Carbon Fiber Technology Facility

Merlin Theodore, PhD (PI)

Amit Naskar, PhD
Chief Scientist, Carbon Fiber Technology Facility

Alan Liby, PhD
Director, Advanced Manufacturing Program

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Project Objective

Reduce carbon fiber (CF) cost by using low cost alternative precursors

Produce quantities of low cost carbon fiber for material and process evaluations and prototyping

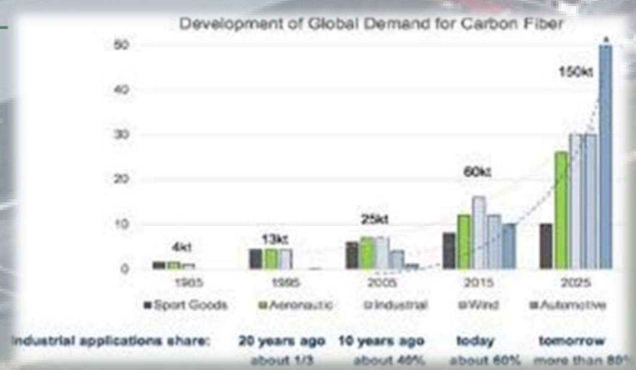
Workforce Development for carbon fiber and advance composites workforce

- Manufacturers in clean energy industries such as wind energy, compressed gas storage, and transportation are seeking ways to reduce costs and energy using lightweight material. Today, material cost drives parts cost. Therefore, manufacturers are in search of stronger, lighter, and **cheaper** materials. Carbon Fiber composites are ideal for such purposes. Carbon Fiber (CF), the key ingredient in CF composites, and has attractive properties such strength, durability, low weight, and corrosion resistance. However, it is costly.

- Barriers to carbon fiber composites adoption in clean energy applications:
  - The scaling to meet high volume manufacturing needed at lower cost.
  - Challenging conversion process to achieve useable properties.
  - Market and Workforce Development

The Carbon Fiber Technology Facility (CFTF) serves as a national resource to assist industry in overcoming the barriers of carbon fiber cost, technology scaling, and product and market development.

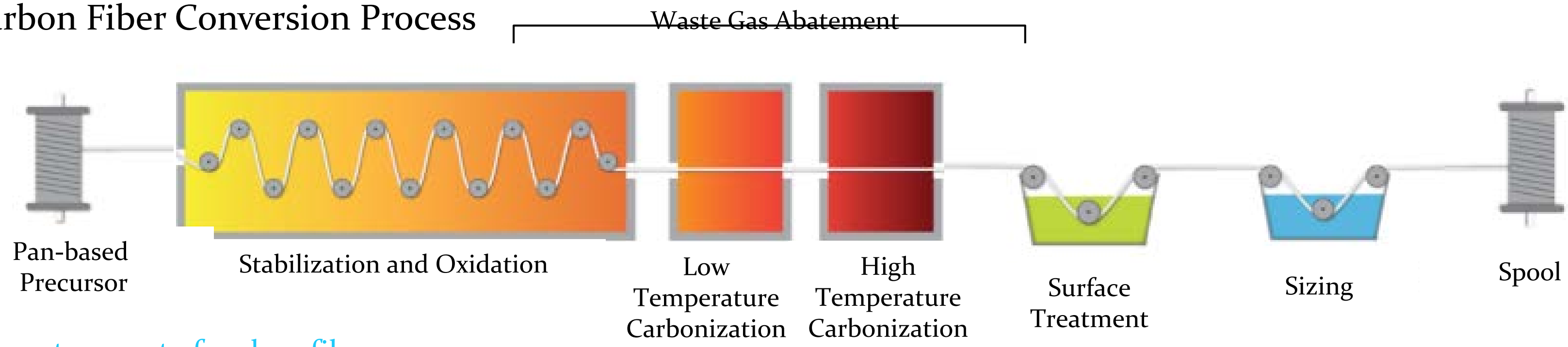
- Demonstrate carbon fiber production using lower-cost precursors and lower energy at semi-production scale.
- Produce low-cost carbon fiber available for evaluation and market development .
- Enable development of domestic commercial sources for production of low-cost carbon fiber.



