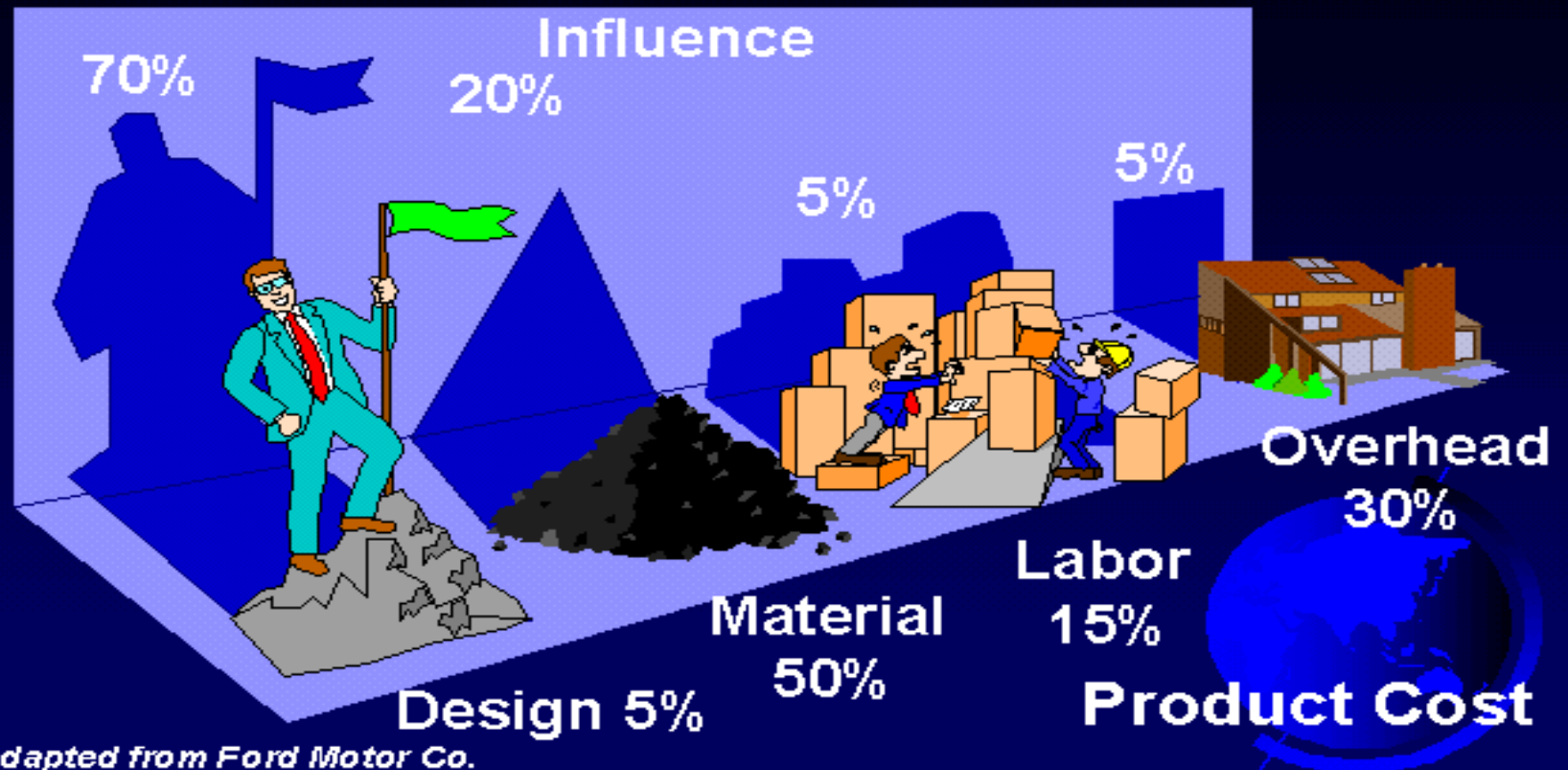
Requirements for Manufactured Fuel Cells

- Commercial Plant Must Also Support
 - Customer Acceptance Testing
 - Certificate of Compliance: Additional testing not req'd at OEM
 - Customer Service: Repairs, Failure Analysis, On-site support

DFMA

Promotes a fuller understanding...

