Manufacturing Demonstration Facility (MDF) & Carbon Fiber Technology Facility (CFTF)

Oak Ridge National Laboratory

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U.S. DOE Advanced Manufacturing Office Technical Resources & Networking Forum
Washington, D.C.
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Program Introduction: What is the MDF?

MDF Mission	MDF Vision
Develop and mature **additive manufacturing and composite technologies for clean energy applications.**	A **competitive America using additive and composite processes in mainstream manufacturing industries.**

1. ***Core Research and Development***
   - **Long-term** R&D in materials, systems, and computation
2. ***Industry Collaborations***
   - **Short-term** collaborative R&D on energy-related fields
3. ***Education and Training***
   - Internships, academic collaborations, workshops, training programs, and university/college curriculum.

Program Introduction: What is the MDF?

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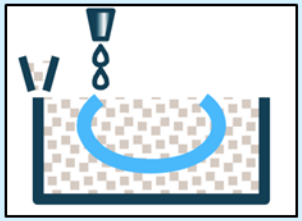
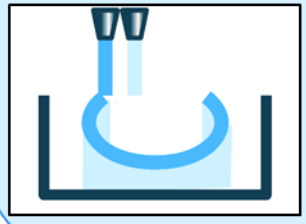
Vat Photo-polymerization

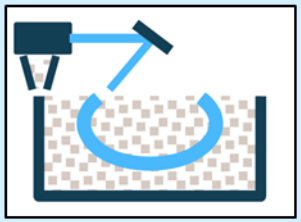
Material Jetting



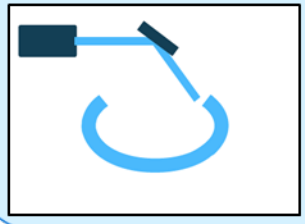
Binder Jetting



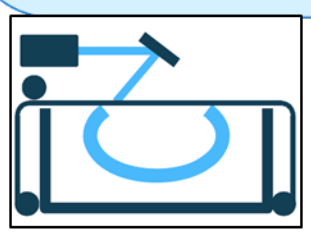
Material Extrusion



Powder Bed Fusion



Directed Energy Deposition



Sheet Lamination

Roland Berger
Strategy Consultants

Industrially relevant, manufacturing-scale equipment focus

Targeting large, fast, cheap production and high performance systems for industry

Program Introduction: Industry Collaborations

DOE National Labs are a world-class **public** resource

Neutron scattering: SNS and HFIR

- World's most intense pulsed neutron beams
- World's highest flux reactor-based neutron source

Leadership-class computing: Titan

- Nation's most powerful open science supercomputer

Advanced materials

- DOE lead lab for basic to applied materials R&D
- Technology transfer: Billion dollar impacts

Advanced manufacturing

- Novel materials
- Advanced processing

How do Labs "open the doors" to industry?
How to small businesses access these resources?

Program Introduction: Industry Collaborations

Explore

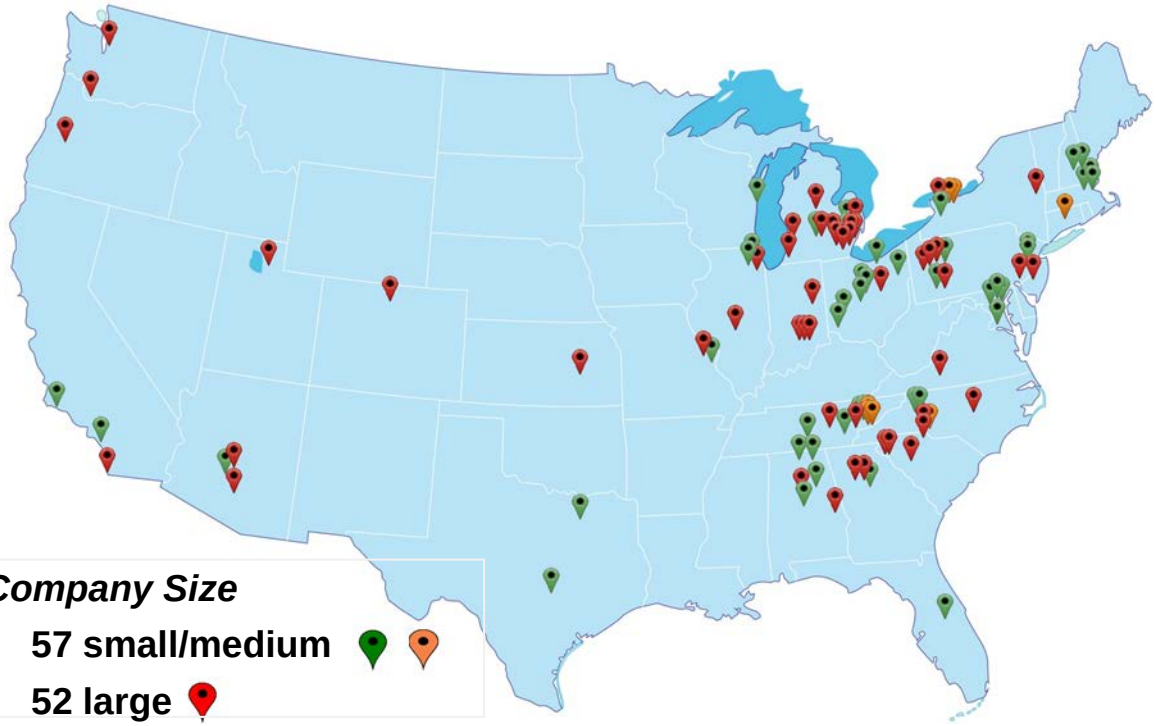
- Opportunity for industry to discover and apply new manufacturing technologies