Daniel Pichler "CarbConsult, Germany Status and Outlook for the Maturing Carbon Fiber Industry" Carbon Fibre Futures Conference (2016)

Technical Innovation

Carbon Fiber Conversion Process



Percentage cost of carbon fiber (Kline)

~50%	~40%	~10%
Precursor	Conversion	Primary finishing and packaging

	Precursor	Conversion	Primary finishing and packaging
Textile	$1.02/lb	40 (457K, 18,280 filaments)	40 spools
Standard	$1.65/lb	120 (50K, 6,000 filaments)	120 spools

Percentage energy of carbon fiber conversion (Das)

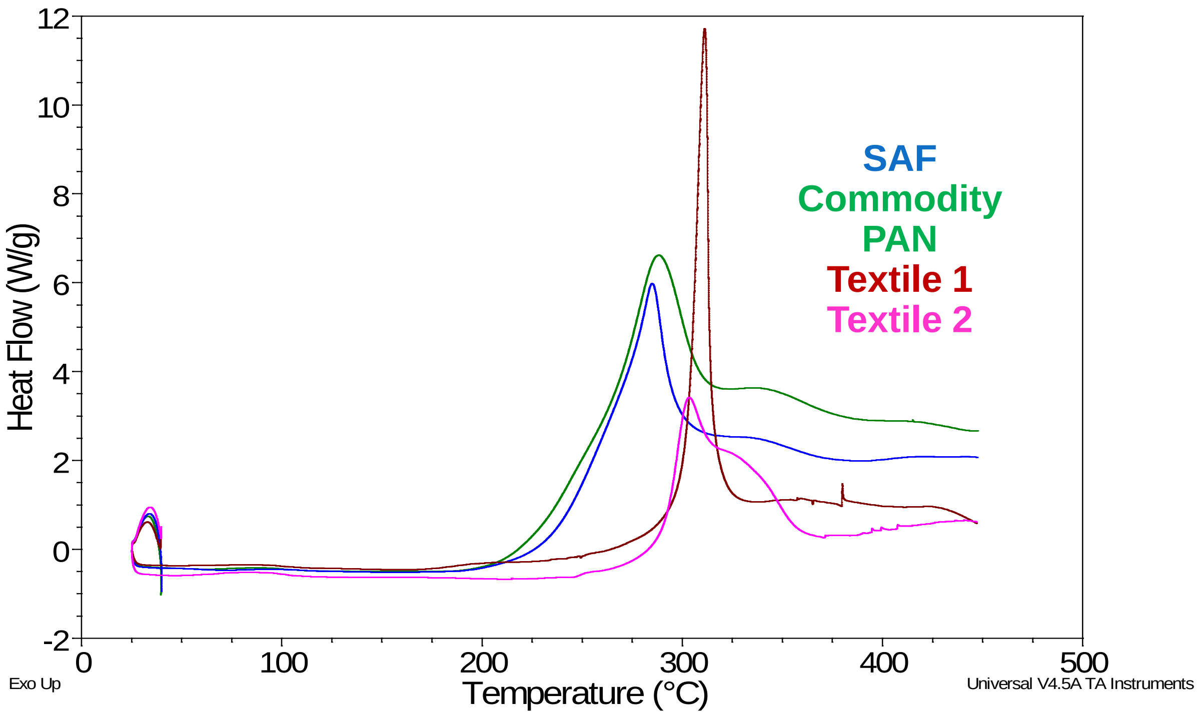
Stabilization and Oxidation	Low Temperature Carbonization	High Temperature Carbonization	Waste Gas Abatement	
~52%	~8%	10%	~14%	~16%

Intellectual property developed around scalable process for producing low cost carbon fiber

- From low-cost, commercially available commodity fiber
- Exhibits properties comparable to industrial grade carbon fibers
- Increase in capacity greater than 2x over traditional conversion process equipment
- Power reduction up to 60% per unit vs. traditional conversion techniques
- Up to 50% cost reduction over traditional production methods

