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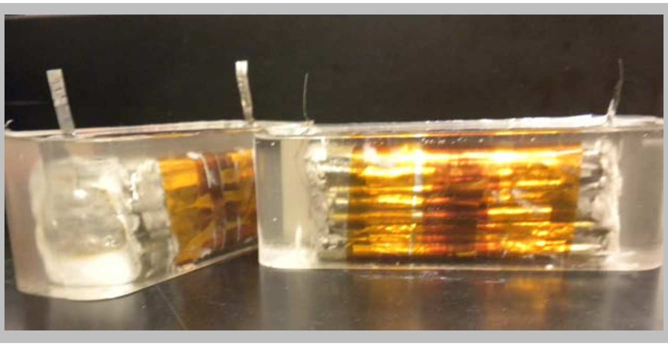

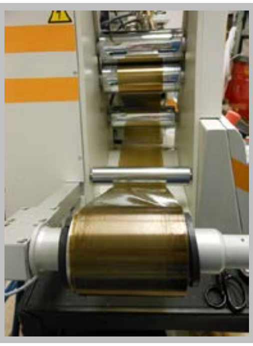

High Temperature Polymer Capacitor Dielectric Films

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May 14, 2013

Project ID: APE009

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Overview

Sandia National Laboratories

Timeline

- Project start: October 2009
- Project end: September 2013
- Percent complete (60%)

Barriers

- Capacitor Cost (up to 23% of inverter)
- Thermal control
- Volume (up to 23% of inverter)

Budget

- Total project funding
  DOE share $2800k (as of 2012)
- Funding received in FY12 -$850k
- Funding for FY13 ($500k)

Partners

- Electronic Concepts, Inc.
- Sandia National Laboratories
- Penn State

Electronic Concepts, Inc.

Relevance

The Problem

DC bus capacitors are currently the largest and the least reliable component of fuel cell and electric hybrid vehicle inverters. Capacitors represent up to 23% of both inverter weight and inverter cost and up to 35-40% of the inverter volume. In addition current thin polymer film capacitors have a ceiling operation temperature (105 °C). High temperature polymer dielectrics are very expensive!

Relevance

Objective

Our objective is to develop and engineer novel inexpensive high temperature polymeric material systems for use as next generation dielectric materials that can be used as a replacement technology for DC bus capacitors in hybrid electric vehicles (HEV) and fuel cell vehicles. Solving problems associated with transitioning from “lab-scale” to “pilot-scale” operations and to produce prototype capacitors

