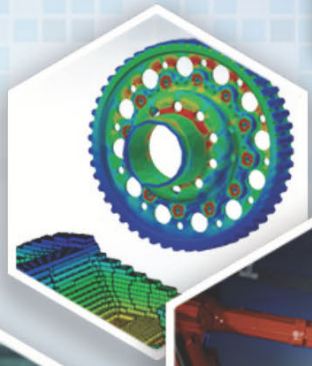


IACMI Facilities and Capabilities Update

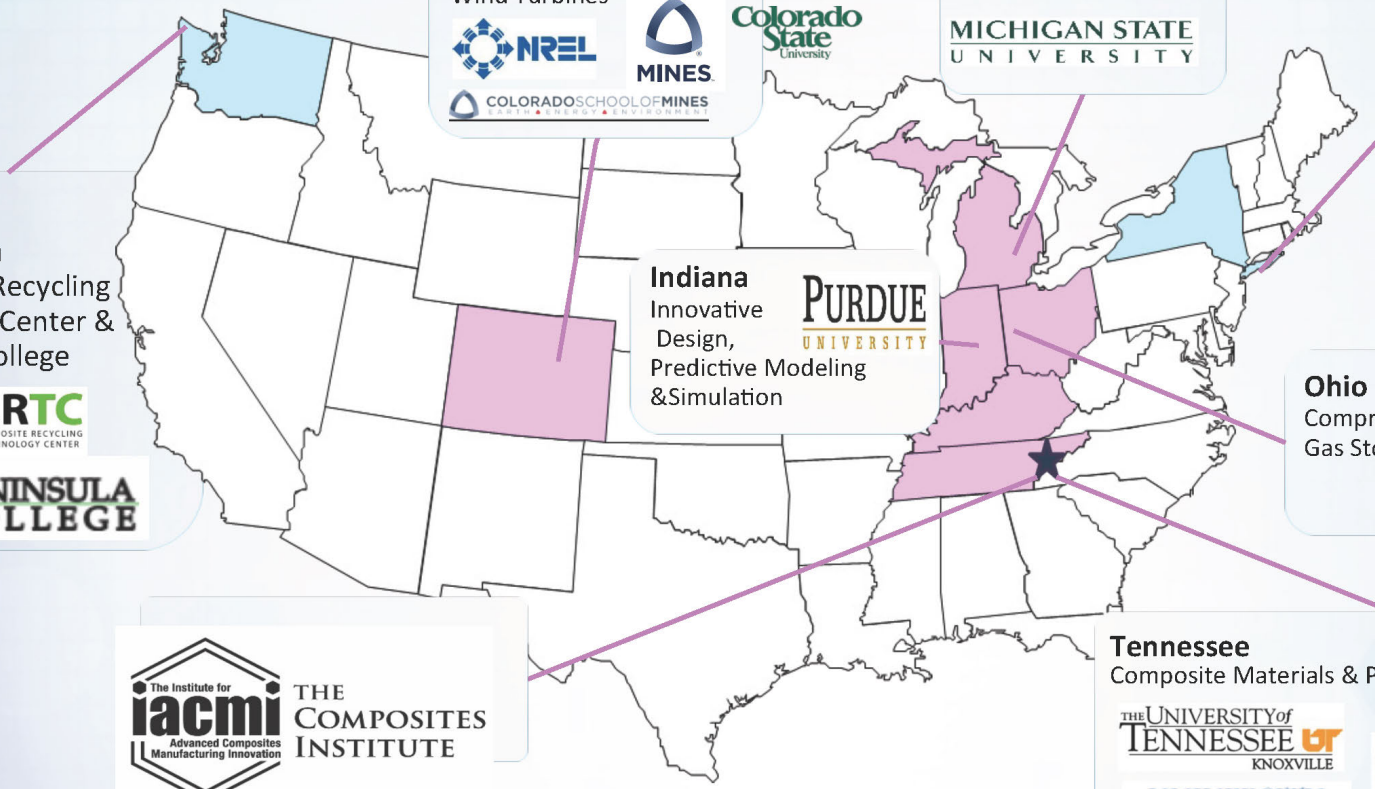
Uday Vaidya

Chief Technology Officer

January 17, 2018

THE COMPOSITES iacmi INSTITUTE

IACMI – A National Institute for Advanced Composites



Colorado
Wind Turbines
NREL
MINES
Colorado State University
COLORADOSCHOOLOFMINES

Michigan
Vehicles
MICHIGAN STATE UNIVERSITY

New York
Composite Prototyping Center
CPC Composite Prototyping Center

Washington
Composite Recycling Technology Center & Peninsula College
CRTC COMPOSITE RECYCLING TECHNOLOGY CENTER
PENINSULA COLLEGE

Indiana
Innovative Design, Predictive Modeling &Simulation
PURDUE UNIVERSITY

Ohio
Compressed Gas Storage
UDRI UNIVERSITY of DAYTON RESEARCH INSTITUTE

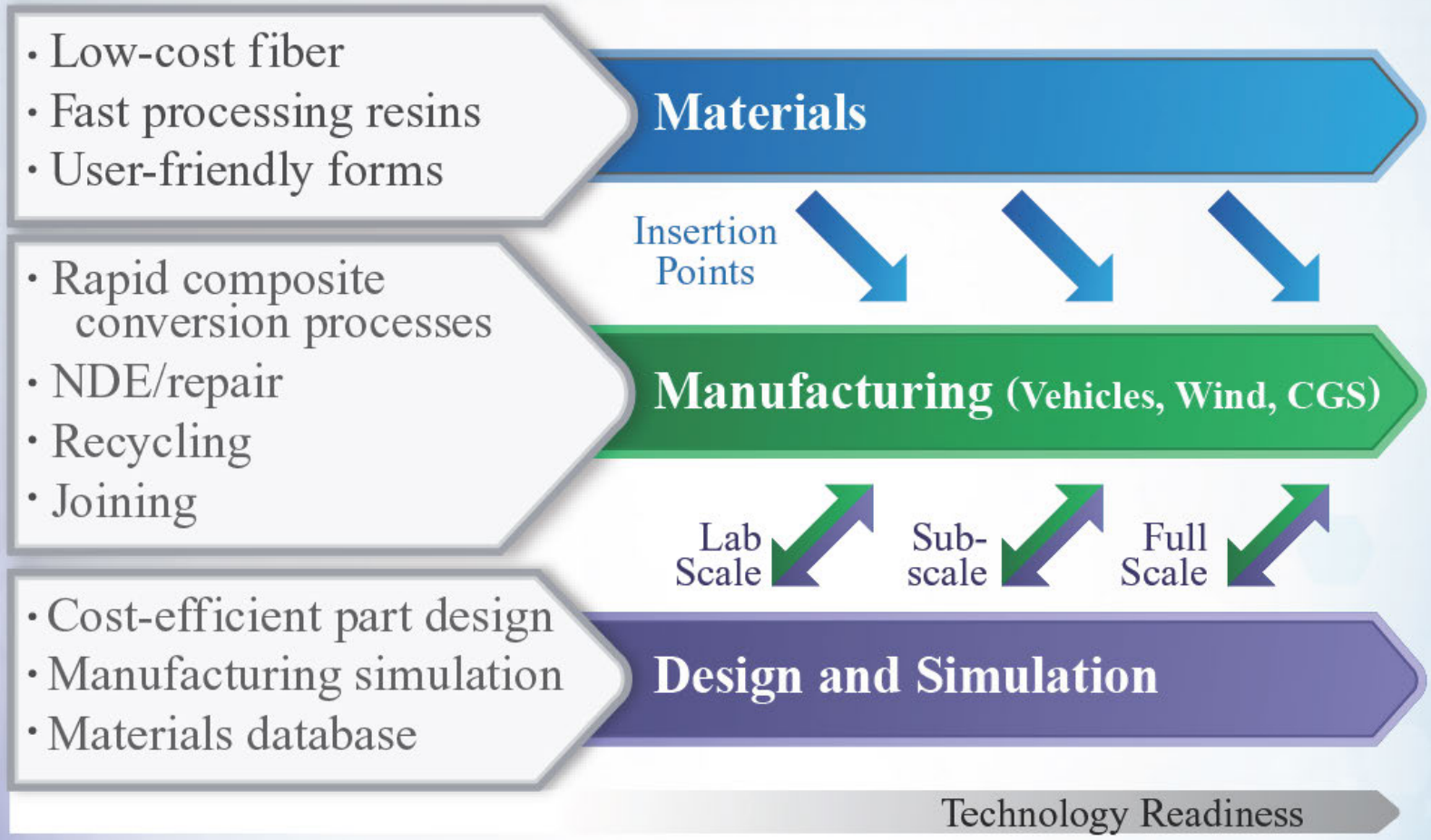
The Institute for iacmi Advanced Composites Manufacturing Innovation
THE COMPOSITES INSTITUTE

Tennessee
Composite Materials & Process Technology
THE UNIVERSITY of TENNESSEE KNOXVILLE
OAK RIDGE National Laboratory
VANDERBILT UNIVERSITY
UNIVERSITY OF KENTUCKY

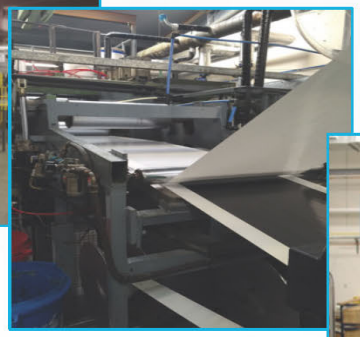
Technical Goals:

- Lower carbon fiber–reinforced polymer (CFRP) cost
- Reduce CFRP embodied energy
- Improve composite recyclability into useful products

