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DOE Hydrogen Program

High Temperature Membrane with Humidification-Independent Cluster Structure

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Overview

Timeline

- Start: June 2006
- End: May 2011
- 60% complete

Barriers

- Low Proton Conductivity at 25-50% Inlet Relative Humidity and 120^{o}C

Budget

- Total project funding
  - DOE share: $1500k
  - Contractor share: $600k
- Funding received in FY08: $346k
- Funding for FY09: $300k

Partners

- Polymer Partner
  - Polymer & membrane fab. and characterization
- Additive Partners
  - Additives synthesis and characterization
- Consultants
  - Polymer, additives, visualization

Acknowledgements

- **DOE: Donna Ho, Terry Payne, Jason Marcinkoski, Amy Manheim, Greg Kleen, Reg Tyler, Tom Benjamin and John Kopasz**
- **UCF: Jim Fenton & Team (Testing protocols, membrane conductivity)**
- **BekkTech, LLC: Tim Bekkedahl (In-plane conductivity measurement)**
- **FCE Team: Pinakin Patel, Ray Kopp, Jonathan Malwitz, Nikhil Jalani**

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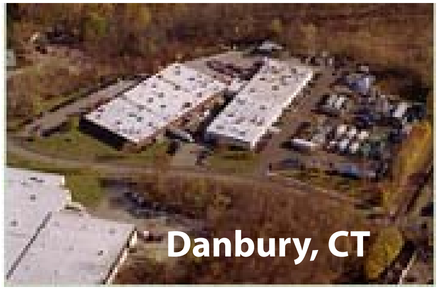
FCE Overview

- **Leading fuel cell developer for over 30 years**
  - MCFC, SOFC, PAFC and PEM (up to 2 MW size products)
  - Over 275 million kWh of clean power produced world-wide (>50 installations)
  - Renewable fuels: over two dozen sites with ADG fuel
  - Ultra-clean technology: CARB-2007 certified: Blanket permit in California
- **Highly innovative approach to fuel cell development**
  - Internal reforming technology (45-50% electrical efficiency)
  - Fuel cell-turbine hybrid system (55-65% electrical eff.)
  - Enabling technologies for hydrogen infrastructure
    - Co-production of renewable H_2 and e^- (60-70% eff. w/o CHP)
    - Solid state hydrogen separation and compression
- **High temp. membrane: leverage existing experience in composite membranes for other fuel cell systems (PAFC, MCFC, SOFC)**



Relevance

Objectives:

- Develop polymer membranes with improved conductivity at up to 120°C
- Develop membrane additives with high water retention and proton conductivity
- Fabricate composite membranes
- Characterize polymer and composite membranes (in-plane conductivity)

Relevance

Impact of HTM:

- Higher conductivity membranes increase power density and efficiency of the fuel cell stack
- Operation at low relative humidity (RH) eliminates need for external humidification → simplifies the fuel cell system
- Operation at elevated temperatures simplifies thermal management (smaller radiator)
- Simpler system increases overall efficiency of fuel cell power plant → contributes to DOE cost goal ≤ $\$45/kW_e$
- Reduced weight of automotive fuel cell system leads to higher fuel efficiency

Approach for the Composite Membrane

Target Parameter	DOE Target (2010)	Approach
Conductivity at: 120°C	**100 mS/cm**	Multi-component composite structure, lower EW
: Room temp.	70 mS/cm	Higher number of functional groups
: -20°C	10 mS/cm	Stabilized nano-additives
Inlet water vapor partial pressure	1.5 kPa	Immobilized cluster structure
Hydrogen and oxygen cross-over at 1 atm	2 mA/cm^2	Stronger membrane structure; functionalized additives
Area specific resistance	0.02 Ωcm^2	Improve bonding capability for MEA
Cost	20 $\$/m^2$	Simplify polymer processing
Durability: - with cycling at >80°C - with cycling at ≤80°C	 >2000 hours >5000 hours	Thermo-mechanically compliant bonds, higher glass transition temperature
Survivability	-40°C	Stabilized cluster structure design

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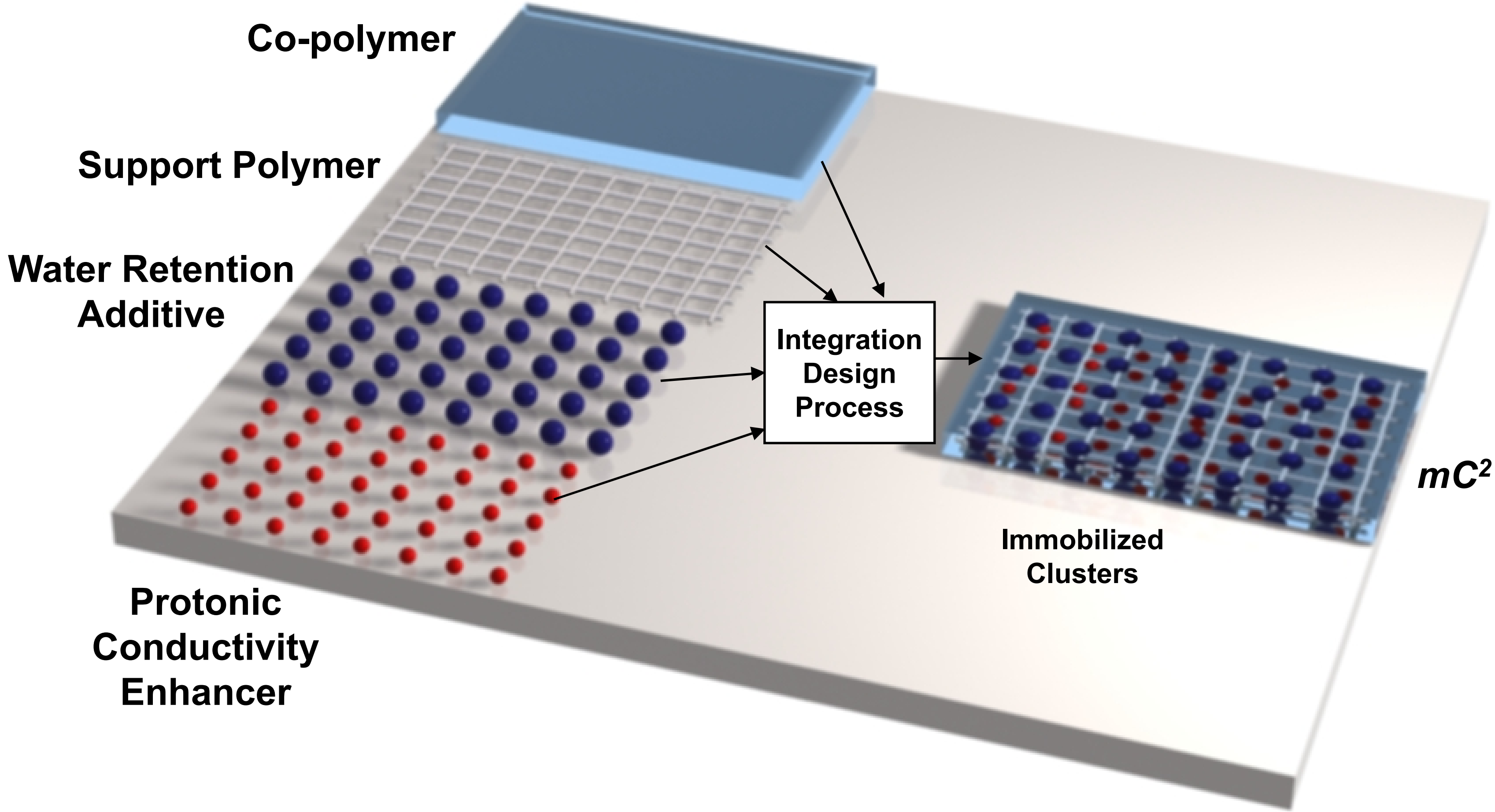
Composite Membrane Concept



