Application of Advanced CAE Methods for Quality and Durability of Fuel Cell Components

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Project ID # FCP16

Overview

Timeline

- March 2003
- September 2007
- 50%

Budget

DOE Funding:

- FY04 : $210K
- FY05 : $210K

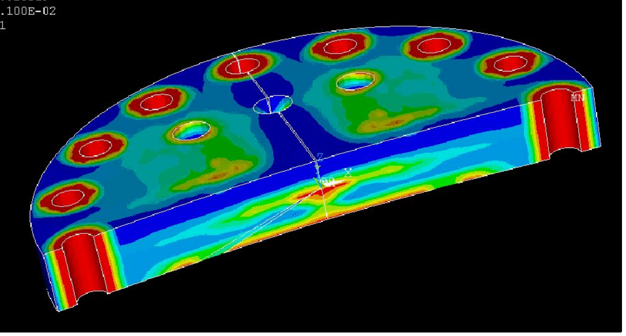
Barriers

- This work has direct impact on overcoming technical barriers such as durability and cost and achieving the DOE's technical targets of energy efficiency and specific power. This project specifically addresses items:
  - "O" (component barriers - stack material and manufacturing cost) and
  - "P" (durability)

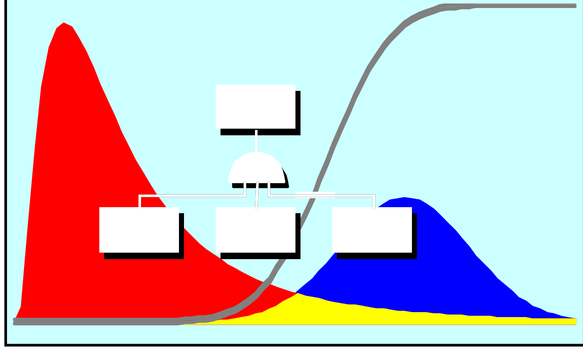
in DOE's Multi-year Research, Development and Demonstration Plan (June 2003, p.3-76).

Industry Partner

- Plug Power



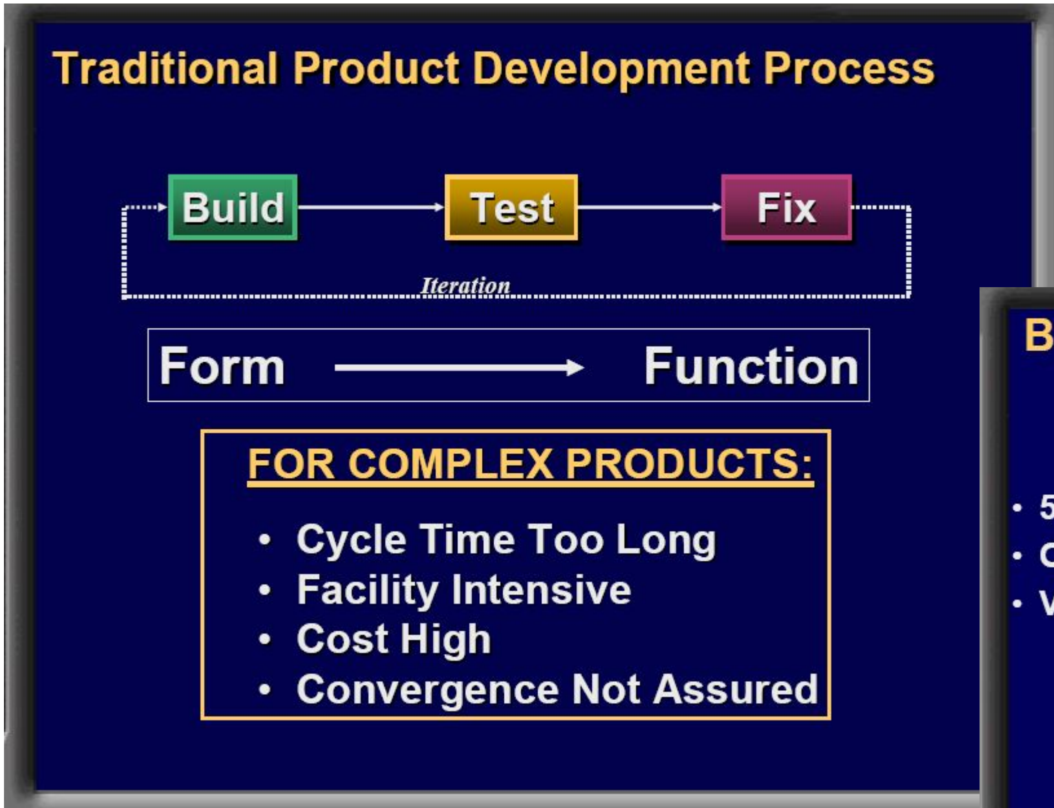
Objectives

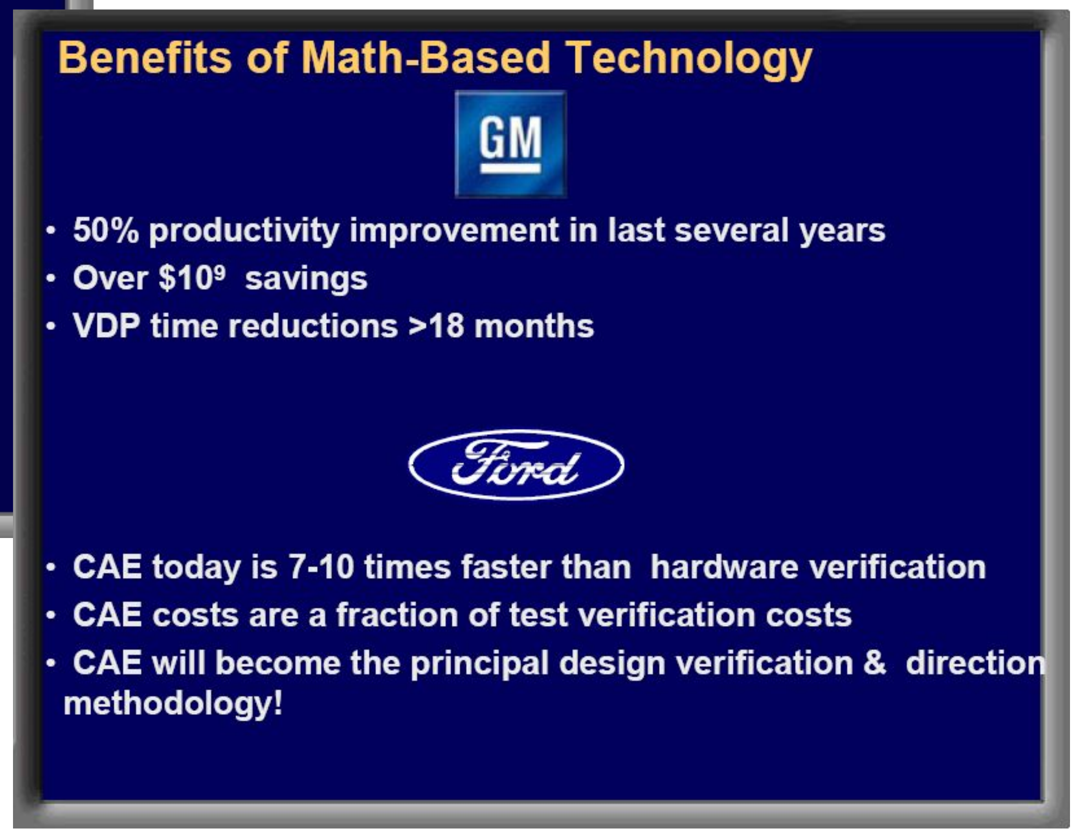


- Accelerate the implementation of fuel cell technologies by integrating the latest computer-aided engineering (CAE) methods with advanced design techniques to overcome key technical barriers and improve reliability, performance, and cost.
  - Work with fuel cell industry partners to apply CAE tools on problems that address key technical barriers.
  - Improve component reliability by applying Robust Design techniques for optimal solutions that account for variations in material properties, loads, and manufacturing processes.
  - Lower costs and development time by reducing the number of prototype components that are built and tested.