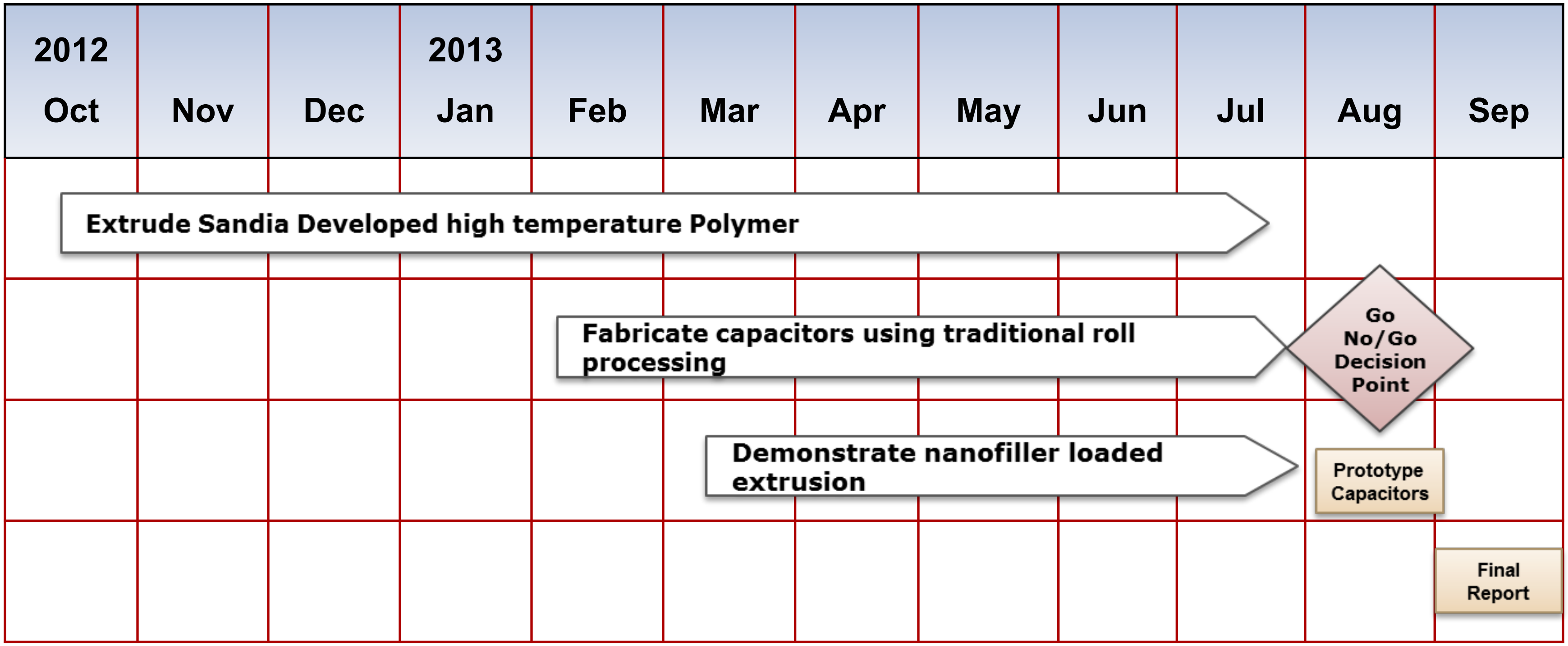
Addresses Targets

Current capacitors lack the temperature, size, and price specifications required for future DC bus capacitors. Our approach simultaneously increases operational temperature (>150 °C), decreases size, and lowers the price of high temperature capacitors ($0.015/μF), while maintaining self-healing properties.

Uniqueness and Impacts

Our approach uses inexpensive monomers/fillers to create a high temperature polymer dielectrics based on ROMP polymerizations which should meet DOE OVT requirements for high temperature capacitor dielectrics.

Milestones



Go No/Go Decision Point: Confirmation of mechanical properties of extruded high temperature polymer film.

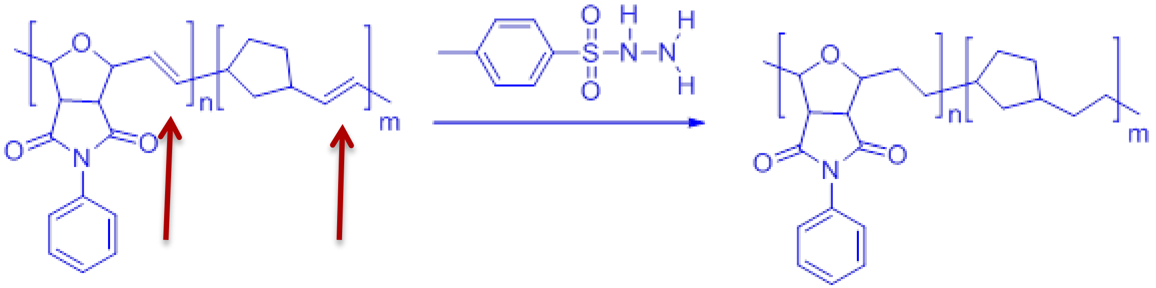
Key Deliverable: 5-10 uF packaged prototype rolled capacitors and demonstration of extruded material containing nanofiller. The capacitors will be evaluated at Sandia and sent to ECI, ORNL, Penn State, and ANL for independent evaluation.

