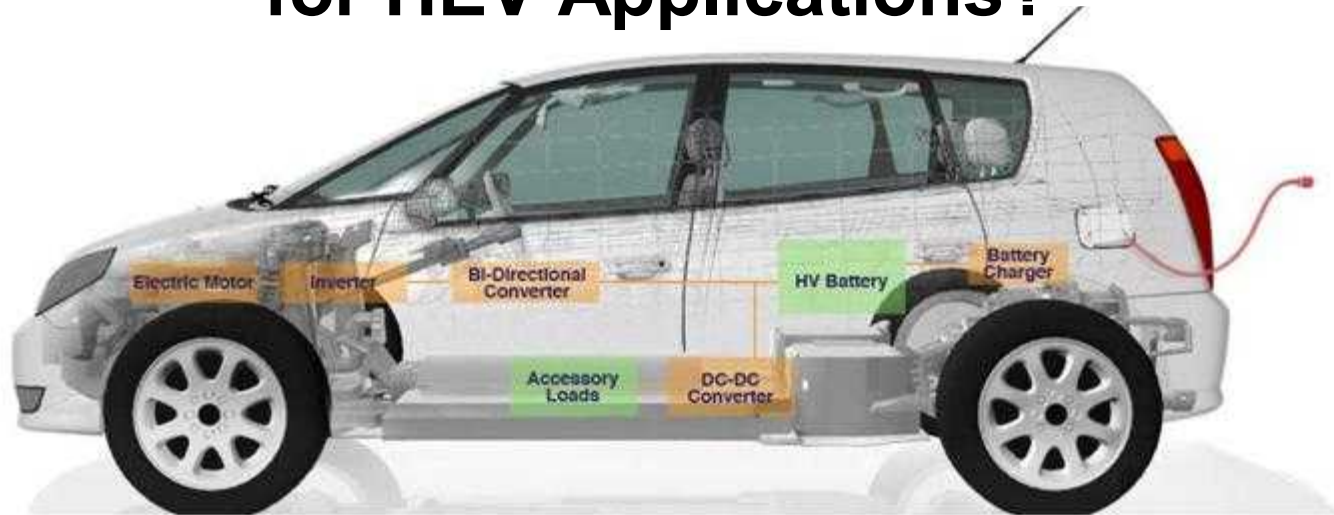


Evaluation of Plasticizer Additives in High Temperature Polymer Dielectrics

Kirsten N. Cicotte, Michele L. Denton, Zac Castillo,
Chris J. Merry, Shawn M. Dirk

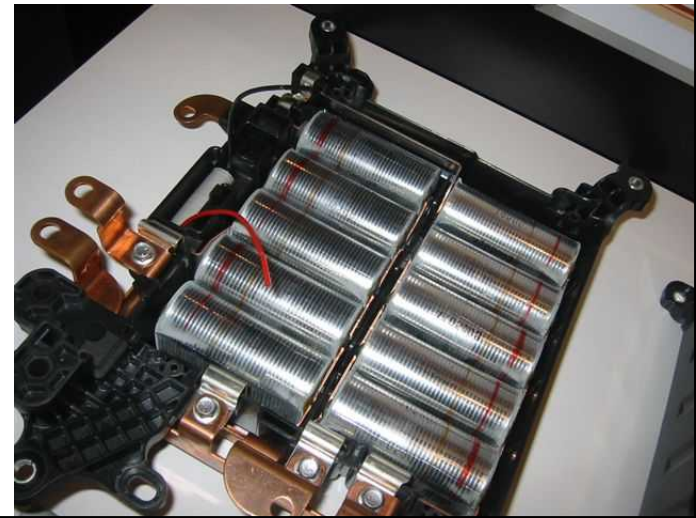
What Makes a Good Capacitor for HEV Applications?