Multi-Component System with Functionalized Additives

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Milestones

Milestone	FY08 Goal	FY09 Goal	Current Status
Characterize Baseline Membrane	complete	-	**complete** ✓
Define Advanced Membrane	complete	-	**complete** ✓
Room Temperature Conductivity	70 mS/cm at 80% RH	-	**74 mS/cm** ✓
Select Preferred Design for mC^2	complete	-	**complete** ✓
Screen Nano-additive Incorporation Options	-	complete	**complete** ✓
Characterize Advanced Membrane	-	complete	**complete** ✓
120°C Conductivity: **Go/No-Go**	-	100 mS/cm at 50% RH	**86-148 mS/cm** ✓

All FY08 and FY09 Milestones Met

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Technical Accomplishments

Major Achievements:

- **Met Room Temperature Conductivity Milestone**
  - **74 mS/cm confirmed by BekkTech**
- **Met High Temperature (120°C) Conductivity Milestone**
  - **86-148 mS/cm for mC^2**
- **Incorporation of Additives into mC^2 at the Nano-scale**
- **All Program Milestones Met**

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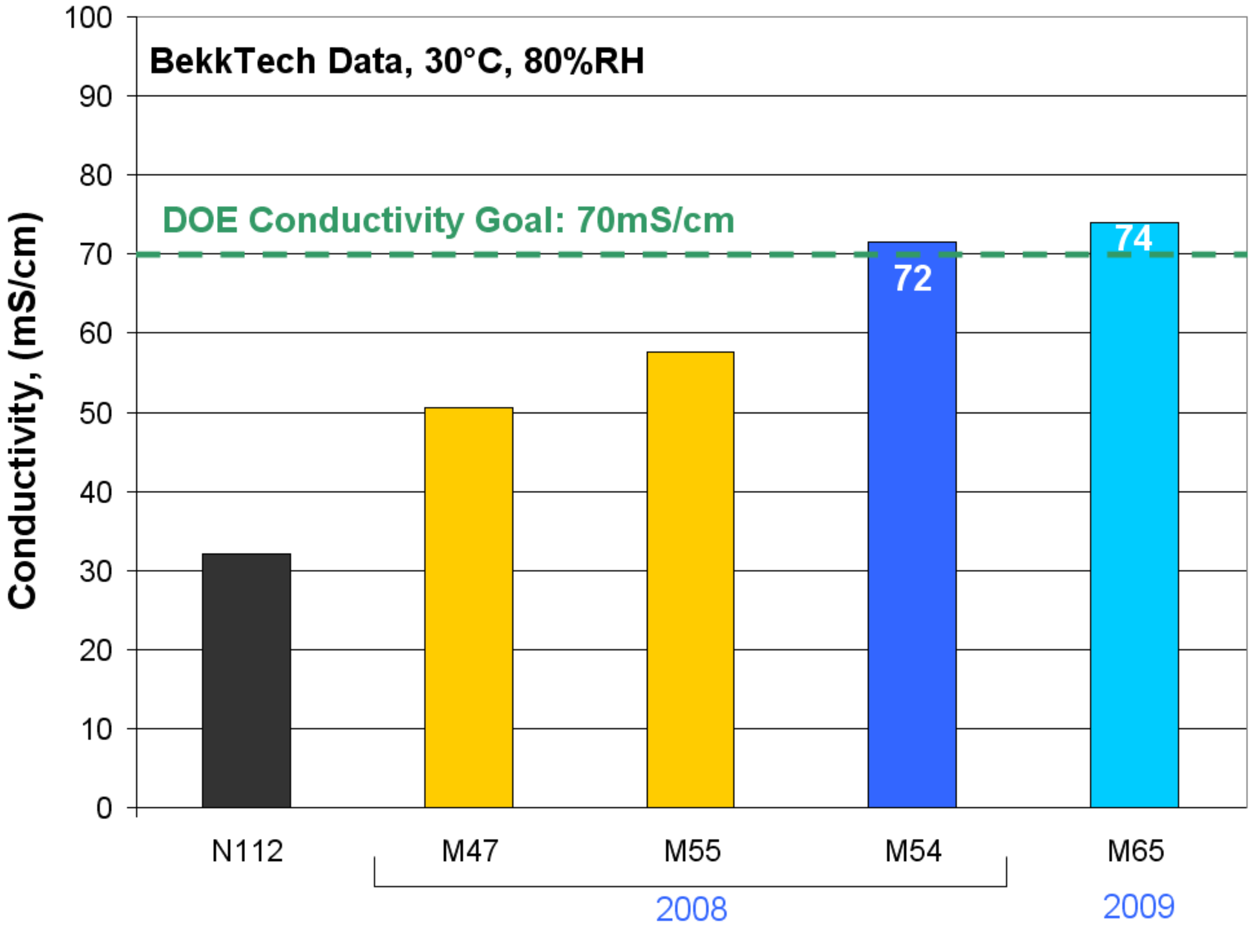
Technical Accomplishments