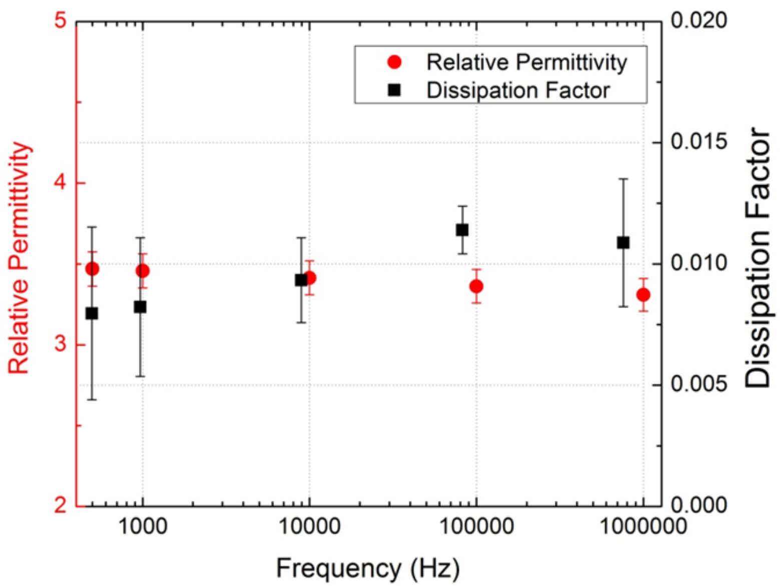
Approach

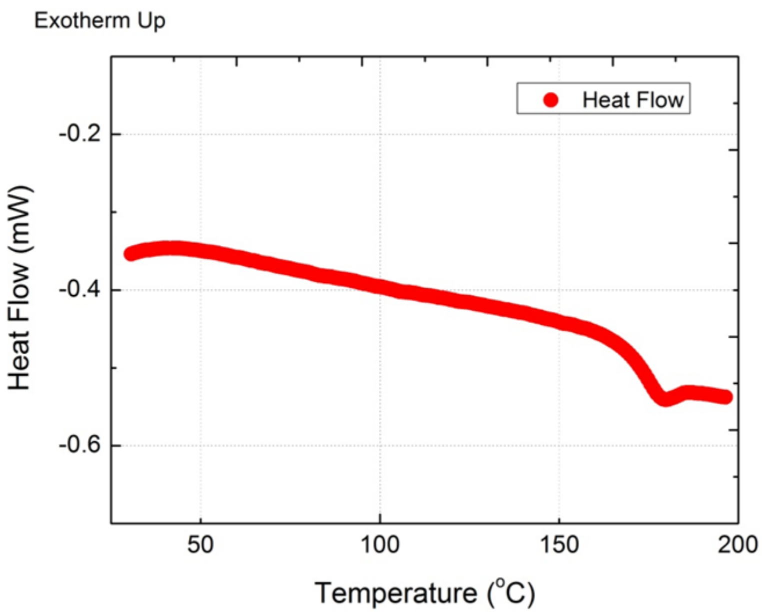
- Developing inexpensive high temperature, high dielectric polymer capable of forming very thin films through controlled polymerization chemistry based on the Ring Opening Metathesis Polymerization (ROMP). ROMP allows for fine control of polymer composition and molecular weight
- Working with ECI to produce prototype capacitors with solvent cast and extruded films
- To improve commercialization feasibility, we are focused on film extrusion for processing
- Develop nano-composites and additives for high temperature polymer dielectrics to improve energy density

Technical Accomplishments

Double bond in polymer backbone was removed (via hydrogenation) to improve the processability of the films (both solvent cast and extrusion)







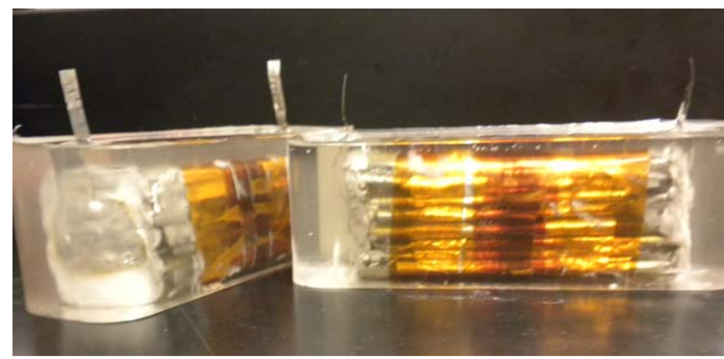
Capacitors

- **Solvent cast films were rolled for capacitor fabrication**
- **Several small capacitors were formed prior to pressing and connecting in parallel**

534 nF capacitor bank

- **Packaged several capacitor banks (~0.5 μF)**
- **Thermal sprayed Babbitt**
- **SnCu leads**
- **Potted in high Tg epoxy**

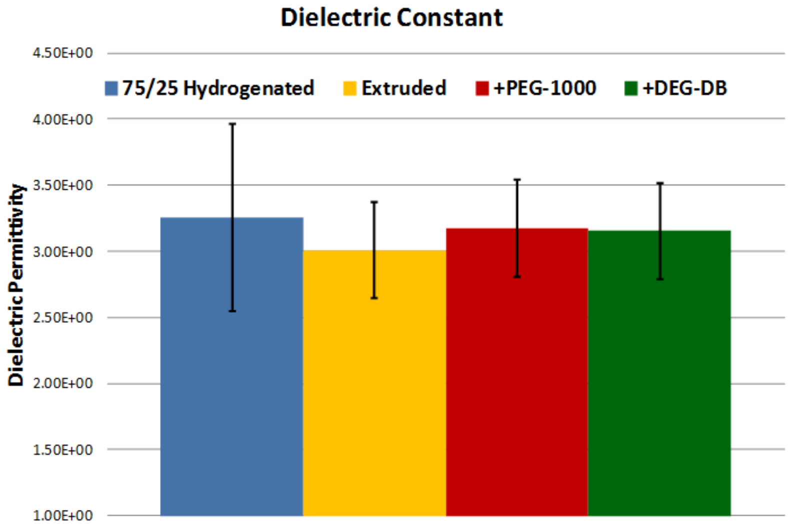
However, for costs concerns, extrusion is preferred

