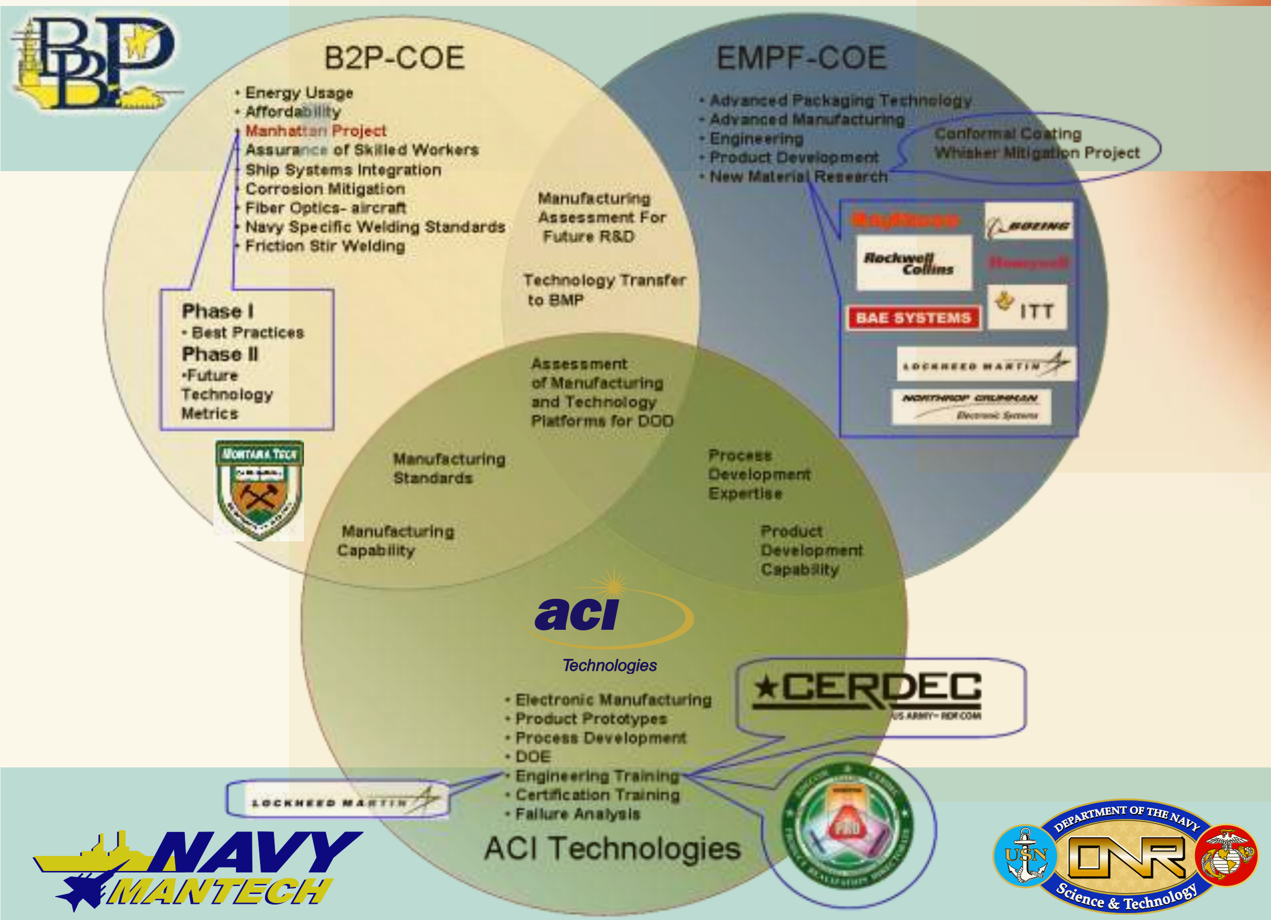
Manufacturing Fuel Cell Manhattan Project

Presented by
Carmine Meola
Rebecca Morris

MFCMP Project Sponsors



Example Special Projects within the B2PCOE

- Energy Usage – Ship Yard Cost Reduction
- Lead Free – Manhattan Project (DOD Leverage)
- Best Practices for Assurance of Skilled Workers
- Best Practices in Ship System Integration
- Advanced Shipbuilding Affordability Technologies
- *Manufacturing Fuel Cell Manhattan Project*

Manhattan Manufacturing Fuel Cell Project

- MFCMP Phase 2
- Location: Butte, MT
- Dates
  - Polymer and BOP Session: March 15 – 20, 2011
  - Ceramic Fuel Cell Session: March 17 – 22, 2011
  - Joint Session Days: March 17 – 20, 2011
  - Leadership Wrap Up: March 23, 2011

Manufacturing Fuel Cell Project

Program Leaders

- Rebecca Clayton – ONR

- Carmine Meola – ACI
- Rebecca Morris – ACI
- Mark Shinners – ACI

- Randy Hiebert – MTT
- Robert Hyatt – MTT
- Jay McCloskey – MTT
- Brian Park – MTT
- Ray Rogers - MTT

Technical Leaders

- Mark Cervi – NSWC Philadelphia
- John Christensen – Consultant
- Marc Gietter – CERDEC
- Leo Grassilli – ONR
- Shailesh Shah – CERDEC
- Mike Ulsh – NREL / DOE

Manufacturing Fuel Cell Project

Participants

- Joe Bonadies – Delphi Corp.
- David Carter – Argonne
- Mark Cervi – GDIT / NSWC
- Paul Chalmers – Hydrogenics
- John Christensen - Consultant
- Aaron Crumm – AMI
- William Ernst – Consultant
- Matt Fay – General Motors
- Marc Gietter – CERDEC
- Leo Grassilli – ONR
- Pat Hearn - Ballard
- Dennis Kountz – DuPont
- Rebecca Morris – ACI
- Randy Petri – Versa
- Joe Poshusta – Protonex
- Jolyon Rawson - Acumentrics
- Steve Rock – RPI
- Kathryn Rutter - Ballard
- Shailesh Shah – CERDEC
- Duarte Sousa – Ballard
- Eric Stanfield – NIST
- Matt Steinbroner – Consultant
- Scott Swartz – NexTech
- John Trocciola – Consultant
- Mike Ulsh – NREL / DOE
- Doug Wheeler – DJW Tech