<u>**Design of Experiments Leading to Accomplishments since last Review:**</u>

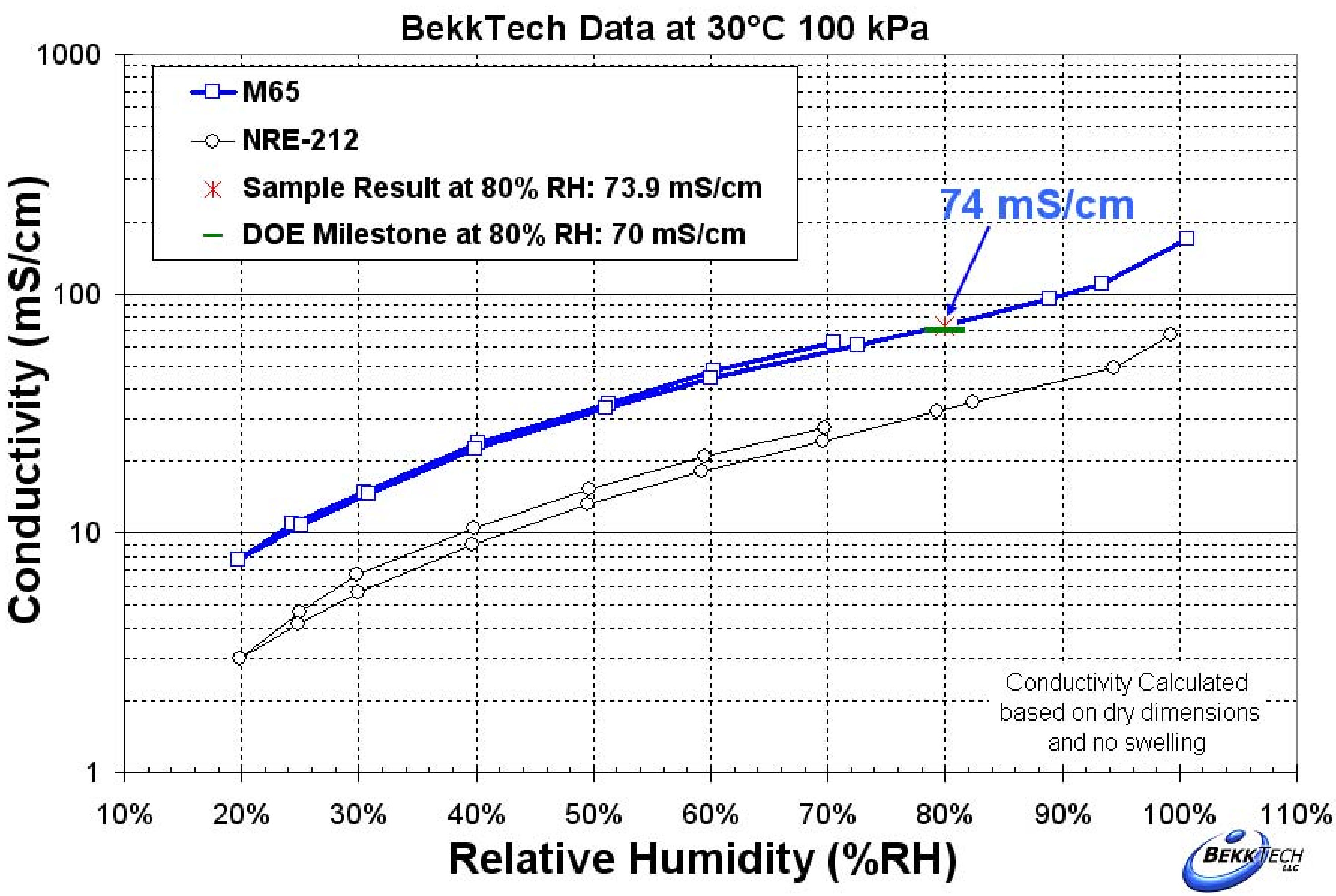
- **Three preparations of improved co-polymer, with successively lower equivalent weight (EW)**
- **Development of new solvent system for improved additive dispersion and casting**
- **Fabrication and characterization of six additive batches (water retaining and proton conducting)**
- **Synthesis of over 10 batches of mC^2, >15 samples**
- **>25 membrane conductivity tests, including 12 samples verified by BekkTech**

Membrane Conductivity at R.T.



Room Temperature Conductivity Goal Met

Membrane Conductivity at R.T.