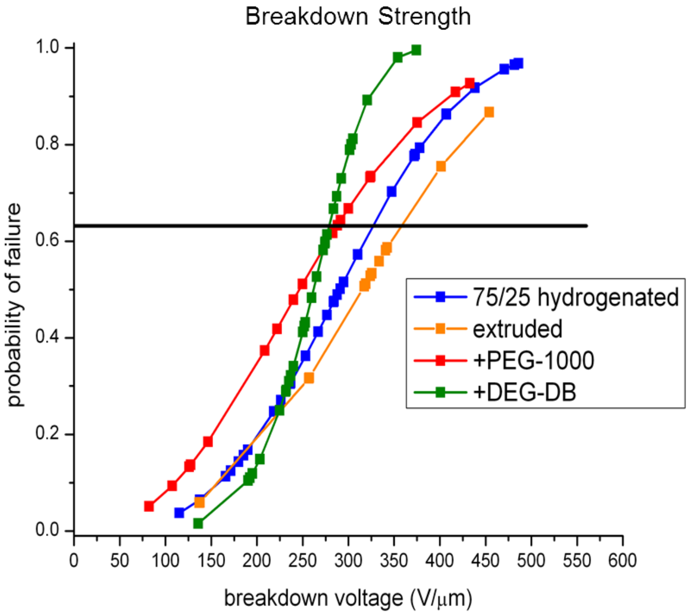


Packaged high temperature polymer thin film capacitors with capacitance of 0.5 μF

Extruded Films

- **Previous work with Collin®, showed they were able to successfully extrude our material**
- **Extruded film had good dielectric properties, but too brittle**
- **To improve the mechanical properties of the film, plasticizer are being pursued.**





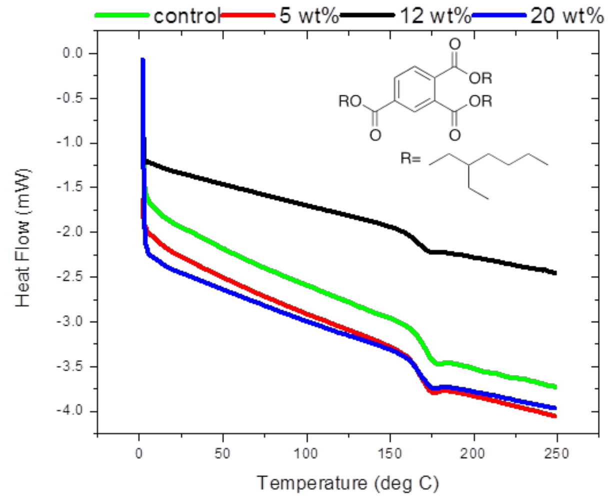
Extruded Films

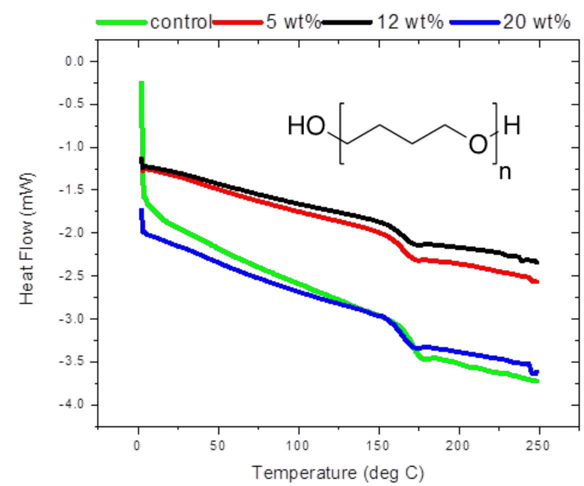
Sandia National Laboratories

- **In order to optimize the conditions (plasticizer, nanocomposites) for our extruded films an extruder was purchased from Collin® for in-house development**
- **Extruder installed and operational in mid-January 2013**
- **Extrude Kg of material at a time. To date several >1Km thin films produced**

Extruded Films

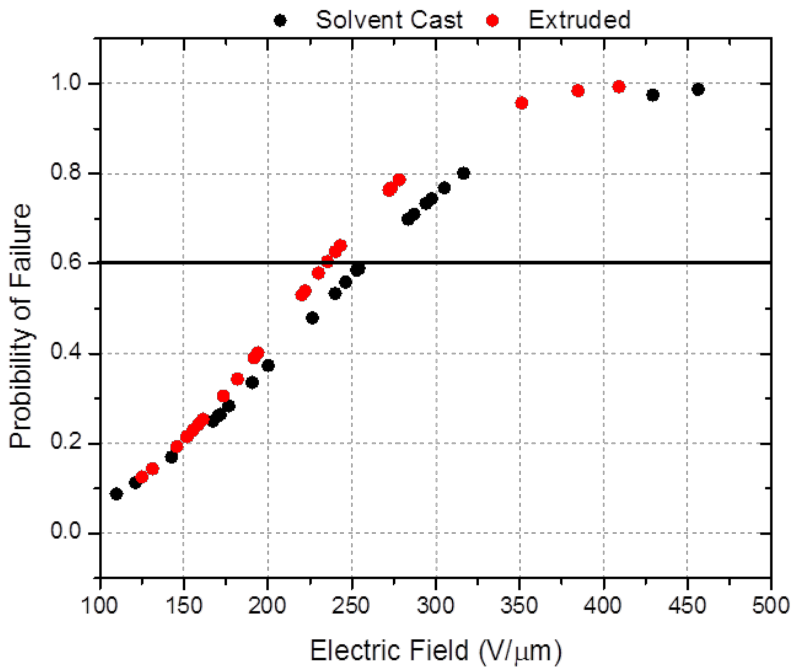
- **We have screened several plasticizers (phthalates, trimellitate, and various wt. terathanes)**
- **Currently, we are focusing on both terathanes and trimellitate due to improved material properties**
- **Good mechanical properties**
- **Various wt% of plasticizer amounts to no substantial loss in glass transition temperature**