An Integrated Approach Is Required



Scale-up Across IACMI Core Partners



Solution spinning line — KY

Carbon Fiber Technology Facility — TN

Pre-preg production pilot/full scale — TN, OH, MI

Pilot-scale PCM 750 ton press — TN, OH

Full Scale PCM 4,000 ton press — MI

IN

THE COMPOSITES iacmi INSTITUTE

Composite Materials and Processes

University of Kentucky

OAK RIDGE National Laboratory

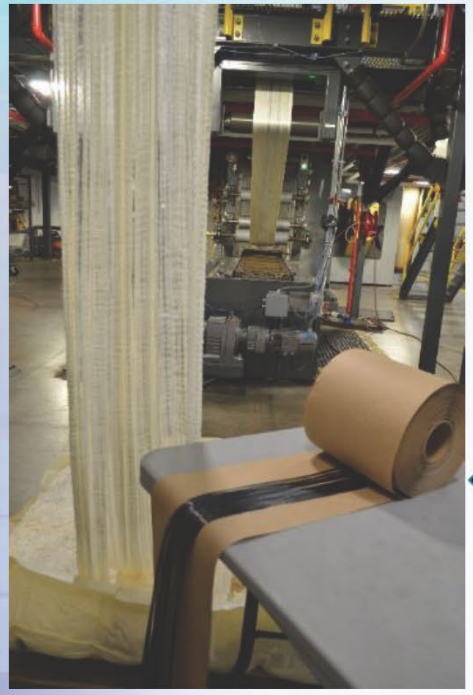
Unique open-access carbon fiber processing capabilities

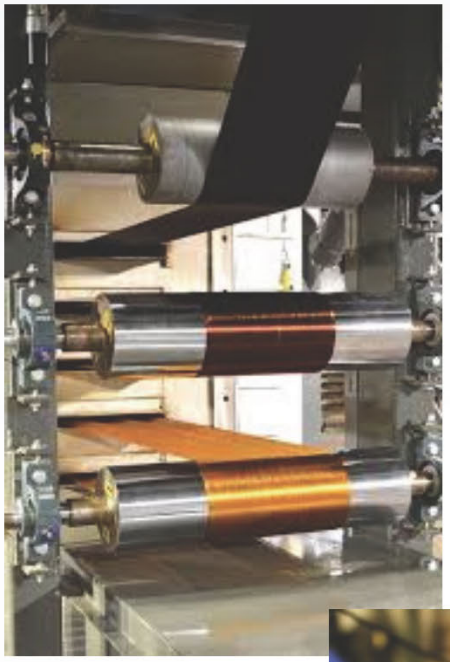
Melt spinning

Bench and pilot scale heat treatment equipment

World's most flexible carbon fiber semi-production facility

Textile PAN based CF





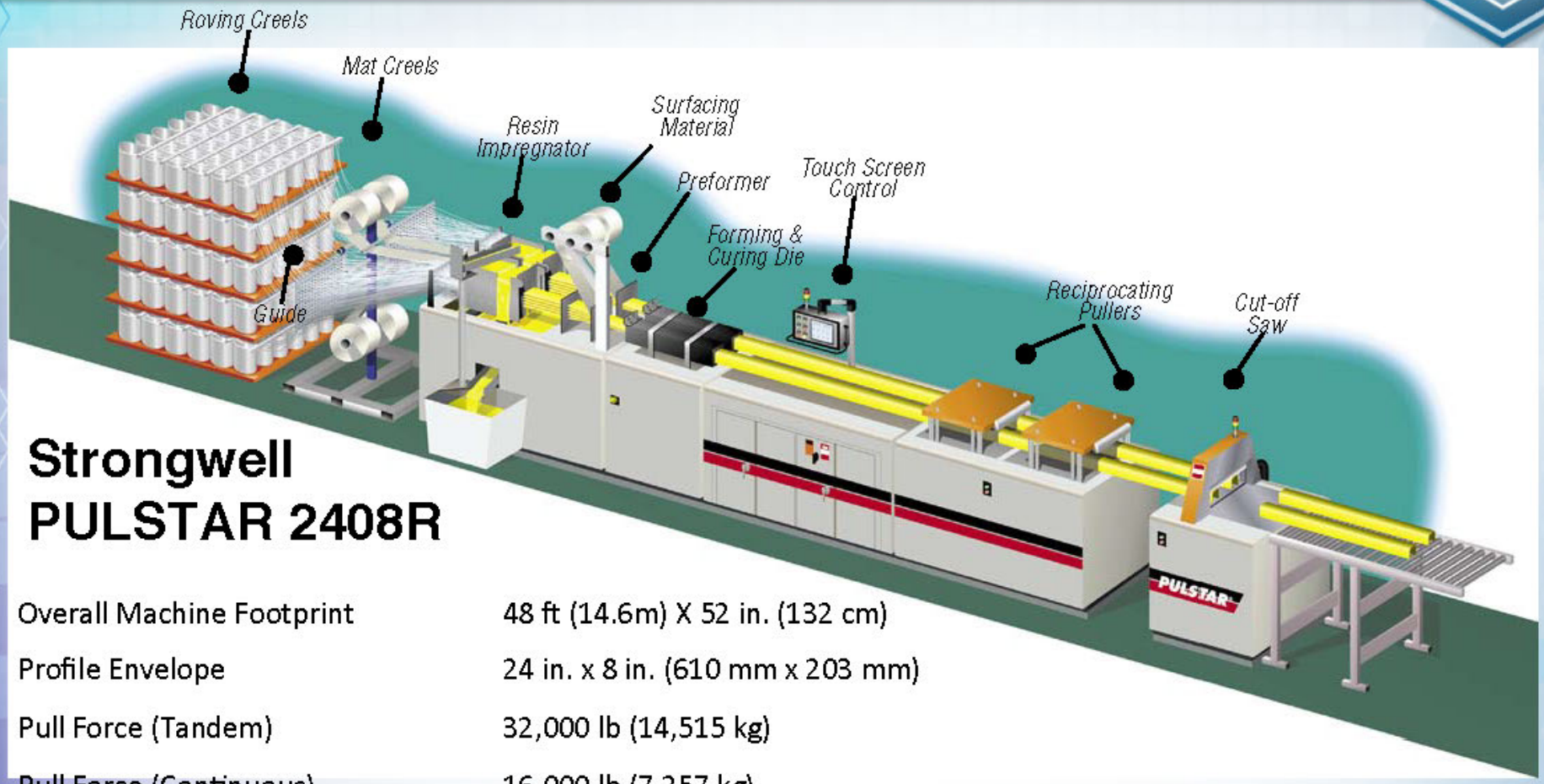
IACMI partner, Oak Ridge National Laboratory, has demonstrated a production method estimated to reduce the cost of carbon fiber as much as 50% and the energy used in production by more than 60%.

IACMI generating properties on composites produced with textile PAN carbon fiber

Big Area Additive Manufacturing

Recent enhancements in physical scale, speed of production, and work in high temperature polymer composites, e.g. PPS/CF

IACMI Pultrusion Machine



Strongwell PULSTAR 2408R

Overall Machine Footprint	48 ft (14.6m) X 52 in. (132 cm)
Profile Envelope	24 in. x 8 in. (610 mm x 203 mm)
Pull Force (Tandem)	32,000 lb (14,515 kg)
Pull Force (Continuous)	16,000 lb (7,257 kg)
Clamp Force	24,000 lb (10,886 kg)
Speed Range	1-120 in./min (2-305 cm/min)

Source: Strongwell

IACMI Pultrusion Machine

Machine delivered to ORNL
Will be installed and mid 2018

RocTool Induction Heating / Fast cycle processing of thermoplastic composites (MDF) installed July 2017

Equipment specifications

- Induction generator DZ150KW
- Tactile interface – RT 21
- Closed cooling unit - R45 model
- Performance cooling
- RocTool Technology / Tool Hardware

IACMI projects

Compression molding

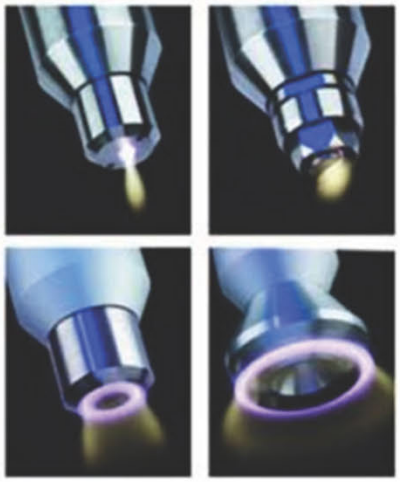
Class A surface finish

Fast cycle time in recycled and virgin carbon fiber thermoplastic mats

Evaluation of range of material forms and resin for processing-quality-cycle times