- **Large Energy Density**
 - **Smaller Capacitors**
- **Low Dissipation Factor**
 - **Capacitor can store charge longer**
- **Large Dielectric Breakdown Strength**
 - **Dielectric films can be thinner**
- **High Operating Temperature**
 - **Capacitors can be used without additional cooling loops (extra radiators = extra cost)**
- **Low Cost (Major driver for auto industry)**
- **Safe**

The Problem

- **Inverter**
 - **Function:**
 - Transform DC to AC current
 - **Requires a high performance DC bus capacitor bank**
- **Capacitors**
 - **Largest and the least reliable component of fuel cell and electric hybrid vehicle inverters**
 - Up to 23% of inverter weight and cost
 - Up to 35-40% of inverter volume
 - **Current thin film polymer capacitors operating ceiling temp low (105 °C)**

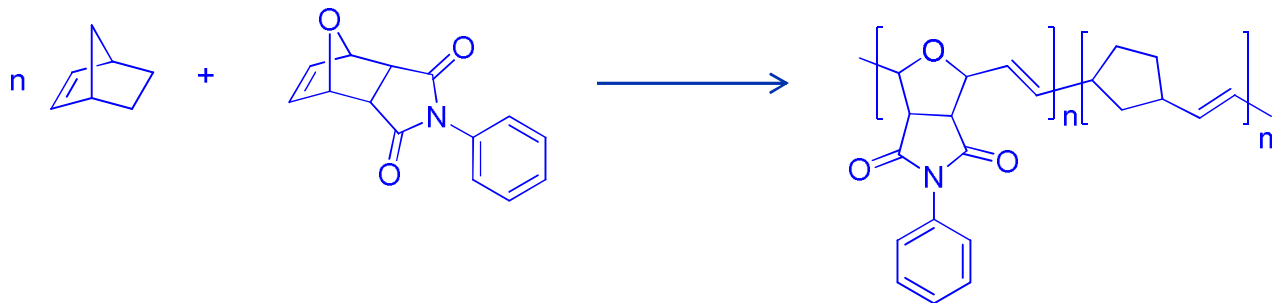


2015 DOE OVT Requirements

- Ceiling operating temperature: **140°C** / 105°C
- Operation: **450 V** / 1000V
- Target volume: **0.6 L** / 2 L

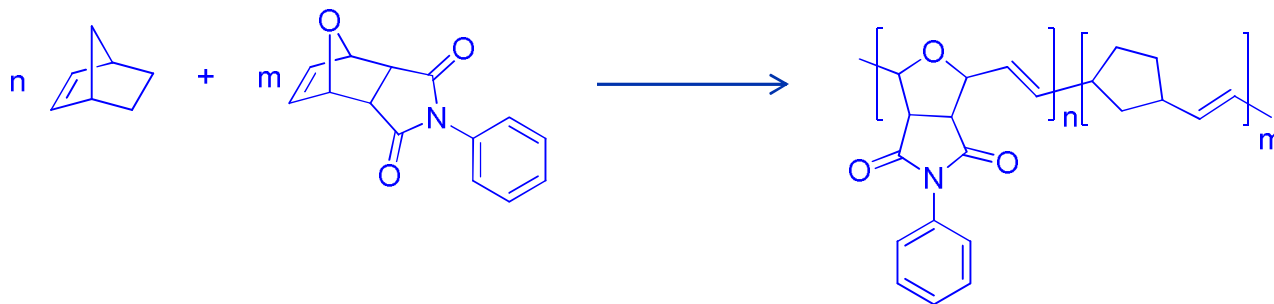
m

- Polymer :
 - **S-POW** (copolymer *N*-phenyl-7-oxanobornene)

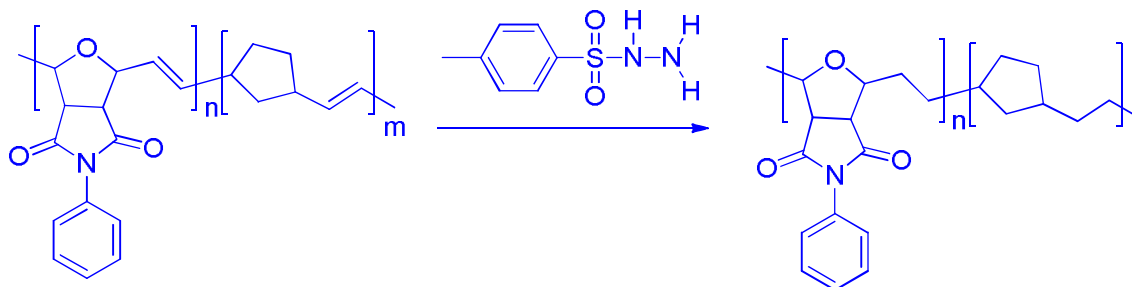


S-POW Optimization

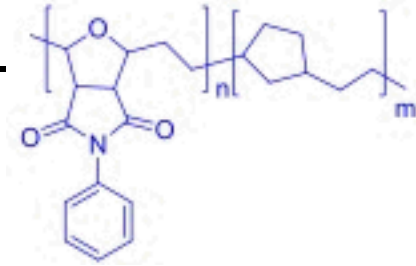
- Altered imide to norbornene in copolymer



