In Plane Conductivity Testing

High Temperature Membrane Working Group
Meeting ACS San Francisco 9-14-2006
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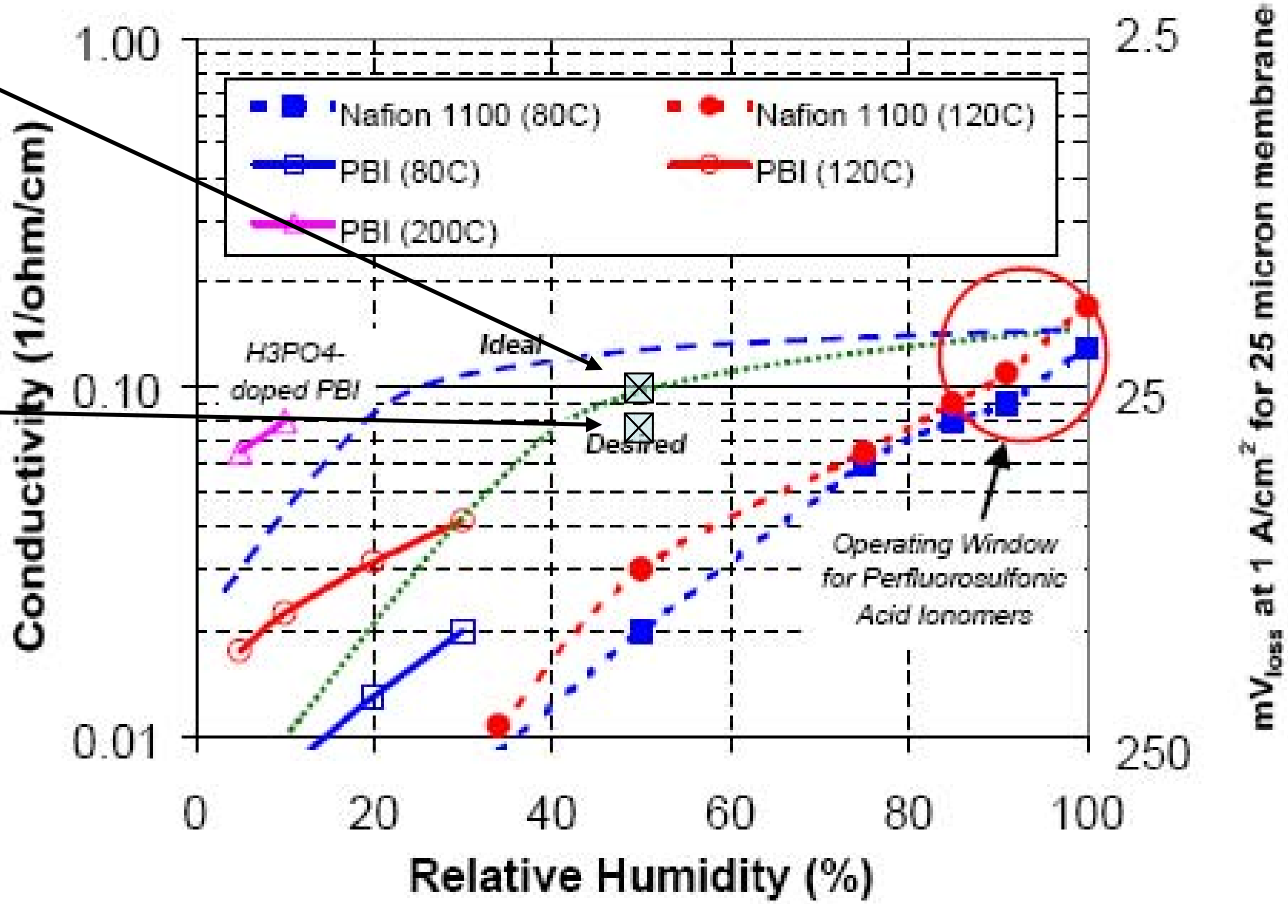
Subcontractor to FSEC/UCF
DOE Award No. DE-FC36-06GO16028