Representative System and parts

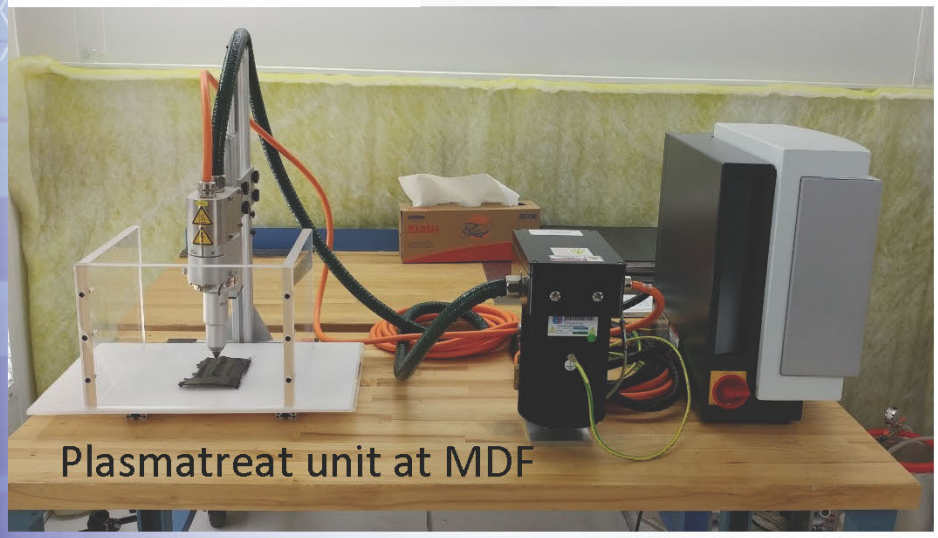
Plasmatreat unit at MDF (Jet - RD1004 / Generator - FG5001 / Transformer - HTR1233) - MDF



Resource Member

Enabling plasma treatment for surface enhancement

Tennessee (in place) and Michigan (planned)



Plasmatreat unit at MDF

- State-of-the-art FG5001 Plasma Generator
- Cleaning, etching, polymerization, surface activation and increased manufacturability.
- Bonding enhancement of low surface energy substrates
- Fiber treatment
- Surface and Interface enhancement
- Overmolding/tape bonding
- Multi-material joining
- Additive manufacturing layer by layer
- Product development

plasmatreat

Recycling Shredder (UTK)

MS-1714 Dual Shaft Shear Shredder

- Feed Chamber Opening: 17″ x 14″
- Discharge Opening: 17″ x 14″
- Infeed Hopper: Open Top: ½ Cubic Yard
- Diameter of Shredding Knives: 7-1/2″ Thickness of Knives: 5/8″
- Motor: 15HP, 1800RPM Voltage: 480/3/60

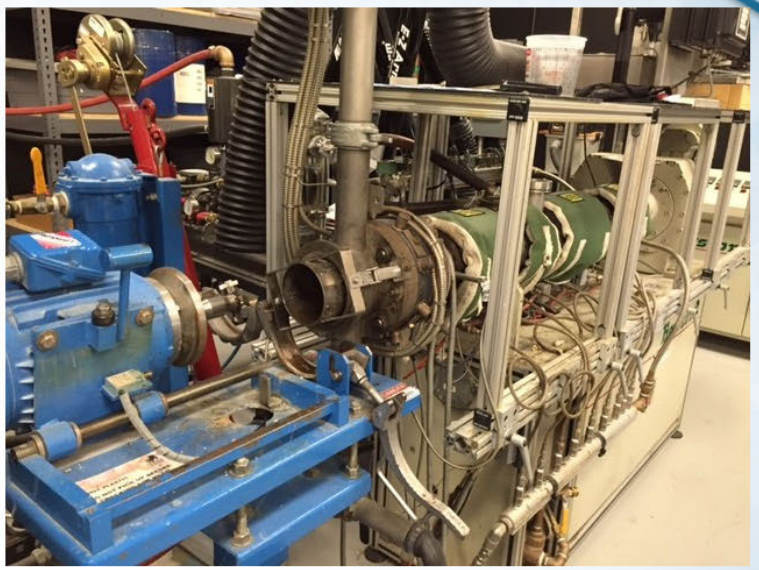
IACMI projects

- Shredding aerospace end of life parts
- Recycling thermoset cured resins and composites
- Glass and carbon fiber thermoplastic shreds
- Reprocessing in extrusion-compression, injection-compression and other downstream processes

Multiphase Compounding – Pelletizing Line (UTK_

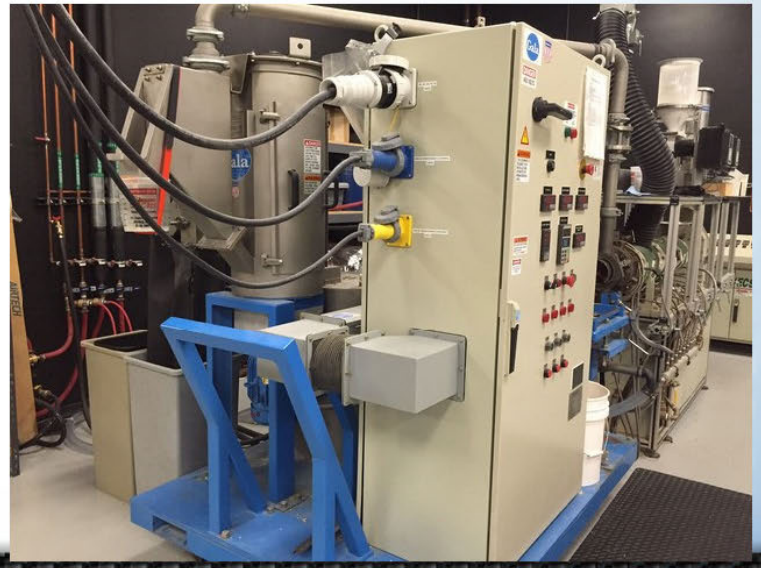
Specifications

- Berstorff Model ZE25x30D Gala Pelletizing Line
- Complete Lab Size Under Water Pelletizing Line
- Screw size – 25 mm
- L/D ratio- 30:1
- 15 HP, Gear Box Ratio 4:1



IACMI Use/projects

- Compounding of LCCF and other fibers with a range of olefin and engineered resins
- Multiphase – syntactic foams and color compounds
- Production of noodles, pellets and tapes
- Feedstock for multiple processes



Sheet molding compound (SMC) line

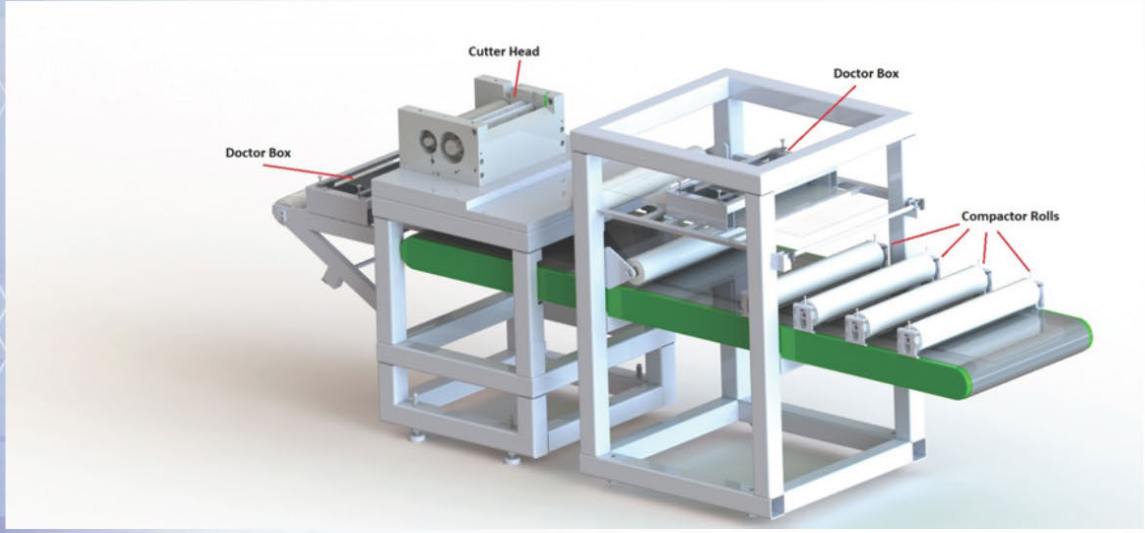
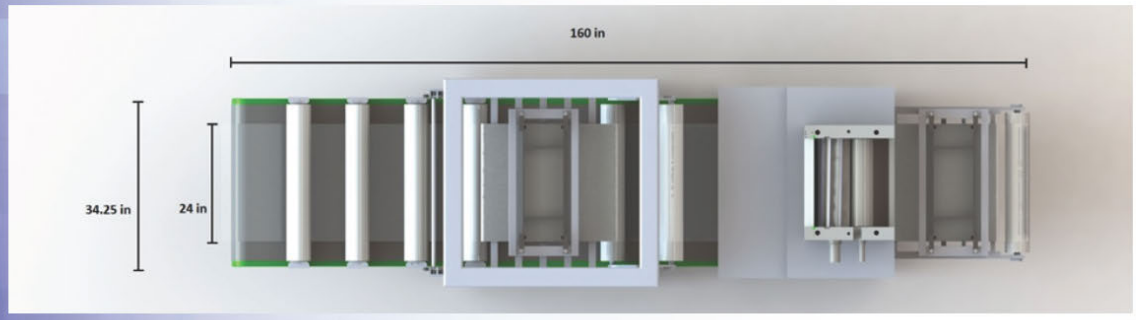