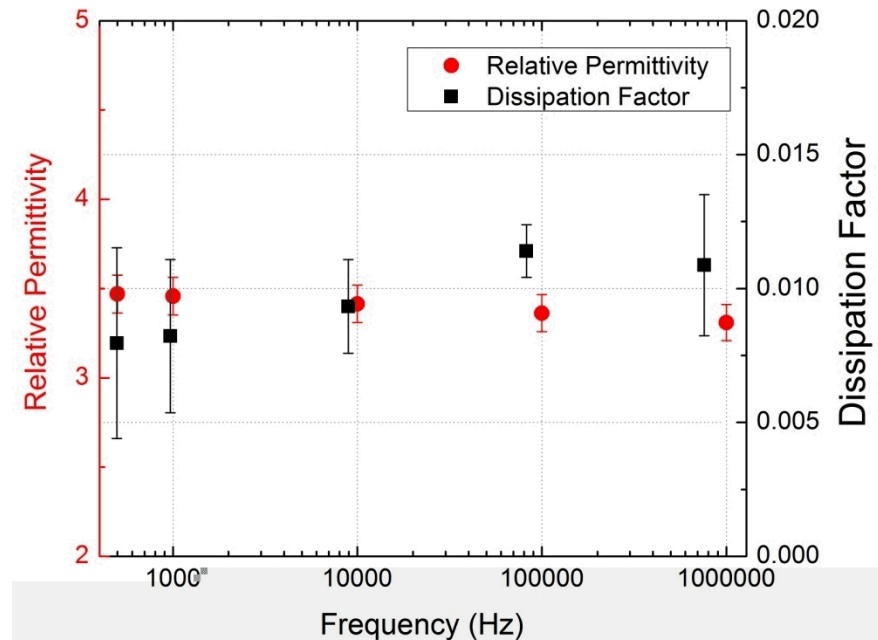
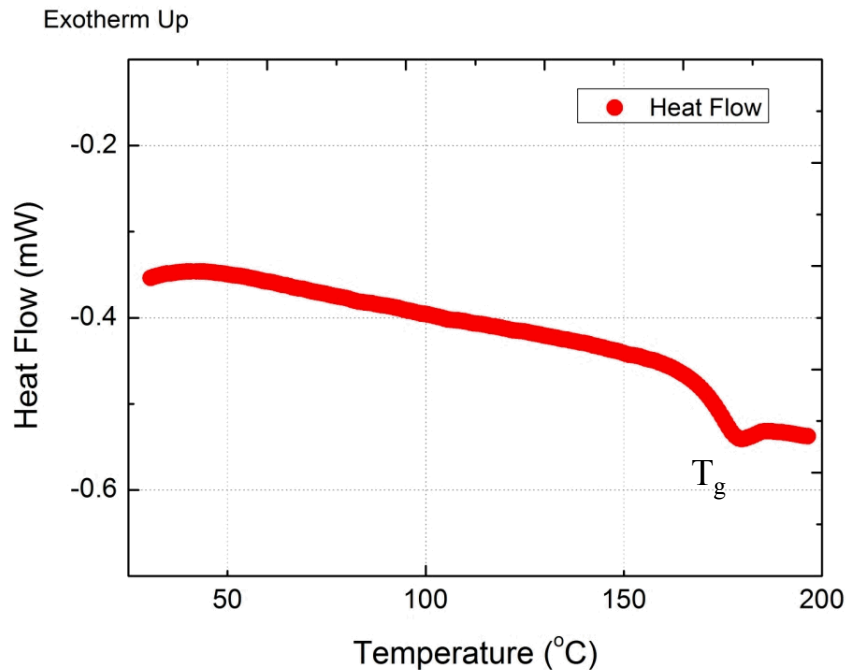
- Hydrogenation of copolymer