DOE Conductivity Goals

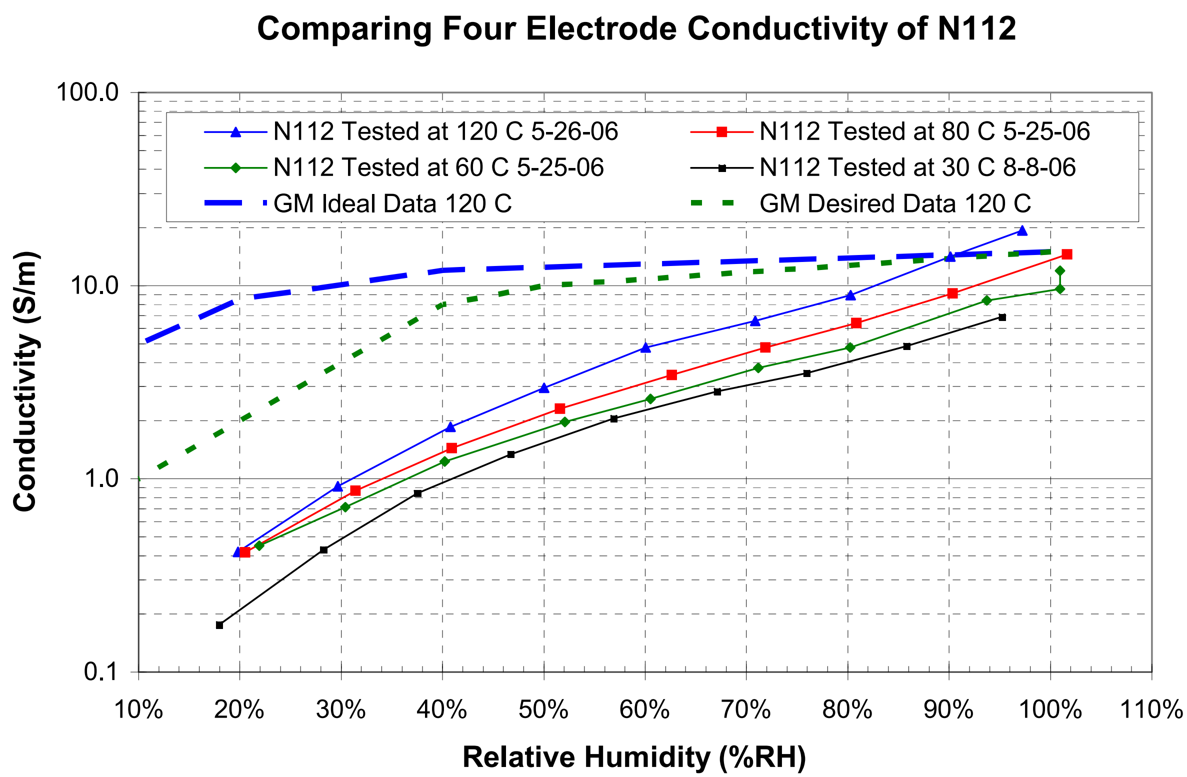
120 C
50% RH
100 mS/cm

Room Temp.
50% RH
80 mS/cm

GM's published conductivity measurements

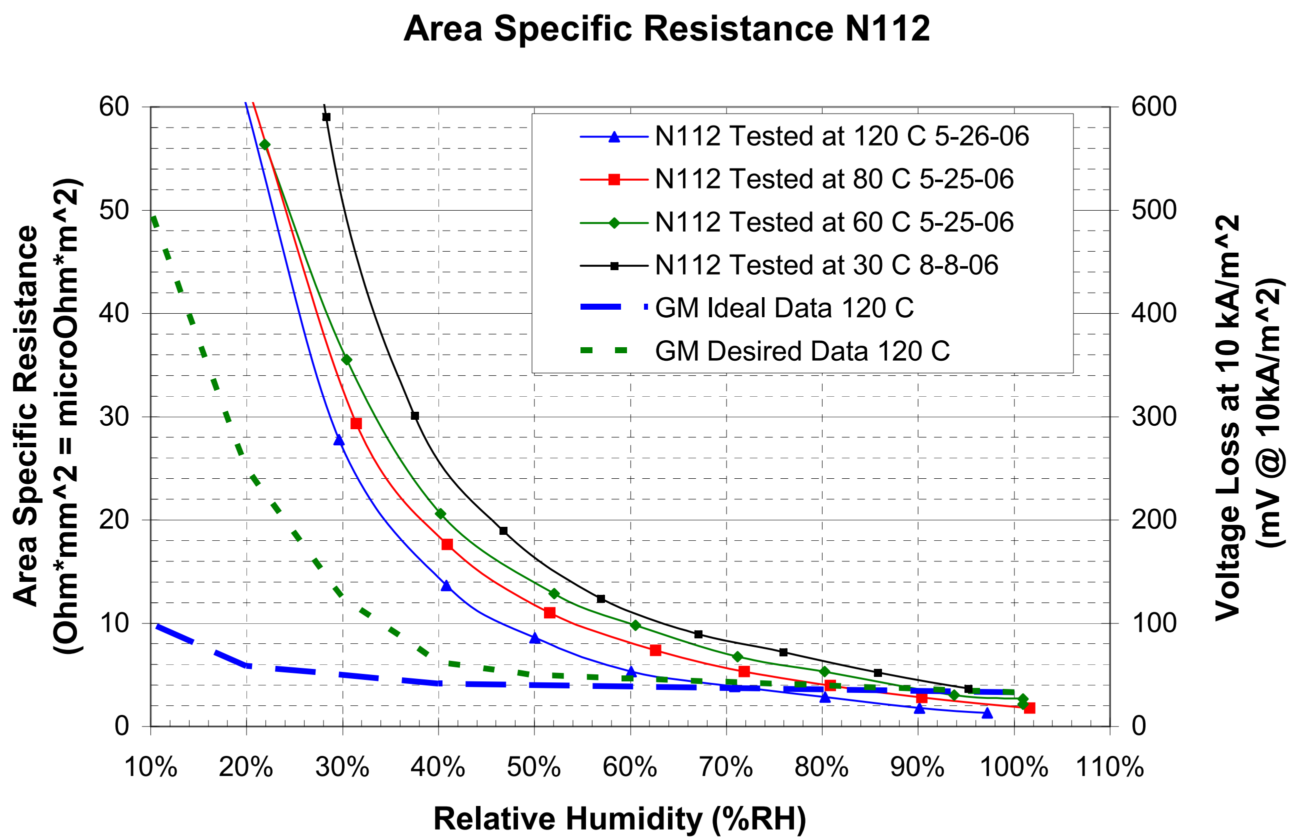


BekkTech Conductivity Measurements



The Character of Membranes must change to meet goals

Area Specific Resistance



The problem of low conductivity is better seen as a voltage loss at 1 A/cm^2 = 10 kA/m^2

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Why we do In-Plane Conductivity

- Great screening tool
- Less skill and equipment required than making and testing a good MEA
- Eliminates other fuel cell performance factors
- Allows for an isolation of moving charge, not creation or annihilation
- High resistance makes for an easier measurement
- Faster
  - Quicker to get on test
  - Quicker equilibration due to no catalyst layer or GDL
- Reproducible
- Produces reliable conductivity values
- Gives good indication of character of the polymer