Technical Innovation

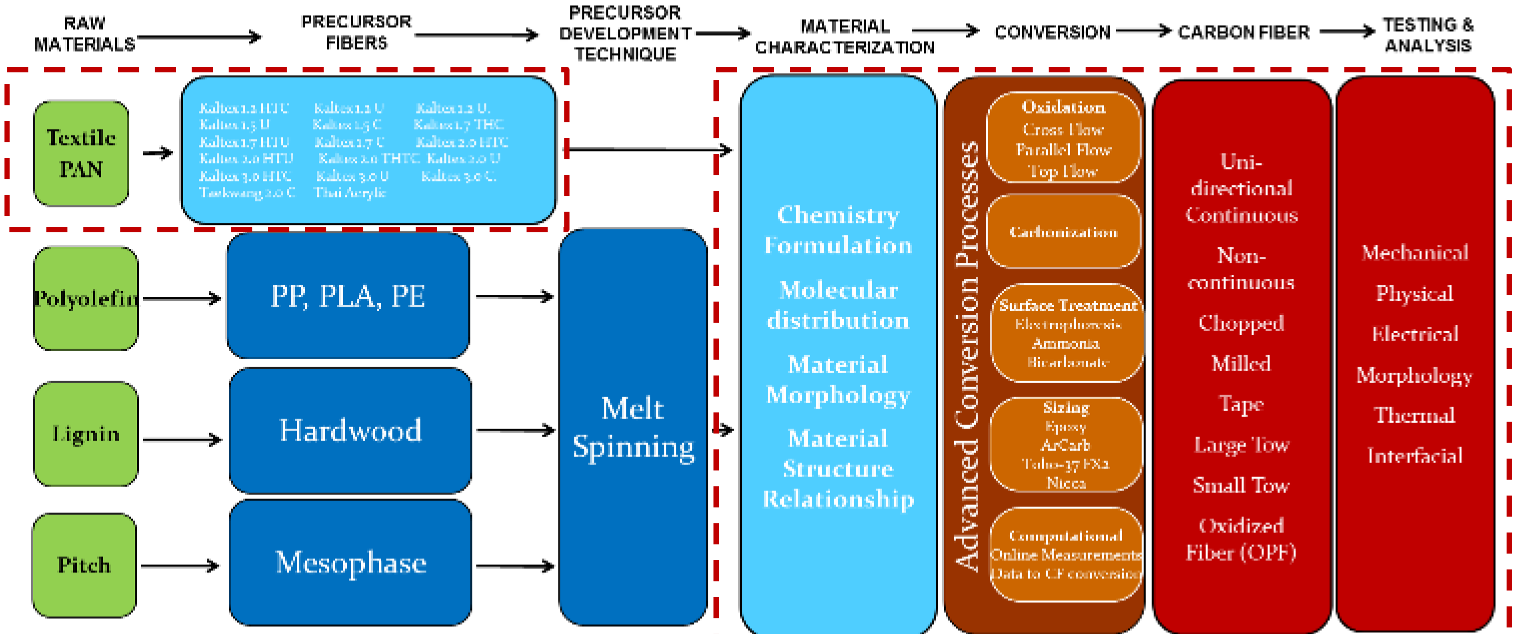
High throughput conversion of the low-cost precursors offers a key advantage.

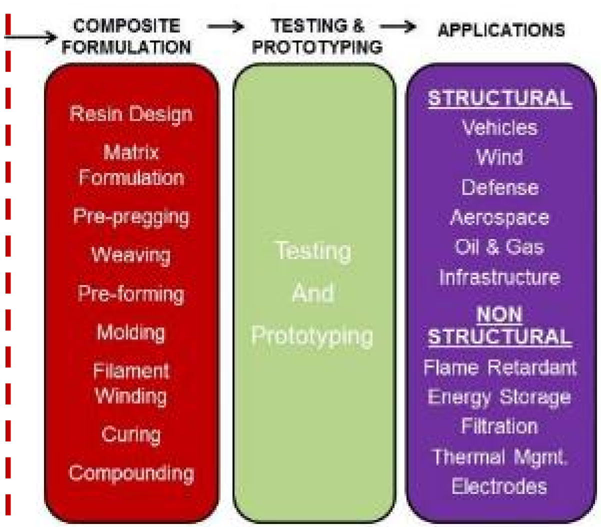


Differential scanning calorimetry (DSC) analysis of the precursors show potential difficulty in stabilizing textiles! ORNL team successfully overcame that deficiency during thermal oxidation of the precursor fibers.