Manufacturing Fuel Cell Project

Objectives , Benefits, and Applications

Objectives Completed

B2PCOE
Montana Tech
SME's

↔

Industry
Academia
Government
FC Consortiums

- Objectives Phase 1 – October 2010
  - √ Identify manufacturing cost drivers to achieve affordability
  - √ Identify best practices in fuel cell manufacturing technology
  - √ Identify manufacturing technology gaps

Manufacturing Fuel Cell Project

Deliverables Phase 2 – March 2011

Manufacturing Roadmap

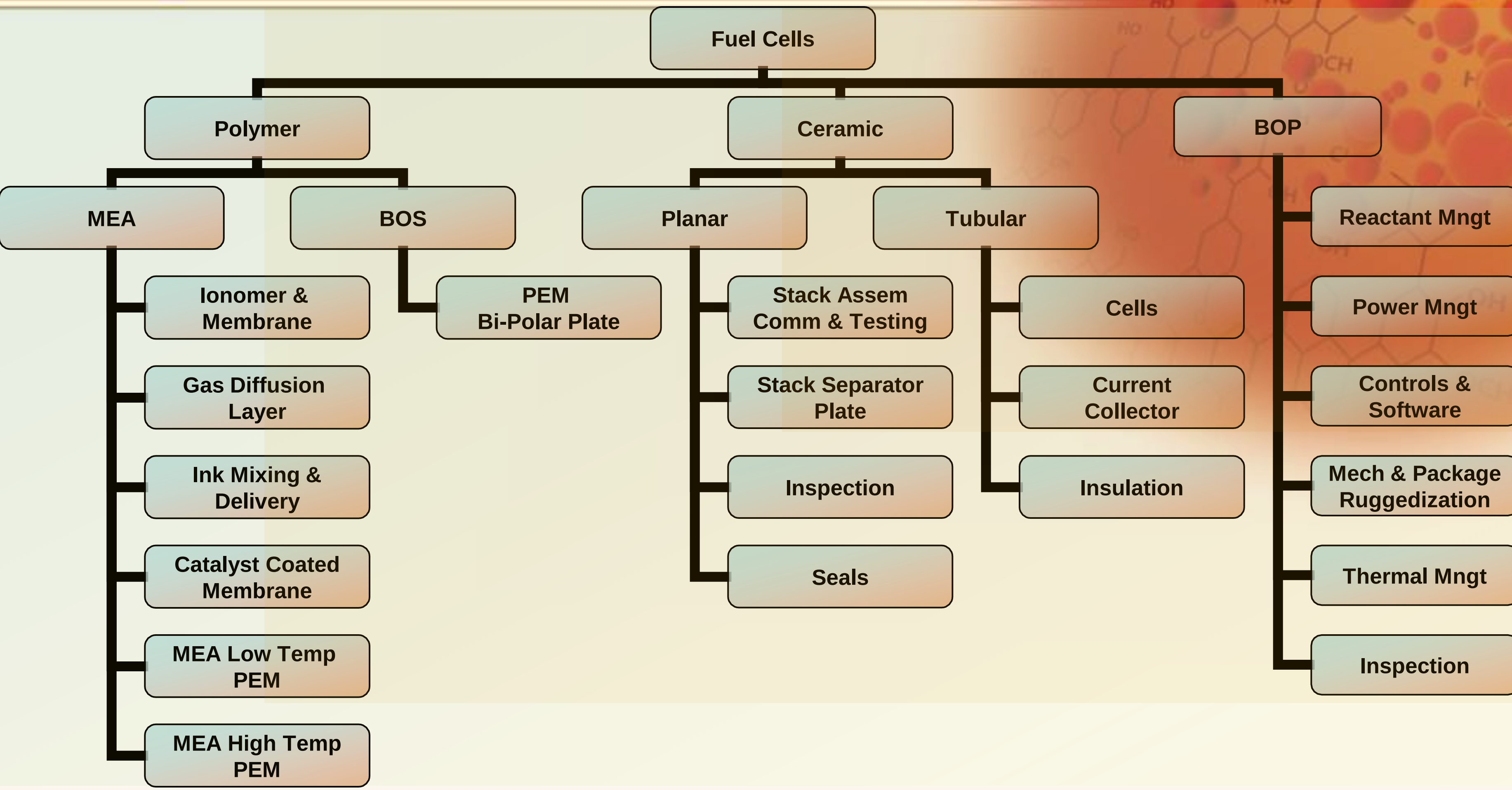
- **Projects to resolve the gaps**
- **Schedule a strategy for effective investment**
  - **Sequence Projects**
  - **Prioritize Projects**
  - **Projects that can benefit all**
- **Manufacturing Fuel Cell Publication: Oct. 2011**

Navy Benefits

Why the Navy Cares

- Reduce logistics and financial footprints for delivering energy
- Increase fuel efficiencies
- Modularity for distributed power systems
- Supplemental Power
- Reduce ship signatures
  - Lower thermal signatures
  - Lower audible noise
- Low maintenance when compared to diesel generators
- Lower hydrocarbon emissions
- Lower SO_2 and NO_2 emissions