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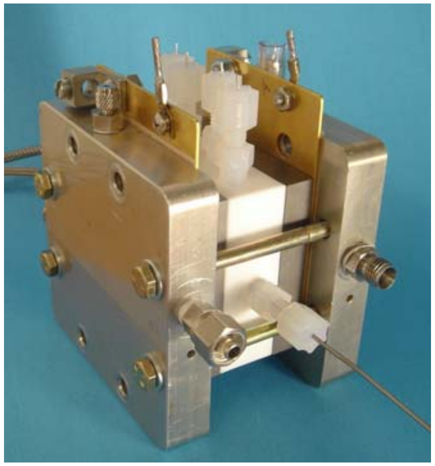
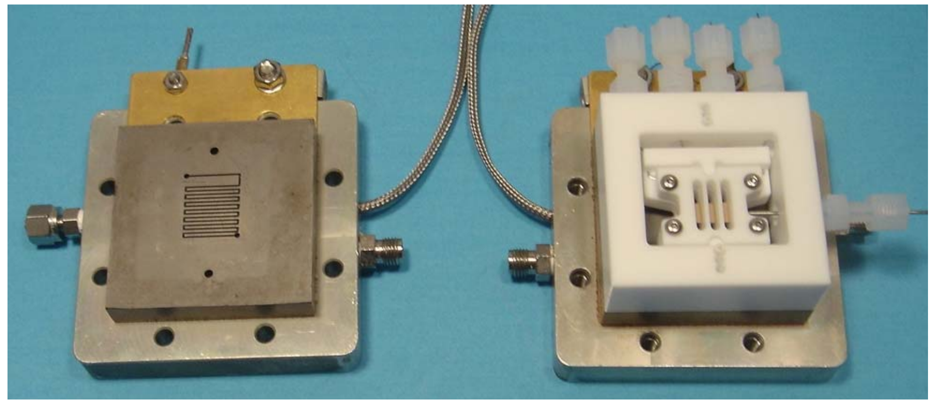
BekkTech's Approach



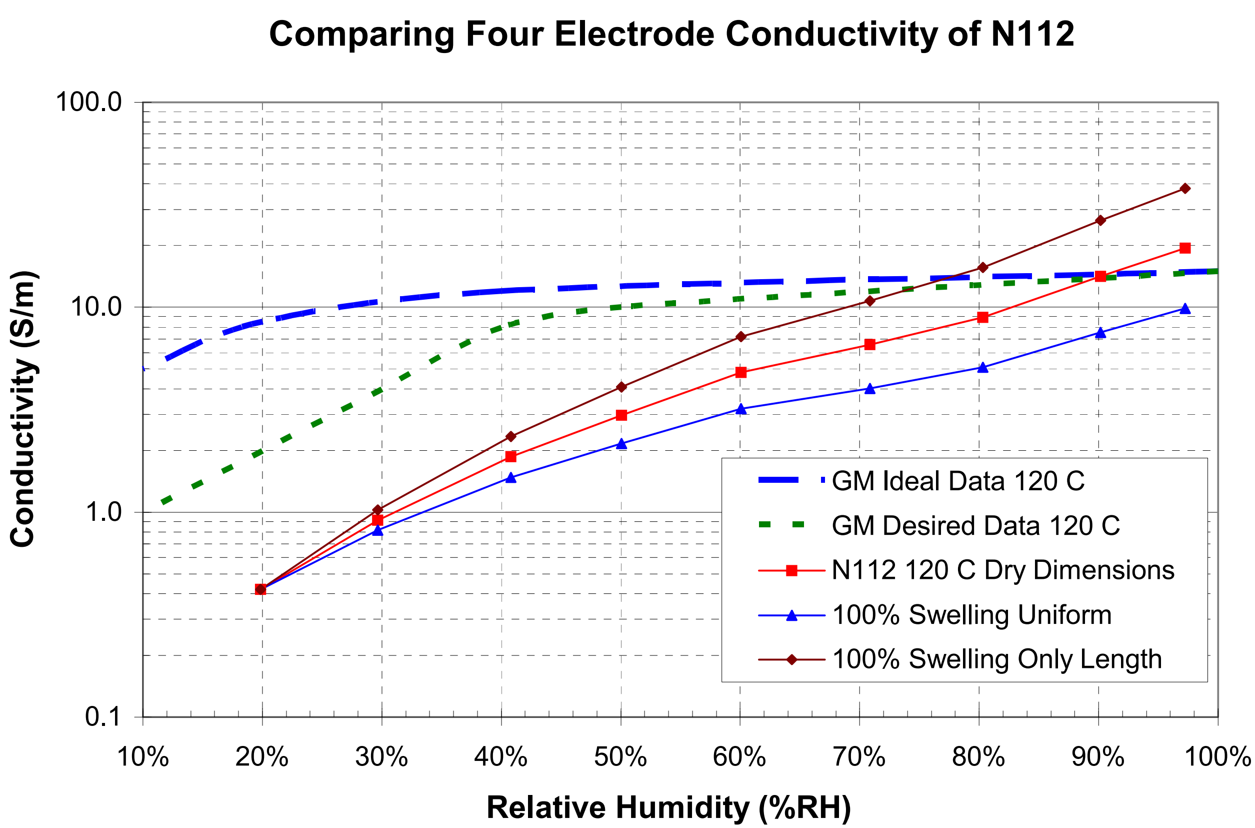


- •Use existing equipment
- •Calibrate system
- •Screening tool
- •Take good samples to single cell testing