Method of Producing Carbon Fibers from Multipurpose Commercial Fibers, (ORNL ID 3583), Pending U. S. Patent Application

Technical Approach

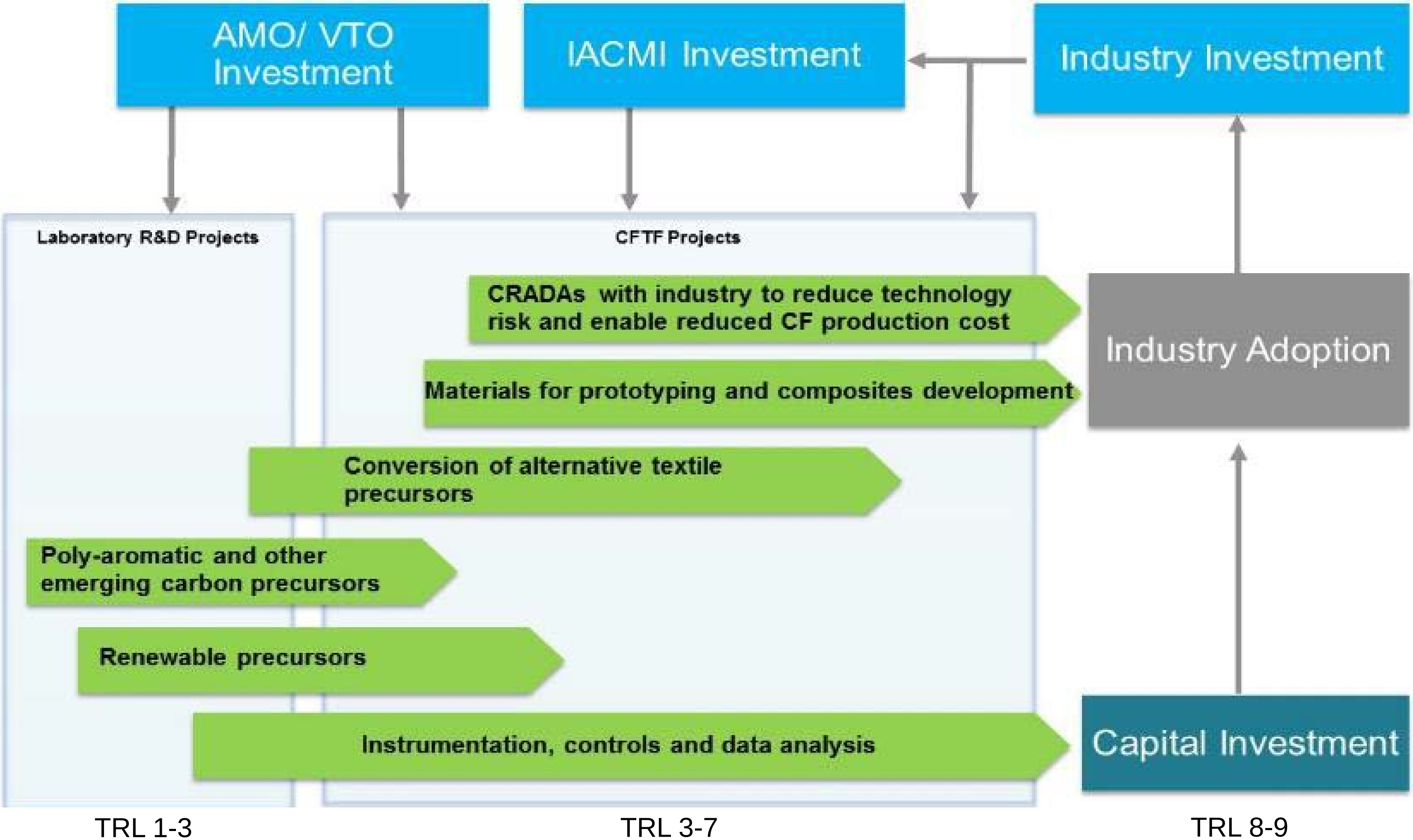




Project Risks and Unknowns

- Process scalability
- Precursor optimization
- Process impact on CF properties
- Instrumentation and process controls
- Conversion to carbon fiber with improved properties
- Conversion of usable intermediates
- Availability of tooling that can handle large tows
- Packaging and handling
- Workforce Development

Transition



Partnerships is hard at work building a “cluster” around carbon fiber and composites