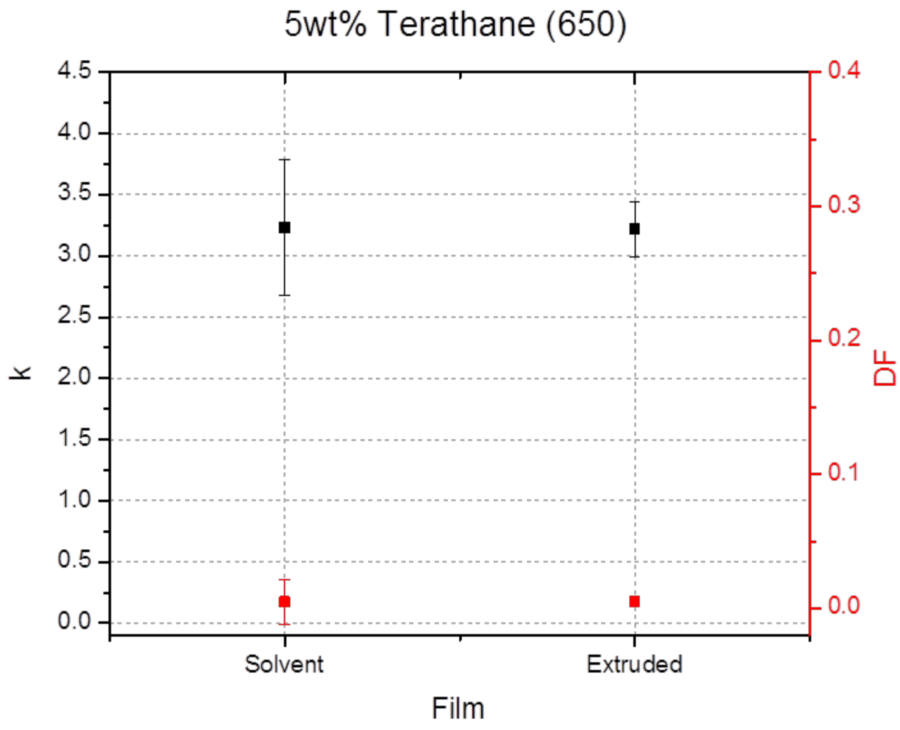




Extruded Films

Good correlation between solvent cast and extruded films (Terathane 650 at 5% wt)!