Approach

utilizing lessons learned from other industries (aerospace, automotive, electronics, etc.)





Source: "GM's Journey to Math: The Virtual Vehicle"
-Steve M. Rohde, Technical Director, General Motors

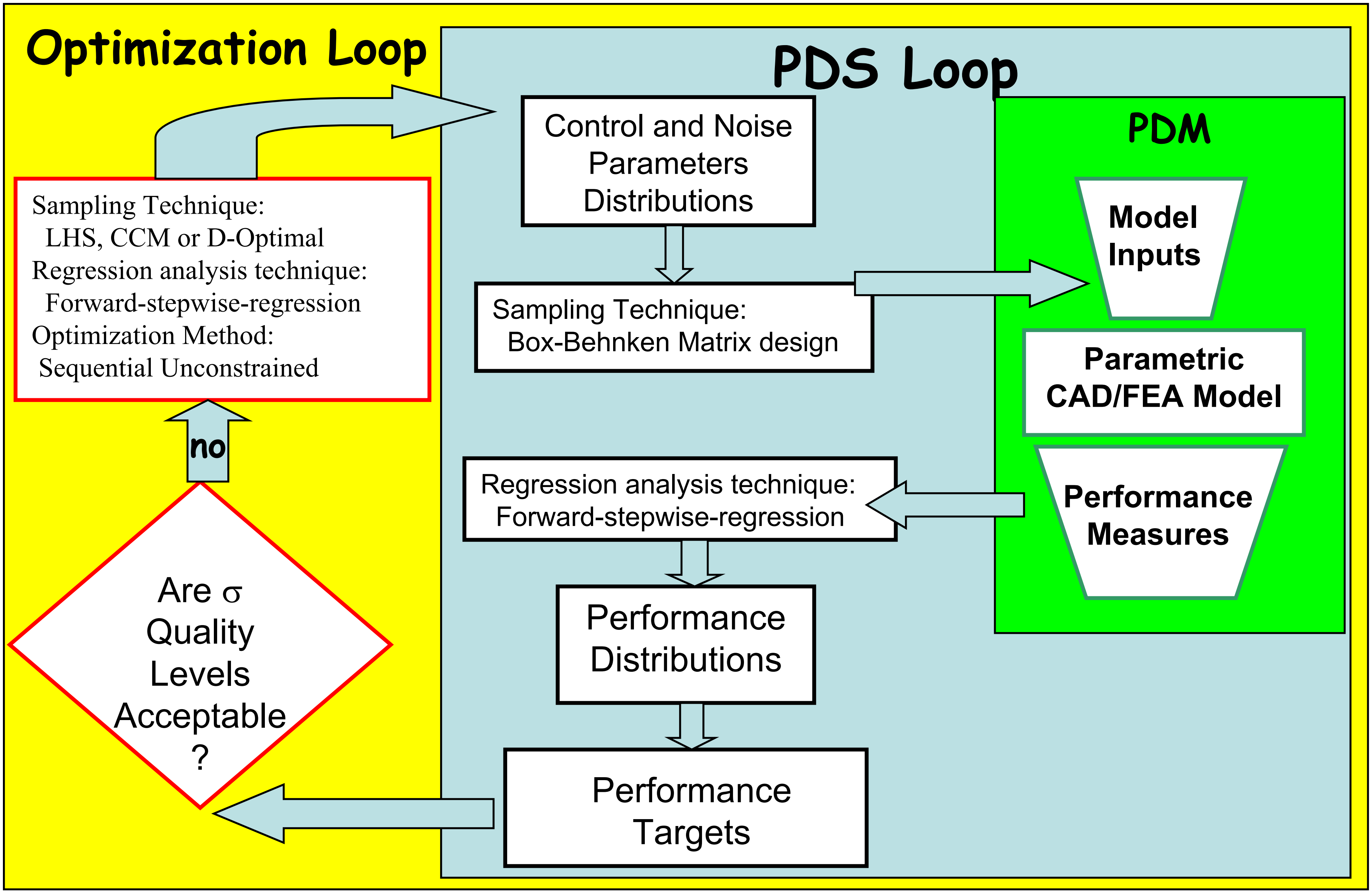
Approach

application of NREL capabilities developed under FreedomCAR

- CAE and Robust Design Tools Being Utilized
  - Topology Optimization for conceptual design
  - Parametric Behavioral Modeling CAD *(not dimension but attribute driven design)*
  - Finite Element Modeling (implicit, explicit, VPG)
  - Multi-physics applications *(structural/thermal, fluid/thermal, electromagnetics,etc)*
  - Optimization integrated with CAD & FEA
  - Design for 6-sigma using CAE (DFSS)
  - Probabilistic Design Methods *(engineering quality into designs)*
  - Design of Experiments Techniques
  - Engineering Resources and Computational Power Available at National Labs