Conductivity Meets DOE Target; >2x Nafion®

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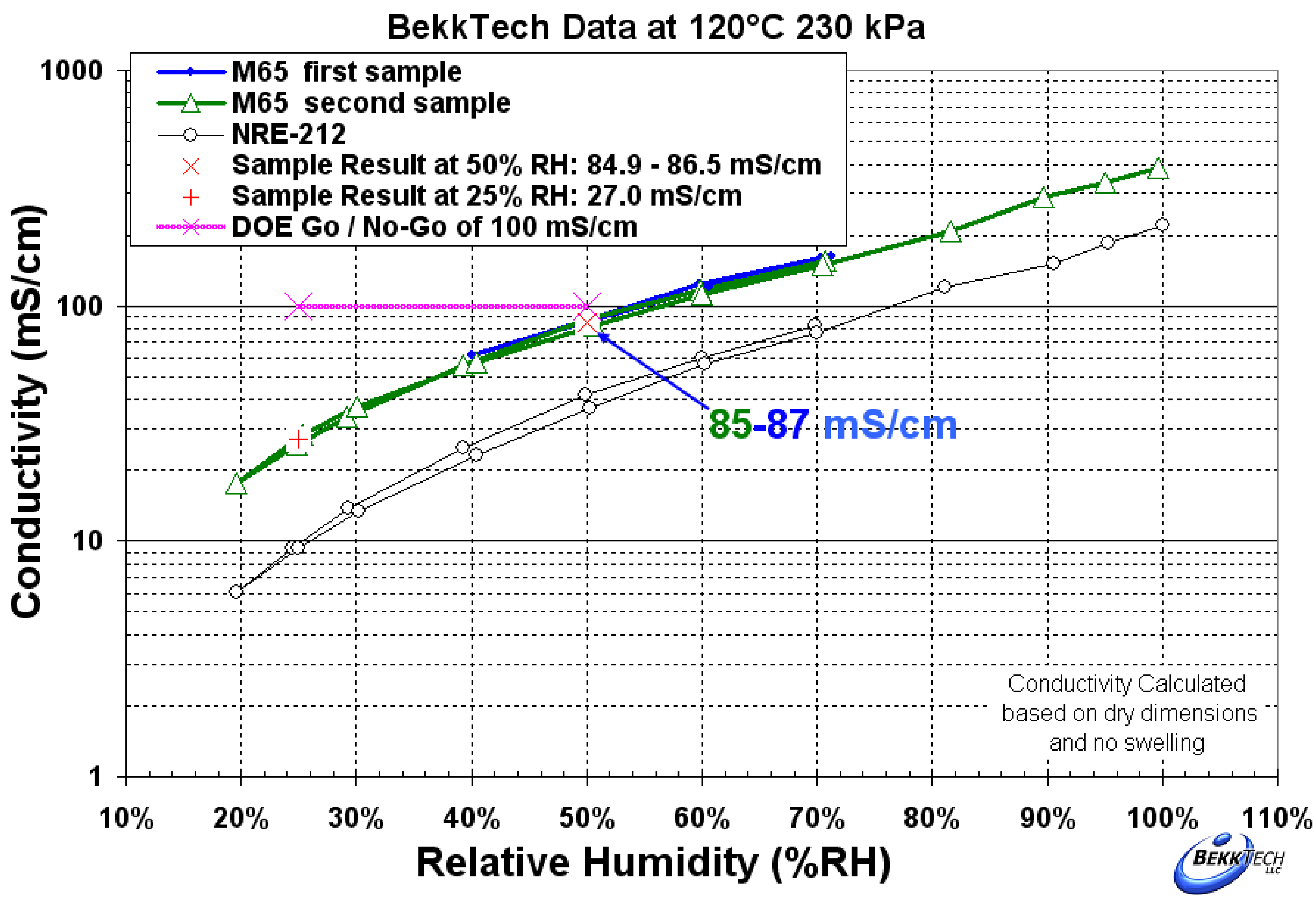
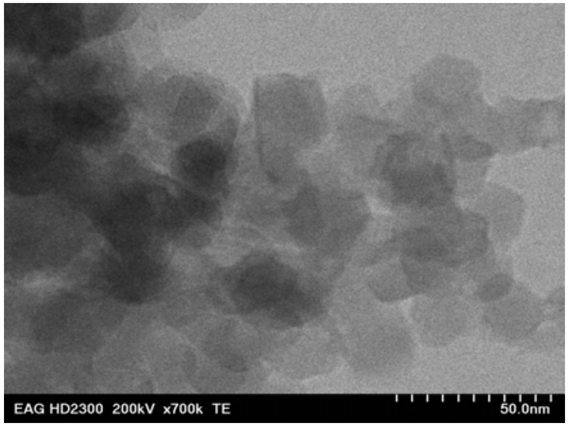
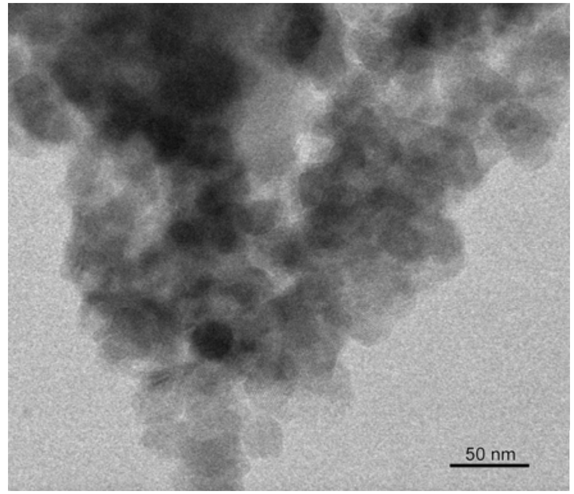
Membrane Conductivity at 120°C



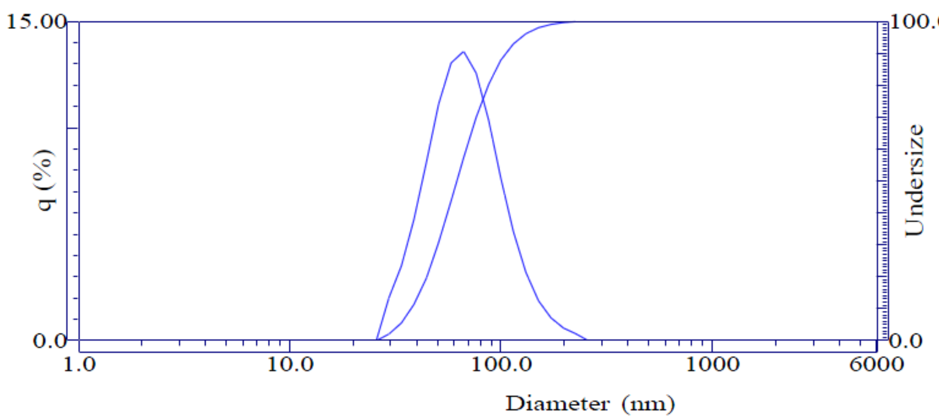
Conductivity Approaching DOE Target; >2x Nafion®