Engage

- Work with MDF staff to develop scope of work

Execute

- Phase 1 $40K, Phase 2 $200K
- 1:1 Cost Match
- Non-Negotiable CRADA
- ~90-day cycle time from review to a signed agreement
- Always available



Company Size

- **57 small/medium**
- **52 large**

Quick Facts

- >100 active or completed projects across 7 technologies
- >60 completed projects
- >75 publications this year
- >17,000 visitors

Program Success: MDF Program

July 2012

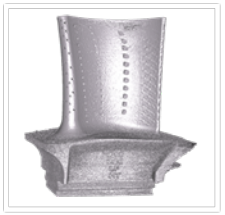
ORNL, Arcam sign CRADA for alloy development, process reliability

Feb 2013

Arcam and DiSanto Technology (Shelton, CT)

sign Strategic Alliance

June 2014



Arcam launches Inconel 718 developed with ORNL

Jan 2015

ORNL and Honeywell produce In718 aerospace component

March 2016

Inauguration of Woburn, MA Office

Sept 2016

GE to buy SLM, Arcam for $1.4billion in 3D printing push

- **CEO Relocates to US**
- **50% Arcam employees in North America**
- **Acquisition of DiSanto and AP&C**

"With the MDF and your help, we have been able to reach world leading research as well as a lot of potential customers"

…"strong development has to a great extent been possible due to your firm [ORNL, MDF]"…

Magnus Rene, CEO and President of Arcam

Technical Collaborations:

S-RAM DYNAMICS

Planetary Systems Corporation

Planetary Systems Corporation

ECM Technologies

Solar Turbines A Caterpillar Company

Quintus Technologies

PRAXAIR

Program Success: MDF Program

Feb 2014

ORNL, Cincinnati sign CRADA

Sept 2014

Strati car printed live at IMTS Show

Jan 2015

Cincinnati BAAM v2; Shelby Cobra goes global

Sept 2015

Additive Manufactured Integrated Energy

Sept 2016

ORNL receives GUINNESS World Record

Jan 2017

TPI uses 3D printed wind blade mold

Creation of Large-scale Polymer Industry

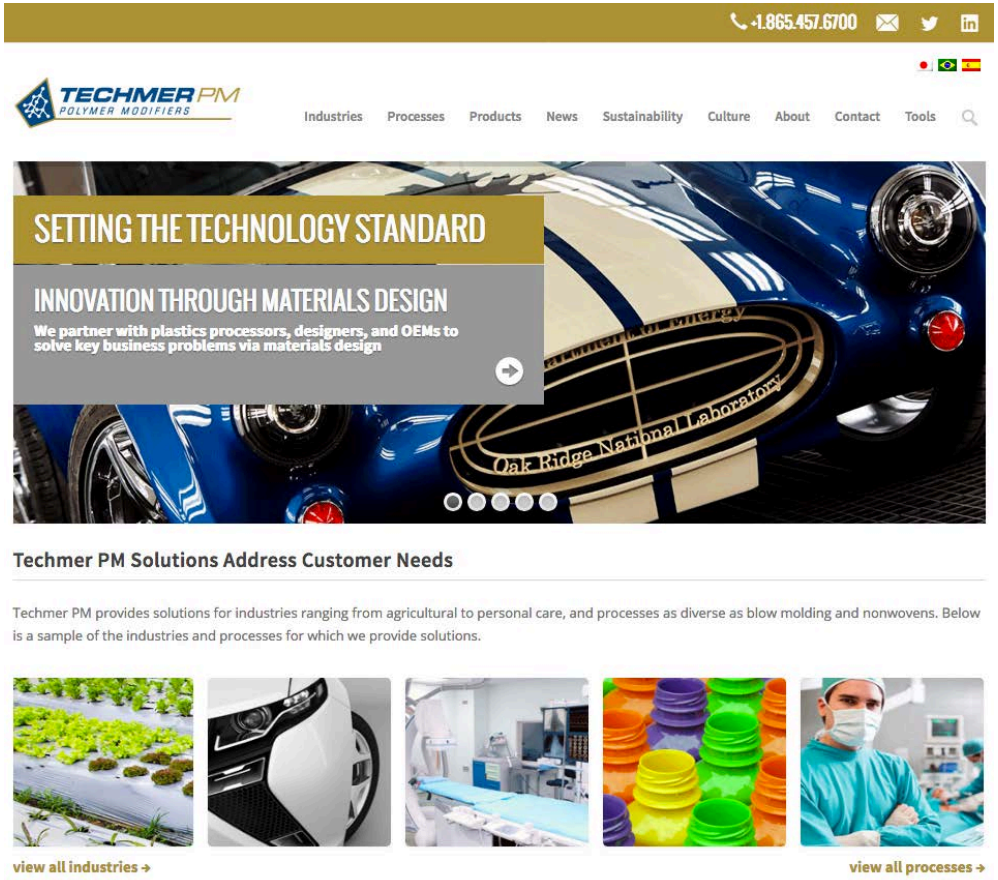
- 13 BAAM Units Sold
- *Over 7 AM Equipment Manufacturers Using/Evaluating Technology*
- *10s to 100s of End Users Evaluating the Technology*
- *New Materials Suppliers*

Technical Collaborations:

Program Success: MDF Industry Collaborations

Rigorous evaluation of Techmer's line of high performance thermoplastic materials for BAAM.

Techmer has sold $1M of pellet feedstock material for AM in last year



"Our innovative carbon-fiber materials are specially formulated for the growing 3-D printing market," - Tom Drye, managing director of Techmer ES.

Materials

Program Success: MDF Industry Collaborations

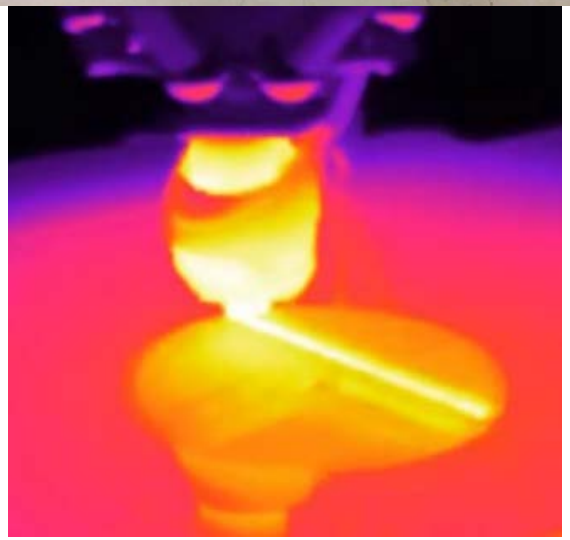
Ajax TOCCO

Ajax TOCCO and ORNL created an induction system for heating Fused Deposition Modeling (FDM)

Wider variety of materials including certain metals

Very low cost and efficient power supply

Response time to 230°C is 1/3rd of resistive heating system



Process

Program Success: MDF Industry Collaborations

Cummins, Inc.

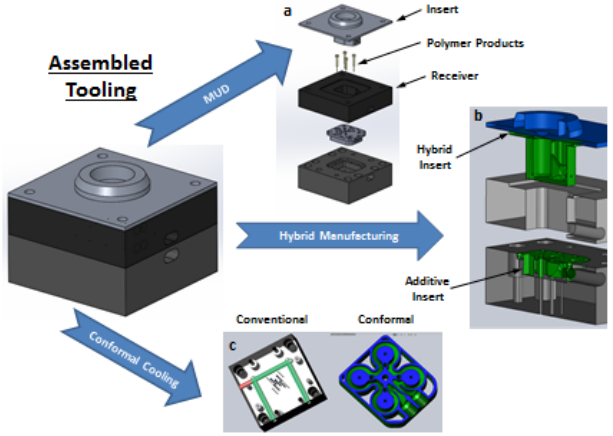
Low-Cost Injection Mold via Hybrid & Conventional Manufacturing

Injection molding tooling costs reduced by > 50%

Parts cooled 25% faster via additive manufacturing (AM) cooling passages

Cummins planning to use permanent basis

Cummins now working with ExOne (process OEM at MDF) on stand-alone partnership.