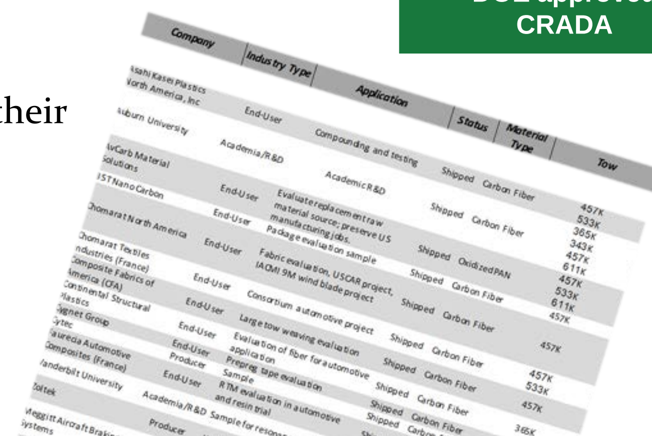
Transition

- Licensing opportunity
  - Two Licensees
  - One Cooperative Research and Development Agreement (CRADA)
  - Another License and CRADA in progress and awaiting approval
- Deployment
  - Over 50 collaborated requests/projects with academia, industry, and other national Labs.
- Mission and Capabilities
  - Industry are able to adopt new opportunities using CF
  - Enhance their processes and capabilities, thus expand their market growth.

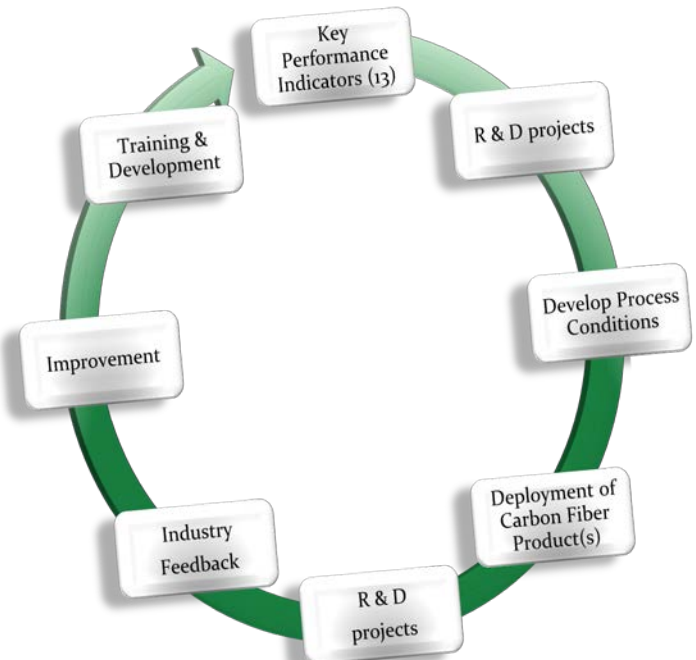
Early June 2015
Invitations to Negotiate Licenses

August 2016
Two Licensees

May 2017
DOE approved CRADA



Company	Industry Type	Application	Status	Material Type	Tow
Asahi Kasei Plastics North America, Inc	End-User	Compounding and testing	Shipped	Carbon Fiber	457K 533K 365K
Auburn University	Academia/R&D	Academic R&D	Shipped	Carbon Fiber	343K 457K 611K
AvCarb Material Solutions	End-User	Evaluate replacement raw material source; preserve US manufacturing jobs.	Shipped	Oxidized PAN	457K 533K 611K
BST Nano Carbon	End-User	Package evaluation sample	Shipped	Carbon Fiber	457K
Chomarat North America	End-User	Fabric evaluation, USCAR project, IACMI 9M wind blade project	Shipped	Carbon Fiber	457K
Chomarat Textiles Industries (France)					
Composite Fabrics of America (CFA)	End-User	Consortium automotive project	Shipped	Carbon Fiber	457K 533K
Continental Structural Plastics	End-User	Large tow weaving evaluation	Shipped	Carbon Fiber	
Cygnet Group					
Cytec	End-User	Evaluation of fiber for automotive application	Shipped	Carbon Fiber	457K
Faurecia Automotive Composites (France)	End-User	Prepreg tape evaluation	Shipped	Carbon Fiber	
	Producer	Sample	Shipped	Carbon Fiber	
Vanderbilt University	End-User	RTM evaluation in automotive and resin trial	Shipped	Carbon Fiber	365K
Zoltek	Academia/R&D	Sample for resonance…	Shipped		
Meggitt Aircraft Braking Systems	Producer				