Additive Development





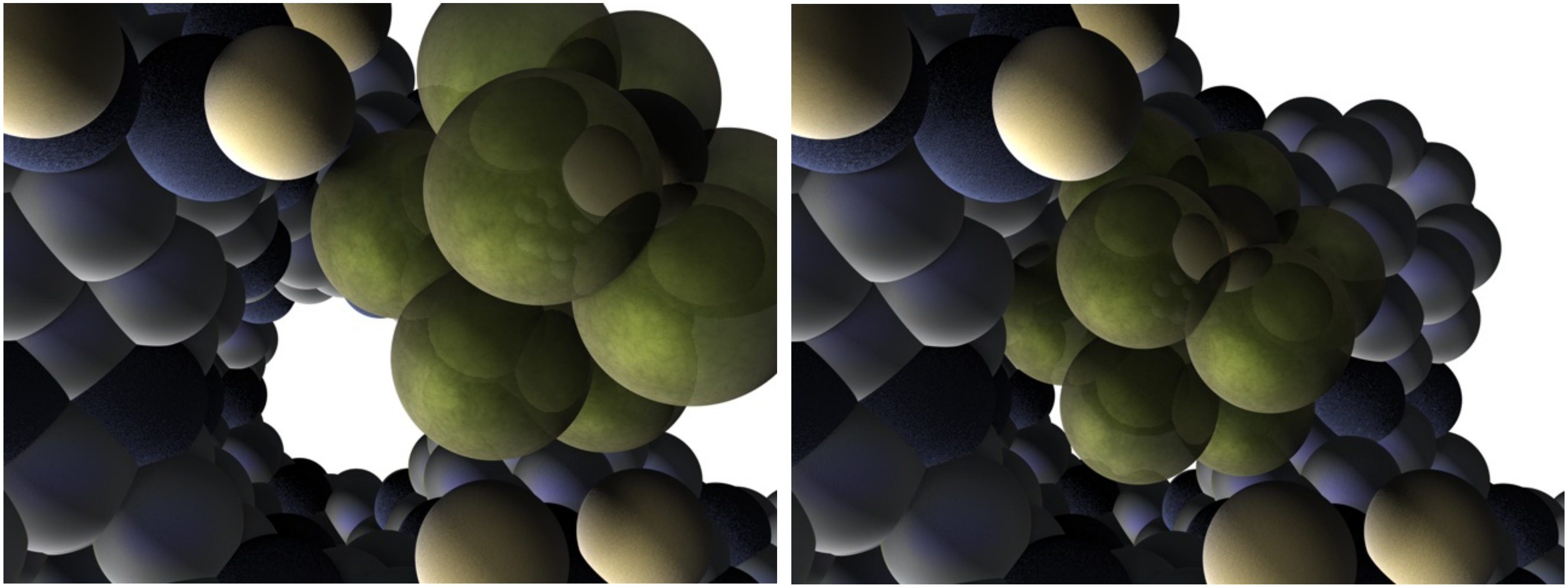
Additive TEM



Additive Particle size <100 nm

Confirmed Structure and Particle Size

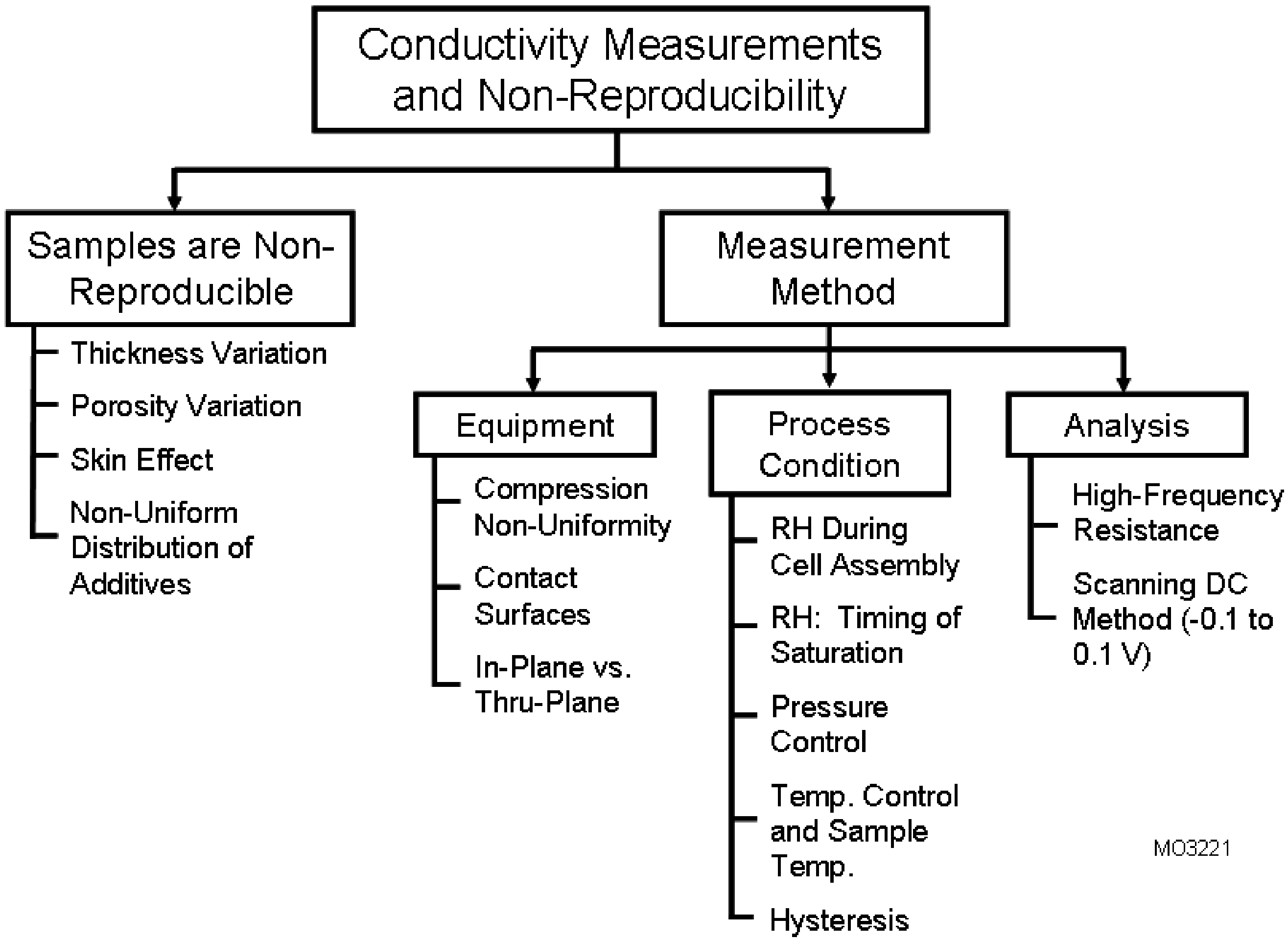
Additive Interaction



Protonic Conductivity Enhancer "docks" onto Water Retaining Additive Pores