Illustration of cutting head of the SMC line

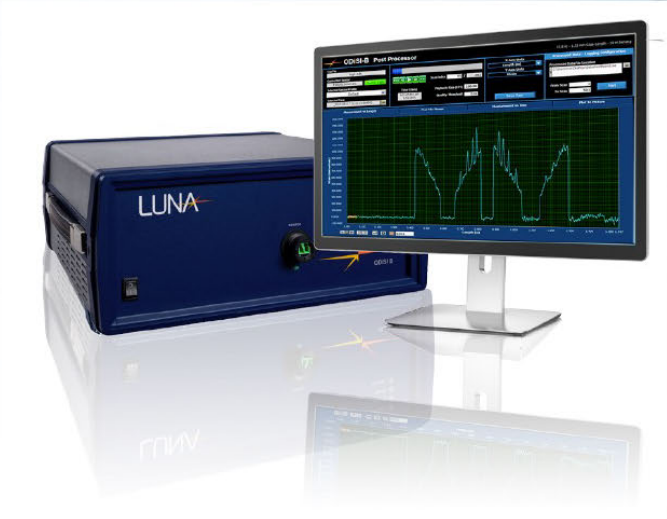


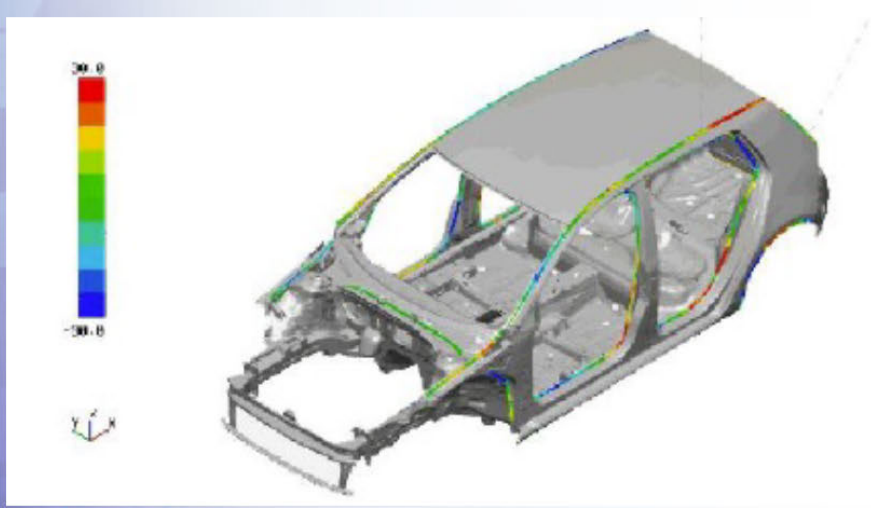
- Custom line (at UT early 2018)
- Produce up to 18” wide SMC
- Glass, carbon, basalt SMC
- For use in multiple IACMI projects
- Materials collaboration with industry partners

Upgrade of LUNA Fiber Optic Strain and Temperature Sensing (ODiSI-B 5.0) System

- **OPT06003 Full SW & HW upgrade - includes ver 5.0.0 and upgrade to electronics, optical network, new standoff, High Definition sensing upgrade, system alignment and test. High-Speed CFG option.**

- **FBI Gauge 3D Visualization Software Package Acquisition**



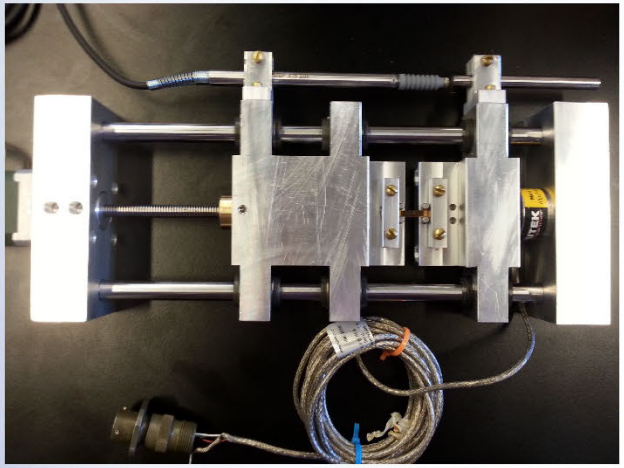


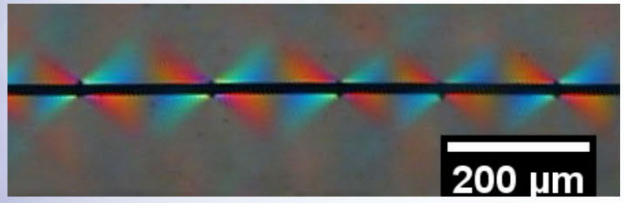
ODiSI - Key Benefits

- High definition sensing offers unprecedented visibility into a design's structural performance
- Low profile and flexible sensors ideal for embedding within composite structures and measuring strain on curved surfaces
- Corrosion resistant, dielectric, and immune to EMI/RFI
- An ideal tool for validating FE models of composite structures

Integrated Load Frame and Olympus BX53 Reflected/ Transmitted Light Microscope

IACMI Use/projects: Interfacial Shear Strength for Optimizing Carbon Fiber Surface/Interphase with Matrix Resin

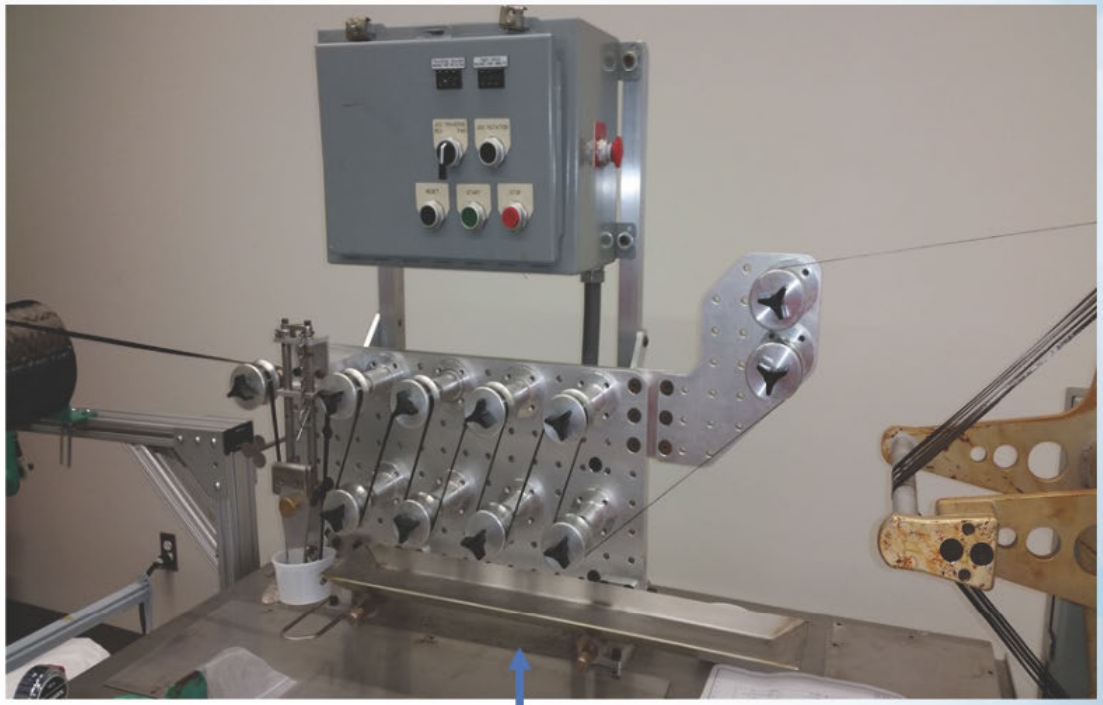




Polarized light images in transmission mode of a fragmented single T700 carbon fiber in an epoxy composite

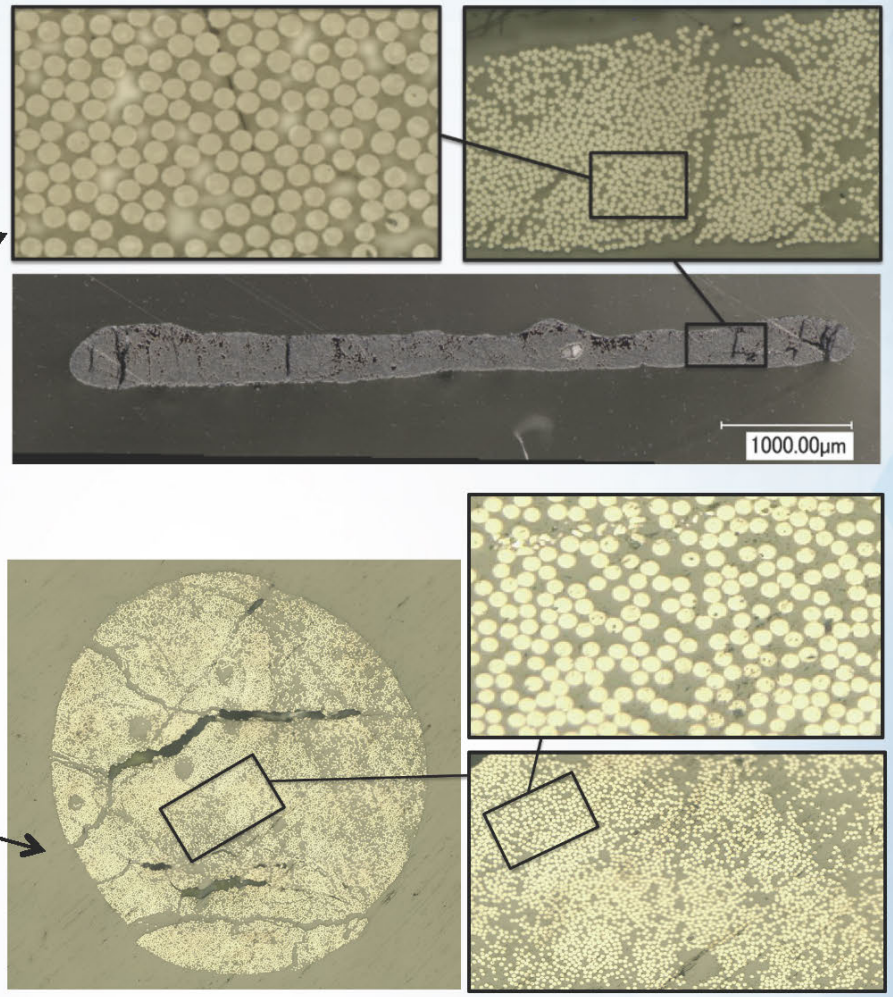
UTK : Lab Scale Flexible Automated Infused Tow and Pre-Preg Manufacturing