A new composites company founded by Tour de France champion Greg LeMond has signed a licensing agreement with the Oak Ridge National Laboratory to commercially produce low cost carbon fiber. The agreement will make the Oak Ridge-based LeMond Composites the first company to offer this new carbon fiber to the transportation, renewable energy, and infrastructure markets and will result in:

- 242 new, highly skilled jobs
- $125M investment locally
- 10 lines producing 140 million lbs. by 2020
  - 16-20 million lbs. in the first year
- New production method reduces production cost by more than 50% and energy consumption by more than 60%

Measure of Success

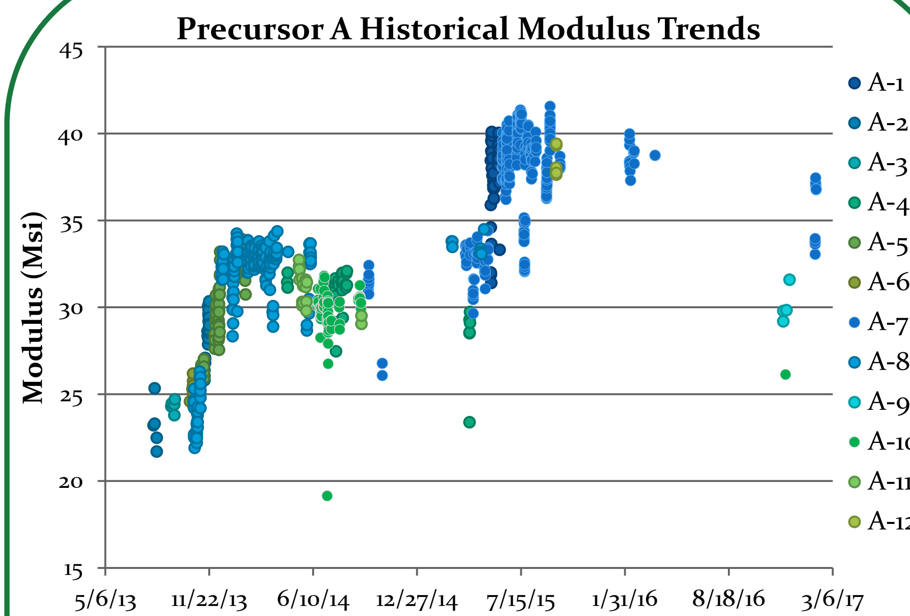
Mechanical Properties Produced and tested by CFTF

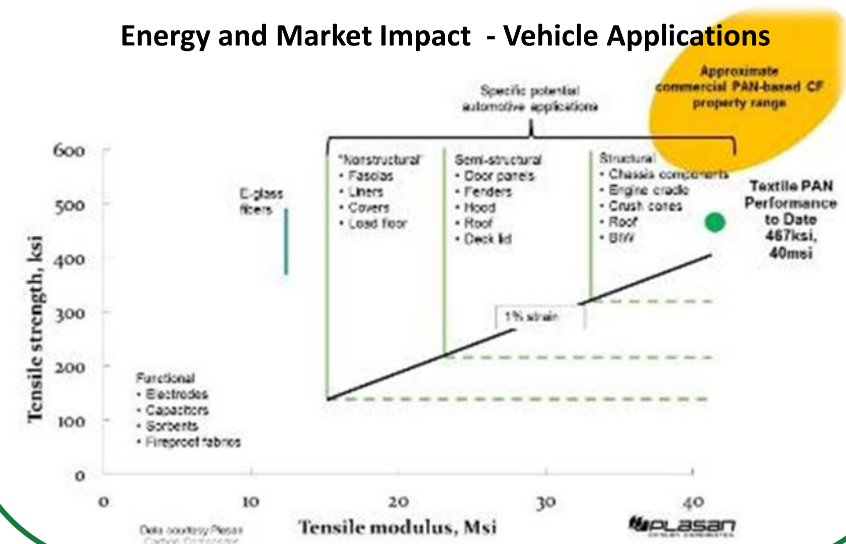
Precursor	Tensile Strength (ksi)	Tensile Modulus (msi)
Kaltex	467.8	40.3
Taekwang	(1) 268.7 (2) 382.6	25.1 36.5
Thai Acrylic* (preliminary)	252.5	26.0