S-POW Characterization

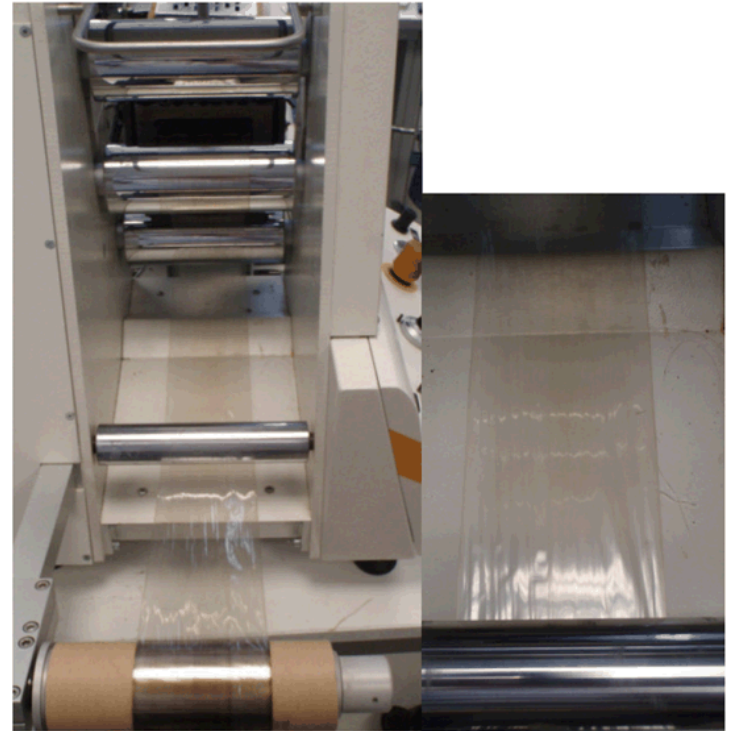


- Recall: 140°C operating Temperature
 - Glass transition temperature (T_g) well above



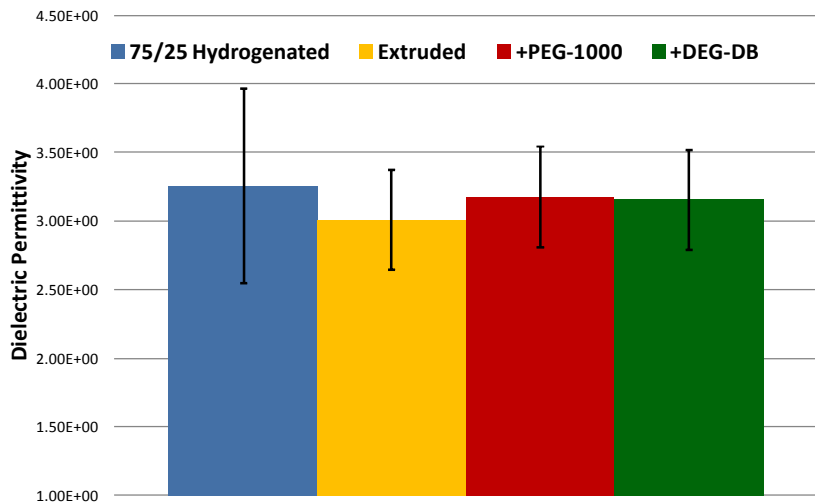
Approach to Thin Films

- With Dr. Collin Co. demonstrated extrusion of thin films.
 - Initially extruded several rolls of polymer with thicknesses of 8-20 μm , but they were **brittle**.
 - plasticizer addition allows for extrusion of 3 μm films with no significant decrease of electrical properties.