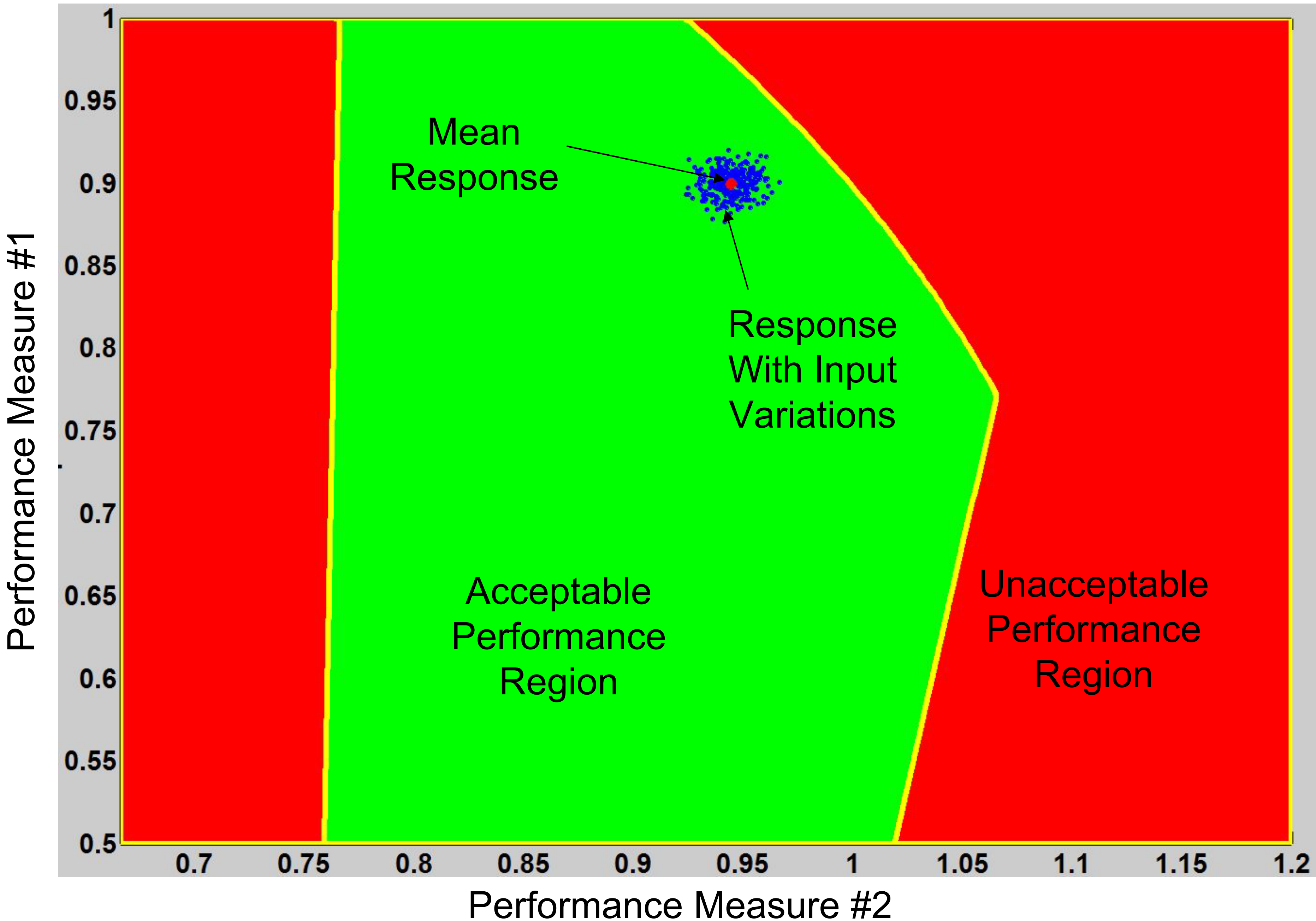
Approach

Re-usable Workflow for Integrating Probabilistic Methods with CAE



Approach

Robust Design – Optimization that Accounts for Input Variations



Approach

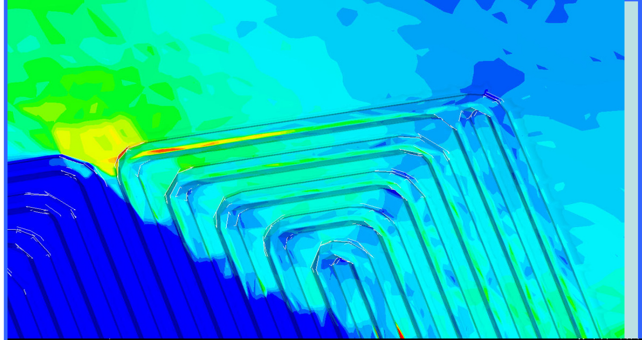
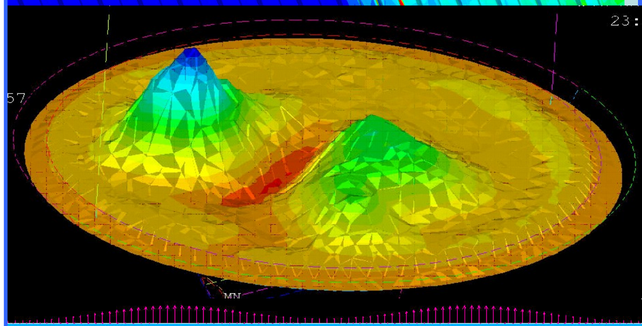
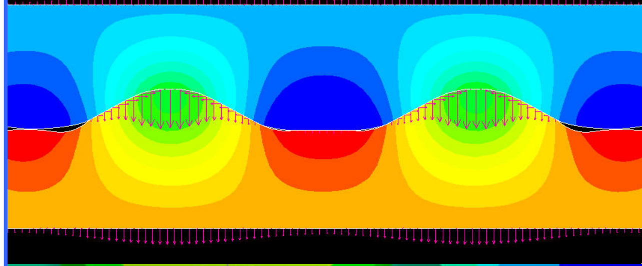
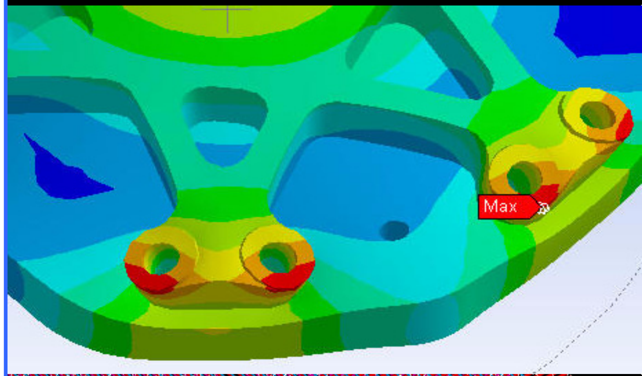
current project applications

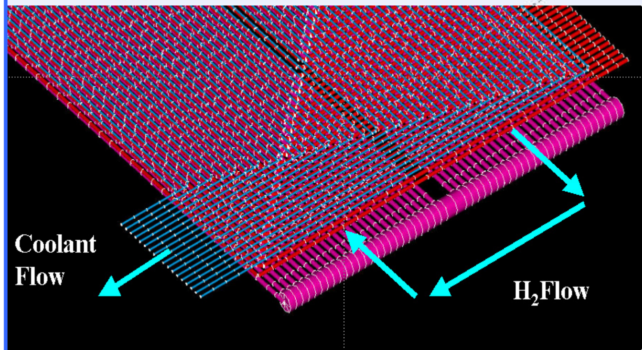
Application of Advanced CAE Methods for Quality and Durability of Fuel Cell Components :

1. **Robust Mechanical Designs** - evaluation of performance impacts due to variations manufacturing, material properties, and loads to achieve optimized component performance.
2. **Component Optimization** – optimization of end-plate designs, bi-polar plate configurations, gasket seals, etc for improved performance.
3. **Flow Optimization** - sensitivity analysis and optimization of component designs for uniform constituent flows.
4. **Robust Thermal Designs** - robust thermal designs through thermal modeling and probabilistic analysis methods.

