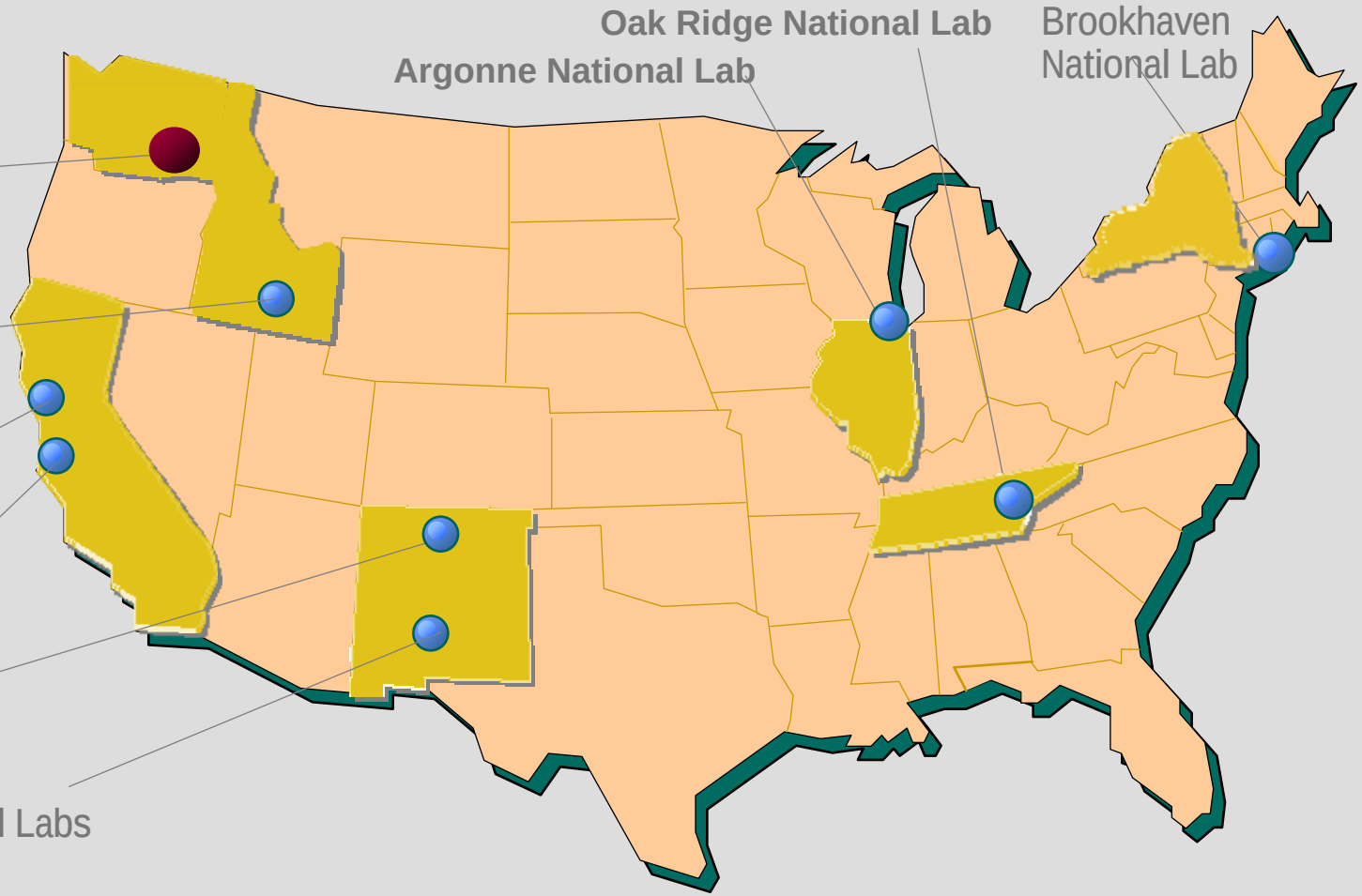
Reinforced Composite Material Research

Energy & Environment Directorate

Jim Holbery, Kevin Simmons, Nghiep Nguyen,
Ken Johnson, Siva Pilli, Dan Howe, Naveen Karri,
Leo Fifield, Cheng Huang

Pacific Northwest
National Laboratory
Operated by Battelle for the
U.S. Department of Energy

Washington is one of only 7 states to host a multi-program DOE national lab



- Pacific Northwest National Lab
- Idaho National Lab
- Lawrence Berkeley National Lab
- Lawrence Livermore National Lab
- Los Alamos National Lab
- Sandia National Labs

PNNL Material Research

Materials R&D personnel at PNNL

- Approximately 300 full-time, 150 PhDs
- *Polymer Composites* - 8 full-time researchers, 3 PhD

Composite Processing Lab

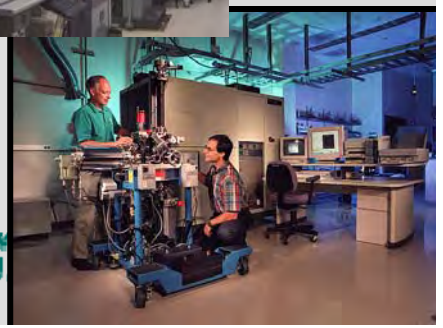
- RTM, Inj. Mold. – 40 ton Arburg, compression presses, extrusion (twin and single screw), Haake 65-150cc rheometer, powder coater, etc.

Polymer/Ceramic Chemistry Labs

- Reactors, casting, colloidal science, furnaces, etc.
- CombiCat Lab: Three 96-well (~2 mL each) robotic systems for synthesis – solution makeup, solids loading, GC, HPLC integrated

Analytical Capabilities

- DSC, DMA, TMA, TGA, DTA, DSC, SEM-ESEM, FIB-TEM, FTIR-ATR, NMR, GC-MS, AFM, STM, XPS-SIMS, Nanoindenter, etc.

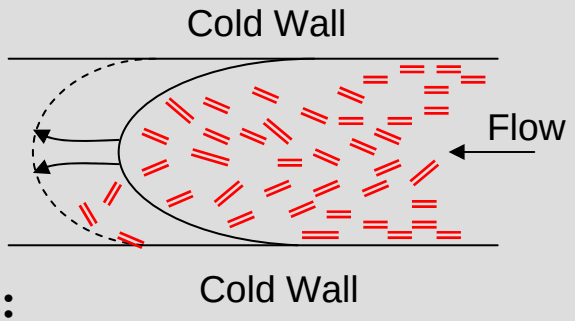


1. Engineering Property Prediction – Long Fiber Thermoplastics

TEAM: PNNL, ORNL, U-Illinois, Moldflow Corp., Ford/GM/DC ($4M/4 Years)

Develop Long Fiber Injection Molded Fiber Orientation Models

- Fiber length range 3~10 mm
- Geometrical restrictions on fiber motion
- Interaction between fibers and fiber domains: fibers organized in domains and locally aligned
- Wall effect may dominate the orientation behavior



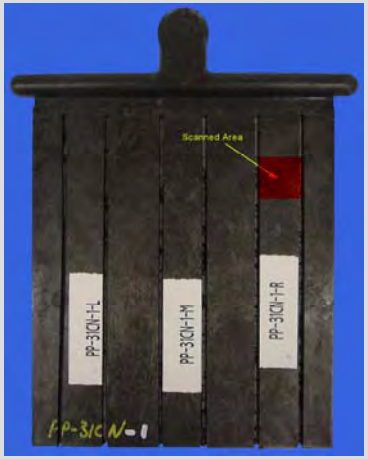
Extend current models

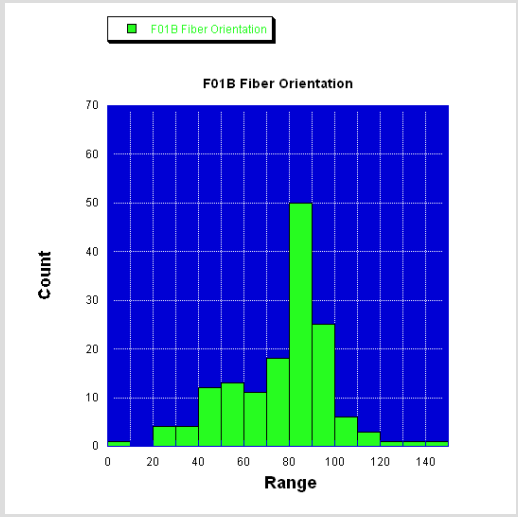
- Explore decoupled fiber orientation & flow kinematics:
  - Express the fiber interaction coefficient C_I in Advani-Tucker or Folgar-Tucker model as a function of the fiber aspect ratio and volume fraction