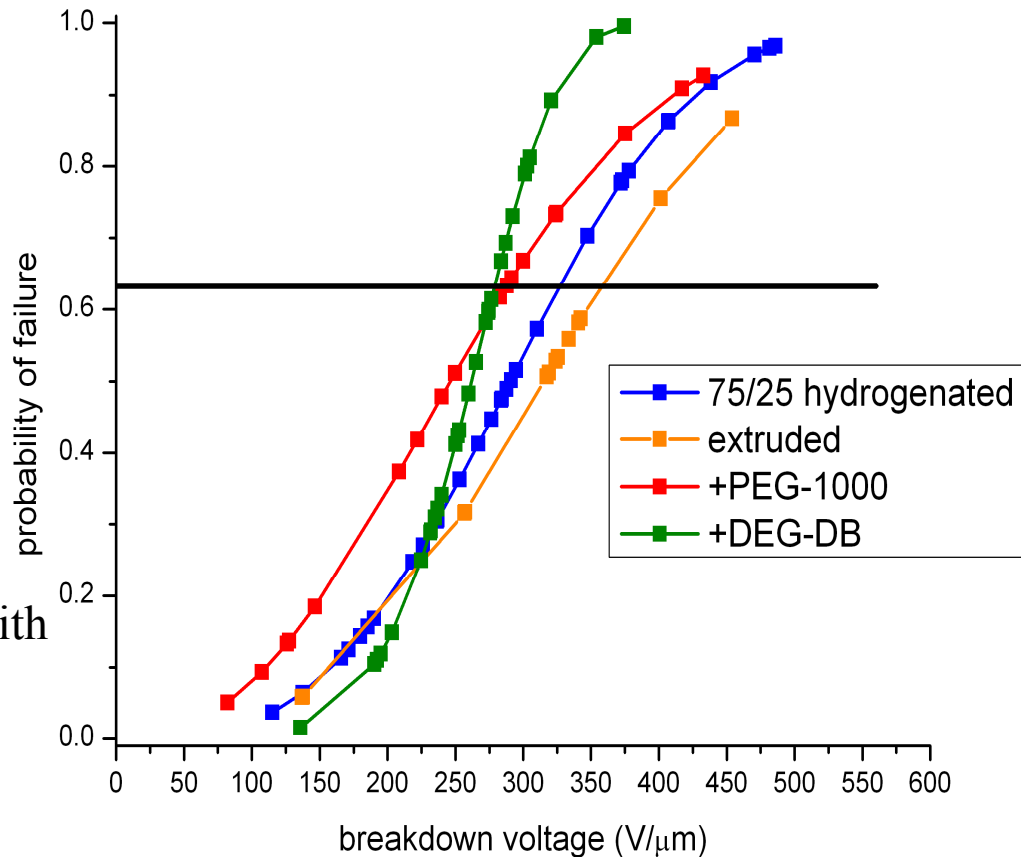


Extruded Films

Dielectric Constant



Breakdown Strength



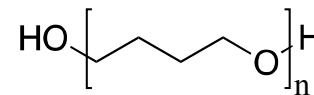
Extruded film with plasticizer
Length ~80 m
(3" wide)

Plasticizer Exploration

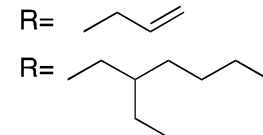
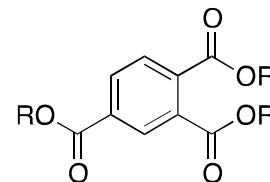
- **Previously examined:**
 - Poly(ethylene glycol) (PEG)
 - Chloroparaffin
 - Diethylene glycol (DEG)

- **Alternatives:**

- Terathane (varying MW)
 - 650, 1400 and 2900



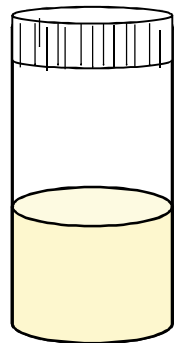
- Trimellitate
 - triallyl
 - trioctyl



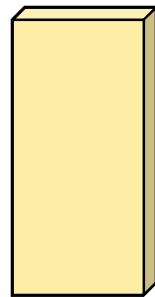
Polymer Processing (Lab Scale)

Film preparation

5, 12 or 20wt%
plasticizer/g S-POW
In 10wt% CHCl₃

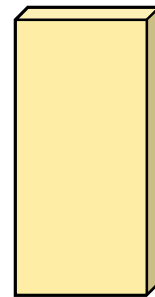


Solvent
casting



Free standing film
~10-15 μm thick

Vacuum oven
70°C overnight

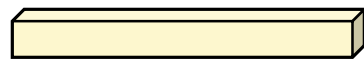


Final film

Characterization Techniques

- Dynamic Scanning Calimetry (DSC)
- Mechanical testing
- Dielectric (DE) measurements
- Breakdown testing