Who Casts the Biggest Shadow?



Adapted from Ford Motor Co.

2000 Boothroyd Dewhurst, Inc.

Requirements for Manufactured Fuel Cells

- Automotive Customer
 - APQP
 - Certificate of Compliance
 - Capable and Controlled Processes
 - Process and Designs Verified and Validated to meet Automotive Application Requirements
 - PPAP (part Submission Warrant)
 - Configuration and Document Control
 - Traceability
 - ISO/TS16949 Certification

Requirements for Manufactured Fuel Cells

- Design

- DFMA incorporates materials, features & tolerances for ease of supply, high volume manufacture, assembly, and service
- Increase consideration for manufacturing yield and material utilization
- Eliminate components, parts and process steps
- Standardize core components across products
- Standardize non-core components across supplier-base

Requirements for Manufactured Fuel Cells

■ Supply Chain

- Form supplier relationships & partnerships to ensure manufacture of fuel cells in volume, resulting in economies of scale to drive down the material costs
- Involve suppliers early in design
- DFMA requirements form Manufacturing into Material and Part Specifications

Requirements for Manufactured Fuel Cells

- Additional Design Requirements

- Multi-component ink mixtures and dispersions
- 3-D unit cell macro and micro-structures
- Adhesive and cohesive layers
- Selective surface treatments
- Heat Treatments
- Reproducible tolerances on finished parts and assemblies
- Finished components and stacks sealed for both Liquids and Gases
- Electrical Isolation and ESD Protection
- Enclosure and Packaging to Automotive OEM Requirements

Manufacturing Technology Status

- MEA

- Design for Manufacturing features incorporated into Design
- Semi-automated Discrete/Continuous
 - Ink mixing and delivery
 - Gas Diffusion Layer
 - Hydrophobic/Hydrophilic Treatments
 - Electrode Fabrication
 - MEA assembly
- Semi-automated Sealing