Manufacturing Fuel Cell Project Taxonomy



Manufacturing Fuel Cell Project

DOD Applications That May Benefit

Target Applications

Soldier Power

Unmanned UAV

Emergency Power

Tactical APUs

Aircraft APUs

Shipboard APUs

Material Handling

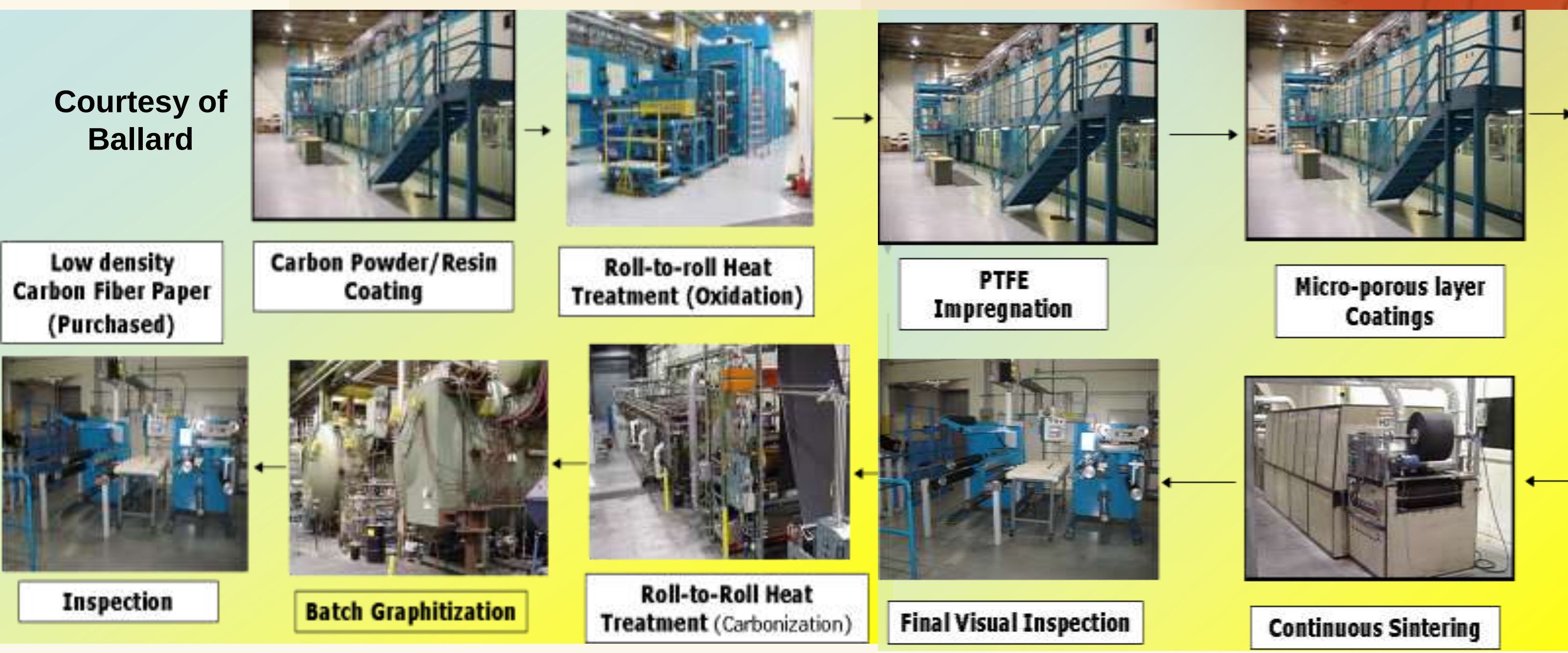
Distributed Stationary Power

System Power in Watts →

1 | 10 | 100 | 1000 | 10000 | 100000 | 1000000

Manufacturing Fuel Cell Project

Cost Drivers
For Polymer Fuel Cells (MEA, BP, BOP)

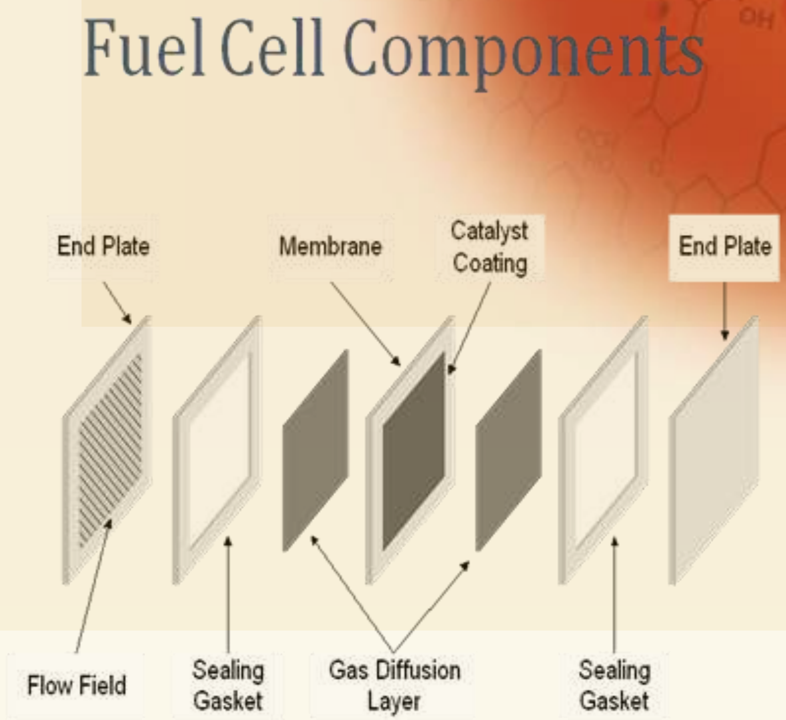


aci BBP NAVY MANTECH ONR CAMP MontanaTech THE UNIVERSITY OF MONTANA

Polymer Membrane Fuel Cell Session

Key Cost Drivers For Membrane Electrode Assembly (MEA)