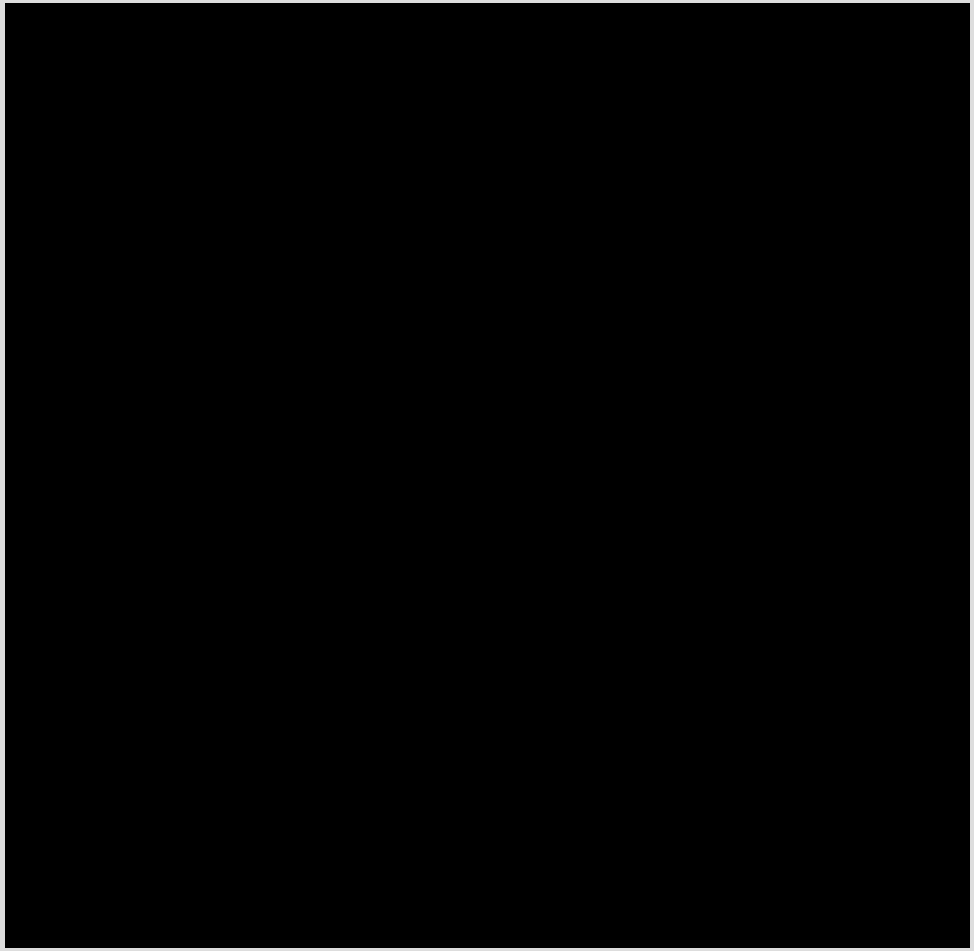
$$C_I = C_I(\textit{Fiber volume fraction, aspect ratio})$$

- Develop a coupled approach
- Account for effects of fibers on flow kinematics
  - Determine the effect of processing conditions and fiber characteristics on the composite

XCT of Ni-coated CF – Polypropylene





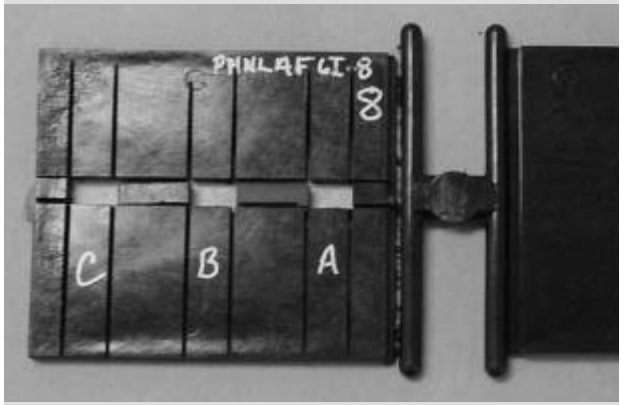


Injection molded ISO plaque, 31% fiber volume, ISO Plaque

Holbery et. al, publication in preparation

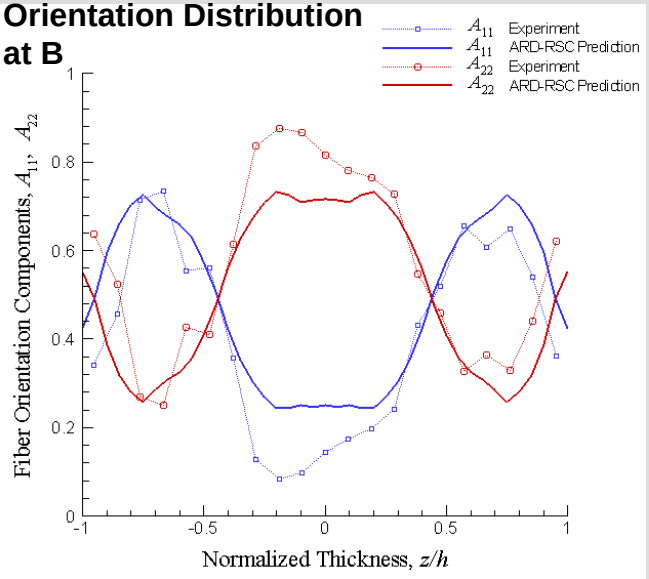
Process Modeling to Property Prediction of Injection-Molded Long-Fiber Thermoplastics

- A new fiber orientation model was developed to incorporate an *anisotropic rotary diffusion* (ARD) term to accurately model fiber-fiber interaction in long-fiber thermoplastics (2007):
  - The constant C_I in the Folgar-Tucker model is replaced by an anisotropic rotary diffusion tensorial term.
  - The new model is being implemented in Moldflow for process-linked-structural analysis

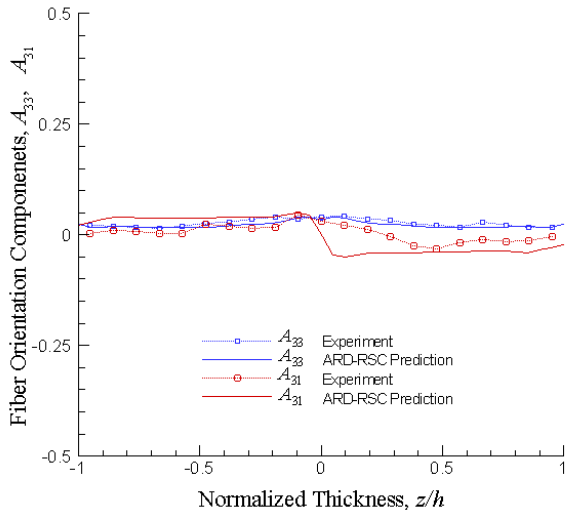


IM long-glass-fiber/PP ISO-plaque: 3 regions denoted as A, B, and C were measured fiber orientation