Manual Method



Automated Method

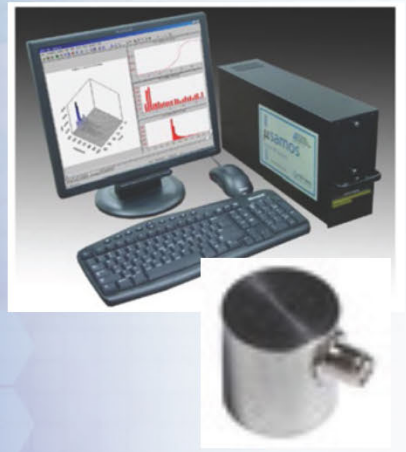
Example Microstructure from Automated Carbon Fiber Tow Manufacturing (UTK) VS Manual Tow Manufacturing Approach (CFTF)

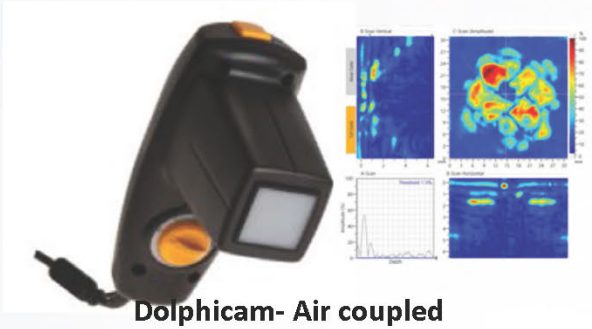


Mobile NDE Lab Technologies

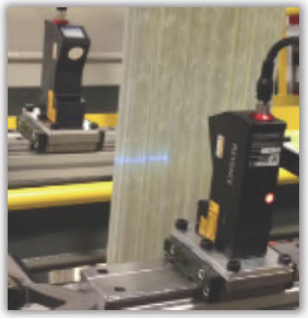
Flaw detection in composites

Mistras Acoustic Emission System 01/2017





Dolphicam- Air coupled active in-line ultrasonic NDE 09/2016

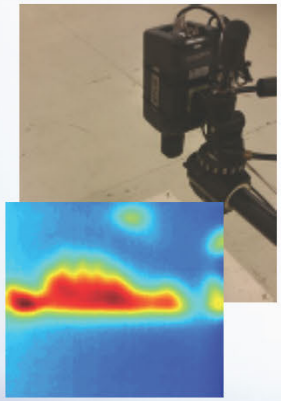


Keyence Laser Profilometer 08/2015

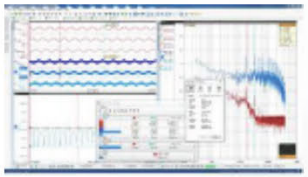
Keyence Laser-Displacement Sensors 08/2015

Cure Monitoring for Composites

Olympus EPOCH 650 Portable Ultrasonic NDE Systems 01/2017



FLIR High Resolution IR Camera 03/2016



HBM 100 Ms/Sec High Speed Data Acq. System 04/2016

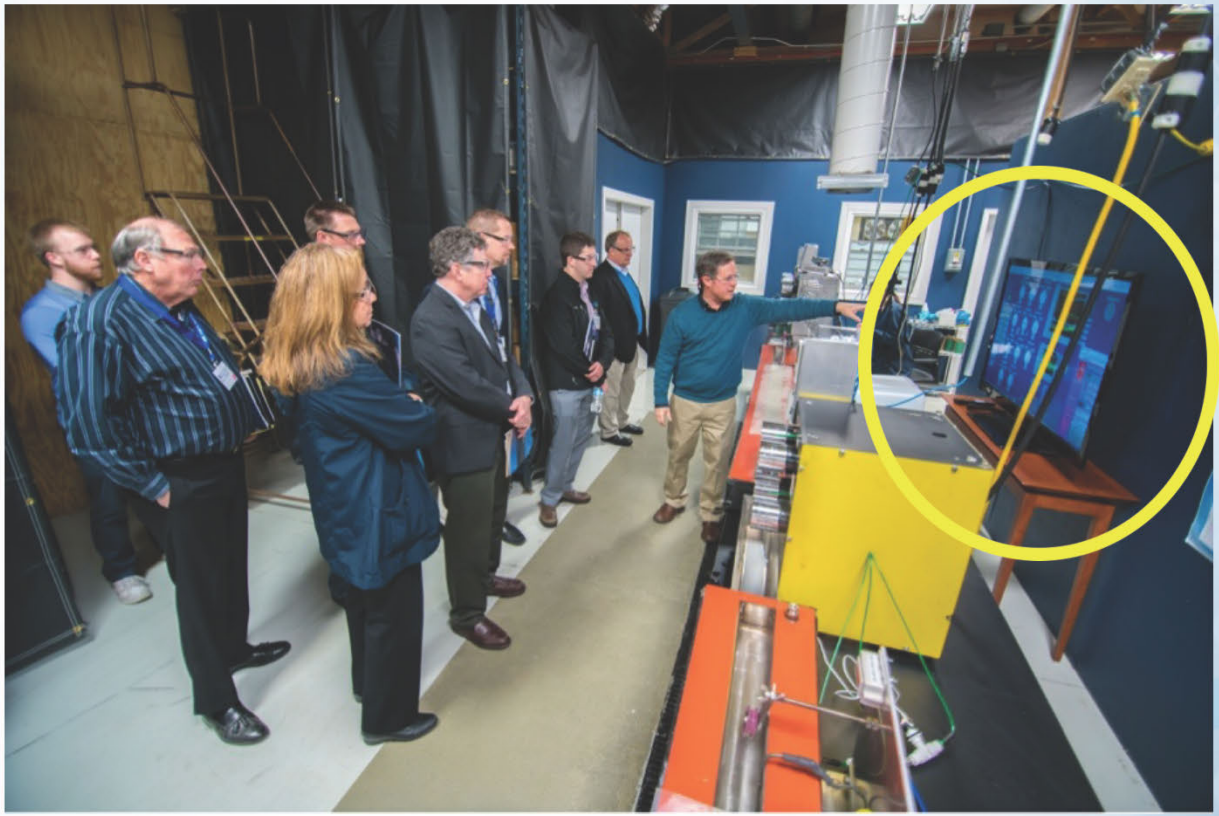
National Instruments PXI 16 bit, 4 MHz signal driver 12/2016

UKY CAER solution spinning line for multifilament continuous tow

University of Kentucky

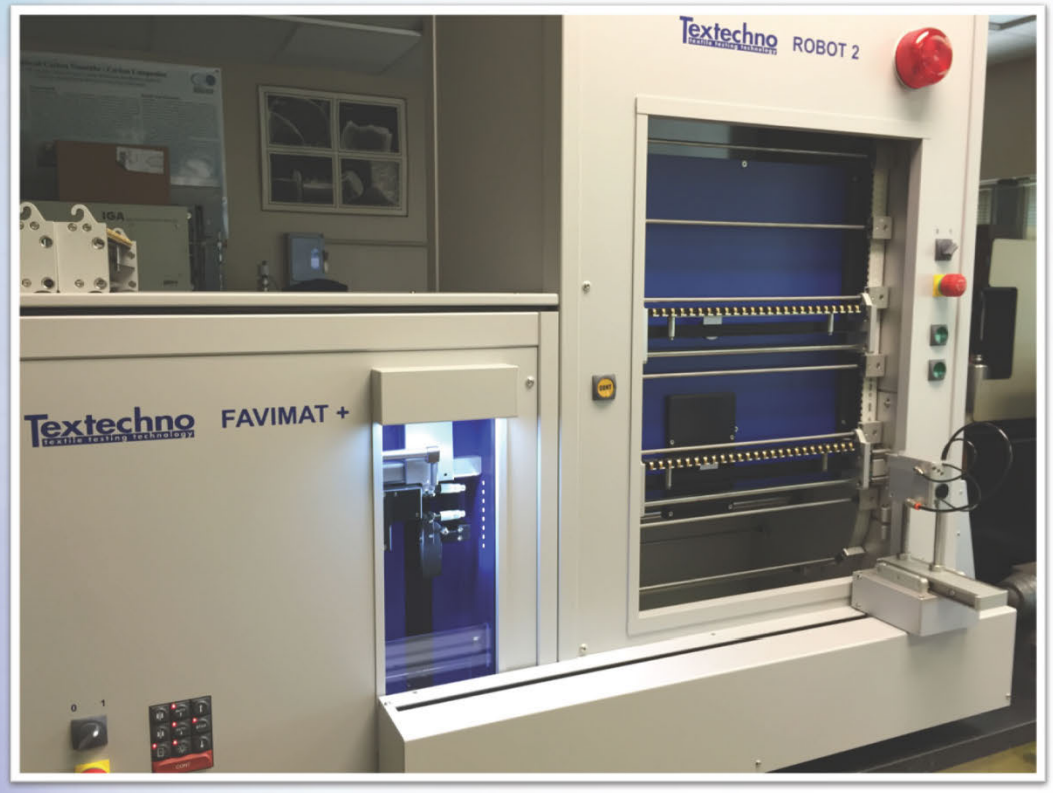
Heads UP, Real-Time Spinning Data Acquisition and Logging

- Polymer dope
  - Flow rate
  - Amount remaining
  - Temperature
- Filtration pressure drop
  - Temperature
- Spinneret pressure drop
  - Temperature
- Tow tension down the line
- Godet drive linear speeds
  - Tow draw ratios