Summary of Accomplishments

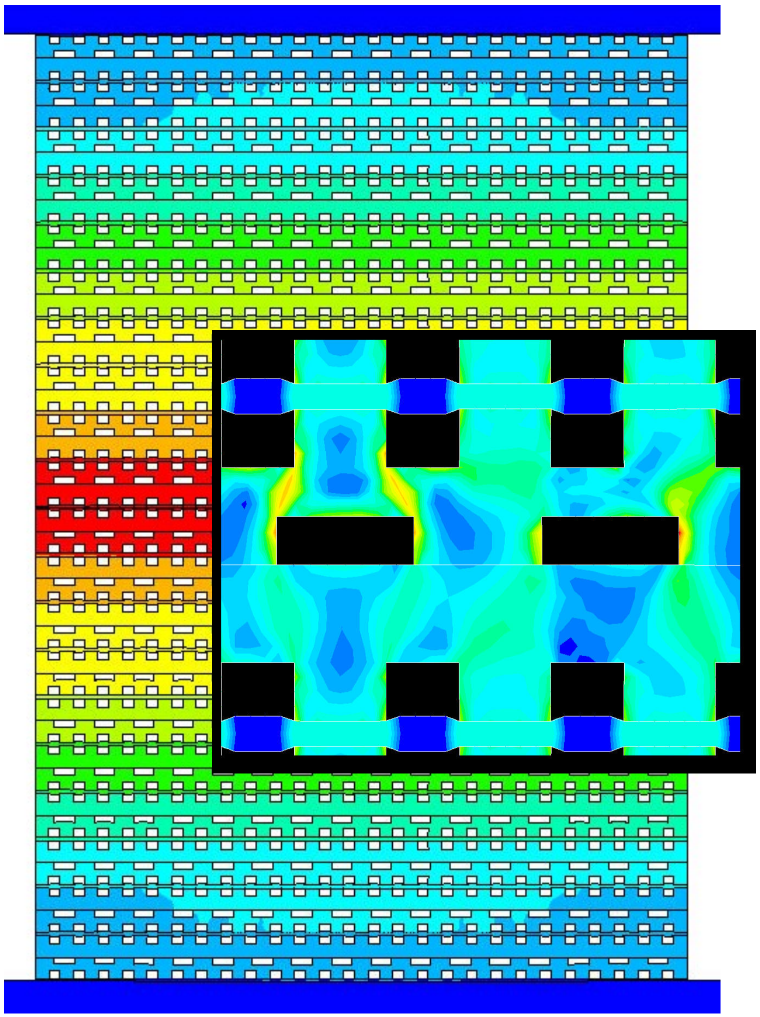
1. **Robust Fuel Cell Stack** – Demonstrated the probabilistic design methodology on a fuel cell stack and applied lessons learned to a number of stack designs
2. **Manufacturing Process Improvement** – Helped improve plate manufacturing processes by modeling Cathode - Cooler Plate Ejection Process.
3. **ATR** - Improved ATR component designs by modeling the effect of thermal fatigue and various component placements/geometries on constituent flow distributions.
4. **Robust Seals** - Determined alternative gasket and groove configurations of the cooler and cell interfaces to provide robust sealing.
5. **H_2 Generation Component Optimization** – Analysis used to guide design changes of bi-polar plates and end-plates for improved strength.
6. **High Temperature Stack** – Innovative new 3D stack thermal/flow model used to conduct design parameter investigations and improve thermal performance.



Technical Accomplishments

Robust Fuel Cell Stack



Objective:

- Determine the effect of manufacturing, loading, and material variations of a fuel cell stack on the MEA's pressure distribution.

Accomplishments:

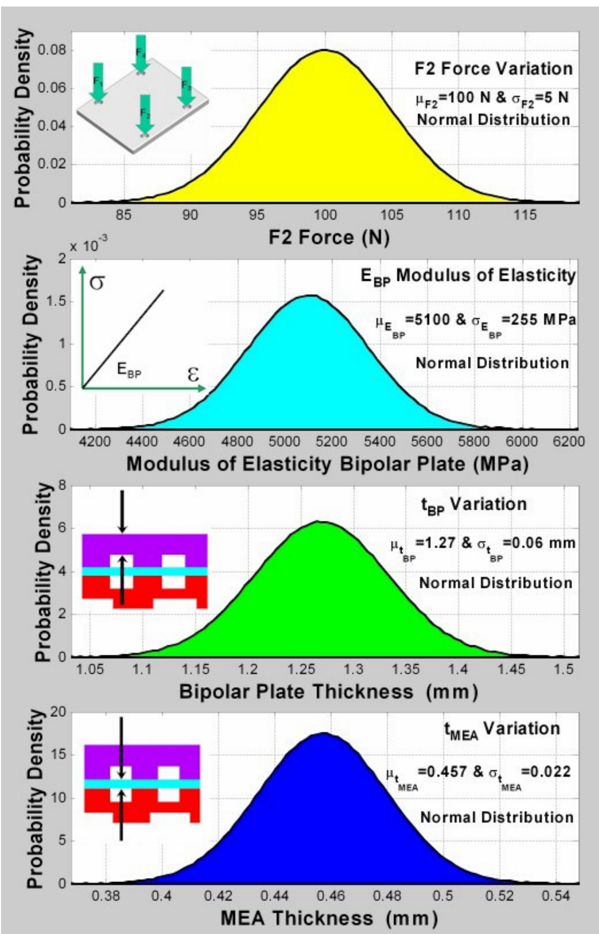
1. Conducted probabilistic variation analysis on effects of material and manufacturing variations on MEA pressure distributions (RIT Paper)
2. Structural bipolar plate analysis evaluates strength impact of gasket location