(1) Initial Experiments (2) Improved Experiments

- IACMI partners fabricate composites with the CFTF CF and results showed comparable to standard composites structures, see table below.
- Enable large scale introduction of low cost carbon fiber into the automotive and clean energy industries with projected 50% reduction in energy/Kg produced.
- Support the auto industry in achieving 2025 CAFE standards

	Thermoplastics (30% CF)							
Resin System	Polypropylene		Polycarbonate		Nylon 66		Ultem	
Carbon Fiber	Commercial	ORNL	Commercial	ORNL	Commercial	ORNL	Commercial	ORNL
Impact (ftlb/in)	1.1	0.95	2.74	2.72	2.89	2.41	2.5	1.69
Tensile strength (ksi)	5.94	6.09	19.06	21.99	27.07	25.87	24.88	23.69
Elongation at break (%)	3.56	2.80	2.26	2.36	2.39	2.59	1.46	1.06
Tensile Modulus (msi)	2.37	2.26	2.04	2.59	2.90	2.52	2.01	2.41
Flex Strength (ksi)	10.92	11.62	32.16	31.40	43.52	38.71	35.91	34.34
Flex Modulus (msi)	1.22	1.26	1.74	1.48	1.91	1.63	1.91	2.26





Project Management & Budget

Tasks	Milestones	Due Date
Collaborative Research and Development to further LCCF	Establish CRADAs with industry partners to reduce technical risk and further develop technology to produce LCCF from large tow textile precursor	9/30/17
Materials for prototyping and composites development	Provide LCCF for prototyping and composites development. ORNL staff will collaborate closely with composites manufacturers using LCCF to understand results and gain feedback to inform further development.	9/30/17
Process developments for alternative textile precursors	Develop process conditions to allow conversion of additional sources of textile acrylic fiber to carbon fiber with properties suitable for use in vehicle applications.	9/30/17
Process monitoring and data analysis to improve process control and accelerate process optimization	Develop process monitoring and data analysis methods to improve process control and accelerate process optimization.	9/30/17

Progress Measurement:

- CFTF have recently developed key performance indicators that will be tracked on a monthly basis.
- Each performance indicator contains subtasks with quantified targets/goal and due dates per quarter.
- Achieved all milestones to date.

	FY 2015	FY 2016	FY 2017
Total Budget	5.5 M	5.3 M	6 M
VTO commitment	1.5 M	1.3 M	1.0 M
AMO commitment	4.0 M	4.0 M	4.0 M
Other commitment			1.0 M

Results and Accomplishments

Technical Accomplishments:

- Demonstrated large volume carbon fiber production utilizing multiple sources of PAN-based textile precursors at a semi-production scale. CFTF have >20 varieties from four suppliers and demonstrated the conversion of 13 types from two of the suppliers thus far.
- Demonstrated reproducible process conditions with multiple lots taking into consideration all variations typical to carbon fiber manufacturing.
- Demonstrated commercially viable properties in comparison to standard and intermediate commercial carbon fiber at ~50% reduction in energy consumption and production cost based on volume throughput (2x).
- Publicly announced breakthrough and acquired 2 licensees and 1 CRADA for the technology. Established several significant collaborations with industries and academic entities to help create market pull for low-cost, industrial grade carbon fiber.
- Development of skilled workforce: Six technology interns are now employed by a licensee, Three technology interns are now employed by UT-Battelle.

Next Steps:

- Correlating fundamental science to CF process and to the CF properties.
- Continuously improve process conditions via research and development projects to achieve higher Tensile Properties.
- Demonstrate quantitative correlation for the process monitoring proven concept(s).
- Develop process conditions and demonstrate high volume oxidation for alternate precursors to target a wider range of applications enhancing engagement with industries including CRADA partners and Licensees for successful commercialization.
- Produce more LCCF with favorable properties for prototyping and testing.

Property (Cross-ply)	LCCF (53% W_f) Epoxy	Zoltek (60% W_f) Epoxy
Tensile strength MPa (ksi)	550 (79.77)	700 (101.52)
Tensile modulus GPa (Msi)	60 (8.70)	58 (8.41)
Flexural strength Mpa (ksi)	600 (87.02)	750 (108.77)
Flexural Modulus Gpa (Msi)	50 (7.25)	48 (6.96)
ILSS, Mpa (ksi)	TBD	48 (6.96)

Credit to IACMI partner

QUESTIONS?


CARBON FIBER
TECHNOLOGY FACILITY
OAK RIDGE NATIONAL LABORATORY