Orientation Distribution at B



Orientation Distribution at B



Effects of Fiber Length and Orientation Distributions on the Elastic Properties of Long-Fiber Injection-Molded Thermoplastics: Part I – Property Prediction**, Submitted to Composites Science & Technology,**
B. N. Nguyen, V. Kunc, B. Frame, J. H. Phelps, C. L. Tucker III, S. K. Bapanapalli, J. D. Holbery, M. T. Smith

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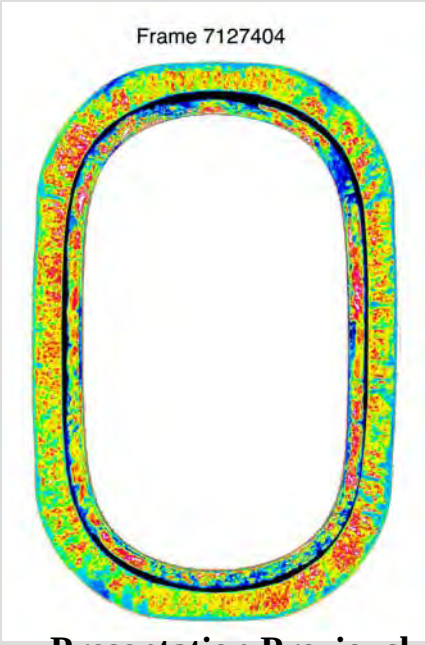
U.S. Department of Energy

2. Analysis of Compression Molded Carbon Fiber/Epoxy Composites

1. **Forming analysis on HexMC CF compression molded hardware.**
2. **Develop NDE techniques specific to chopped CF material.**
3. **Develop property prediction algorithms specific to chopped fiber CF.**
4. **Develop accelerated moisture uptake test for CF composites.**

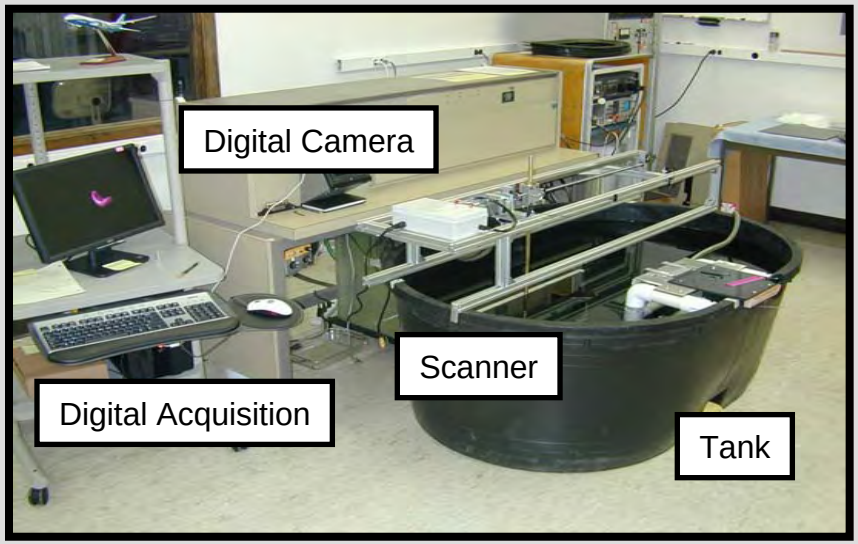


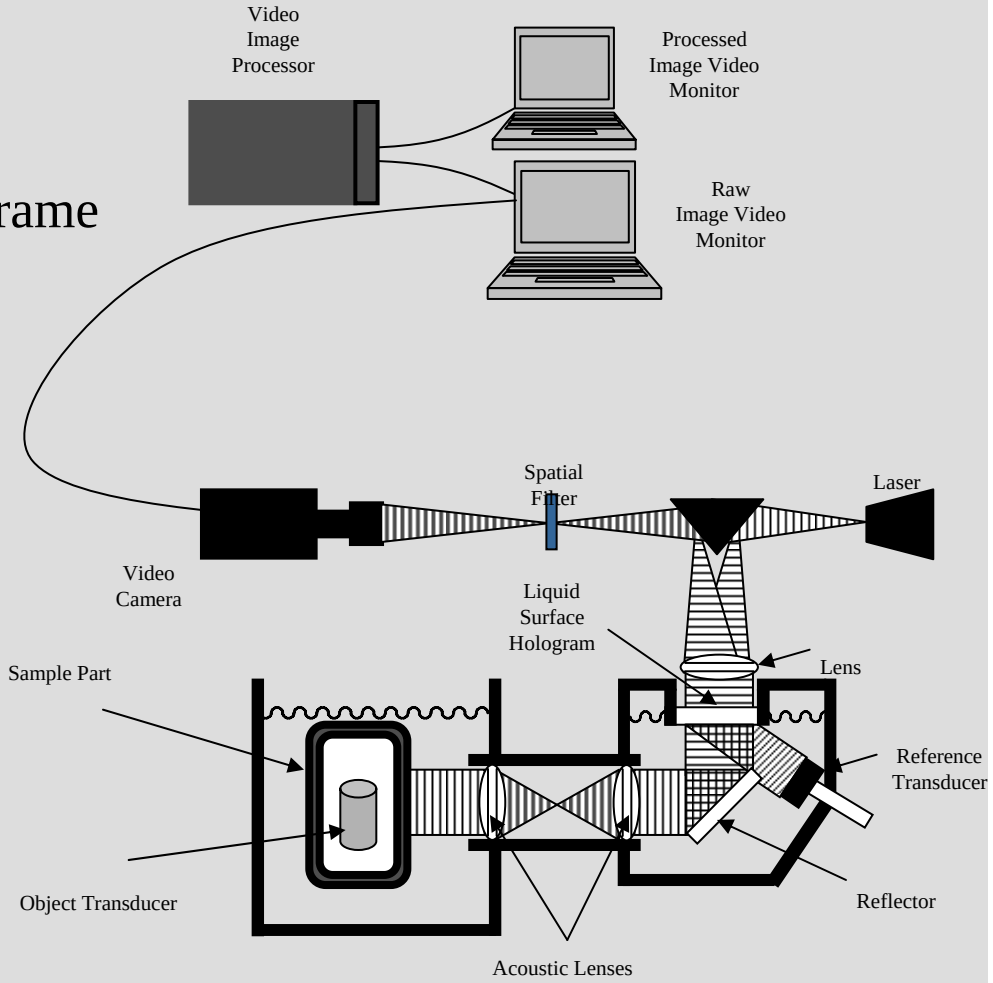
Presentation Previously Approved: Boeing Commercial & Hexcel Composites

Real Time Ultrasonic Inspection System (RTUIS)

Liquid surface ultrasonic detector that produces an instantaneous two-dimensional image

1. Speed
   - Instantaneous Image
   - 2.5” x 4.0” FOV, 6μsec
   - 60 frames/sec; 5625 pixels/frame
   - 20 m^2/hour
2. Resolution
   - 3 wave lengths
   - 1mm at 5MHz