Conductivity Measurement Concerns

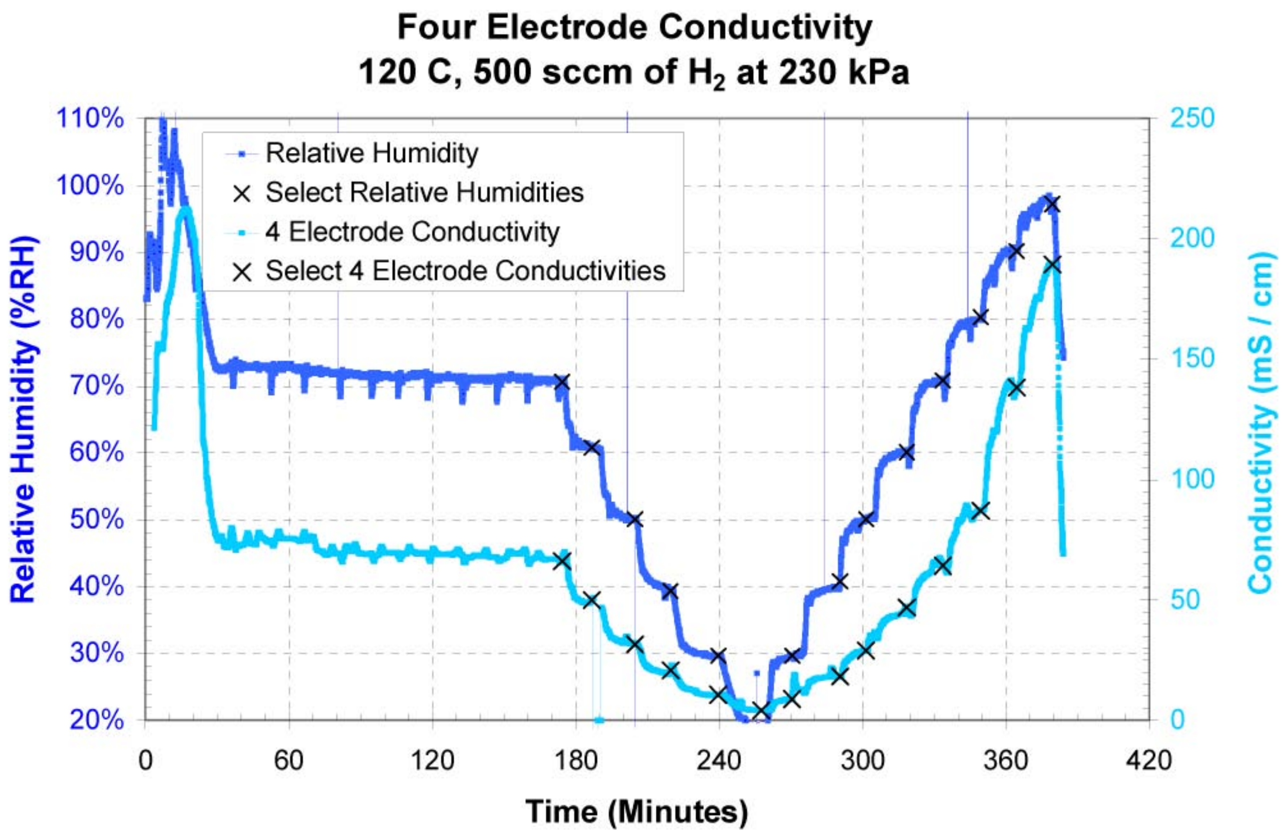
- Affect of membrane swelling
- Affect of membrane history

Swelling as a function of RH



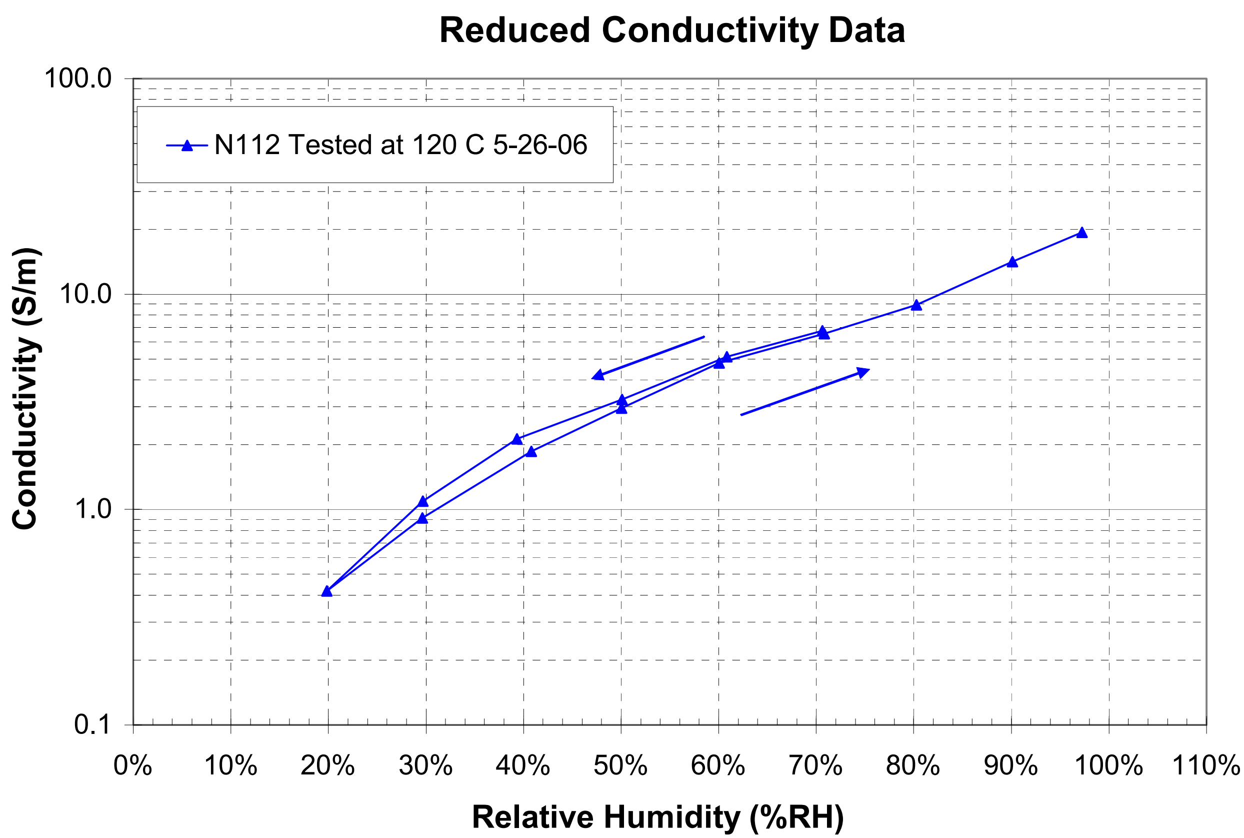
Swelling assumptions do not dramatically change where we are relative to membrane performance goals