GDL – Continuous Fabrication & Heat Treatment



GDL Fabrication

GDE - Continuous Processing



Finished



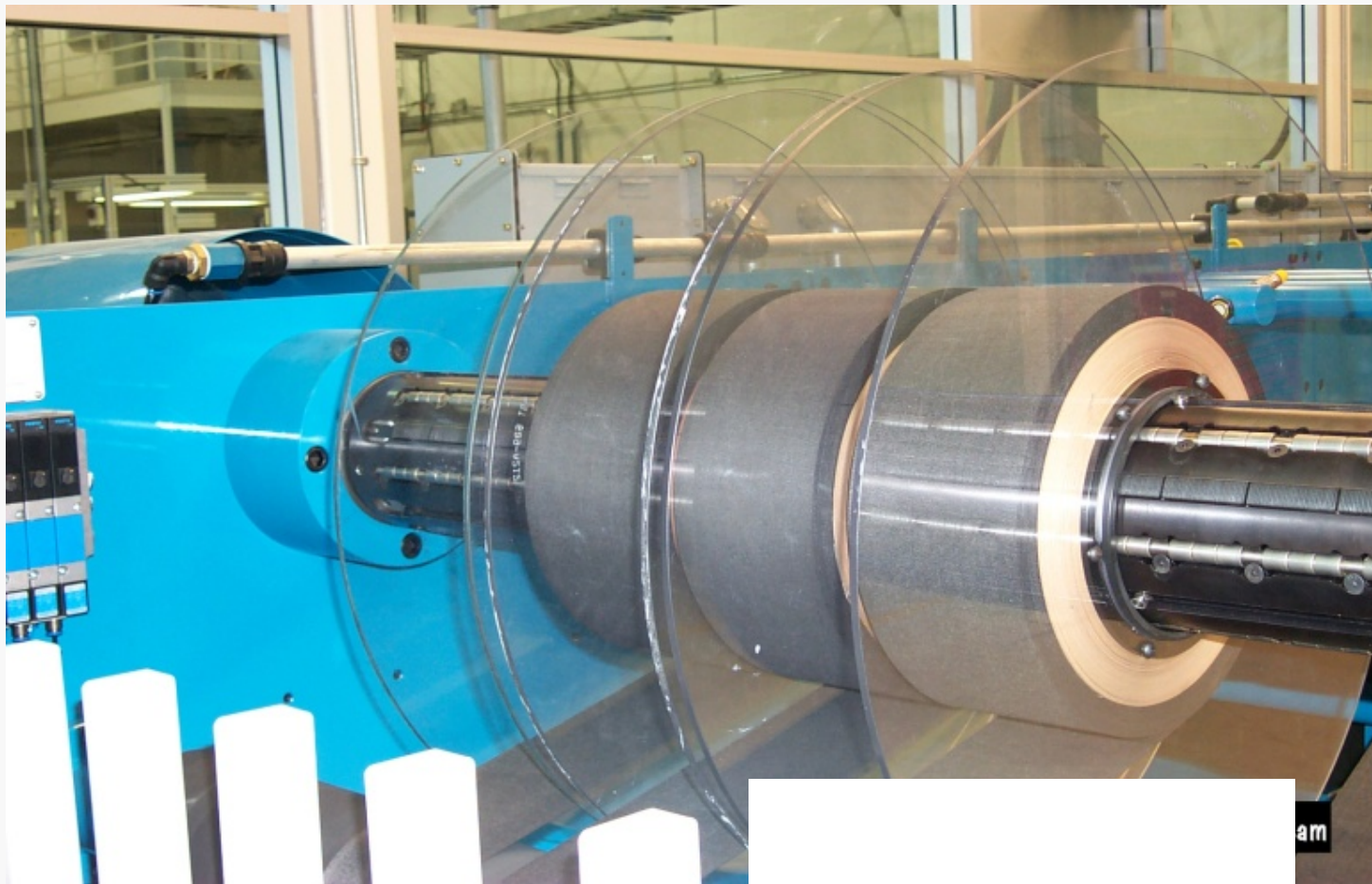
Treating

Catalyst Coatings
(GDE)