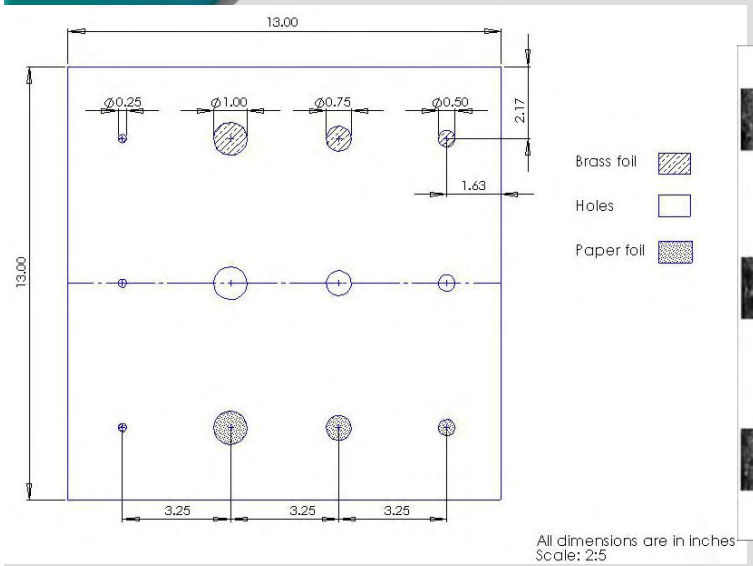


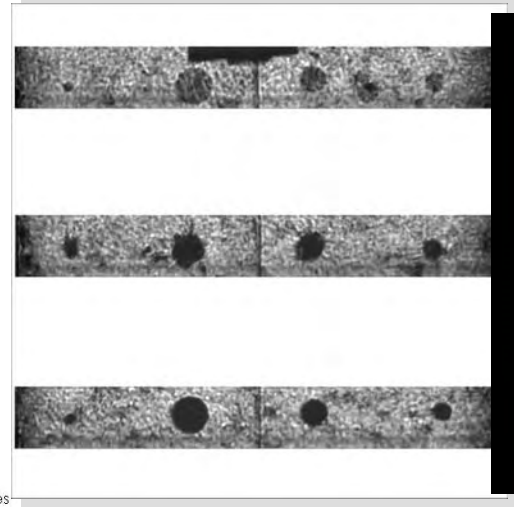


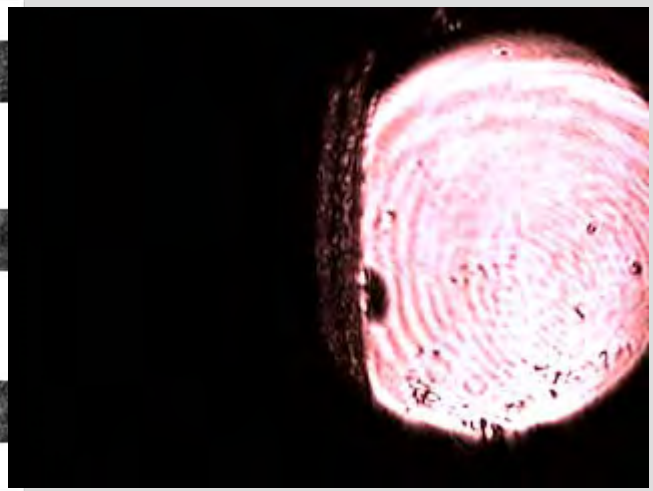
PNNL Patented System

Pacific Northwest National Laboratory
U.S. Department of Energy

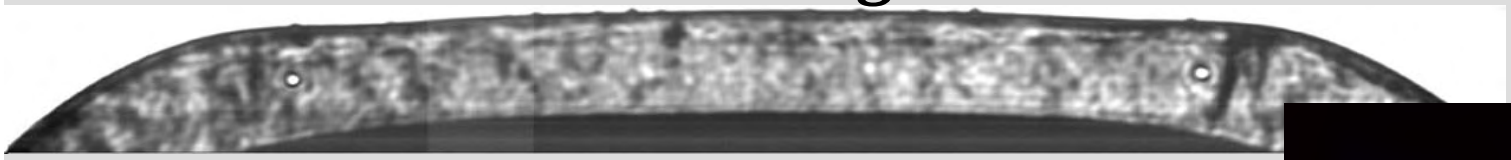
Plate with Known Defects/Inclusions

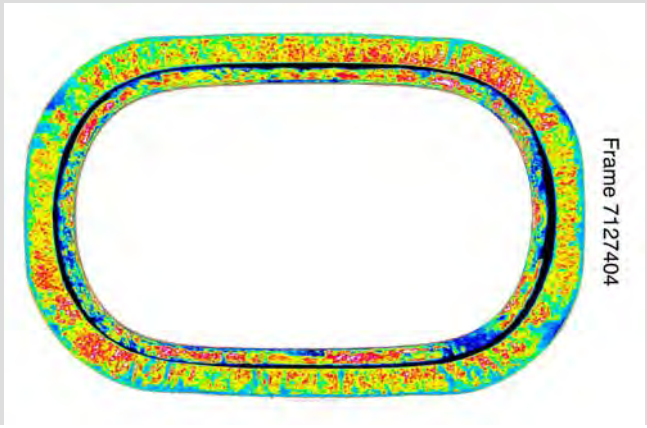






Boeing-Hexcel Part





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3. Natural Fiber Composites

DOE/Automotive Composites Consortium Funding
$2.5M, 3 years, start date June 1, 2007

- Enablers for large-scale automotive insertion:
  - Fiber preparation – from the farm to manufacture
  - Moisture absorption - thermal degradation during processing
  - Fiber preform – tailoring, hybrid architectures & molding (SMC)

Flax, hemp, sisal, wool and other natural fibers are used to make **50** Mercedes-Benz E-Class components.

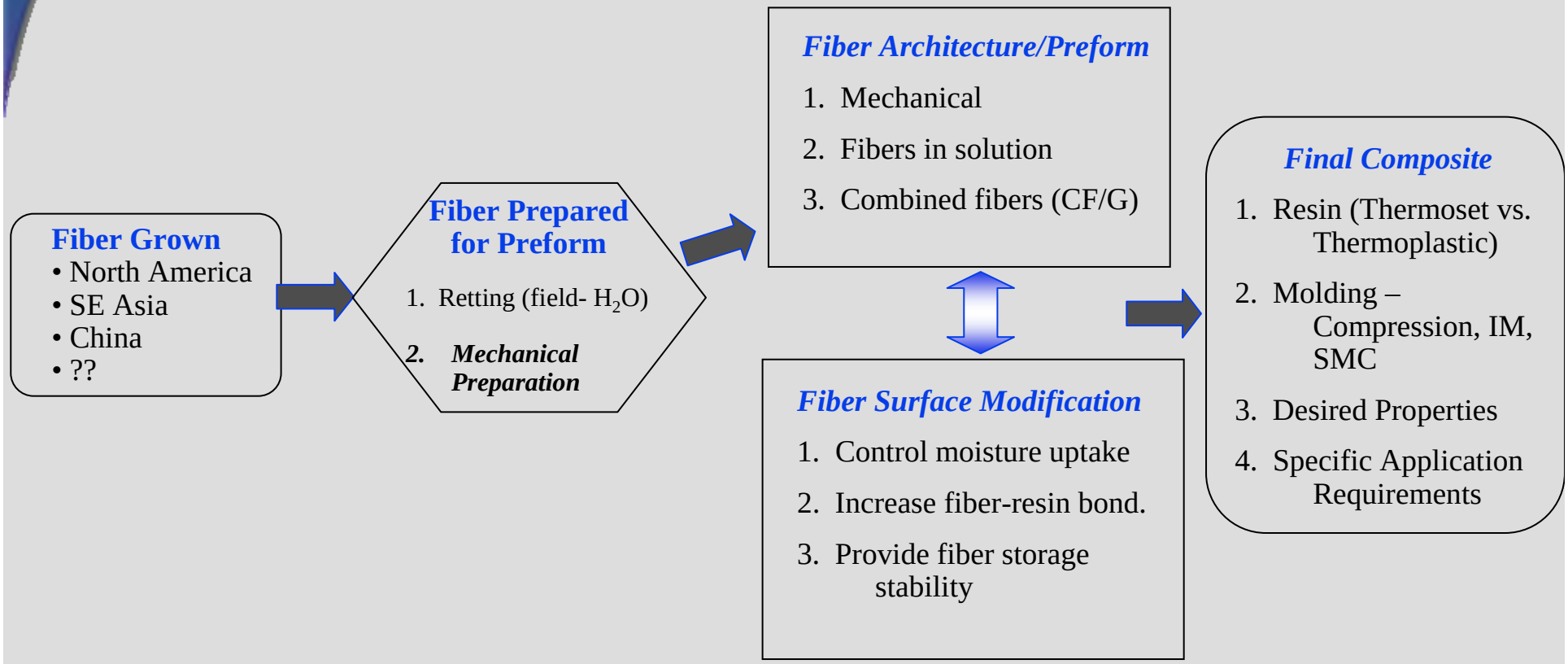
Mercedes-Benz S-Class has 42.7 kg of natural fiber components: Door & pillar inners, head liner, rear cargo shelf & trunk components, thermal insulation