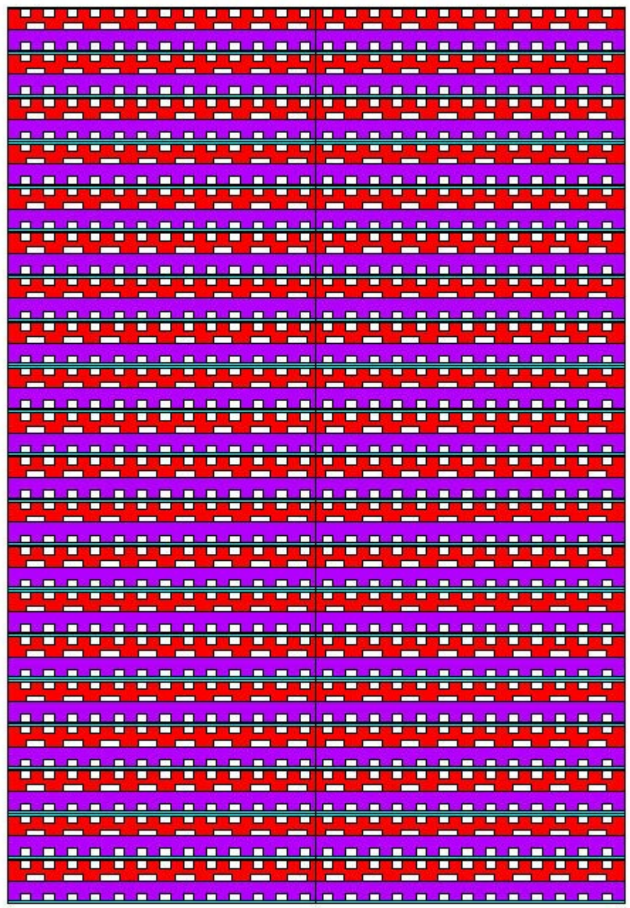
Technical Accomplishments

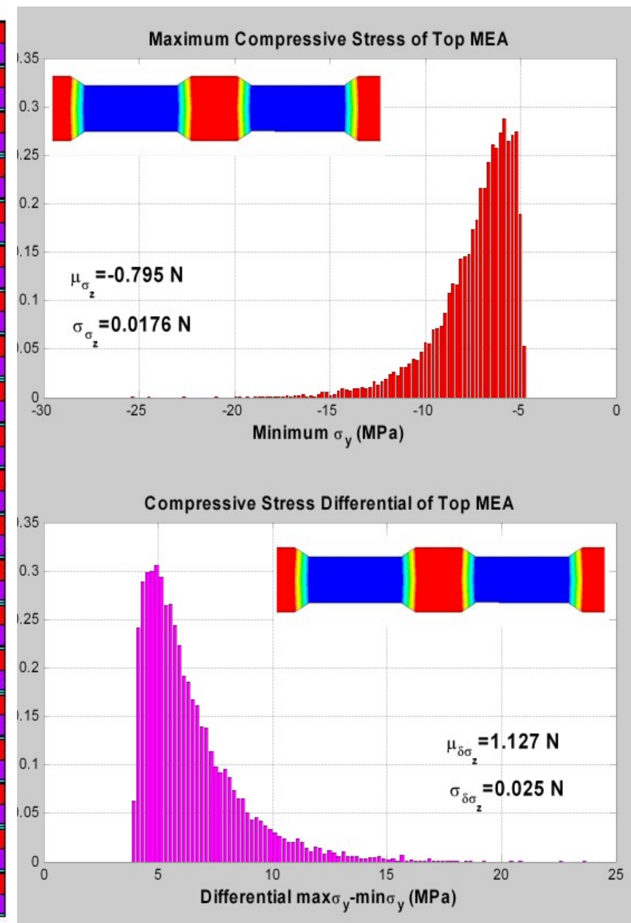
Robust Fuel Cell Stack

RIT Paper: "*Effect of Material and Manufacturing Variations on MEA Pressure Distribution*"

Statistical Distribution of Material and Manufacturing Variations → **Parametric FEA Model of Fuel Cell Stack** → **Statistical Distribution of Output Performance Measures**

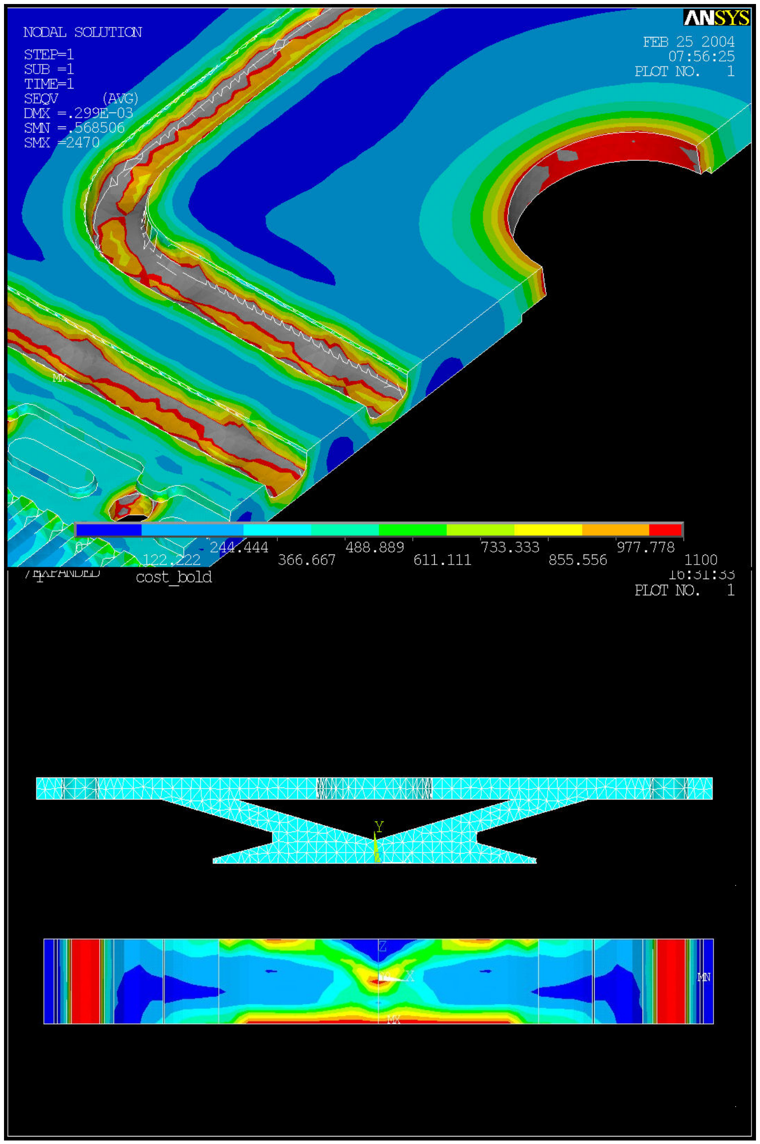






Technical Accomplishments

Hydrogen Generation Component Optimization



Objective:

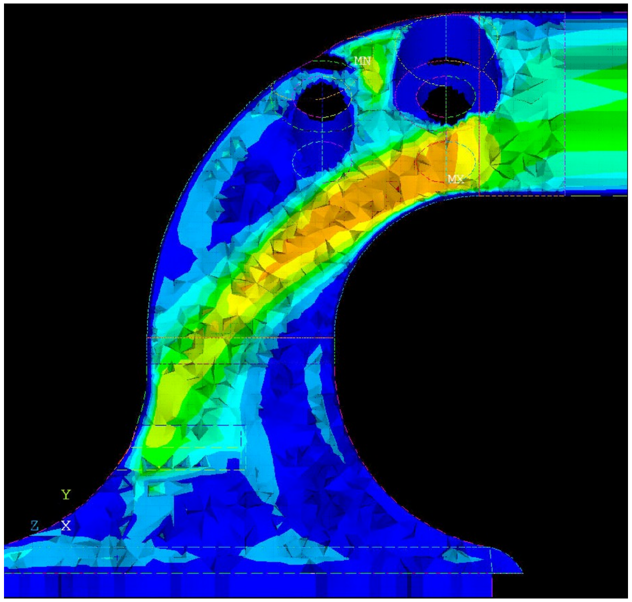
- Optimization of end-plate and bi-polar plate designs for reduced end-plate mass and improved MEA and bi-polar plate loading characteristics

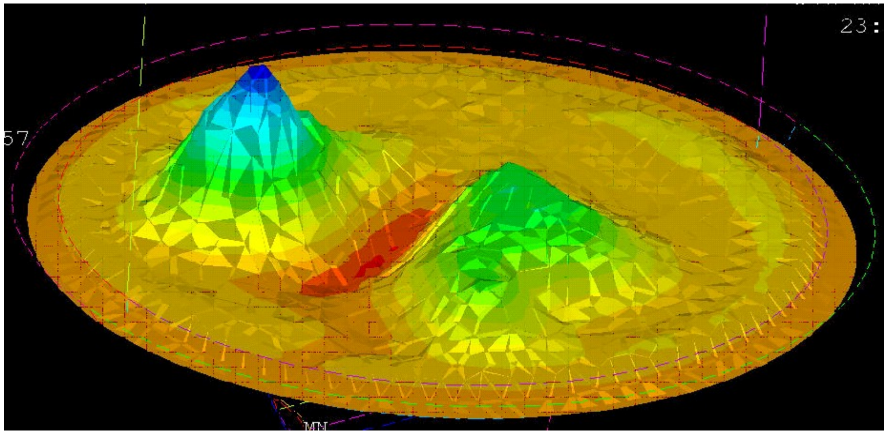
Accomplishments:

1. End-plate analysis leads to improved bolt pattern and plate geometry to avoid plate cracking during assembly.
2. Topology optimization leads to new innovative design concepts
3. Rapid Stress Analysis reduced the number of component prototypes built and tested.