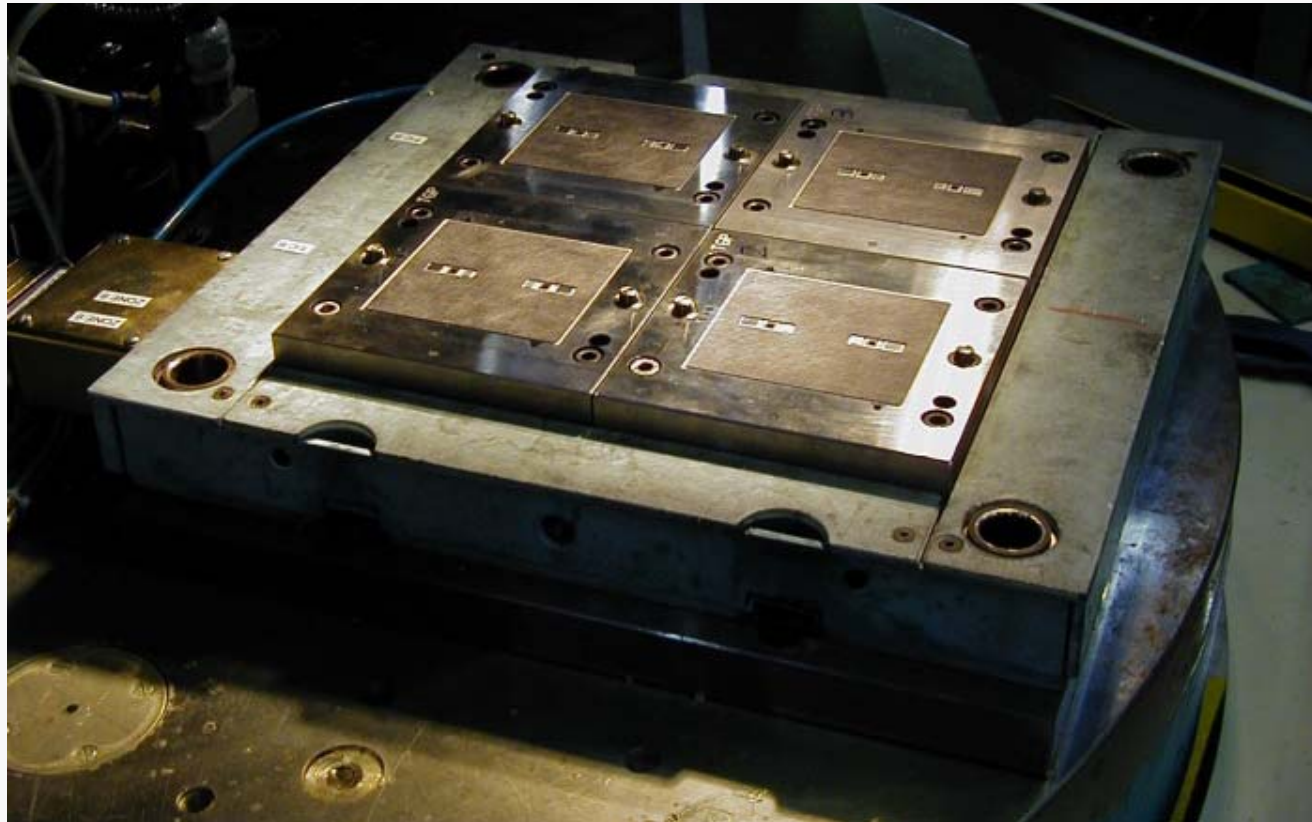
MEA – Continuous Assembly



MEA –Flexible and Continuous Sizing

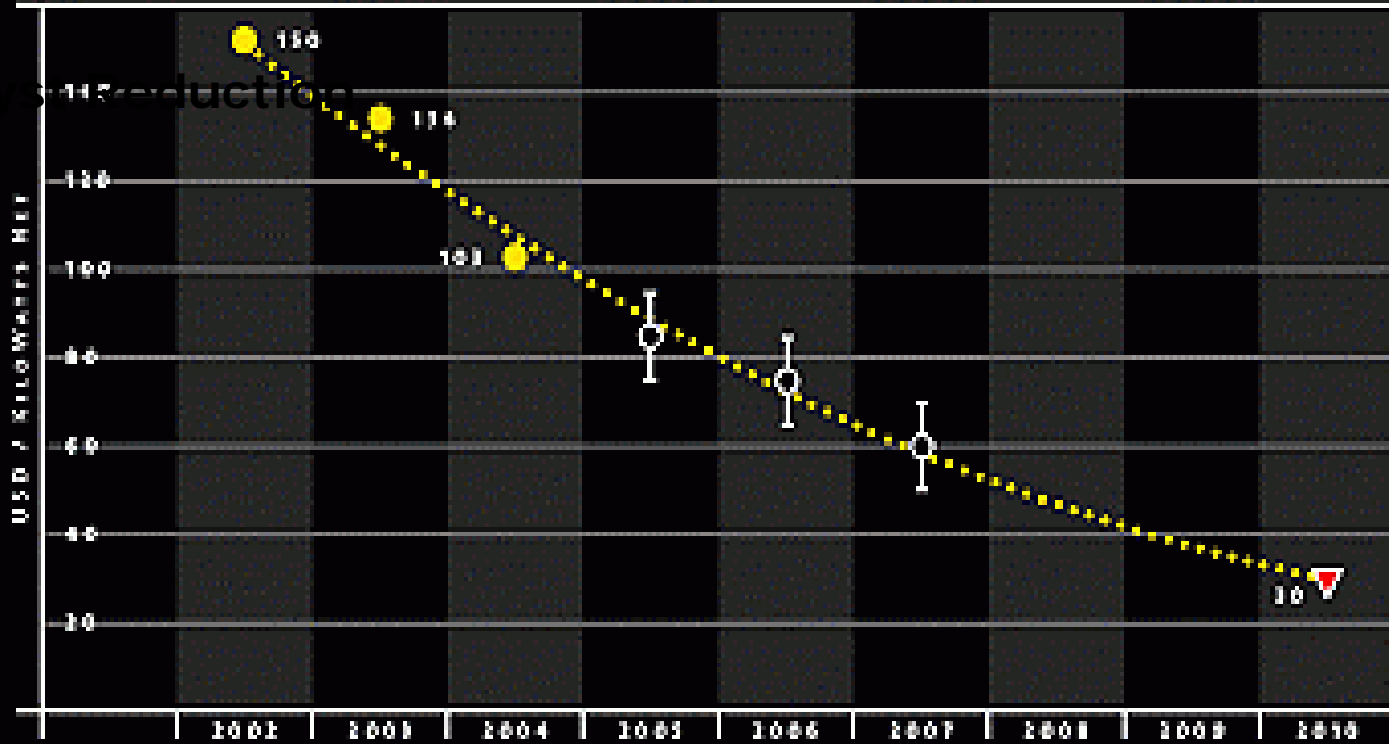


MEA – Semi-automated Sealing