Typical Natural Fiber Properties

Property	E-Glass	Hemp[2,3]	Flax[3]	Ramie	Kenaf[4]	Coir[3]	Sisal[3]	Jute[3]	Wood Fiber[1]
Cost ($/lb)	~ 1.10	0.30	0.33	?	0.24	0.20	0.36	0.20	??
Density (g/cc)	2.62	1.47	1.4	1.5	1.45	1.25	1.33	1.46	0.6 – 1.1
Tensile Strength (MPa)	**3400**	**550-900**	**800-1500**	500	**930**	220	600-700	400-800	900-1500
Specific Strength (s/ρ)	**1275**	**~475**	**~800**	333	**641**	176	488	410	??
Elastic Modulus (GPa)	73	70	60-80	44	53	6	38	10-30	10 - 80
Specific Modulus (E/ρ)	**28**	**~47**	**~26-46**	29	**36**	5	29	7-21	**??**
Elongation at Failure (%)	4.8	1.6	2.7-3.2	3.6-3.8	1.6	15-40	3-7	1.5	??
Moisture Absorption (%)[4]	-	**6-12**	**8-12**	8-17	10-12	8	10-22	12-14	12-14

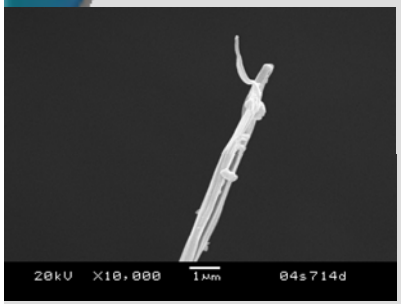
1. Peltola, P., "Green Composites", Chapter 5, CRC Press 2004.
2. Hempline, Inc., Ontario, Canada.
3. Eichhorn, S.J., et al., J. of Mat. Sci. (2001) 36, pp. 2107-2131.
4. Natural Fibers, Biopolymers, and Biocomposites, Mohanty et al., CRC Press, p. 41, 2005.

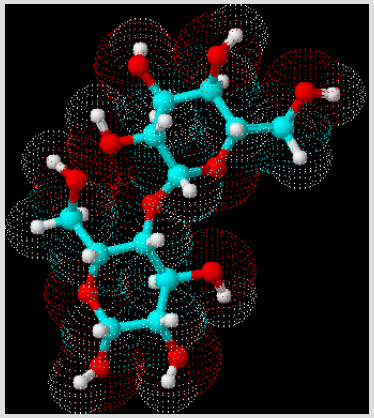
Natural Fiber Composite Roadmap

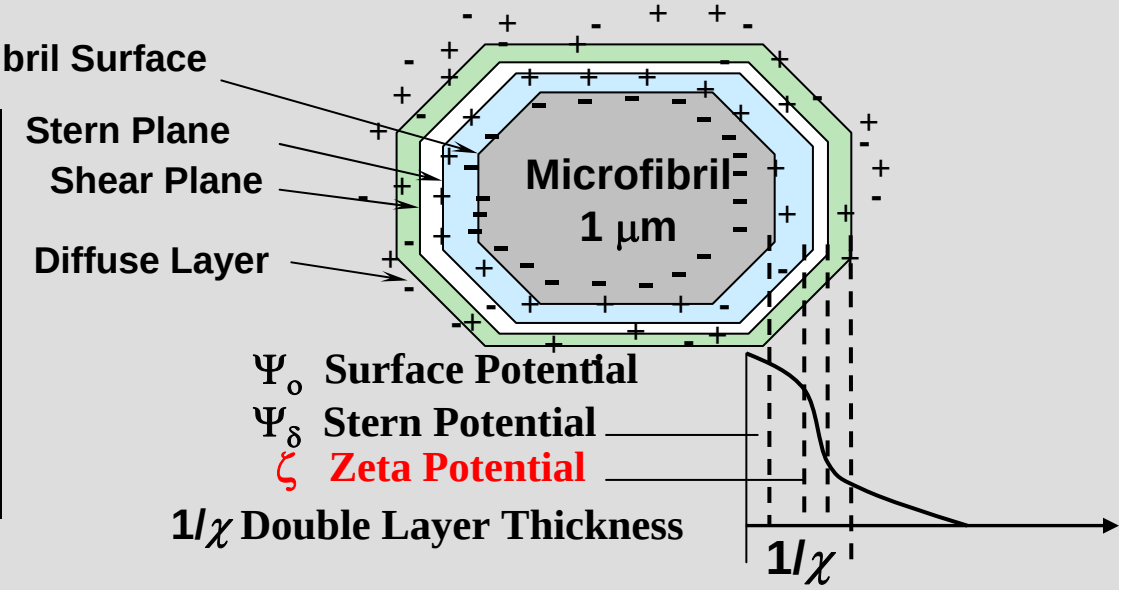


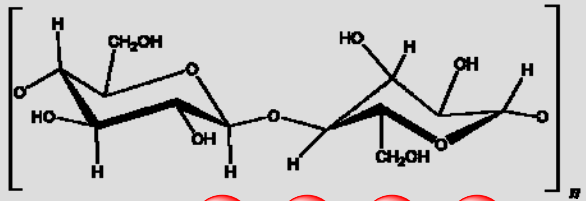
PNNL Current Research

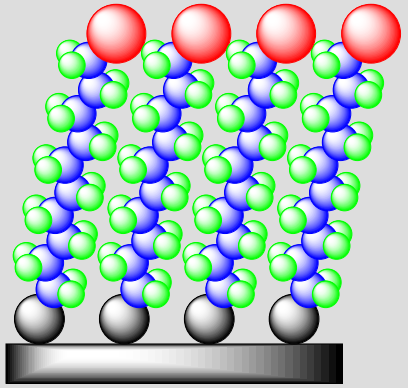
Natural Fiber Surface Modification



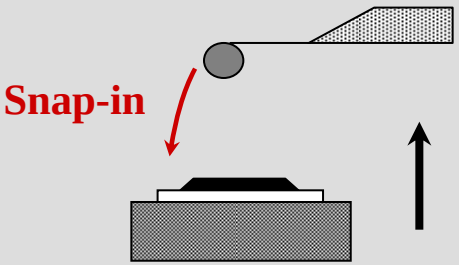


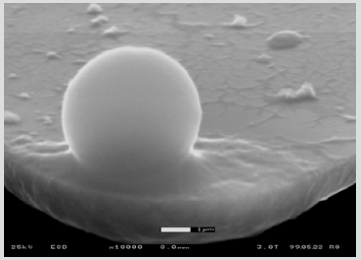






AFM Adhesion Measurement





Holbery, J.D., et.al., J. of Micromechanics and Micromaterials, 10, 85-92 (2000)

Holbery, J.D., et.al. Phys. Rev. D, Oct. (2000)

Holbery et al, in review J.Poly. Sci.