- Electrode
- Pt group catalyst
- Membrane
- GDL / Seals
- Assembly

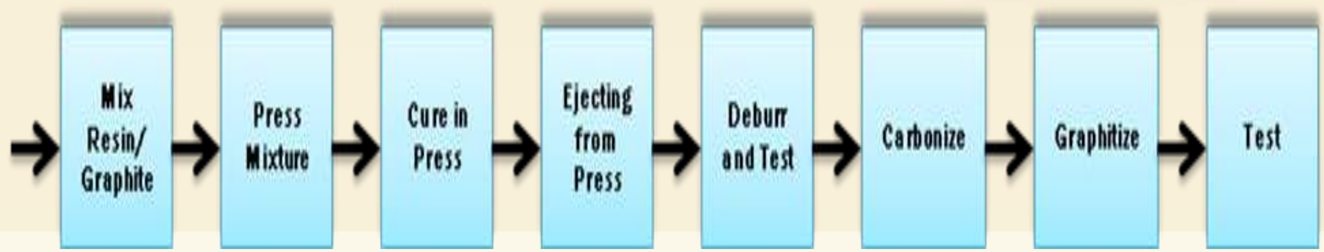


Key Cost Drivers For PEM Bipolar Plates

- Bipolar Plate
- Labor
- End Plate
- Stack Sealing
- Hardware
- Packaging

Low Temp BP Manufacturing Process

High Temp BP Manufacturing Process



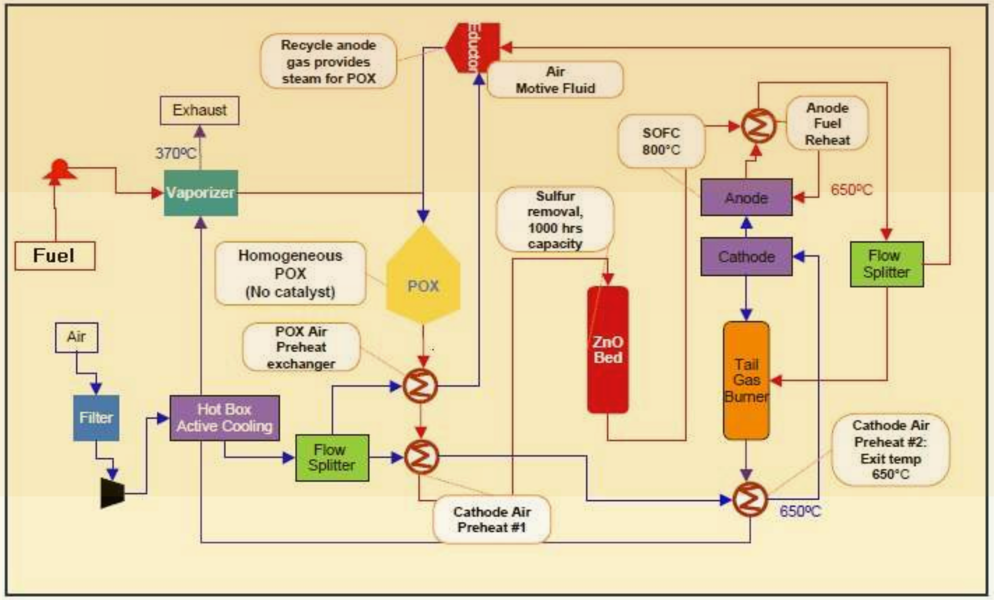
BOP for Polymer & Ceramic Fuel Cell Session

Key Cost Drivers BOP

- Stack
- ATR / Reactant Management
- Mechanicals Packaging
- Controls
- Thermal Management
- Power Conditioning / Management
- Balance of Hot Zone

Example of SOFC Heat Removal

The SOFC system flow diagram shows that equipment for heat removal (and recovery) and fluid movement plays a critical role in the system.



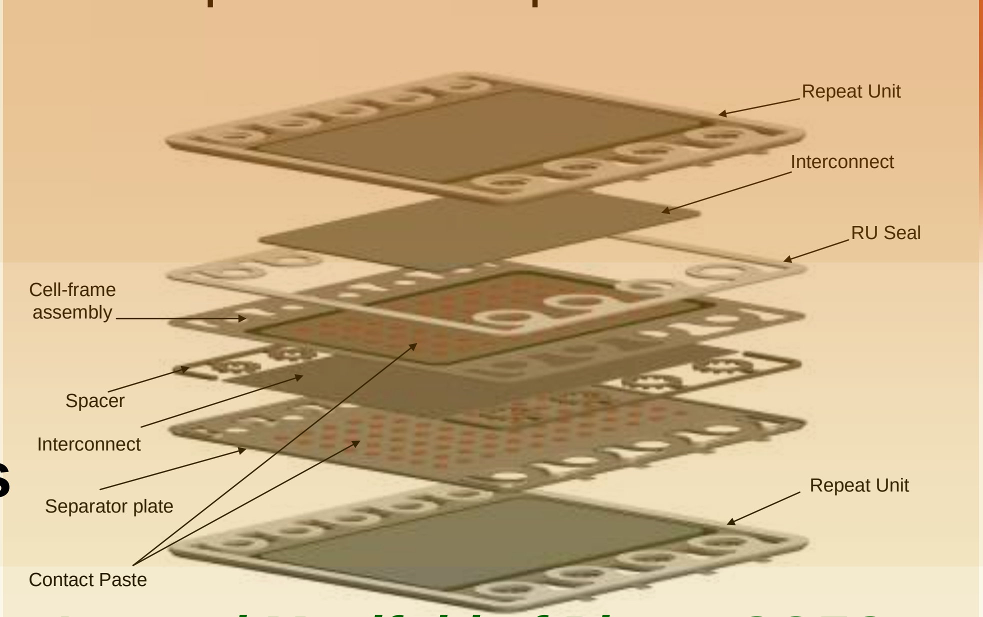
Manufacturing Fuel Cell Project

Cost Drivers
For Ceramic Fuel Cells (Planar, Tubular)

Ceramic Membrane Fuel Cell Session

Key Cost Drivers For Planar Designs

- Planar Cells
- Separator Plates
- Seals
- Manifolds
- Compression Means
- Contact Layers
- Terminal Conductor Plates

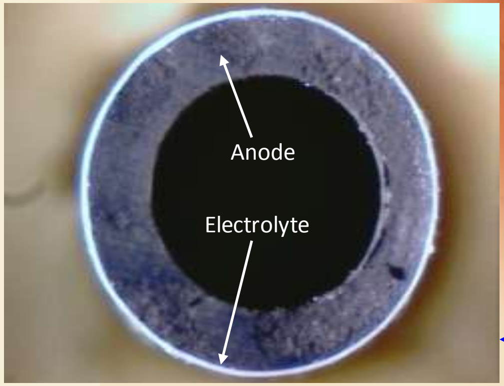


Internal Manifold of Planar SOFC

Ceramic Membrane Fuel Cell Session

Key Cost Drivers For Tubular Designs

- Recuperator
- Current Collection
- Cell
- Insulation
- Burner
- Reforming
- Seals
- Mechanical Enclosure
- Manifold



← *Tubular SOFC*

Coil Winding for Current Collection →

Manufacturing Fuel Cell Project

Path Forward

aci NAVY MANTECH CAMP MontanaTech THE UNIVERSITY OF MONTANA

Manufacturing Technology Gap Categories

Manufacturing areas where projects have been Identified to resolve gaps

- **Production Automation**
- **Production Material**
- **QC during Manufacturing**
- **QC for Product**
- **BOP Hardware**
- **BOP Performance**
- **Materials**
- **Design Performance**
- **Design Controls**

Total of 70 Gaps Identified →

About 32 Projects recommended to Address Cost Savings

Polymer Projects

- **Manufacturing cost trade-off analysis on raw material**
- **Reduce PT loading to 0.15 g/m^2**
- **Develop patch coating**
- **Direct coated layers on membranes**
- **Develop paper GDL for HTPEM**
- **Develop continuous mixing process**
- **Improve ink mixing process**
- **Direct coating layers on GDL**

Polymer Projects Continued

- Process development for mitigation from discrete to continuous
- Develop X-Y gradients H_2 rich inlets to H_2 depleted outlets
- Reduce critical design requirements and defect rejection criteria
- Development of a low cost resin for HTPEM bipolar plates
- Measurement of vapor pressure of phosphoric acid over HTPEM
- Utilize metallic bipolar plates for LTPEM