Interaction Strengthens Synergy between Water Retention and Proton Conduction

Membrane Conductivity Measurements



Improved Sample Reproducibility
Increased Measurement Reproducibility

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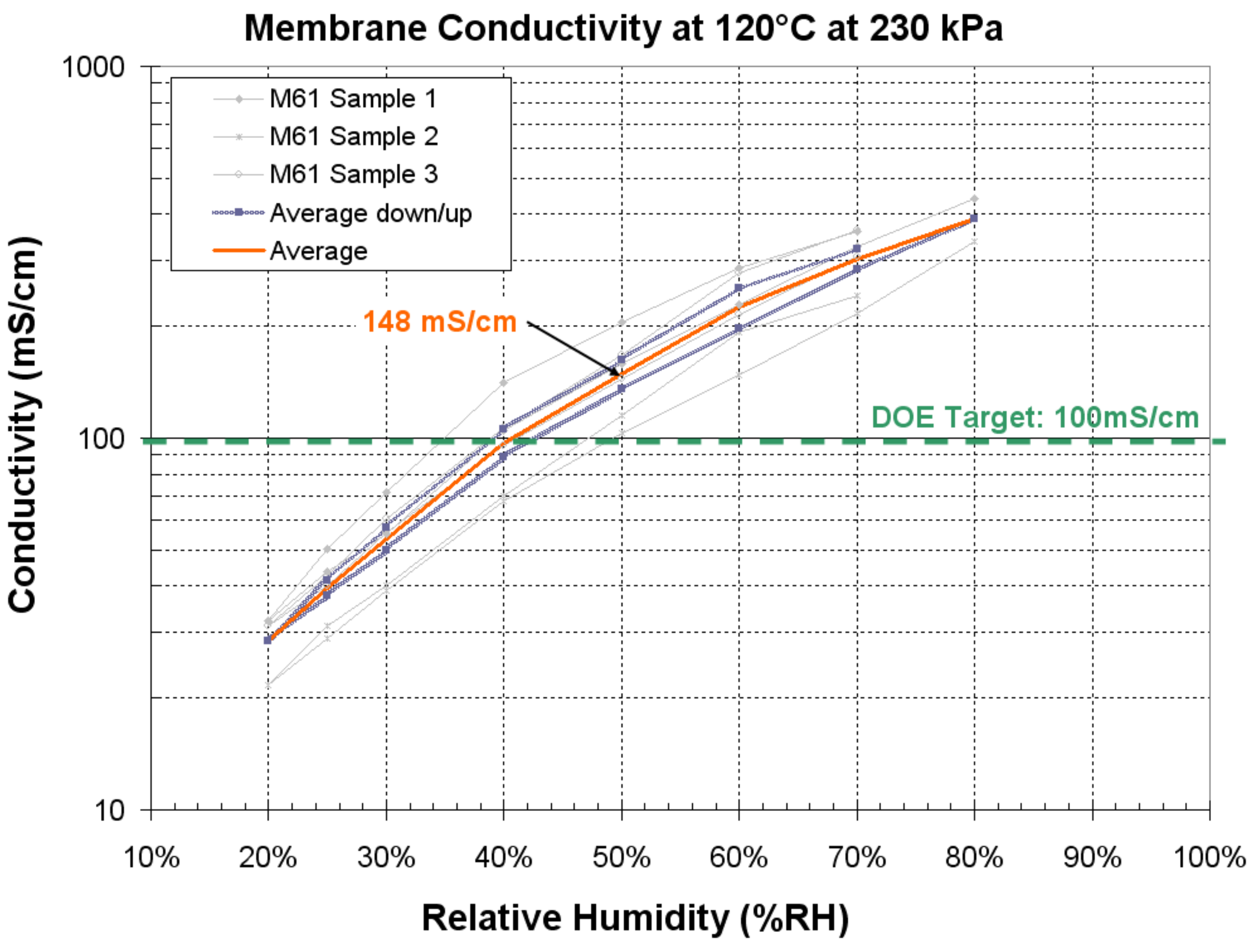
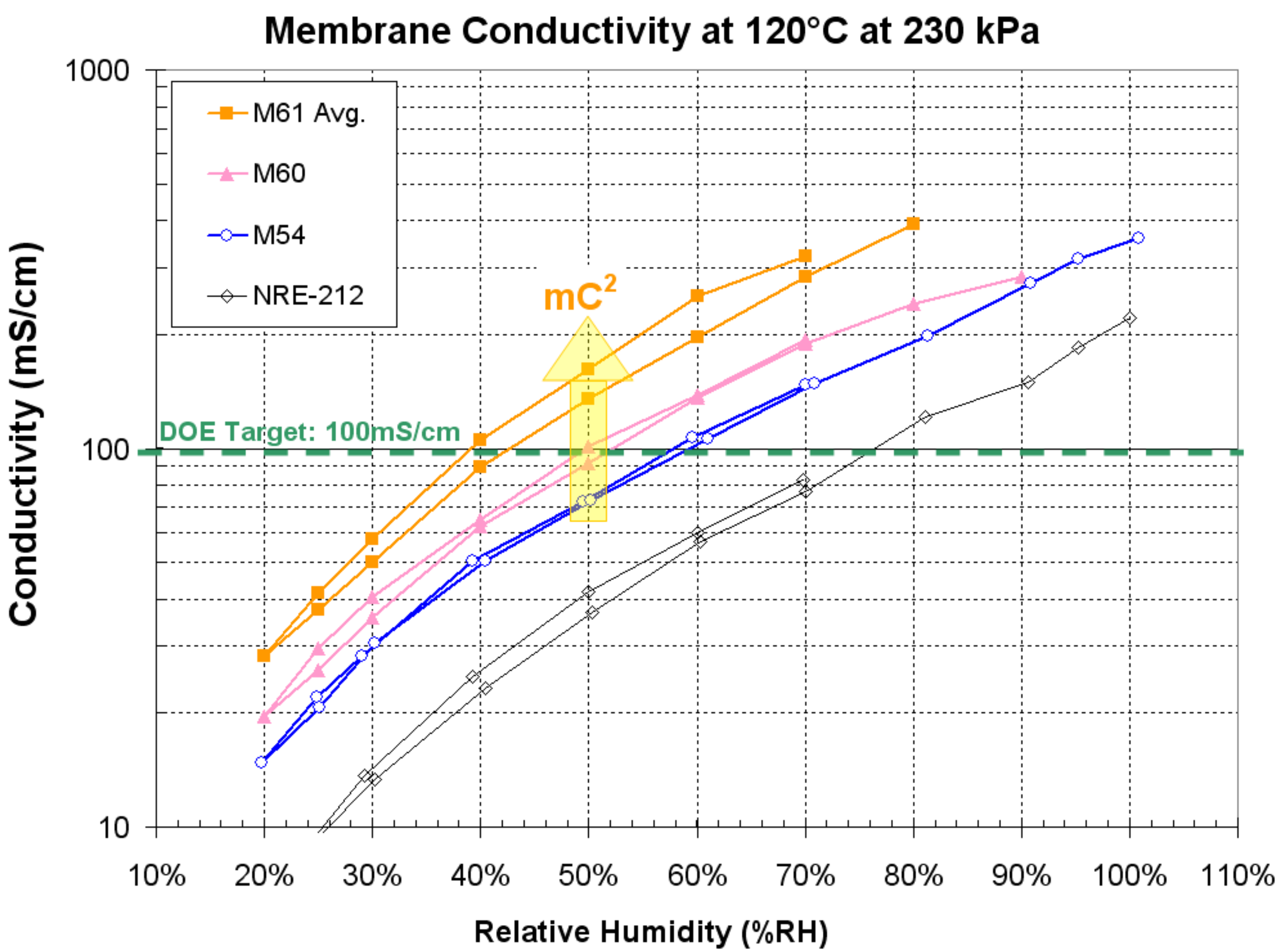
Conductivity Reproducibility