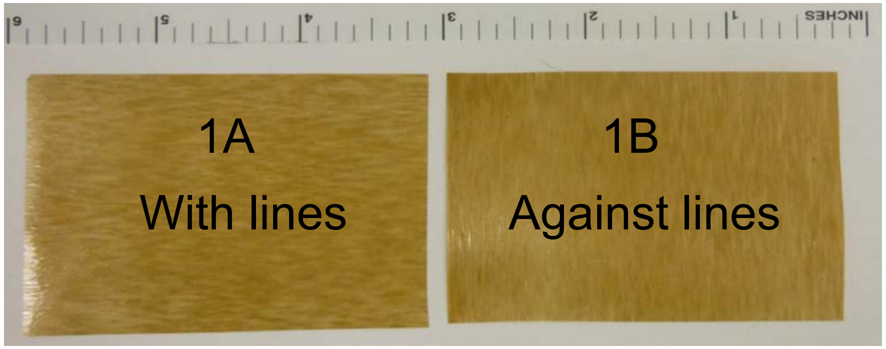


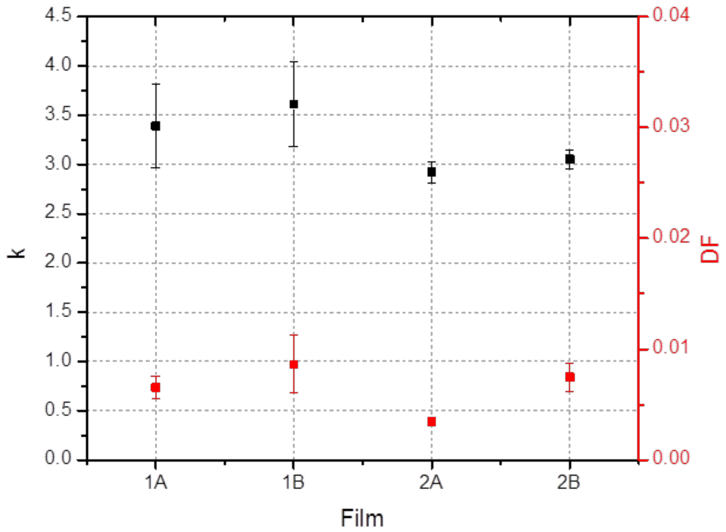
Extruded Films

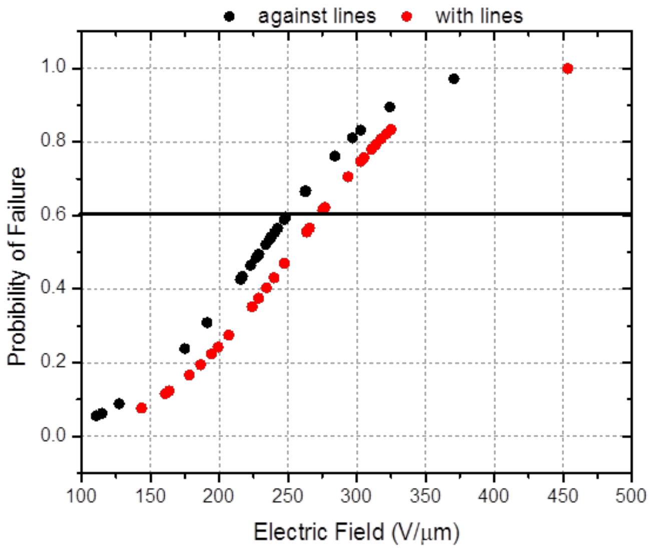
- **With 10% trimellitate, a 3ft long capacitor was rolled**
- **Capacitance of 9.5nF**
- **Dissipation factor of 0.004**
- **In the process of packaging several capacitor banks; Thermal sprayed Babbitt, SnCu leads and potted in high Tg epoxy**

Extruded Films

- **Film extrusion is still being optimized**
- **We are seeing physical defects (lines) in the film after extrusion**
- **These line have an impact on the breakdown voltage**
- **We are currently working with Collin® to remove these defects**