In-Plane Conductivity Protocol



To get reproducible results a consistent wet up and testing sequence must be followed

Reduced Nafion Data

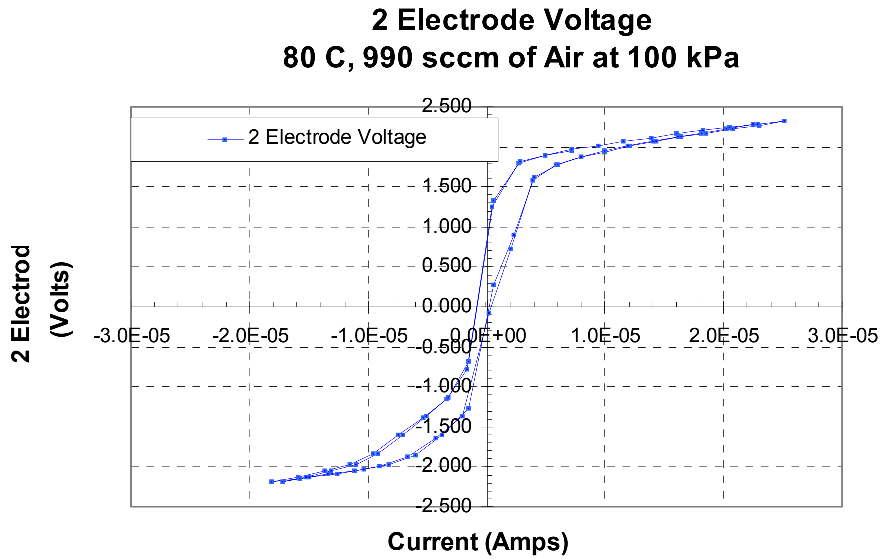


Reduced data plot for conductivity. Notice Hysteresis.

In-Plane Conductivity Concerns

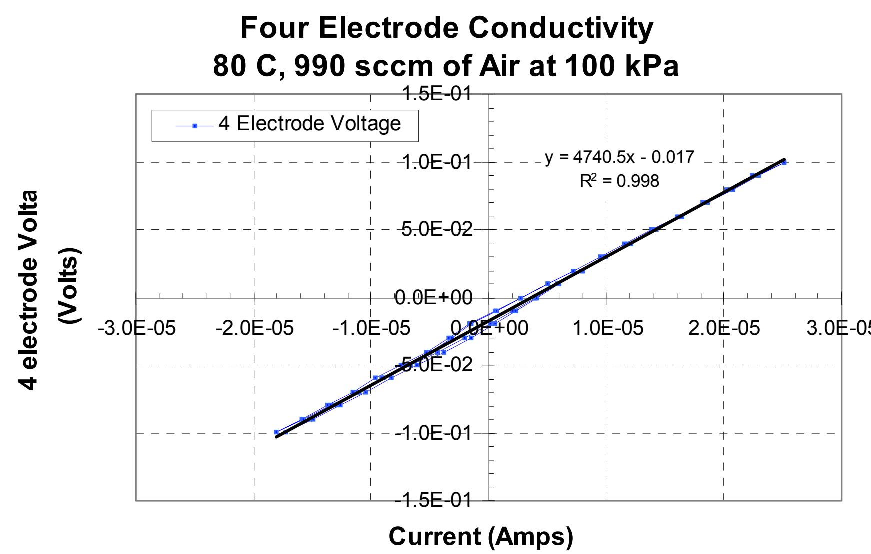
- How do I tell if my data is valid?
- Can we separate surface conductivity from bulk conductivity?
- What about electronic conductivity?
- What about anisotropic membranes?