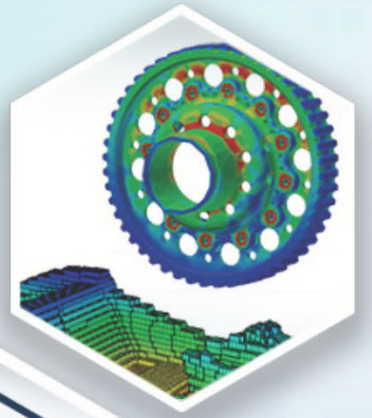
University of Kentucky

Robotic Single Filament Tensile Testing and Linear Density



- FAVIMAT +
- Vastly increases single filament testing efficiency
  - 100s of filaments per sample

University of Kentucky



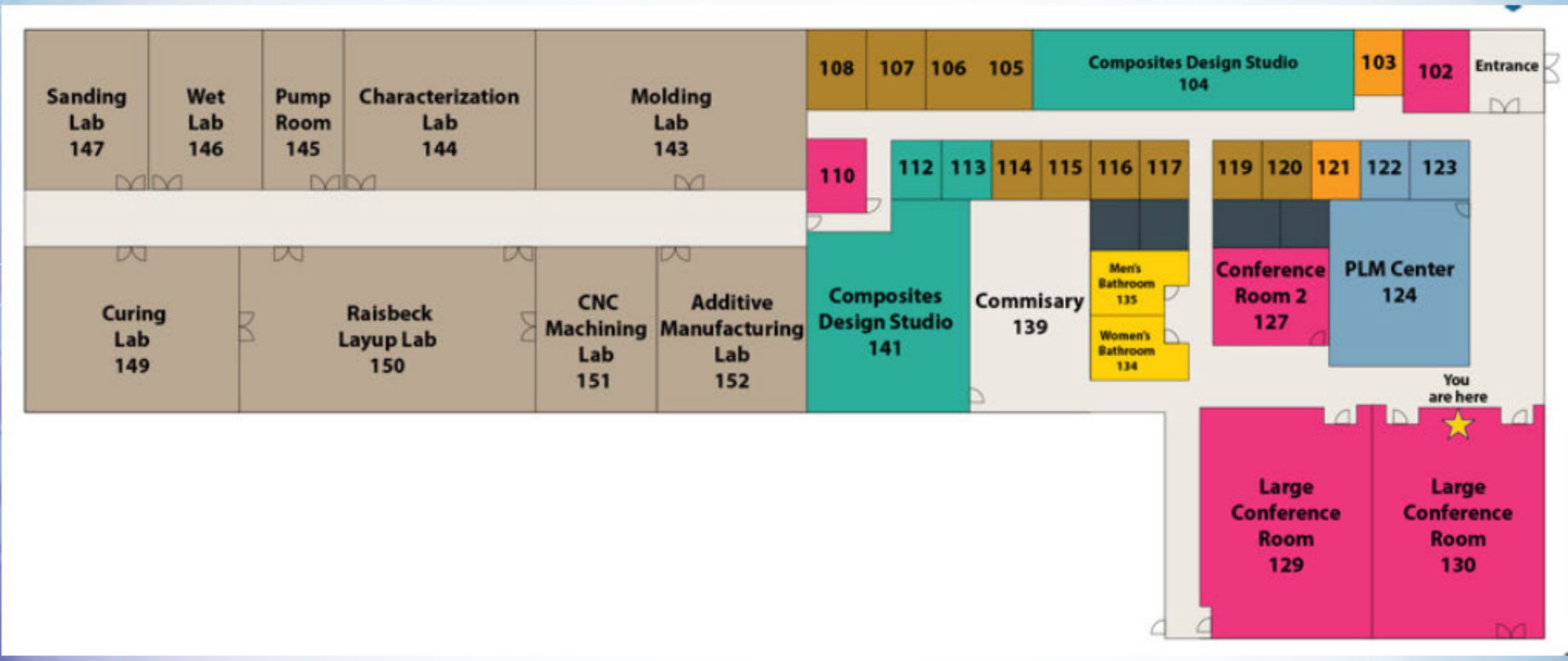
THE COMPOSITES iacmi INSTITUTE

Design Modeling and Simulation

PURDUE UNIVERSITY

Indiana Manufacturing Institute

IMI Labs, Offices, and Conference Rooms



Simulation Software

Integration of many major commercial simulation tools

esi get it right®

PAM-FORM
PAM-RTM
PAM-DISTORT
PAM-CRASH

DASSAULT SYSTEMES

CATIA
SIMULIA
BIOVIA
ENOVIA
DELMIA

Altair

HYPERWORKS
MDS

AnalySwift

SwiftComp
VABS

DASSAULT SYSTEMES | The 3DEXPERIENCE Company

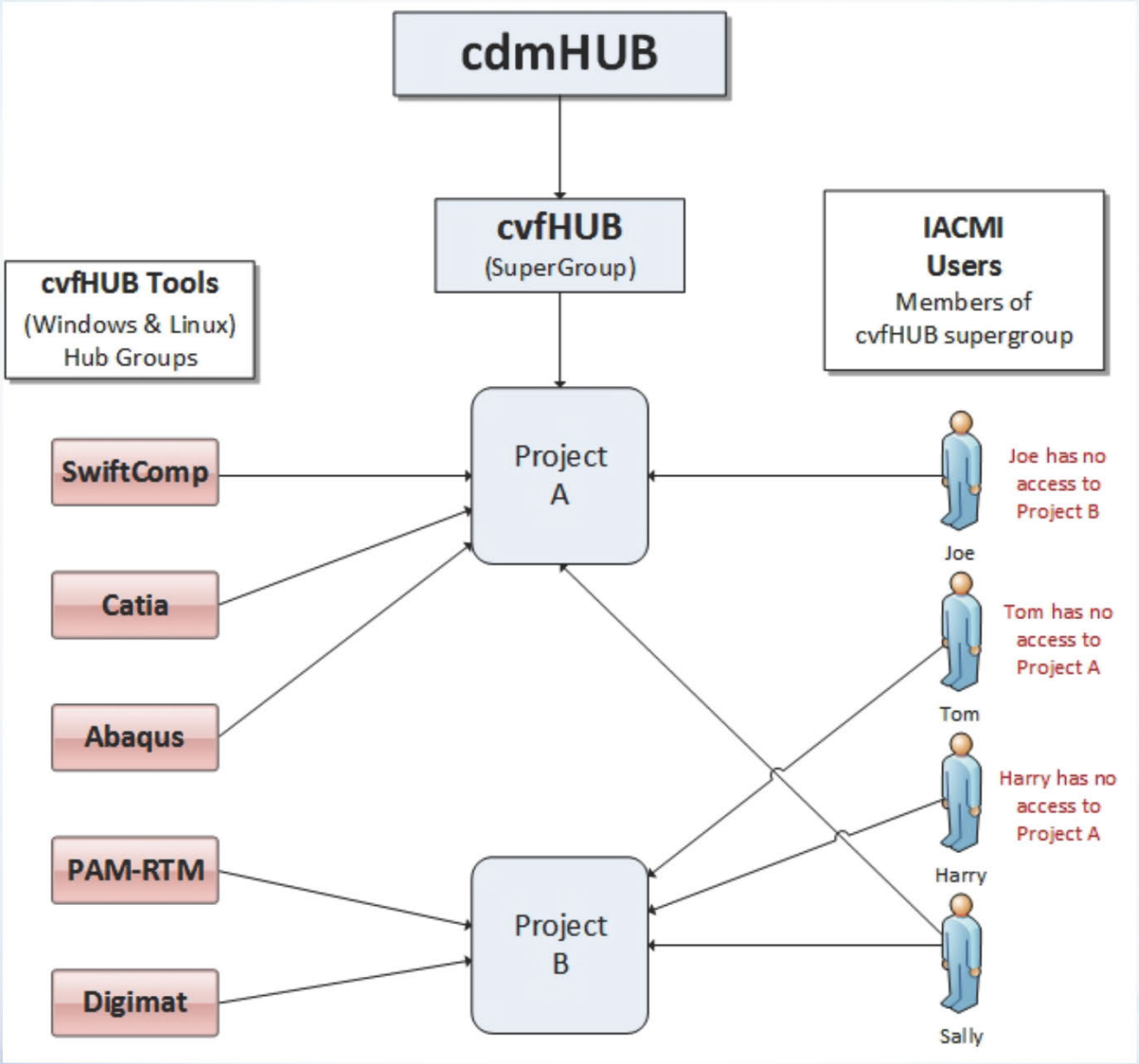