Ceramic Projects

- **Protective coatings for metallic stack components**
- **Defect free electrolyte layer**
- **Manufacturing of low-cost , high-efficiency insulation packages**
- **Solid oxide fuel cells stack manufacturing ,commission and testing**
- **Net shape manufacturing of stack methods**
- **Solid oxide fuel cell automated assembly**
- **Automation of current collection application for tubular SOFC**

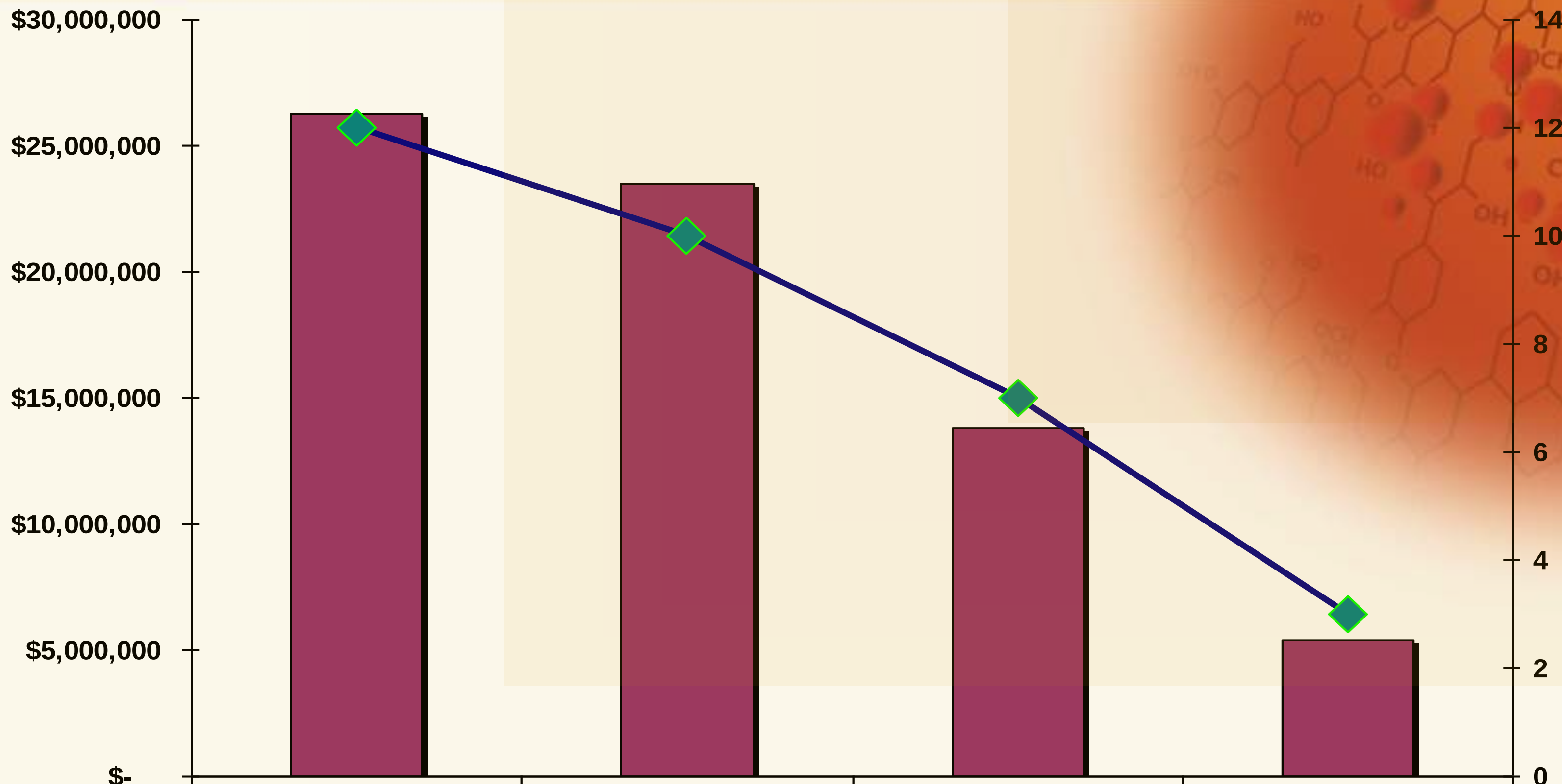
BOP Projects

- Manufacturing of low-cost, high-efficiency heat exchangers
- Liquid metering pumps for sub kilowatt reformed based FC systems
- Best practices for manufacturing anode gas movement devices
- Manufacturing improvements for fuel cell humidification systems
- Specification analysis for fuel cell power systems
- Liquid flow meter for sub-kilowatt reformer based FC systems

Fuel Processing Projects

- **Improve Sulfur Sensor for logistics fuels**
- **Improve desulfurization of JP-8, JP-5, F76**

FC Area vs Costs by Projects



	Polymer	Ceramic	BOP	FP
Cost	$26,276,694	$23,456,956	$13,821,200	$5,375,185
Projects	12	10	7	3

Recommendations

- **Implement discrete projects that will have an immediate benefit to reducing fuel cell cost**
- **Establish CALCE or SAMETAC type consortium for fuel cells**
- **Recommend consortium specific projects**
- **Establish manufacturing working group**
- **Propose a phase III power management and integration session**
- **Propose a plan to the ONR for an alternative energy COE for Naval Platforms**

Discrete Fuel Cell Projects

- Application specific - will have cost benefit to Navy and other DOD programs
- Immediate benefits < 3 yrs
- Unique to manufacturer – proprietary to a degree - will result in cost reduction of fuel cell systems

Consortium Projects

- Addressing (DoD) specification "Feature Creep"
- Cross-cutting development of automation capabilities for cells and stacks
- Understanding critical-to-quality parameters for ceramic powder specification and enhancing supply chain leverage
- Developing transfer functions for the linkages between manufacturing variability and cell performance/durability
- Developing solutions for the transition from solvent- to aqueous- based processing
- Developing methods (protocols and transfer functions) and support equipment to enable accelerated lifetime testing for SOFC cells and stacks

Consortium Benefits

- Establish government-industry consortia to address over-arching issues
- Not cost effective for individual companies to address themselves
- Work would benefit all industry
- Supports the competitiveness of the North American fuel cell manufacturing base
- Benefit from capabilities across federal agency labs and academia
- Would incorporate non-disclosure agreements where necessary