Technical Accomplishments

Auto-thermal Reformer





Objectives

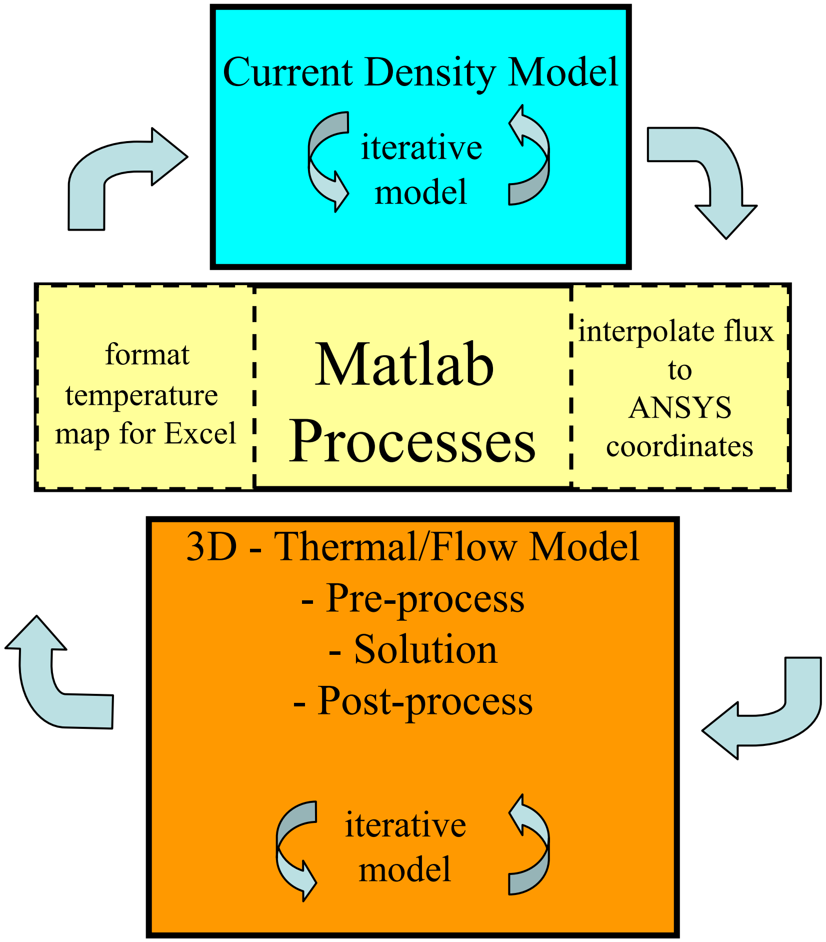
- Evaluate the structural integrity and fatigue life of the ATR Subsystem subjected to thermal loading
- Evaluate Catalyst Effectiveness - Flow analysis (CFD)

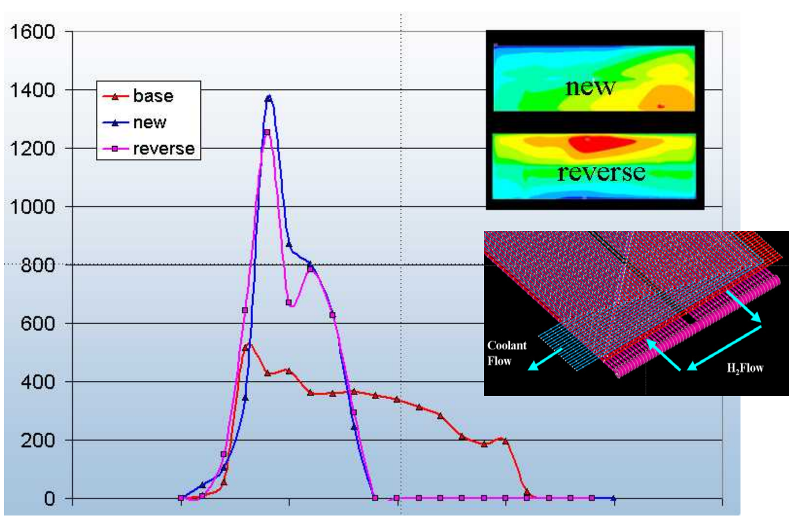
Accomplishments:

1. Performed thermal fatigue analysis on several components and suggested design improvements to improve ATR structural integrity.
2. Improved ATR efficiency by evaluating the effect of various glow plug positions and radiation Heat Shield on the Thermal Behavior and evaluating alternative design configurations.

Technical Accomplishments

High Temperature Stack





Objective

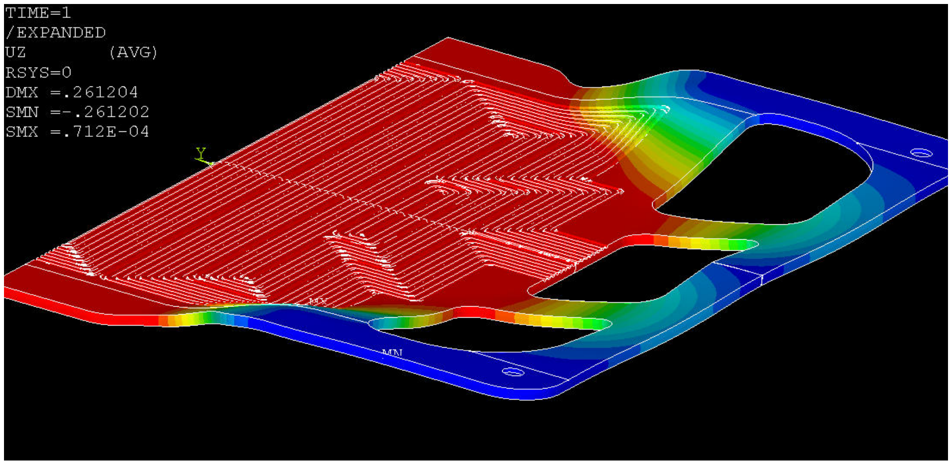
- Improve the thermal performance of the bi-polar plate with multi-physics modeling (*electro-chemical, thermal, fluid flow*)

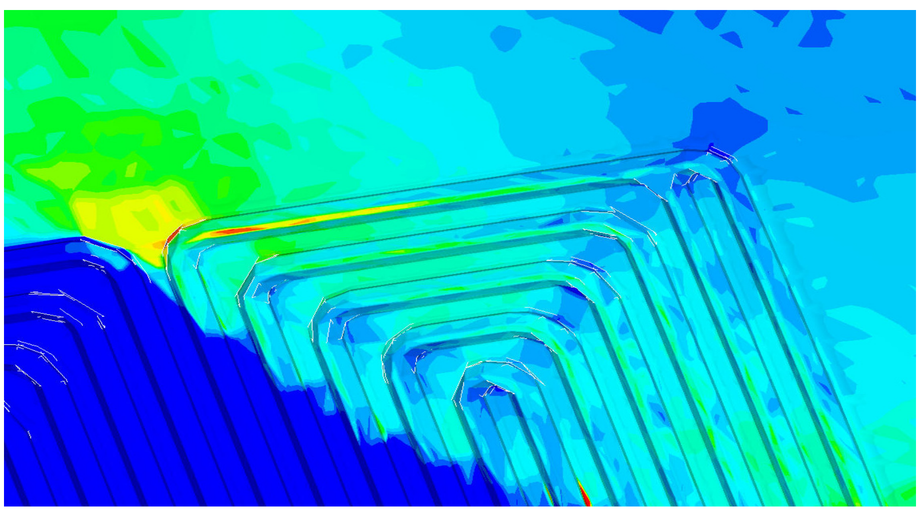
Accomplishments:

- Developed a modeling process that integrates 3-D thermal, flow, and current density simulations.
- Conducted Taguchi screening of design parameters (flow rates, material properties, channel geometries, etc.) on temperature distributions and pressure drops.
- Modeled alternative coolant flow paths for improved thermal performance.