MEA C FUEL CELL STACK COST

■ Catalyst Reduction



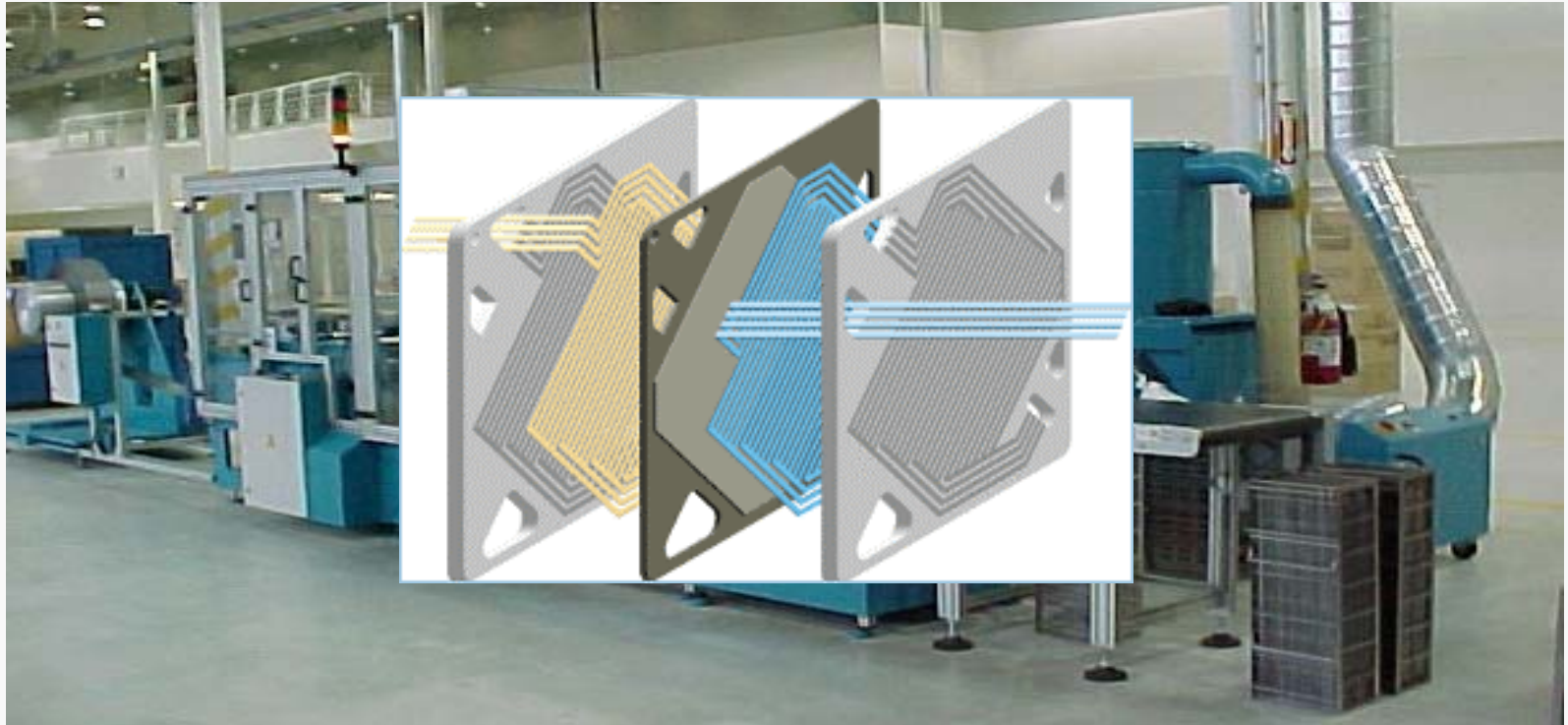
High-volume cost model assumes production of 500,000 units/year