Hemp-Kenaf Compression Molding

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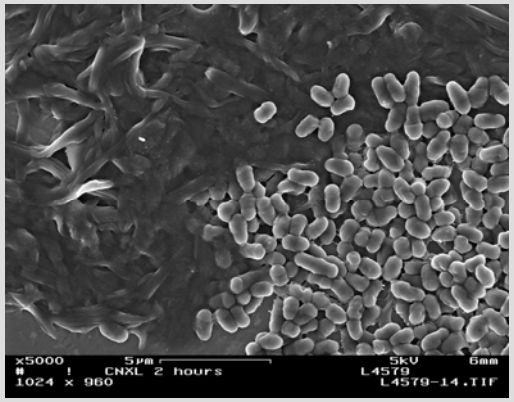
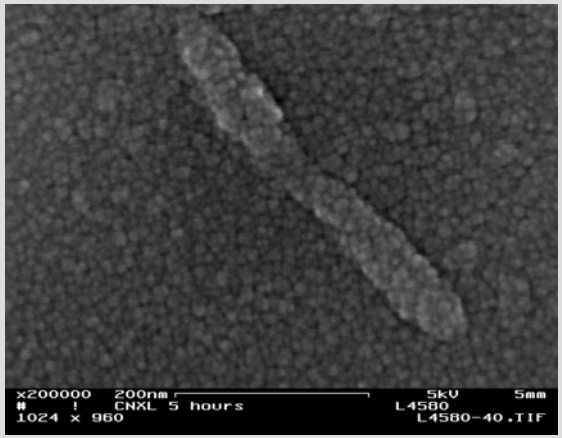
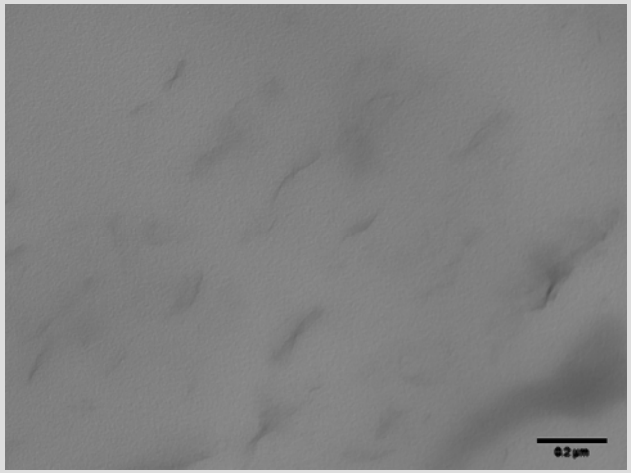
4. Nano-Scale Composites

Bio-based Materials



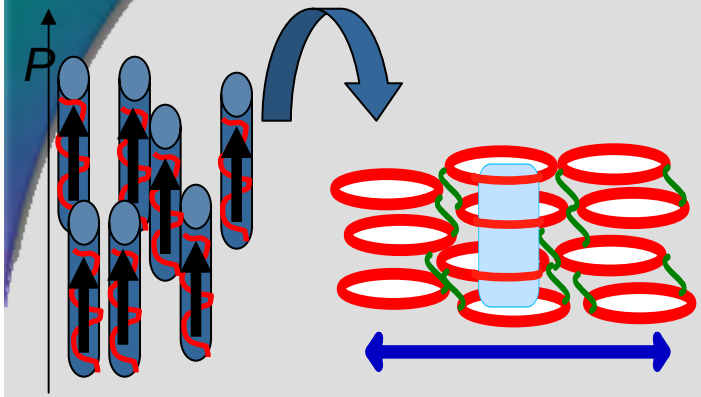




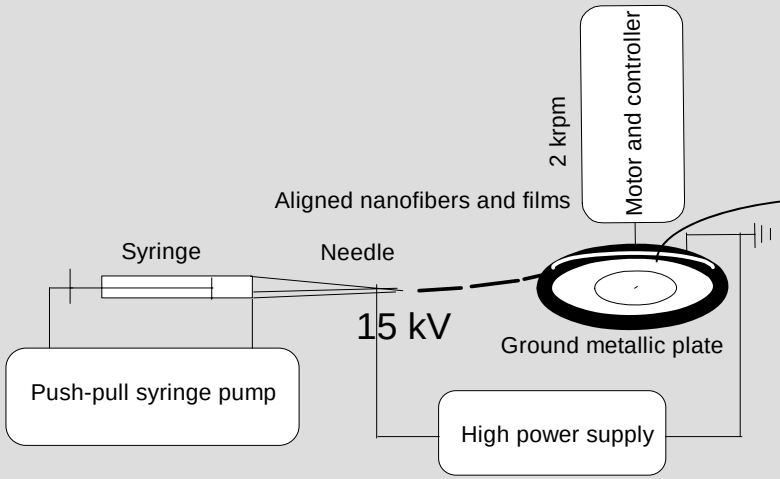
Synthesis of Cellulose Nanocrystals

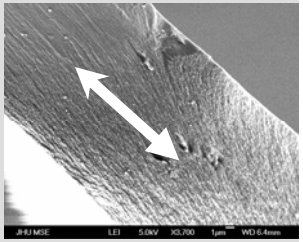
Collaborate with Kaichang Li, OSU and Mike Wolcott, WSU
Holbery et al., Amer. Soc. Composite Proceedings, 2007
Holbery et al., J. of Comp. Matls., in review

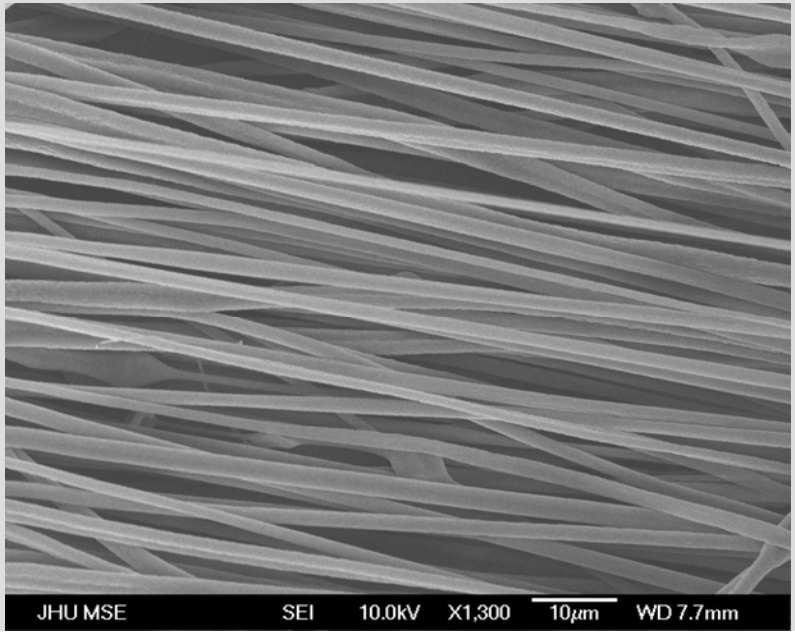
Specialty Composites Electro-spinning Polymer Fibers and Textile Composites