Linear Response = Good Data



2 Electrode data will only be linear in hydrogen

4 Electrode data should always be linear!



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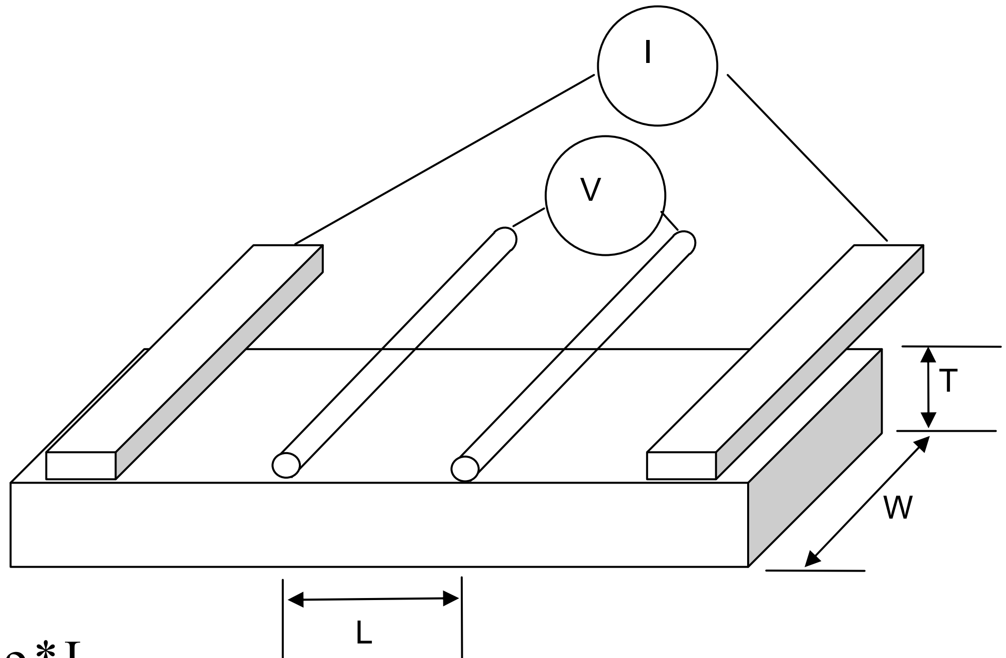
Surface Vs Bulk Conductivity

Assuming only Bulk Conductivity



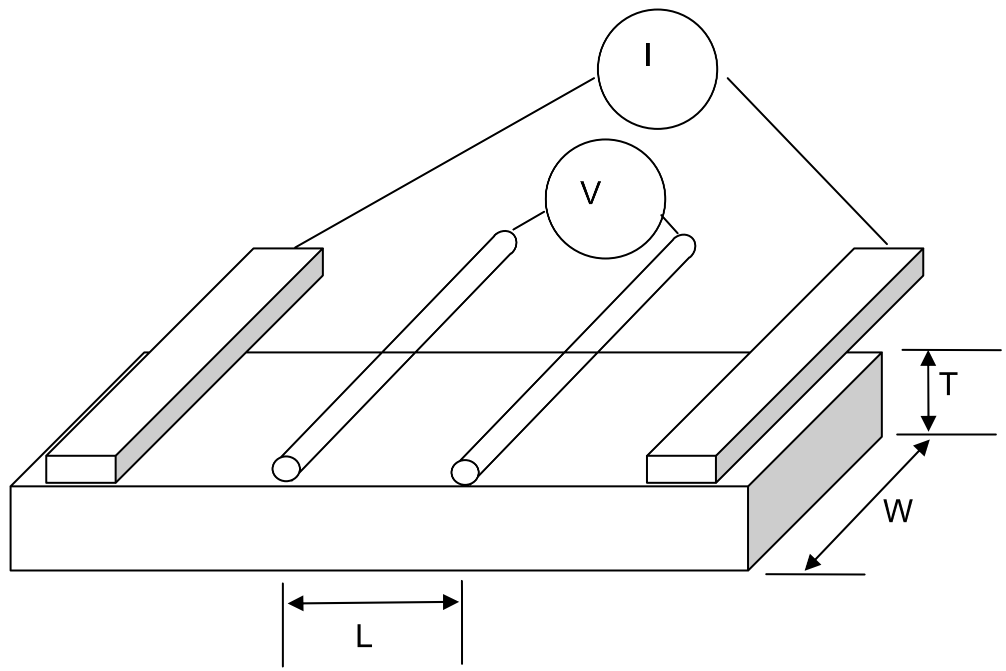
$$R = \frac{\rho * L}{A} = \frac{\rho * L}{W * T}$$

$$\rho = \frac{R * W * T}{L}$$

$$\sigma = \frac{1}{\rho} = \frac{L}{R * A} = \frac{L}{R * W * T}$$

Surface Vs Bulk Conductivity

Assuming only Surface Conductivity



$$\sigma = \frac{1}{\rho} = \frac{L}{R * A} = \frac{L}{R * (W + T) * 2 * SkinThickness}$$

Surface Vs Bulk Conductivity

Ratios Assuming Bulk Conductivity

$$\frac{\sigma_1}{\sigma_2} = 1 = \frac{\dfrac{L_1}{R_1 * W_1 * T_1}}{\dfrac{L_2}{R_2 * W_2 * T_2}} = \frac{R_2 * W_2 * T_2}{R_1 * W_1 * T_1}$$

$$\frac{R_1}{R_2} = \frac{W_2 * T_2}{W_1 * T_1}$$

Ratios Assuming Surface Conductivity

$$\frac{\sigma_1}{\sigma_2} = 1 = \frac{\dfrac{L_1}{R_1 * (W_1 + T_1) * 2 * SkinThickness}}{\dfrac{L_2}{R_2 * (W_2 + T_2) * 2 * SkinThickness}} = \frac{R_2 * (W_2 + T_2)}{R_1 * (W_1 + T_1)}$$

$$\frac{R_1}{R_2} = \frac{W_2 + T_2}{W_1 + T_1}$$

$$W >> T \Rightarrow W + T \approx W$$

$$\frac{R_1}{R_2} \approx \frac{W_2}{W_1}$$

Surface Vs Bulk Conductivity

Example Ratio Calculations

W1 (mm)	W2 (mm)	T1 (microns)	T2 (microns)	Bulk R1/R2 (unitless)	Surface R1/R2 (unitless)
3	3	50	50	1.00	1.00
3	6	50	50	2.00	1.98
3	3	50	100	2.00	1.02
3	6	50	100	4.00	2.00

To separate out Surface from Bulk Conductivity, samples of different thicknesses must be tested.