- Actual Cost to Date
- Projected Target Cost / Range
- ▼ 2010 US DOE Target - \$30/kW Net for fuel cell stack

Manufacturing Technology Status

- Bi-Polar Separator Plate
 - Design for Manufacturing Features incorporated into Design
 - Discrete/Continuous
 - Flowfield Embossing
 - Semi-automated
 - Plate Sealing
 - Plate Assembly

Continuous Plate Fabrication

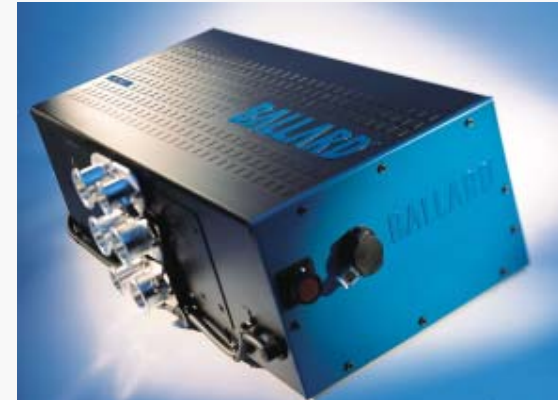


Semi-Automated Plate Sealing



Manufacturing Technology Status

- Stack & System Assembly
 - Design for Assembly features
 - Integrated Unit Cell Sealing
 - Manual/Semi-automated
 - stack assembly
 - electrical continuity and leak testing
 - compression and fastening
 - Manual Packaging



BALLARD[®]
power to change the world[®]

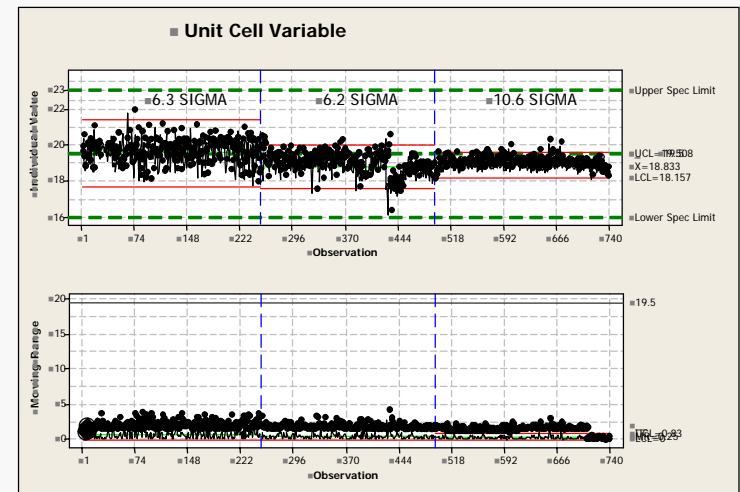
Semi-Automated Stack Assembly



Manufacturing Technology Status

■ Quality Control & Assurance

- Unit Cell Processes under SPC
- Non-contact/destructive gauging
- Key processes Six-Sigma capable
- 100% stack (accelerated) testing to customer requirements
- 100% stack leak testing
- 100% material batch and configuration traceability
- 100% process variable data collection
- Key process variables correlated to key product requirements
- Integrated Plant Data System (iPDS) and document control system
- Automotive Supplier Certified (ISO/TS16949)



Semi-Automated 'End-of Line' Quality Testing





Barriers To Be Overcome ...

1. OEM Requirements Cascade
2. Customer Application and Acceptance Testing
3. Hydrogen Leak Test Capability
4. Unit Cell microstructure manufacturing
5. Design for Six Sigma
6. Automotive qualified suppliers

The Future is closer than we think

75 Cars and 35 Buses in operation today



DC/Ballard Fuel Cell Bus operational in Reykjavik, Iceland