Technical Accomplishments

Manufacturing Process Improvements





Objective:

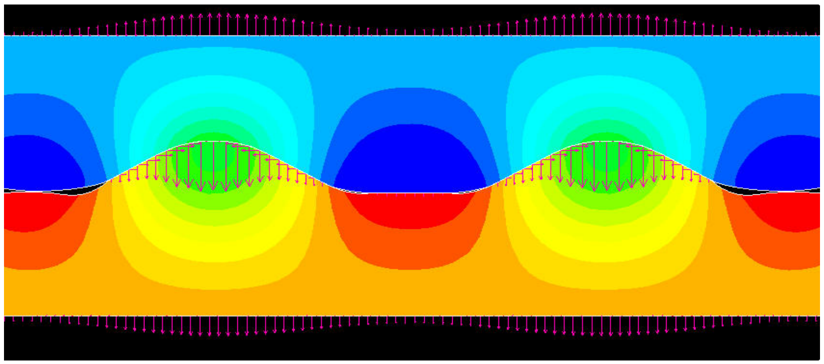
- Utilize FEA to investigate bi-polar plate crack initiation during manufacturing process
- Develop Recommendations for crack avoidance

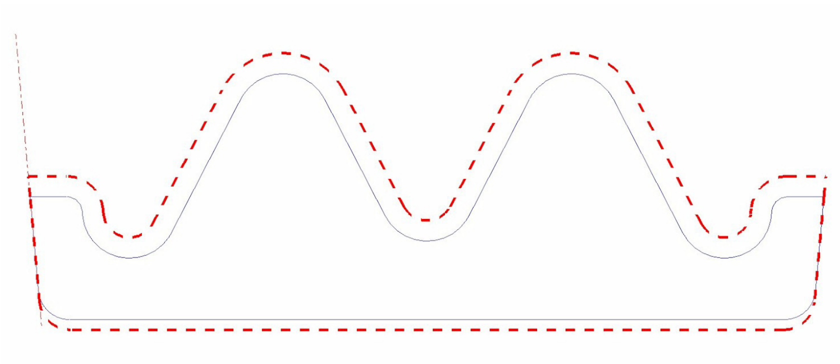
Accomplishments:

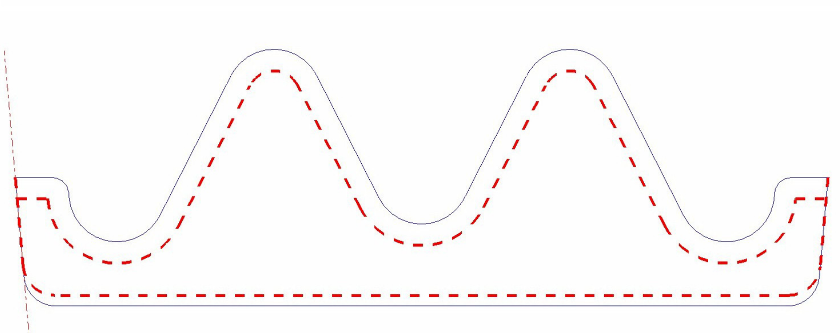
- Developed Finite element model that accurately predicted crack formation/location.
- Contributed to the development and selection of several process alternatives.
- Conducted modeling of process alternatives

Technical Accomplishments

Robust Gasket Sealing







Objective:

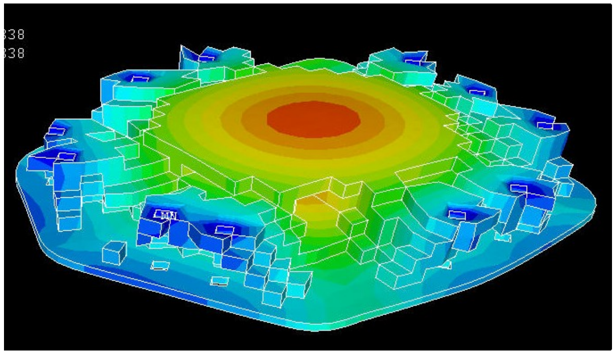
- Determine alternative gasket and groove configurations of the cooler and cell interfaces to provide robust sealing

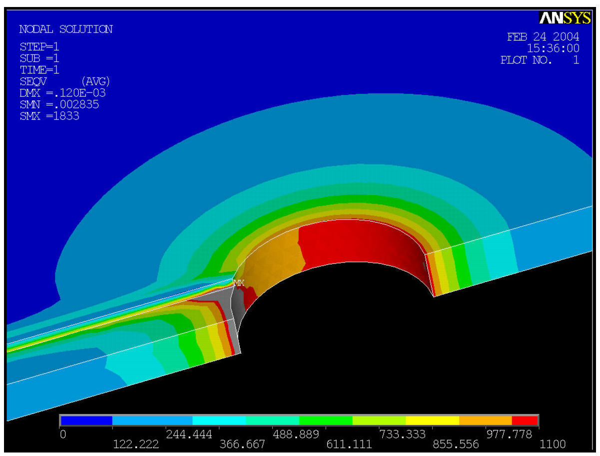
Accomplishments:

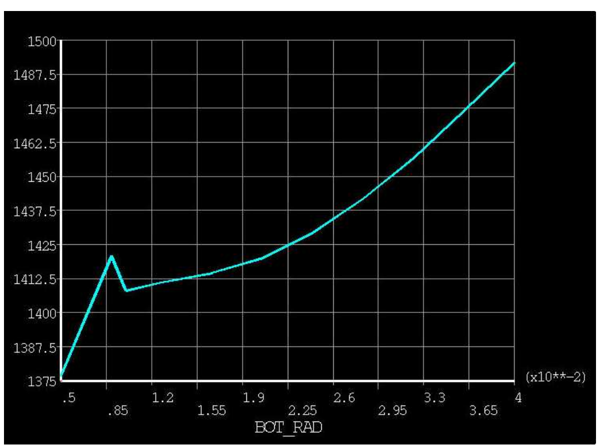
- Developed non-linear, parametric gasket seal analysis model that accounts for variation in gasket and seal geometry, material properties, and loading.
- Performed analysis using parametric sweeps to identify the shape and size of the to provide the required sealing force.
- Transferred the gasket analysis process to Plug Power.

Technology Transfer

CAE Methods for Fuel Cells







Objective:

- Transfer lessons learned and process methodologies to industry partner.

Accomplishments:

- NREL conducted a two-day workshop on Advanced CAE Methods for Plug Power Engineers
- Techniques covered:
  - parametric modeling, parametric sweeps, design of experiments, optimization, topology optimization, and behavioral modeling.
- Fuel Cell applications included:
  - cathode plate modeling and stress analysis, gasket groove stress analysis, end-plate topology optimization, and end-plate behavioral modeling.