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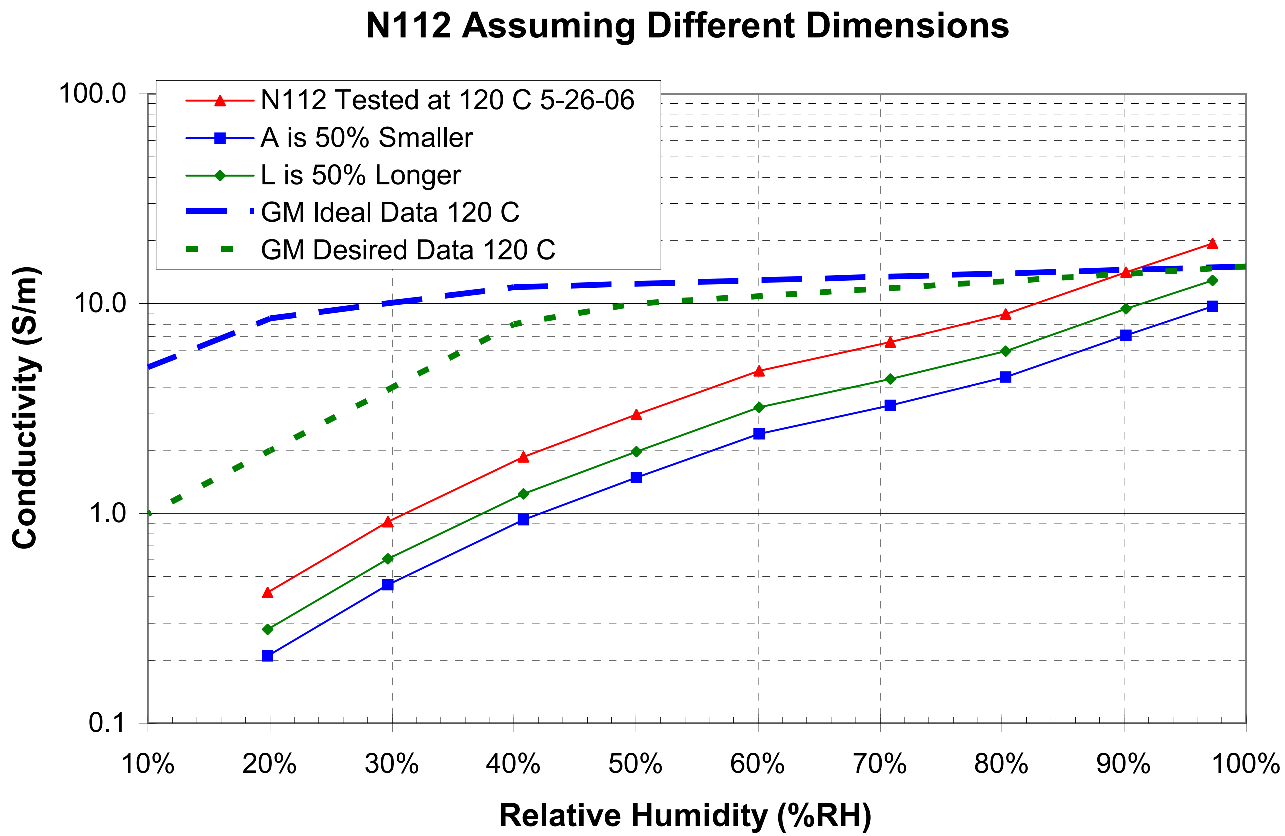
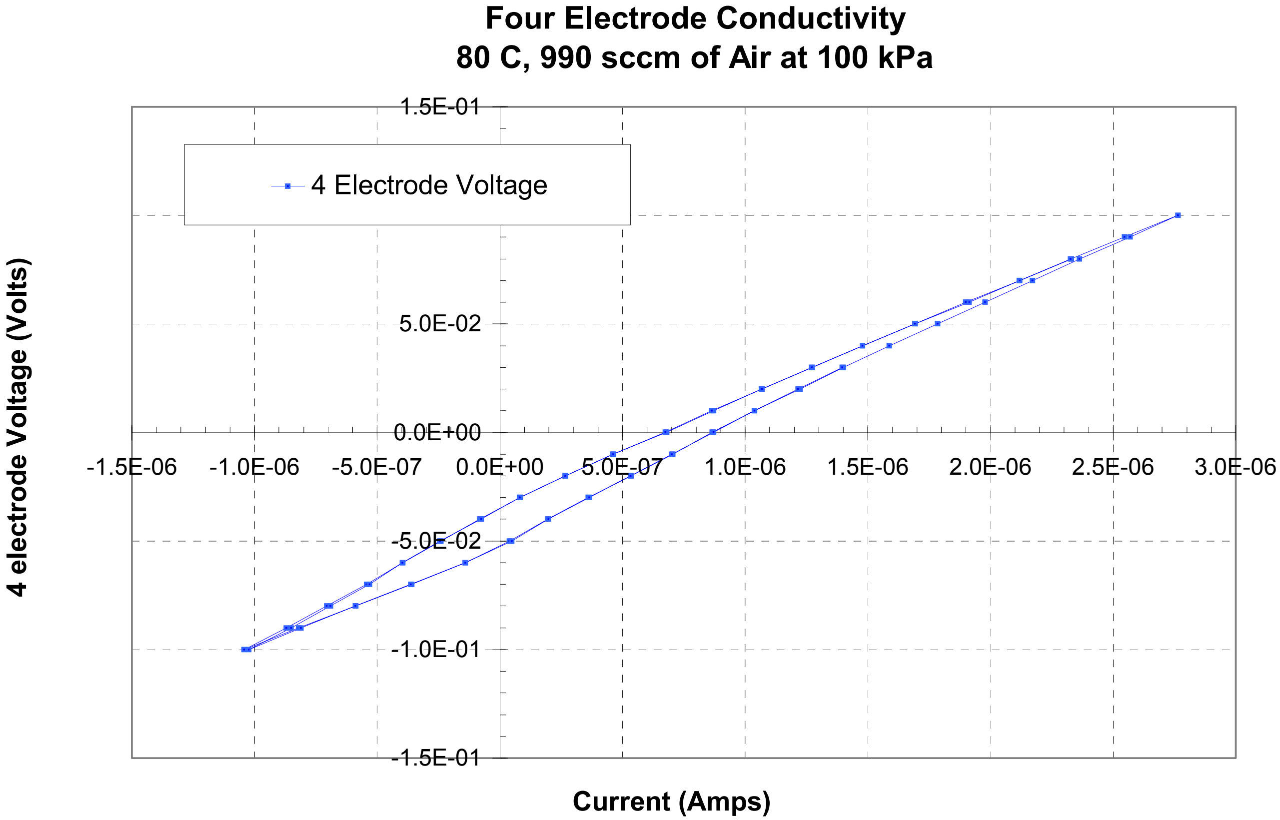
Anisotropic Membranes