Manufacturing Working Group

- Continue collaboration and 'esprit de corps' developed in the MFCMP
- Forum for labs / academia to report on new developments related to manufacturing
- Capture manufacturing needs and issues for DoD and DOE consumption and action
- Group to be informed on DoD application requirements and developments by DoD fuel cell TWG
- Group possibly hosted by FCHEA or NDIA Manufacturing Division

Power Management and Integration

- FC power management issues were discussed in Phase I but not addressed fully
- Integration of FC power management into DoD deployed systems needs to be developed (e.g., integration with other renewables, and hybrid systems)

Path Forward

- ONR has begun funding efforts of MFCMP recommendations
- MFCMP team will brief ONR and other DoD PMs on the findings and potential cost savings to secure additional funding
- Propose a development of an alternative energy center of excellence

Q&A

Carmine Meola
610 362 1200 x 235
cmeola@aciusa.org

Rebecca Morris
610 362 1200 x 102
rmorris@aciusa.org

http://www.aciusa.org
http://www.navyb2pcoe.org

Back Up Slides

Fuel Cell Project Scope

MFCMP Scope:

Power ranges

- **<0.5 kW (man portable / man wearable)**
- **0.5 kW< Power range < 10kW (mobile power)**

Fuels: Hydrogen and reformed hydro-carbons

- **Packaged Fuels < 0.5 kW**
  - **Near term solution**
  - **Move through the supply chain like batteries**
  - **Examples: methanol, ethanol, propane, butane, chemical hydrides, hydrogen**
- **Logistics Fuels > 0.5 kW (long term solution)**
  - **Long Term Solution**
  - **Examples: JP-8, diesel**

Applications

Navy Applications

- **Unmanned Vehicles (Unmanned undersea vehicles, UAV, UGV)**
- **Submarine Emergency Power**

- **Ship Service (0.5-2.0 MW)**
- **CHP base housing / apartments**
- **CHP PX, Fire Station**
- **Material Handling/Fork Lifts (DLA)**
- **Automotive (Camp Pendleton, 6 ea GM vehicles planned)**

Applications

ARMY Applications

- Soldier Portable Power
- Battery Charging
- Power Source (hybrid configurations)
- Remote Sensors
- UAVs / UGVs
- Vehicle Auxiliary Power
- Base Camp Power

USMC Applications

- Man-portable Charger, CERDEC, 250 W
- Portable Power, TARDEC
- Tactical Wheeled Vehicle Onboard Power, CAASCOM, 5-10 kW

Polymer Membrane Fuel Cell Session

Major Key Manufacturing Needs Identified for MEA

- Ink mixing to coating operation - minimize time
- Ink processing through continuous methods
- Correlating QC measurements to requirements
  - What tests are necessary?
- Need on-line /real time QC testing techniques
- Raw material traceability
- Relate existing metrics and to downstream product requirements
- Maximum utilization of catalyst
- High production volumes will need quick turnaround testing of subsystems

Polymer Membrane Fuel Cell Session

Key Manufacturing Needs Identified for Bi-Polar Plates

- For LTPEM the bipolar plates need the use of alternate graphite resin compositions to facilitate easier molding
- Testing and evaluating critical design parameters of bipolar plates (BP)
- A low cost metallic plate would use more conventional manufacturing process- thus lowering cost
- For HTPEM it is critical to reduce multiple heat treatments for cost reduction
- For HTPEM find a method to employ air cooling process to replace high water pressure /steam mixture

BOP for Polymer & Ceramic Fuel Cell Session

Key BOP Manufacturing Needs Identified

- Autothermal Reformers (ATR) need to operate at temperatures near or below 800°C to eliminate the use of high cost metal alloys; the latest ATR designs & catalyst appear to have resolved this issue
- Catalytic Partial Oxidation Reformers susceptible to coking issues- requiring insulative housing and filter systems
- The CO_2 and CO removal process are not designed to suit small scale reformate clean-up
- Water management systems need to utilize more efficient designs to reduce weight and cost over the present membrane modules

Balance of Plant - cont

- **Commercial fuel and oxidant delivery as well as air supply components generally do not satisfy the specifications for the critical parameters for fuel cell applications**
- **Heat exchangers also fall into this category**
- **When feasible, safety and control systems should transition to software based systems**
- **Alternate plate fin exchangers may provide a more cost effective solution, providing low material and manufacturing costs**

Ceramic Membrane Fuel Cell Session

Key Planar Manufacturing Needs Identified

- Assurance of stack quality is labor intensive requiring a more mechanized approach to assure consistency at higher volumes
- Optimization by the means of decoupling QC process would increase throughput and reduce cycle time
- There is little industry standardization for stacks. The Capital equipment to produce larger volumes is a significant cost
- An accelerated testing strategy needs to be developed for stacking as well as BOP. i.e. thermal cycling, load cycling, etc for lifetime prediction
- Optimization of coating and material selection for end plates, bipolar plates and flow field is needed.
- There is a lot of material waste in seals. A dispensing or molding process for forming seals would reduce cost