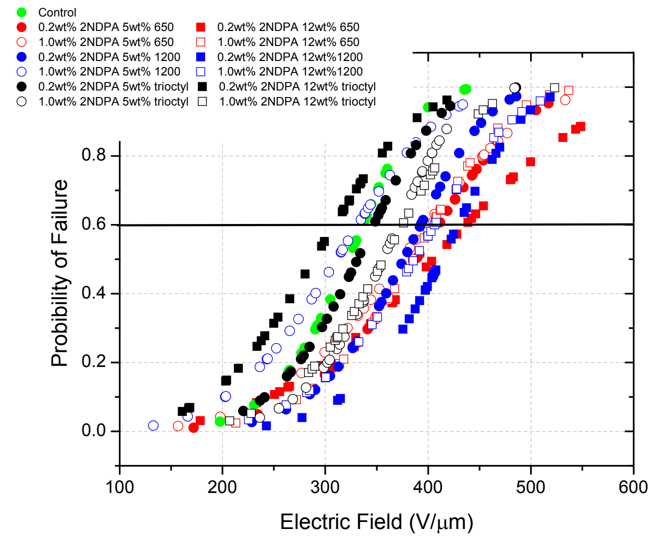


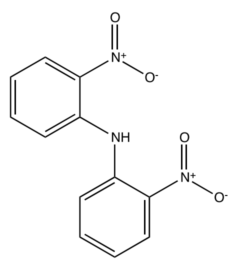




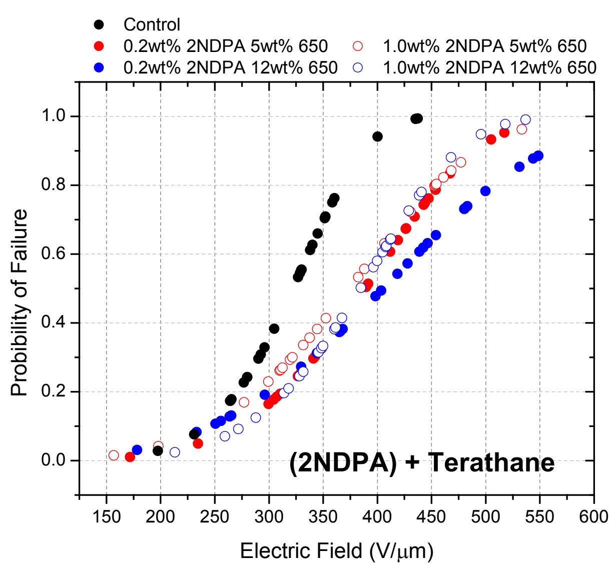
Advanced Additives

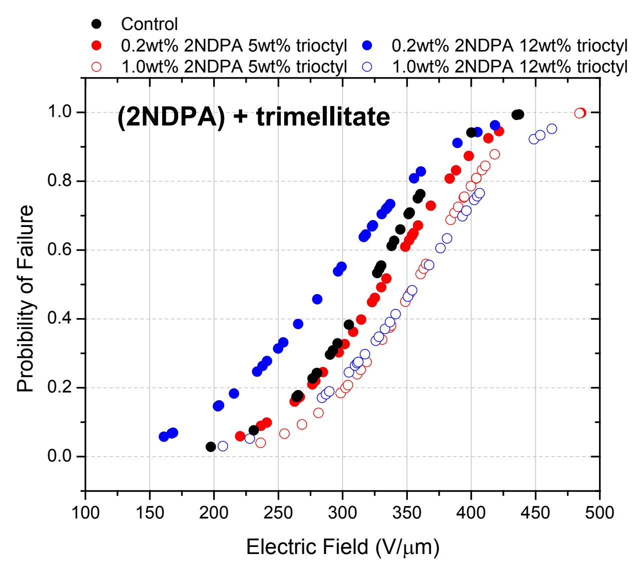
- **We are working on additives and nano-composites to further increase the energy density of capacitors made with the Sandia developed dielectric**
- **2NDPA has shown large increases in BDV**
- **Examined that 2NDPA in combination with plasticizers (terathane and trimellitate) show higher BDV**



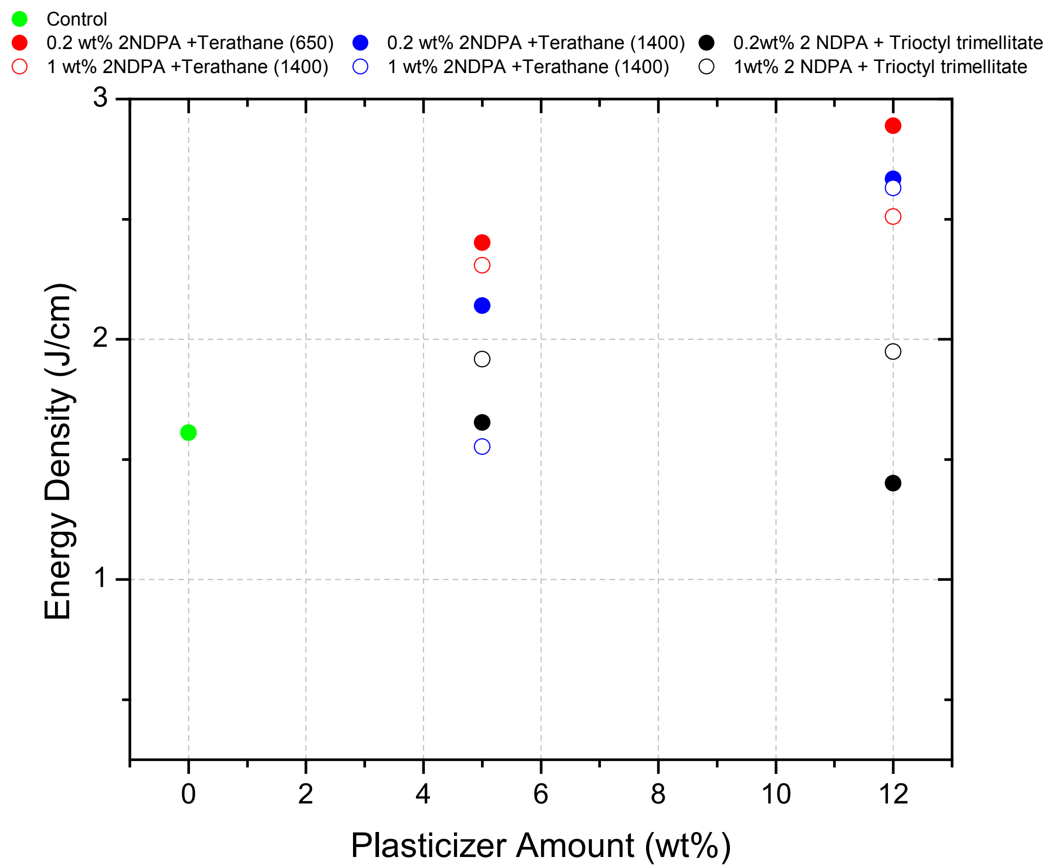


2,2'-dinitrophenylamine (2NDPA)