digimat

CONVERGENT MANUFACTURING TECHNOLOGIES

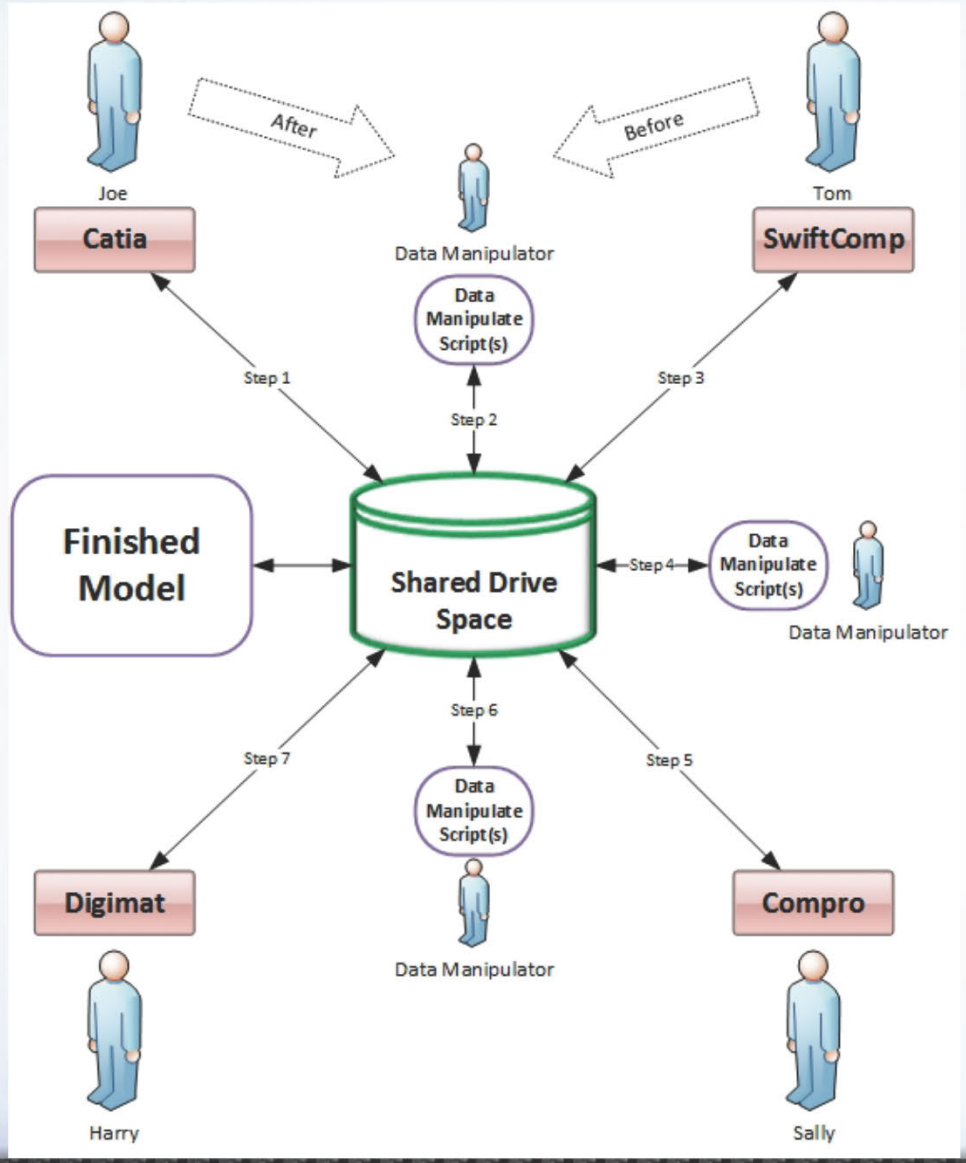
COMPRO
RAVEN

Moldex3D
MOLDING INNOVATION

Project team member access on cvfHUB

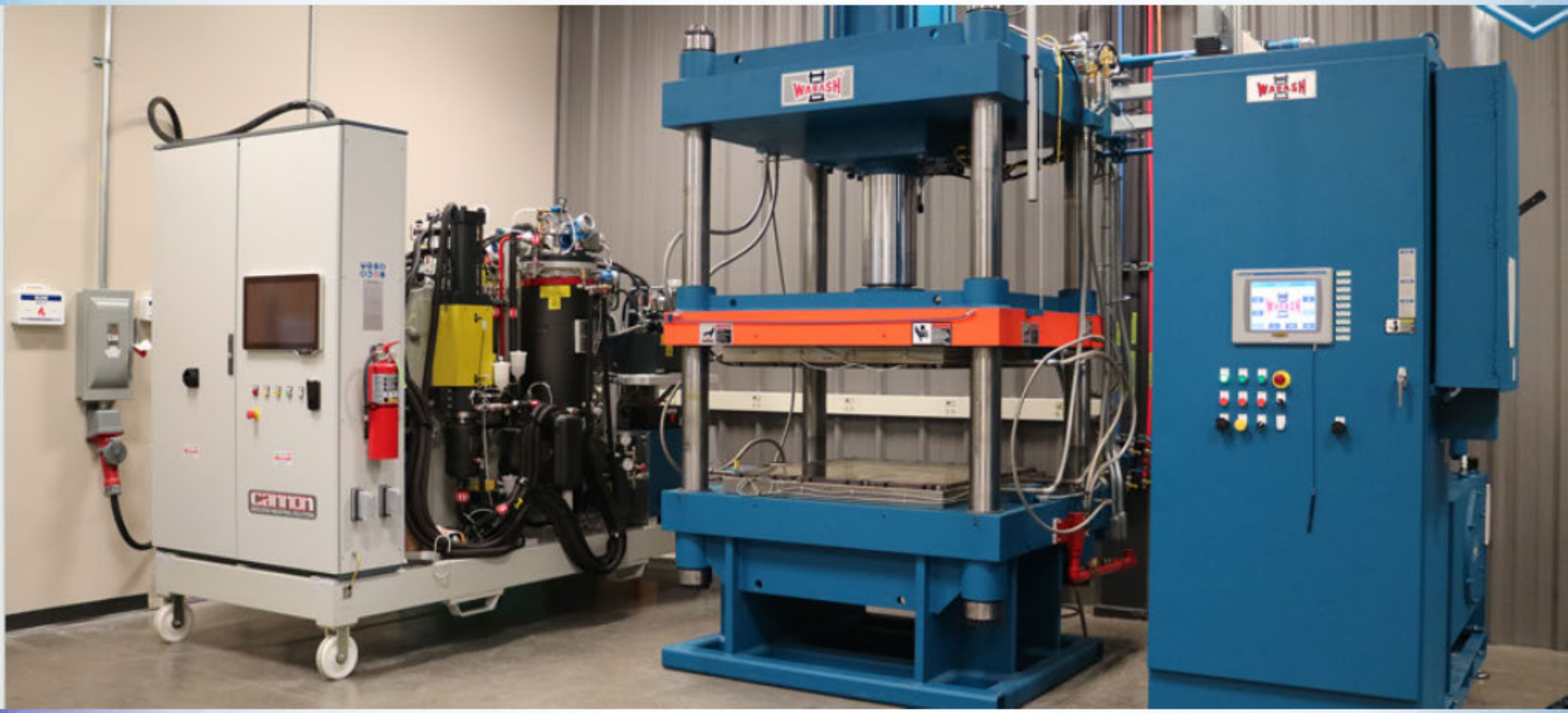


Project collaboration on cvfHUB

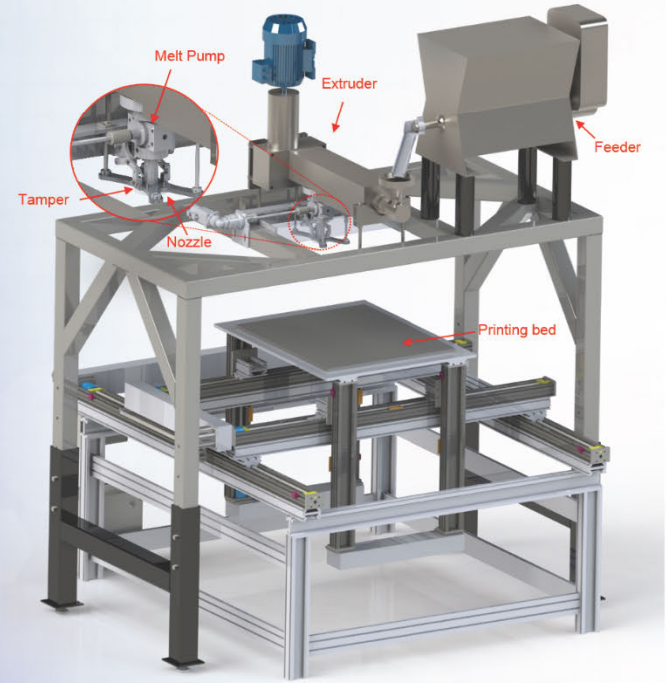


Validation Labs

Compression Molding and HPRTM



Additive Manufacturing



Composites Molding Tools Printed

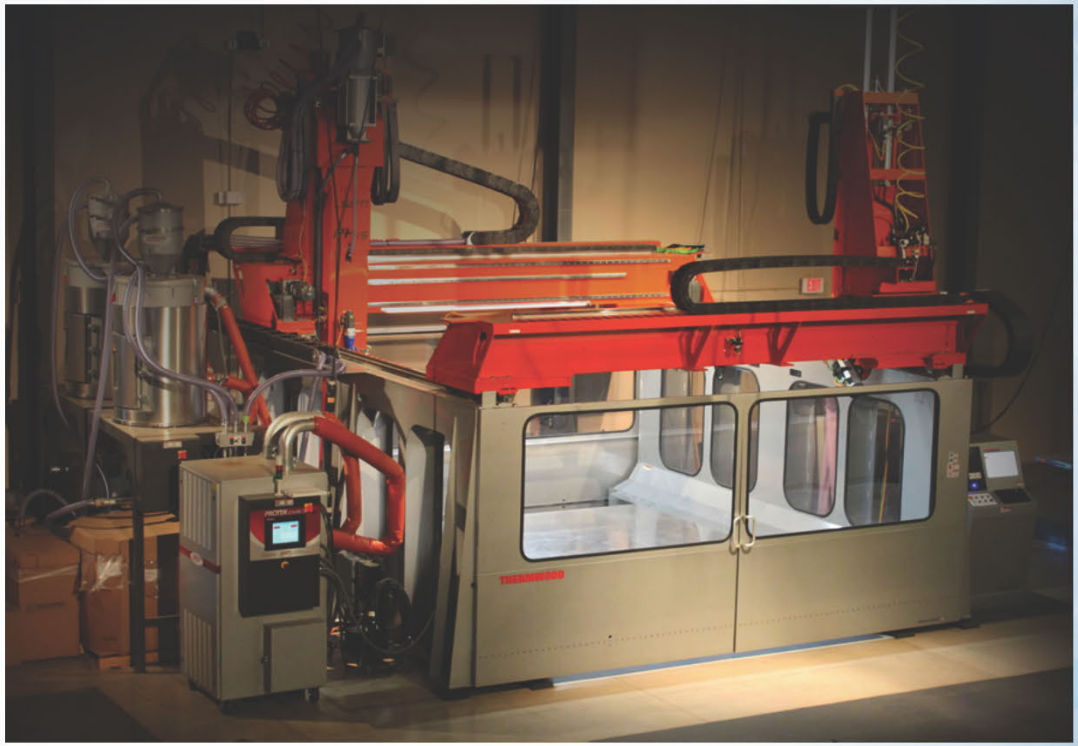
50% Carbon Fiber/PPS

Thermoforming Tool

Compression Molding Pin Bracket Tool

LSAM Access

- Large Scale Additive Manufacturing (LSAM) machine
- Combines polymer FDM with machining in same cell
- 10 ft x 10 ft working envelope
- Purdue can create print program and Thermwood will print at their facility in Dale, IN as contributed cost share