Aligned helical Rod-like LC Peptide Biopolymers







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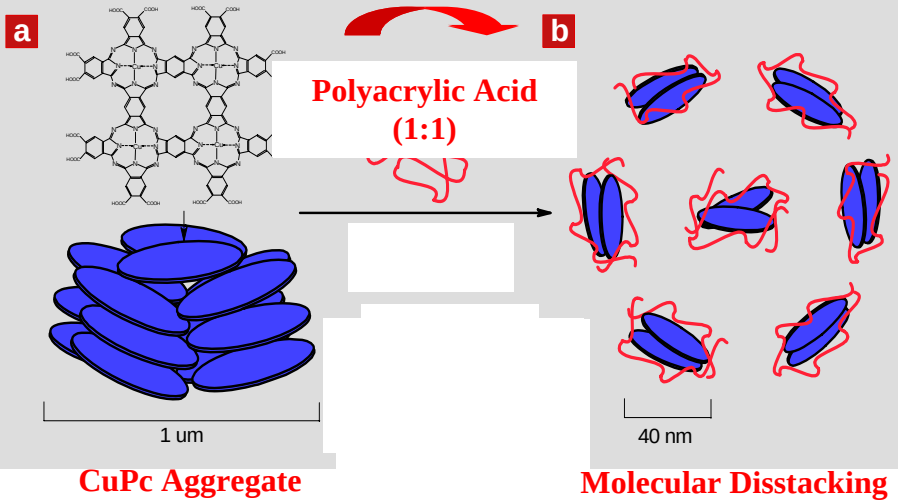
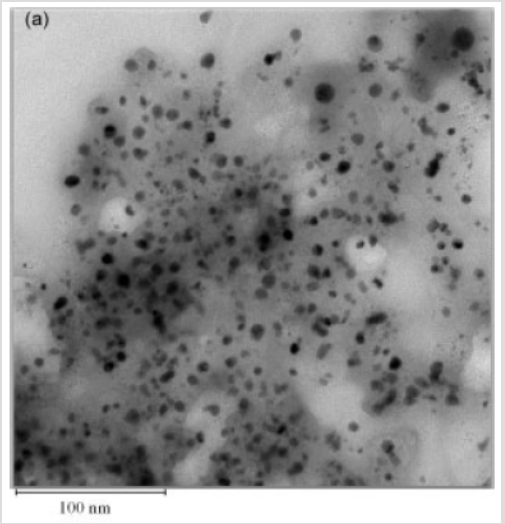
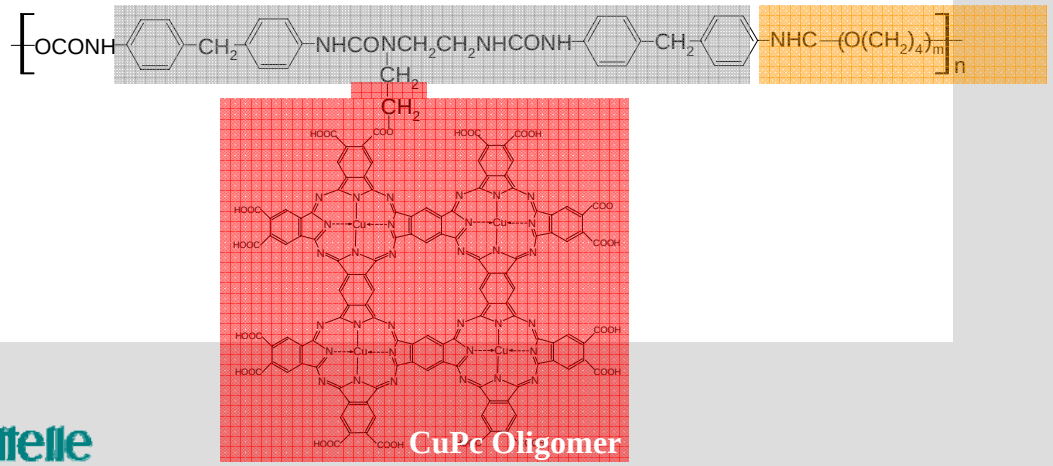
5. All-Organic High-Dielectric-Constant Composite Actuator Materials

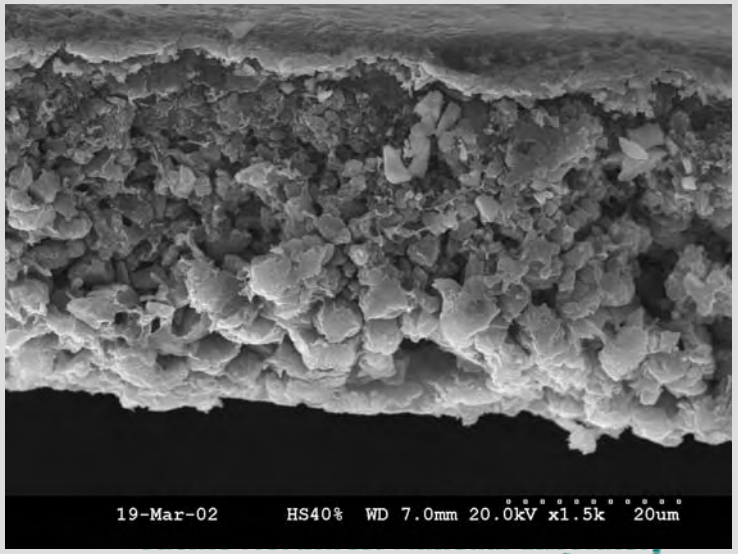
- **Filler Surface and Interface Modification**





- **Filler Chemical Grafting and Polymerization**





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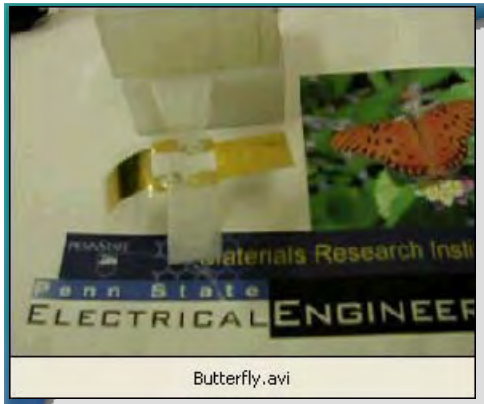
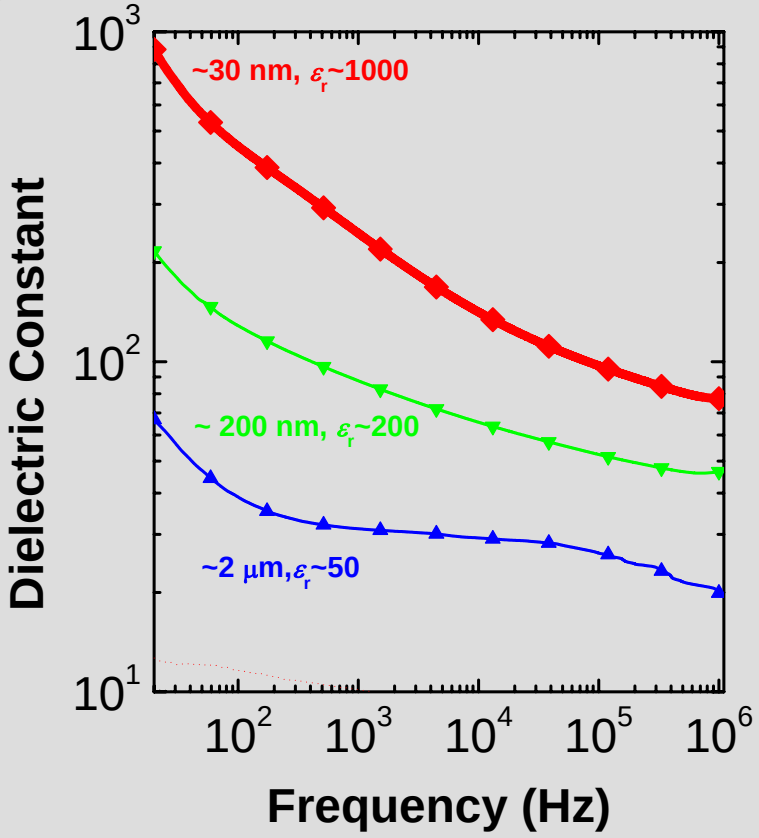
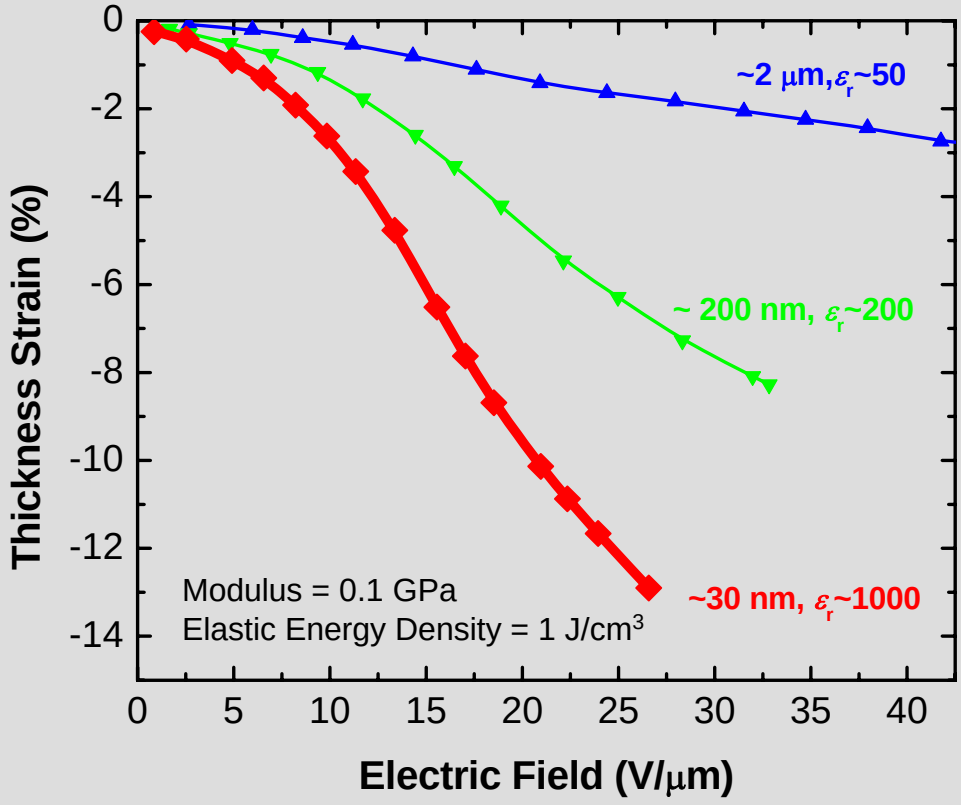
U.S. Department of Energy