All Three Samples Tested Exceed DOE Target

Effect of Additives on Conductivity



Additives Increase Conductivity → mC^2 Concept Validated

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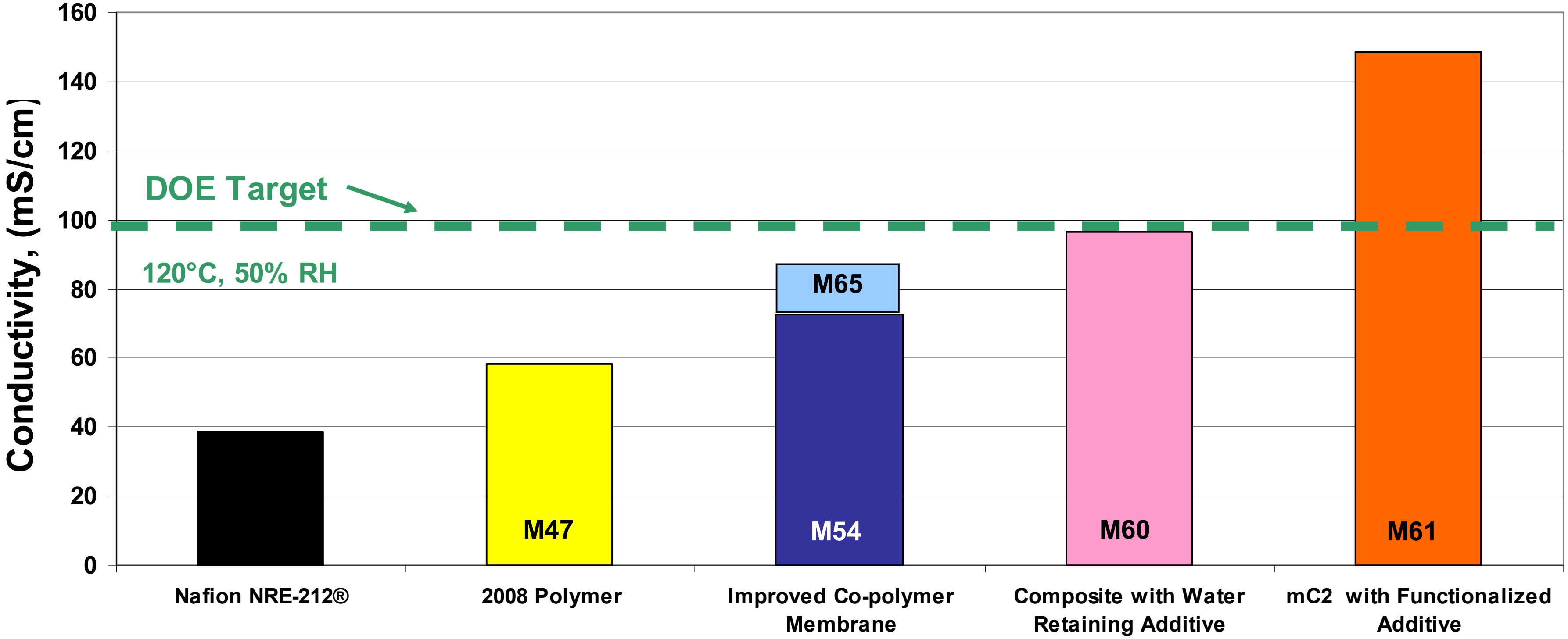
Membrane Conductivity at 120°C