"That's why we like to leverage partnerships with Oak Ridge… We can work with them and increase our comfort level with a new technology before we invest and incorporate it into our own facilities."

Roger England, Director of Materials Engineering and Technology, Cummins

End user

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Carbon Fiber Technology Facility

Reduce carbon fiber cost by using low cost alternative precursors

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

Develop training program for the future advanced carbon fiber and composites workforce

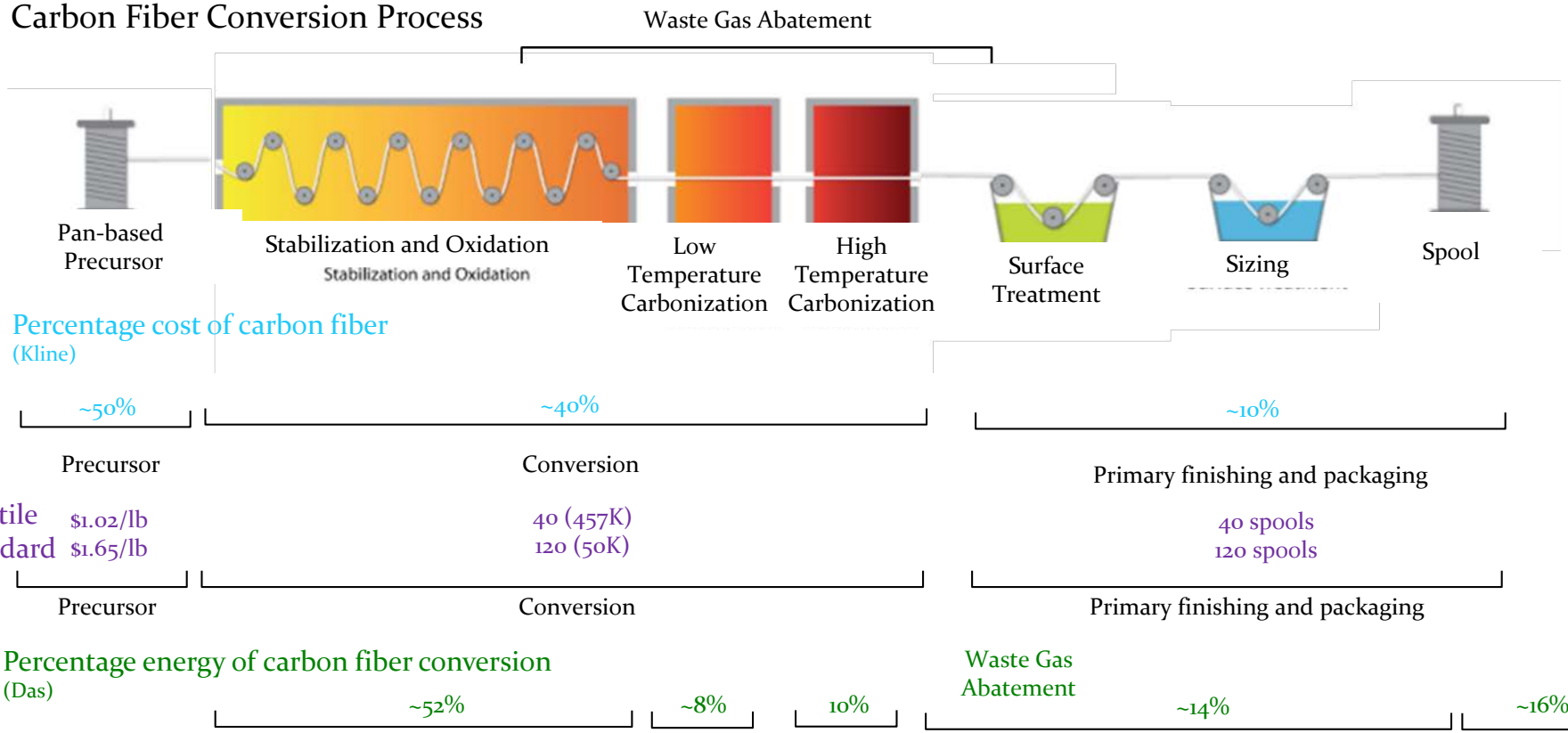
The Carbon Fiber Technology Facility (CFTF) serves as a national resource to assist industry in overcomingthe barriers of carbon fiber cost, technology scaling, and product and market development. CFTF is intended to be the bridge from R&D to deployment and commercialization and other clean energy applications.