Notice that the character of the membrane shows through even though the individual values are incorrect.

Electronic Conductivity



Mixed ionic and electronic conductors in non-hydrogen environments show four distinct linear regions.

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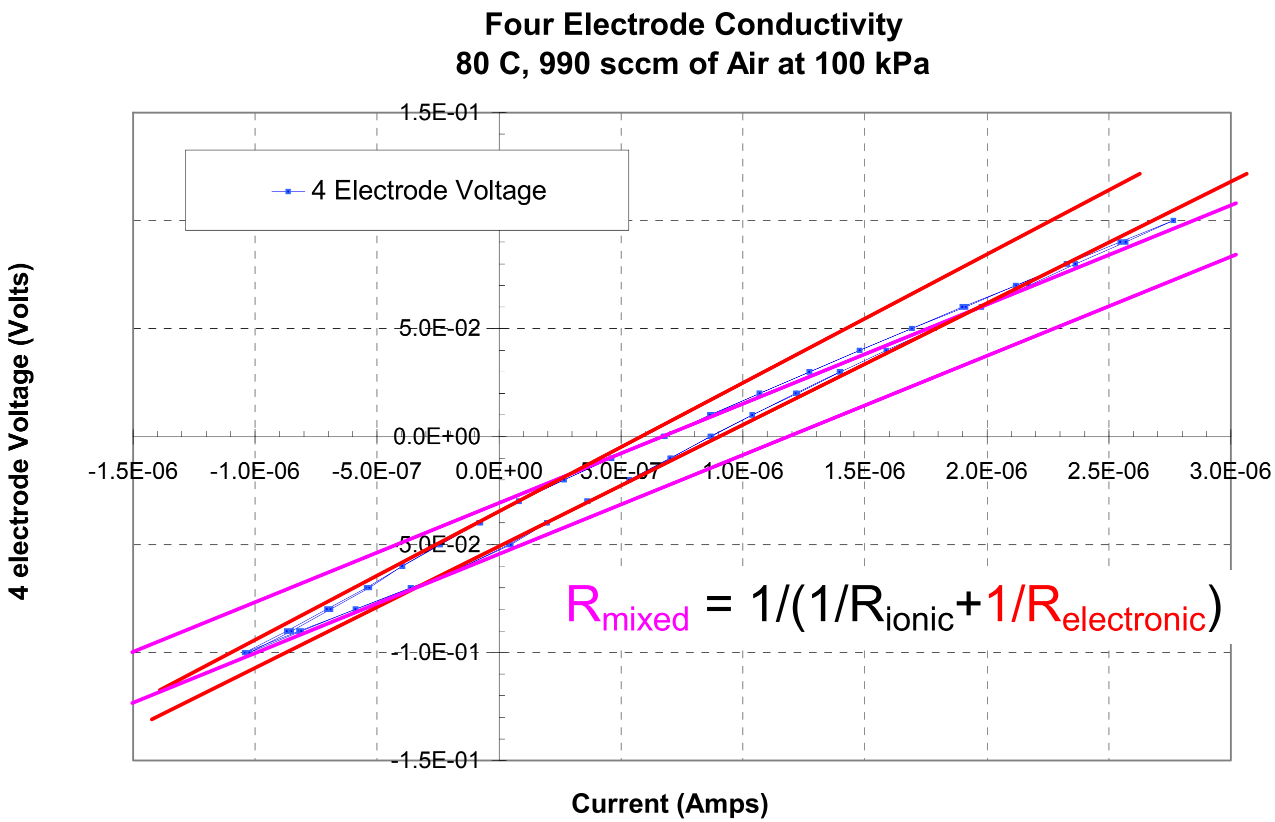
Separate Electronic and Ionic



Ionic and electronic components can be estimated.

In-Plane Conductivity Summary

- Great screening tool
- Easy
- Fast
- Shows the character of the membrane
- Focuses on conductivity, other variables are eliminated

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Future Work

- Test commercially available samples. Make data available to testing community.
- BekkTech will be part of setting and publishing standardized test protocols for this program
- BekkTech will test one sample per year from each DOE HTM Program member as a measurement of progress
- Work with FSEC and Scribner Associates to show correlation between in-plane and through-plane measurements.