Future Work

- Remainder of FY2005
  - Complete analysis of heat exchanger design alternatives and the effects of material, geometry, and load variations for high temperature stack application.
  - Integrate manufacturing process capability to evaluate robustness of gasket seal designs.
- Plans for FY2006
  – Project diversification with new partners and Advanced CAE applications:
    - Fuel Cell & Storage Design for Manufacturability and Quality accounting for material, load, and manufacturing process variations
    - Carbon storage design space investigations, thermal analysis using probabilistic methods
    - Hydrogen storage safety – reduce prototypes through CAE modeling with multiple load cases with design variations
  – Continued robust design optimization of high temperature stack thermal design, gasket seal and stack components.

Publications and Presentations

ASME International

First International Conference on
Fuel Cell Science, Engineering and Technology
April 21-23, 2003, Rochester, New York, USA

EFFECT OF MATERIAL AND MANUFACTURING VARIATIONS ON MEAS PRESSURE DISTRIBUTION

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National Renewable Energy Laboratory
A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Innovation for Our Energy Future

Application of Advanced CAE Methods for Quality and Durability of Fuel Cell Components

by
Ken Kelly, Andreas Vlahinos, Vahab Hassani, Keith Wipke

In collaboration with
Plug Power, Jim Stathopoulos

National Center for Manufacturing Sciences
September 27th, 2004

Case Study
www.nafems.org

Dealing With Variability in Design

Probabilistic Design Methods build understanding of reality's randomness and scatter in modelling.
Dr Andreas Vlahinos Advanced Engineering Solutions

Thanks to the development of probabilistic design methods, the definition of a robust design is changing. Until recently, a design was considered robust if all the variables that affected its life had been accounted for and "brought under control." The meaning of robustness is shifting, however, to a measurement of the product design's insensitivity to those variables.

In more concrete, businesslike terms, a robust design is one that meets customer expectations at an affordable cost regardless of customer usage, degradation over the life of the product, and variations in its manufacturing, suppliers, distribution, delivery and installation. All of these can exhibit a high degree of randomness and scatter.

The key difference is how randomness and scatter are handled in the analyses. Designers and engineers have traditionally handled them with safety factors. Some safety factors are derived from observation and analysis (empirical) but many are pure guesswork. In those cases, the bigger the guess, the bigger the risk, the bigger the safety factor - and the more the product is overdesigned.

This portends a revolution in the strategies by which new products are designed. According to Dr. Andreas Vlahinos, described by his peers as a "passionate knowledge worker" and principal of Advanced Engineering Solutions LLC (AES), Castle Rock, Colorado, there are two major drivers for new design strategies:

- Safety factors cannot, of themselves, guarantee satisfactory performance and they do not provide sufficient information to achieve optimal use of available

Six-Sigma quality levels early in the design process, we 'make it right the first time;' therefore we eliminate the

capabilities of design optimisation and verification software such as capabilities in the Probabilistic Design System (PDS) from ANSYS Inc. PDS has been available for a number of years; more than 100 companies worldwide are using it.

View History
"Neatness Doesn't Count," Feature Article, January 2004

mechanical engineering | FEATURES | DEPARTMENTS | MARKETPLACE | NEWS UPDATE

feature article

neatness doesn't count

The design for a fuel cell confronts the fickleness of the real world.

This article was prepared by staff writers in collaboration with outside contributors.

It started like a lot of projects, with a few coincidences. A fuel cell developer in Latham, N.Y., needed to know that its latest product could tolerate the randomness of commercial manufacturing. A couple of its engineers went to a technical conference where they heard an engineering consultant from Castle Rock, Colo., talk about probabilistic design. Meanwhile, the National Renewable Energy Laboratory in Golden, Colo., was turning its attention to probabilis developing energy devices.

It came together as an experimen Department of Energy to use vir Sigma methods to understand th design on the electrical performa

Plug Power Inc., working on a p called GenSys, wanted a robust perform as needed despite inevit materials and assembly. Compar consultant they had heard, Andr operates Advanced Engineering explore the latest design.

mechanical engineering MAGAZINE ONLINE

September 2004 • NREL Milestone Report

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Milestone Report

Application of Advanced CAE Tools for Quality and Durability of Fuel Cell Components

Milestone Progress Report

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National Renewable Energy Laboratory, Golden, CO

Andreas Vlahinos
Advanced Engineering Solutions, Castle Rock, CO

Prepared for the DOE
Office of Energy Efficiency and Renewable Energy
Hydrogen, Fuel Cells, and Infrastructure Technologies Program

In fulfillment of the September 2004 Milestone/Deliverable of the Fuel Cell Subtask entitled "Application of Advanced CAE Methods for Quality & Durability of Fuel Cell Components"

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National Renewable Energy Laboratory
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Publications

- Kelly, K., Vlahinos, A., Rodriguuez, P., Innovative Thermal Management of Fuel Cell Power Electronics,1st International Conference on Fuel Cell Science, Engineering and Technology, Rochester Institute of Technology, Rochester, NY, April 22, 2003
- Kelly, K., Vlahinos, A.,, Stathopoulus, J., Effect of Material and Manufacturing Variations on MEA Pressure Distribution, 1st International Conference on Fuel Cell Science, Engineering and Technology, Rochester Institute of Technology, Rochester, NY, April 22, 2003
- Vlahinos, Andreas, Dealing with Variability in Design, Probabilistic Methods Build an Understanding of Randomness and Scatter in Modeling, Benchmark Magazine, October, 2003.
- Vlahinos, Andreas, Neatness Doesn’t Count, The Design for a Fuel Cell Encounters the Fickleness of the Real World, Mechanical Engineering Magazine, American Society of Mechanical Engineers, January, 2004.
- Kelly, K., Vlahinos, A., Application of Advanced CAE Methods for Quality and Durability of Fuel Cell Components, NREL 2004 Milestone Report, September 2004.
- Kelly, K., Vlahinos, A., Advanced CAE Tools Applied to Stationary Fuel Cells, NREL 2003 Milestone Report, September 2003.

Presentations

- Kelly, K., Vlahinos, A., Engineering Quality and Durability into Components using Robust Design, Presented to DOE, March 12, 2003.

- Kelly, K., Vlahinos, A., Application of Advanced CAE Methods for Quality and Durability of Fuel Cell Components: Presented with updated materials to:
  - NREL Hydrogen Fuel Cell Review Panel, December 10, 2003
  - Plug Power, September 14, 2003
  - DOE and Plug Power, June 24, 2004
  - National Center for Manufacturing Sciences, September 27, 2004
  - University of Minnesota, Initiative for Renewable Energy Environment, October 7, 2004
  - University of Hawaii, January 15, 2005
  - Battelle, February 7, 2005.

- Kelly, K., Vlahinos A., Two-day Workshop on CAE Methods for Fuel Cells, Presented to Plug Power on February 16, 2004.

- Regular project updates presented to DOE, NREL, and Plug Power teams.

Hydrogen Safety

- *To date, NREL's direct involvement on this project has been in developing computer models, simulation processes, conducting analyses, and recommending design improvements.*
- *All model verification tests and implementation of improved designs have been performed by our industry partner using industry accepted hydrogen safety practices.*