Project Objectives

- Develop and demonstrate carbon fiber production using lower-cost precursor materials at semi-production scale.
- Produce and make available low-cost carbon fiber in sufficient quantity to enable evaluation and market development for application of carbon fiber composites with lower cost and environmental impact.
- Enable development of domestic commercial sources for production of low-cost carbon fiber, including workforce development.
- Develop additional precursors and deeper understanding of process variables and control to enable further reductions in cost and energy impact of CFRP composites.

Technical Innovation

Carbon Fiber Conversion Process



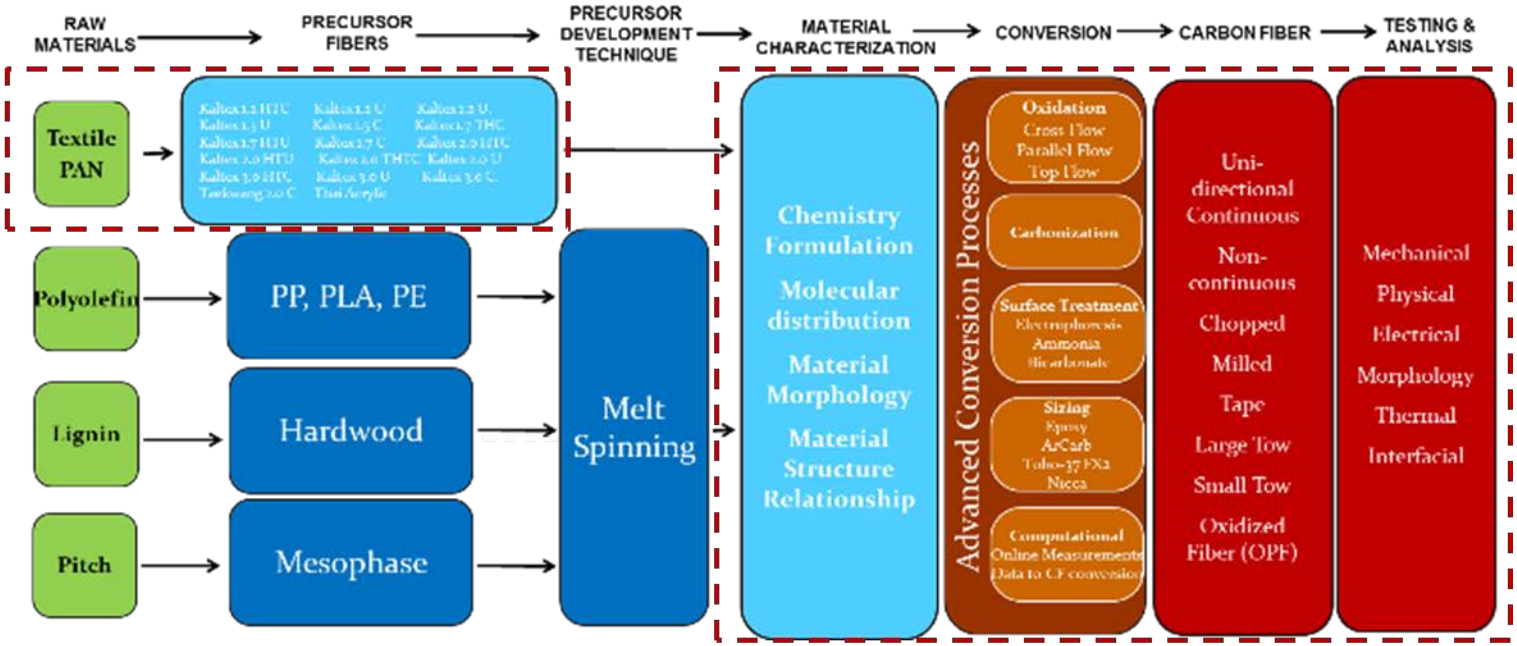
Intellectual property developed around scalable process for producing low cost carbon fiber

- 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 Approach

- Integrated approach to low-cost carbon fiber manufacturing R&D
- Identify high potential, low cost alternative precursors
  - PAN-based Textile Precursors
- Develop optimal mechanical properties of resultant carbon fiber from alternative precursors and correlate structure-property relationships.
- Provide sample quantities with favorable properties to industrial partners for testing based on DOE approval
- Address feedback from industrial partners
- Improve carbon fiber manufacturing costs metrics
- Industry collaborations

Technical Approach



Project Risks and Unknowns

- Process scalability
- Precursor Optimization
- Process impact on CF properties
- Instrumentation and controls
- Conversion of usable intermediates
- Availability of tooling that can handle large tows
- Packaging and handling
- Workforce Development

erwise restricted information.

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 variation 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.

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

Transition and Deployment

- 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