Exceeded 100 mS/cm Goal

>3x Improved Membrane Conductivity *vs.* NRE-212

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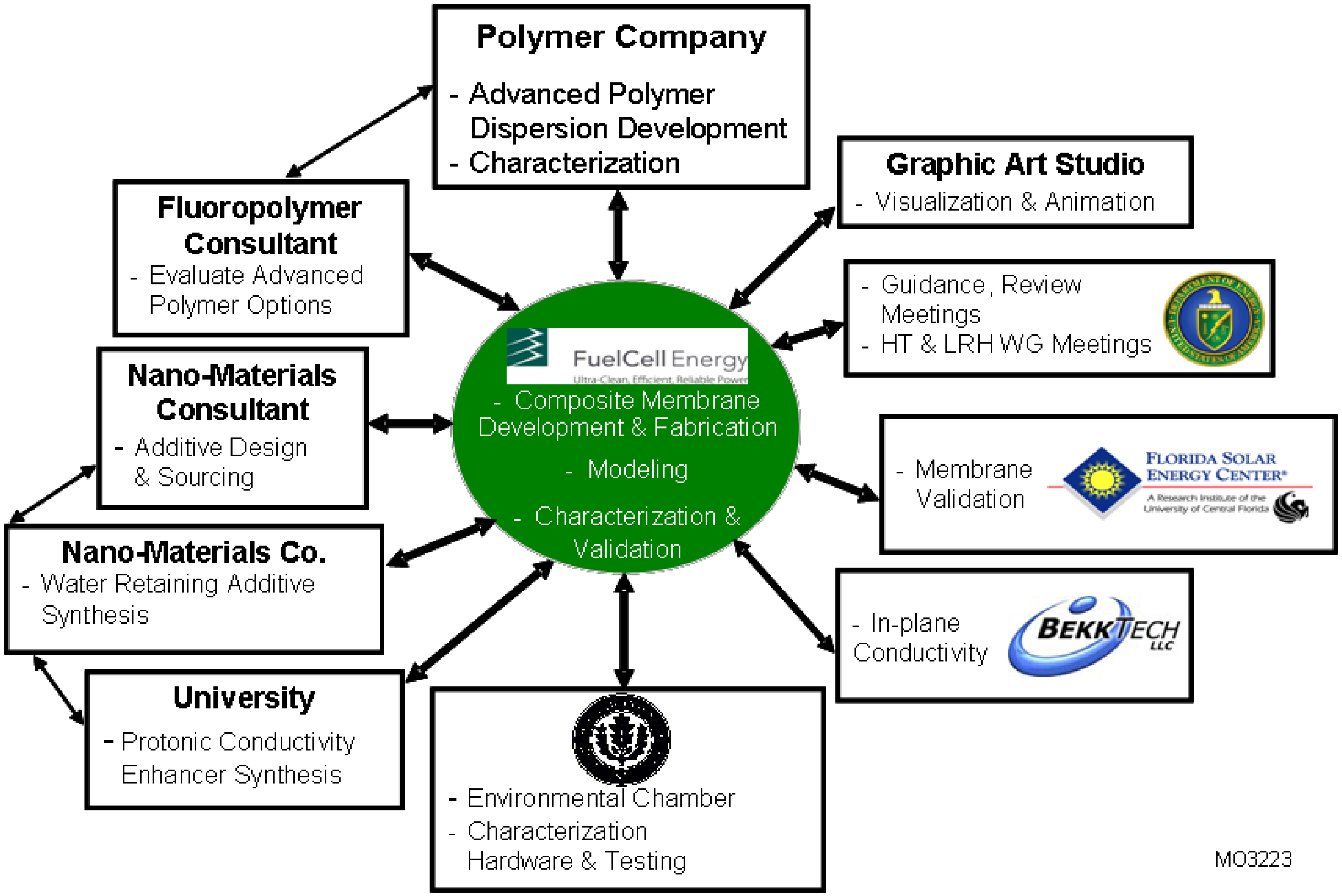
Collaborations



Comprehensive Team Integrates Specialized Expertise

Proposed Future Work

- **Continue to develop advanced polymer dispersions**
- **Optimize and further simplify integration of additives**
- **Expand membrane characterization to track progress towards DOE 2015 targets**
- **Cell testing at 95 and 120°C**
- **Durability Testing**

Proposed Future Work

Upcoming Key Milestones:

- **Go/No-Go decision for composite membrane (46 month milestone)**
- **Select low-cost, long life membrane design (50 month milestone)**
- **Readiness to meet DOE targets (1000 hr stability test – 52 month milestone)**
- **Membrane/MEA evaluation by DOE (annually)**

Project Summary

- Fabricated 3 polymer iterations, 6 nano-additive batches and >10 composite membrane batches
- Improved mC^2 uniformity and conductivity with concurrent process simplification
- Integrated additive functionalization and composite membrane fabrication
- Demonstrated >2x improved conductivity at 120°C over 2008 (>3x higher than NRE-212®)

Project Summary Table

DOE 2010 Technical Targets for Membranes for Transportation Applications				
Performance Parameter	Units	2010 Target	Standard Membrane Nafion® NRE-212	FY08-09 Result
Conductivity at 30°C and 80% RH	mS/cm	70	33	74
Conductivity at 120°C and 50% RH	mS/cm	100	39	86-148

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