Ceramic Fuel Cell Session

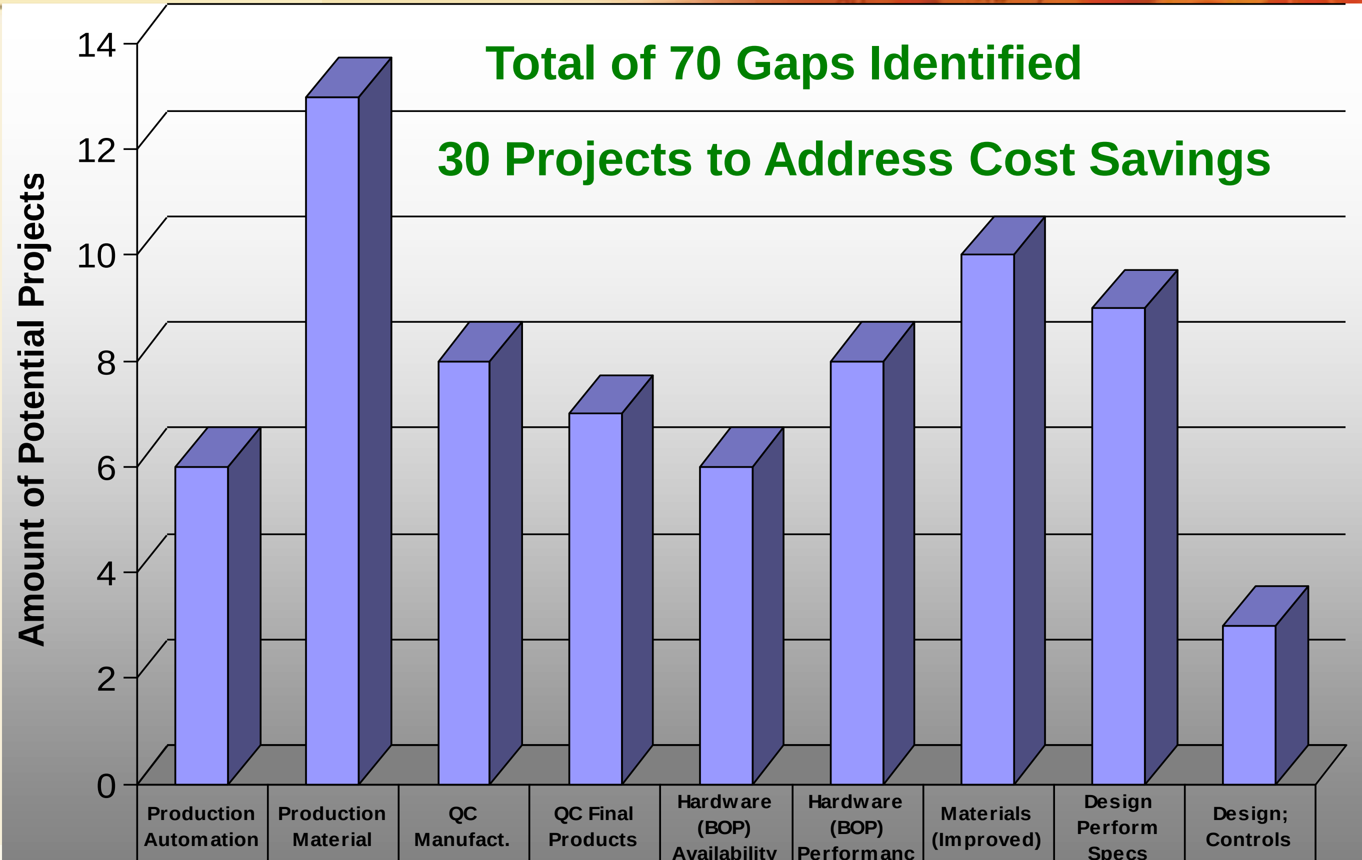
Key Manufacturing Needs Identified

- Dimensional tolerances of tubes difficult with high aspect ratio tube with thin walls
- The application of a uniform electrolyte layer on the tube is challenging and is prone to yield loss
- Current collector process needs to be automated with high rate wire winding and tie off
- Current QC test for both planar and tubular FCs require in-process testing prior to stack assembly to reduce cost. This includes analysis of powders batches, slurries, tape cast, green tape, electrolytes, etc.
- The relevant tests must be identified that will affect the quality of the overall stack

Manufacturing Technology Gap Categories

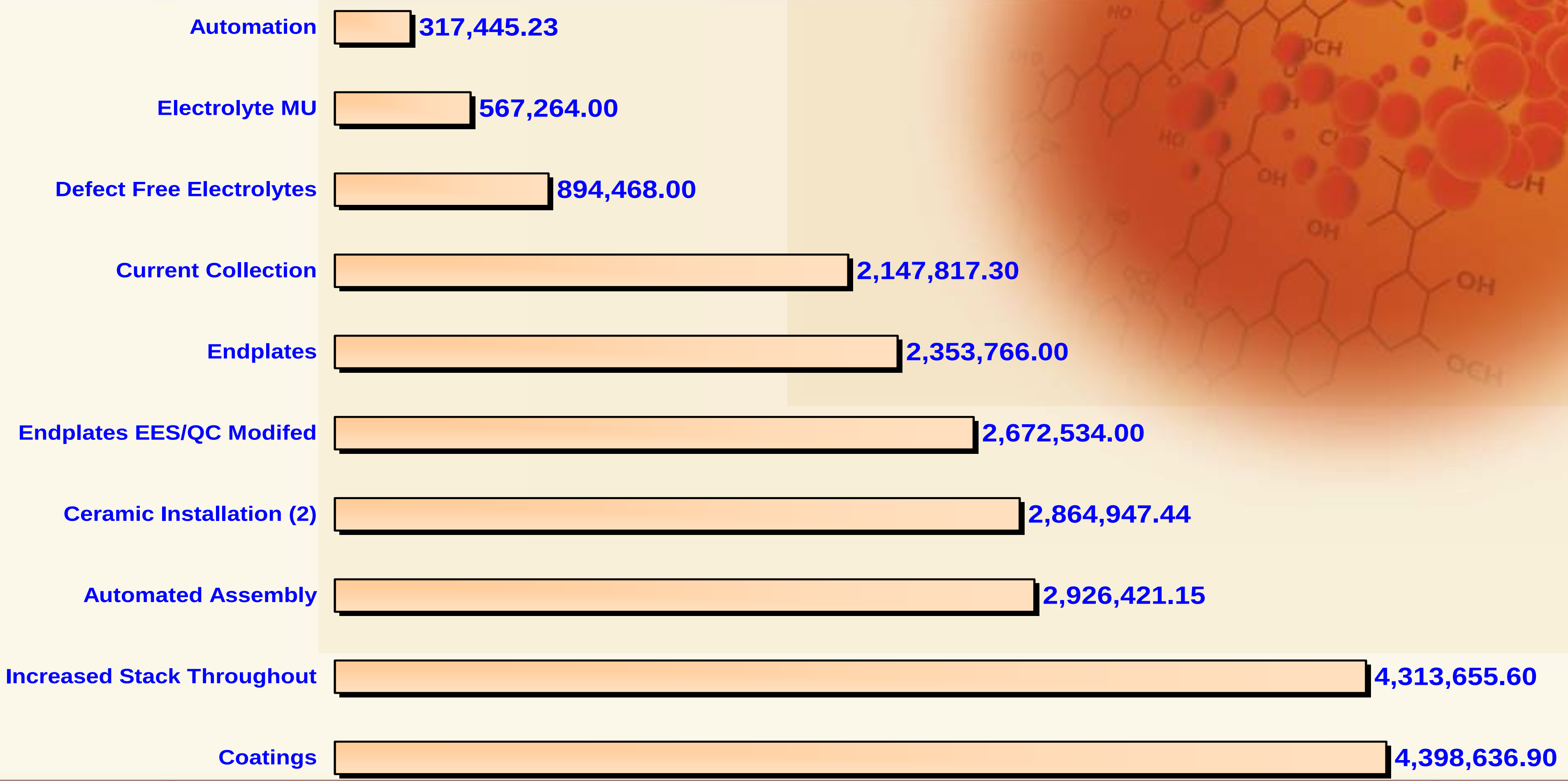
Manufacturing areas where projects have been Identified To resolve gaps