High-Dielectric-Constant Nano-Phase Polymers and NanoComposites in Low-Voltage Actuation







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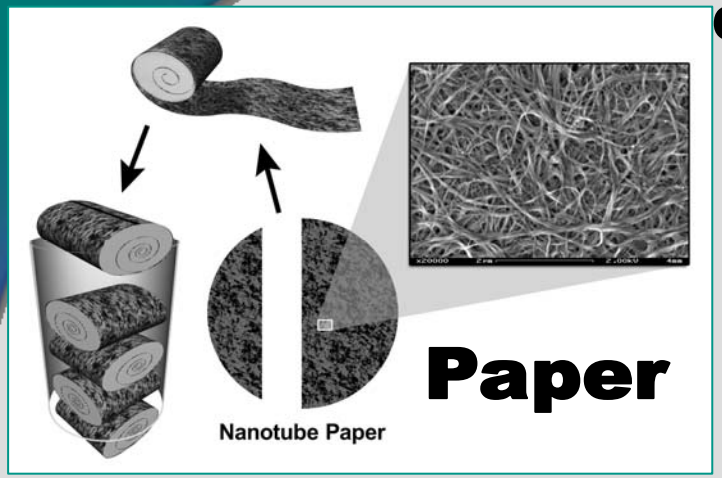
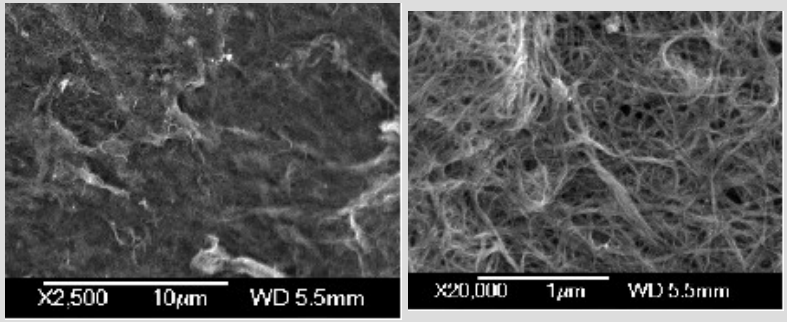
Nano-Scale Fiber Composites

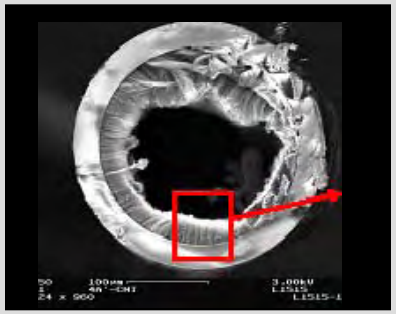
Carbon Nanotube Research

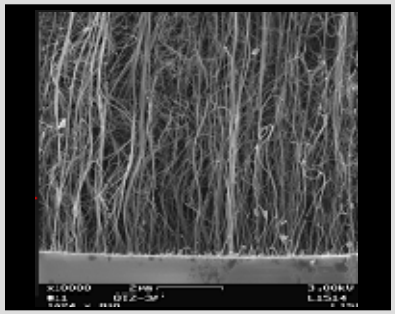


- Commercial CNT's – PNNL has grown CNTs from various sources
- Developed inexpensive process to produce CNT paper
- Produced paper from carbon fibrils
- Potential sensor, industrial applications

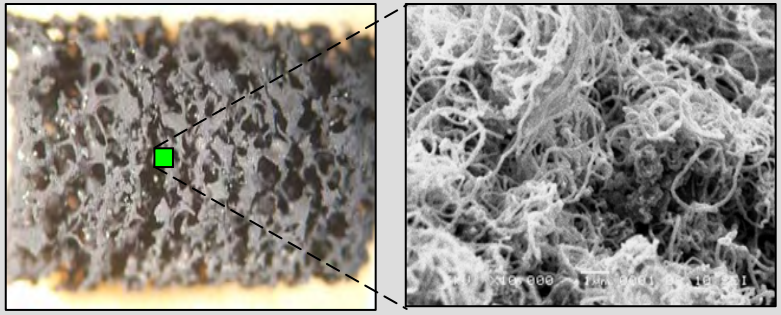


Capillary

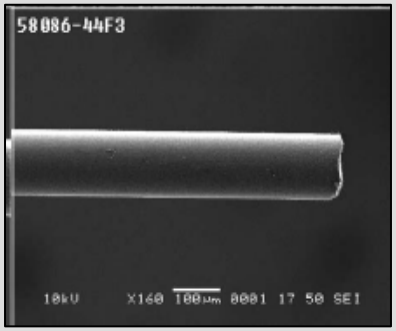


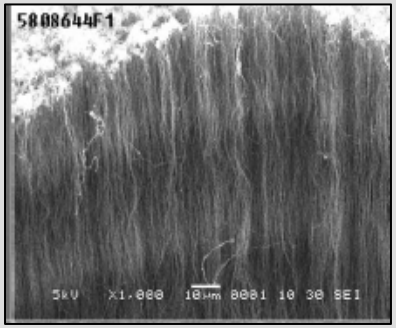


Foam



Fiber





Battelle

Pacific Northwest National Laboratory
U.S. Department of Energy

Researchers: L Fifield, J Holbery

Collaborators

1. Manufacturers
   - Ford Motor Company
   - General Motors
   - Chrysler
   - Hewlett - Packard
   - Material Innovation Technology
   - Meridian Automotive
   - Continental Automotive Systems
   - Moldflow
   - Albany International
2. Materials Suppliers
   - KenGro Inc. (MS)
   - Stemergy Inc. (Ontario, Canada)
   - Ashland Chemical
   - AOC
   - Reichold Chemicals
   - Hexcel
3. Universities
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Thank You

***Pierce Alan Holbery* – Bringing joy since August 3, 2007**