DE/Breakdown Sample preparation

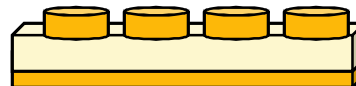


Cut 5 x 4.5 mm sample

Deposit Au



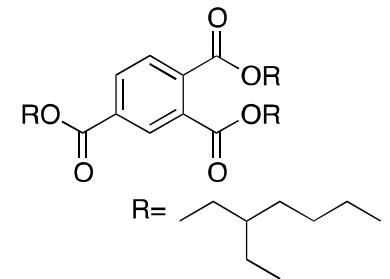
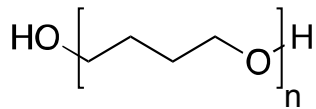
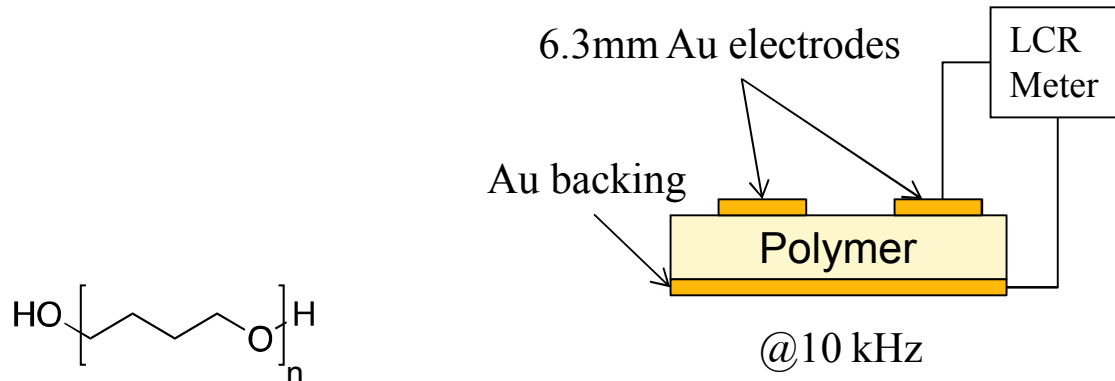
50 nm