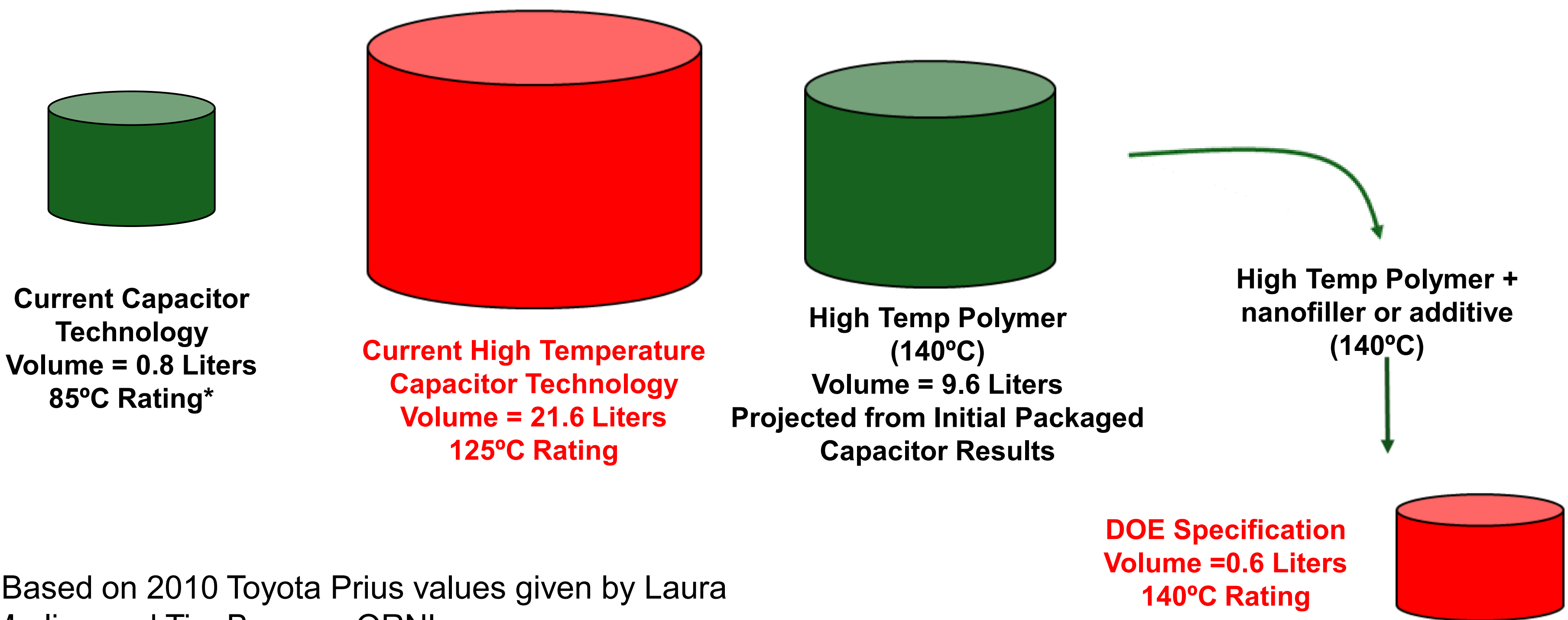
Advanced Additives



- **The higher BDV of the 2NDPA additive in combination with plasticizers (terathane and trimellitate) can increase energy density by factor of 2**

Capacitor Volume

Our high temperature polymer will enable high temperature capacitor volume to be cut in half. Nanoparticle fillers will enable polymer capacitor volume to shrink even further.



*Based on 2010 Toyota Prius values given by Laura Marlino and Tim Burress, ORNL

Slide from Mike Lanagan

Collaborations and Coordination with Other Institutions

Working to fabricate polymer films
– Joe Bond
– Dr. Collin® Company

Coordination
– Penn State
• Mike Lanagan
– Argonne National Laboratories
• Uthamalingam (Balu) Balachandran

Future Work

- **Continue optimize the extrusion of our materials**
  - **Send extruded rolls to ECI for prototype capacitor build and testing**
  - **In house winding and capacitor build (SNL develops capacitors for NW complex)**
  - **Send these in house capacitors to collaborators at Penn State, ANL and ORNL for independent testing**

- **Continue to optimize nanocomposites by incorporating ceramic particles and additives using an in situ technique we have developed**

Summary

- Identified and evaluating an inexpensive a norbornene-based high temp polymer as an alternative dielectric material

- We have shown that we can extrude this material, which is of vital importance for pilot scale production

- Demonstrated extruded polymer with lengths >1 Km

- Extruded "in-house" hand rolled capacitors have displayed a capacitance of 9.5nF and dissipation factor of 0.004

- Developed in situ nanoparticle and additive technique that homogenously incorporates into our polymer