- **Production Automation**
- **Production Material**
- **QC during Manufacturing**
- **QC for Product**
- **BOP Hardware**
- **BOP Performance**
- **Materials**
- **Design Performance**
- **Design Controls**

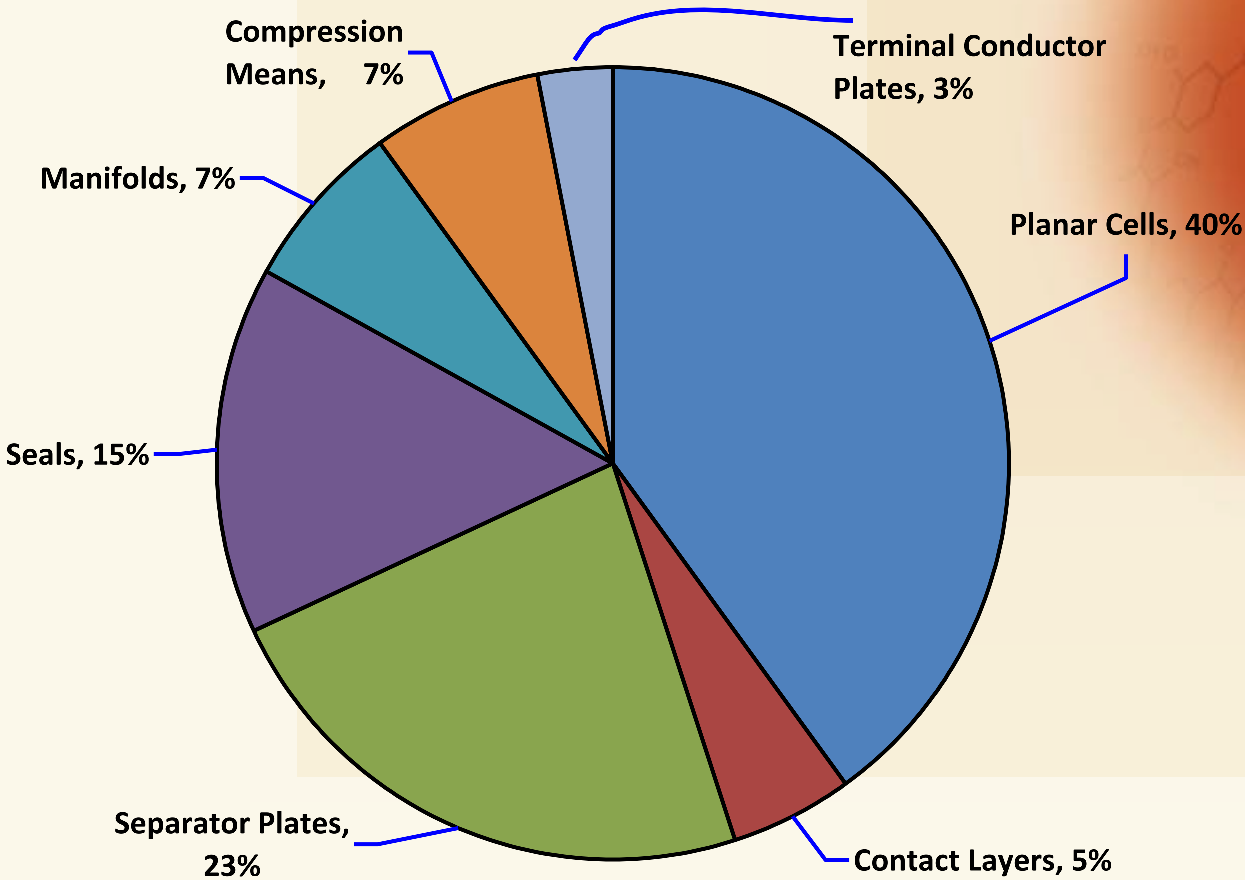


	Production Automation	Production Material	QC Manufact.	QC Final Products	Hardware (BOP) Availability	Hardware (BOP) Performanc	Materials (Improved)	Design Perform Specs	Design; Controls
Series1	6	13	8	7	6	8	10	9	3

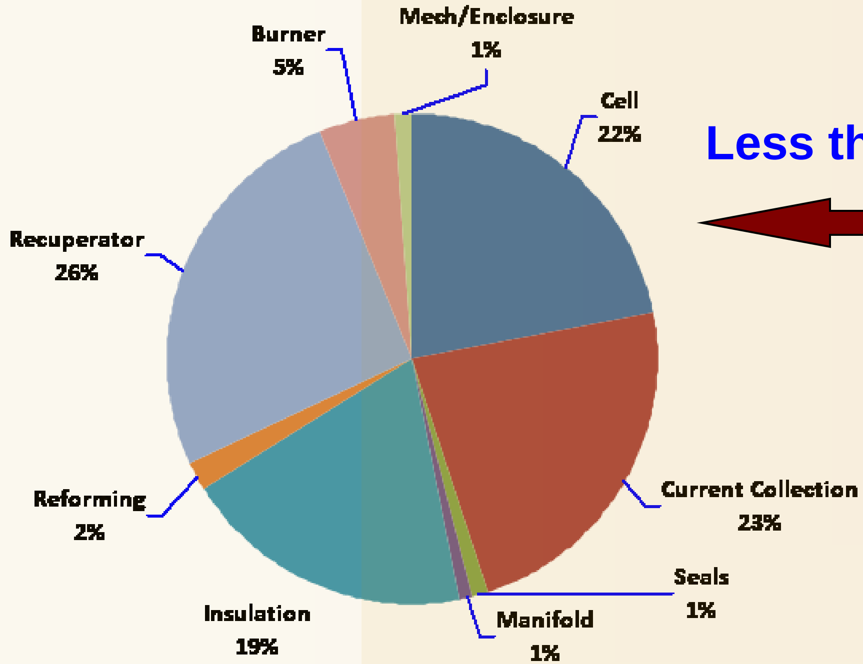
Ceramic Projects



Ceramic Planar Costs



Ceramic Tubular Costs



Less than 500 watt systems

Greater than 500 watt systems