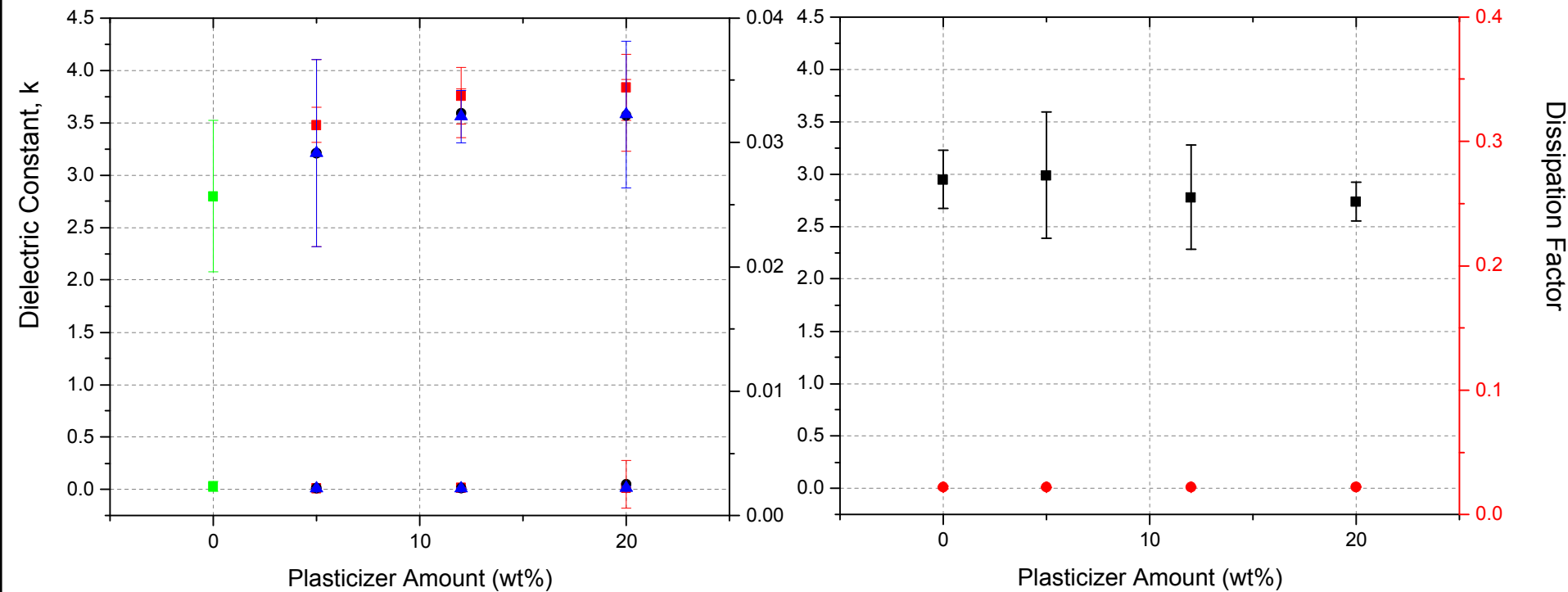
50 nm

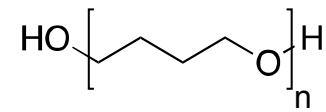
30 6.3 electrodes (d = 6.3mm)

Dielectric Characterization



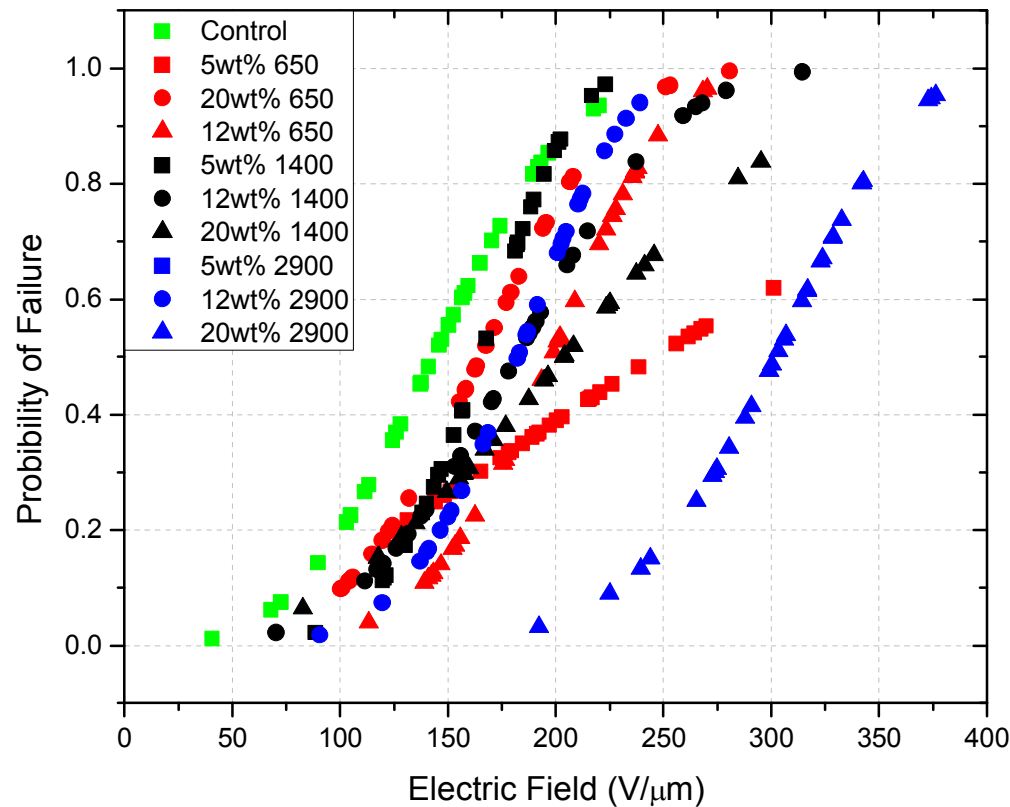
■ Control ■ 650 ● 1400 ▲ 2900





Effect of Plasticizer – Breakdown

- All terathane (wt%) added to S-POW polymer increased breakdown strength over control (green)





Conclusion

- **S-POW exceeds DOE OVT 2015 program goals**
- **Explored numerous plasticizers**
 - **Verified no negative effect on electric properties seen with terathane series as well as trioctyl Trimellitate**
- **Demonstrated S-POW can be extruded**
 - **Addition of plasticizers improves material properties**



Acknowledgments

- **Shawn M. Dirk**
 - Michele L. Denton
 - Kylene S. Johns
 - Zac Castillo
 - Chris Merry