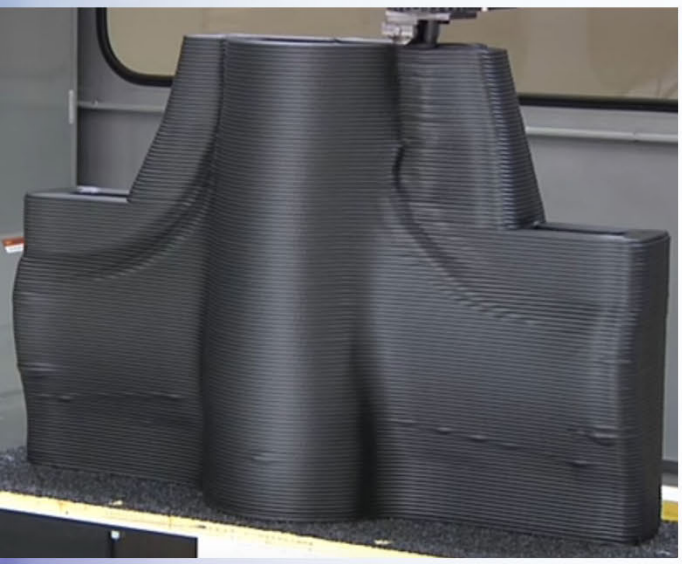
LSAM
Large Scale Additive Manufacturing

THERMWOOD

PURDUE UNIVERSITY

Example Application

Print

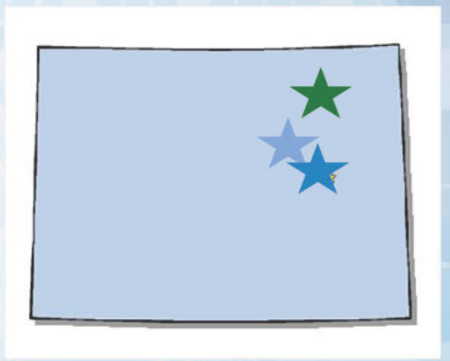


Machine

Finish

LSAM
Large Scale Additive Manufacturing

THERMWOOD



THE COMPOSITES iacmi INSTITUTE

Wind Turbines

MINES

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Colorado State University

IACMI Wind TA Composites Manufacturing and Education Technology (CoMET) Facility

- Manufacturing space focused on composite manufacturing innovation
- 55’ x 200’ – 10,000 sq. ft.
- Adjacent to blade test facility
- Full-scale blade component manufacturing

Infrastructure upgrades

Fabric rack and cutting tables

Electrical – 208V, 240V, 480V

Dual Crane System

- Two crane system permits handling of long parts like blades and tools
- 2 x 10 ton capacity
- Rails run length of facility

MVP Automated Dispensing Machine

- MVP automated mixing and dispensing machine
- Designed for use with polyesters, vinyl esters and ELIUM® thermoplastic

Graco Automated Dispensing Machine

- Graco automated mixing and dispensing machine
- Designed for use with epoxy infusion systems

Large Capacity Vacuum Pump

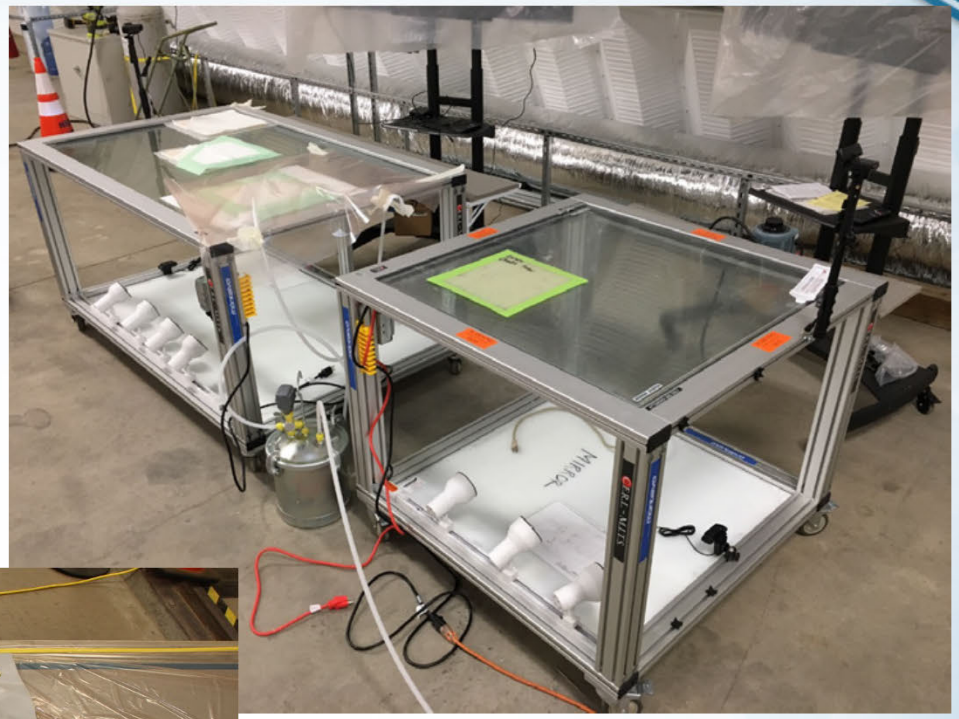
- Multiple station valves enable up to eight individual vacuum sources for larger infusions

Pump Courtesy DowAksa

Glass molding tables

- Glass tables enable two side observation of infusion flow
- Smaller of the two tables is heated to study effects of temperature

Heater blankets with 77C capability



Wind Blade Tooling

48.7m blade tip mold
Courtesy GE

48.7m shear web mold
Courtesy GE

Wind Blade Tooling

9m BSDS blade components
Courtesy TPI Composites

Portion of 45m spar cap infusion mold
Courtesy DowAksa

IACMI 9m Demonstration Blade

- Blade Dimensions:
  - Length: 8.325 m [27’-3.75”]
  - Root Diameter: 0.535 m [21.05”]
  - Max Chord: 0.789 m [31.06”]
  - Root Laminate Thickness: 32.25 mm [1.27”]
- Blade Weight and Center of Gravity
  - Weight: 116.82 kg [257 lbs]
  - Spanwise CG 2.197 m [7’-2.5”]

THE COMPOSITES iacmi INSTITUTE

Compressed Gas Storage

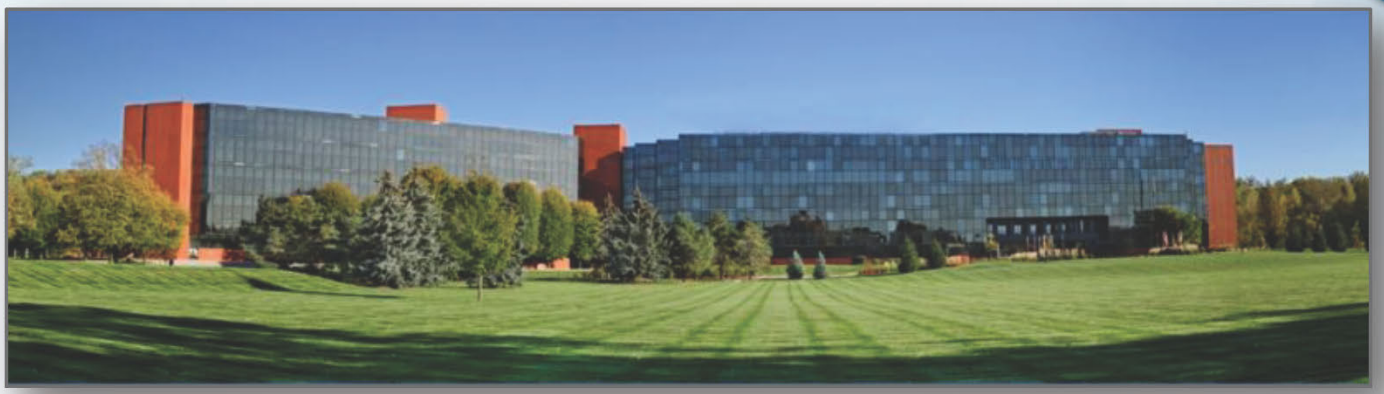
UDRI UNIVERSITY of DAYTON RESEARCH INSTITUTE

Composites Manufacturing at UDRI

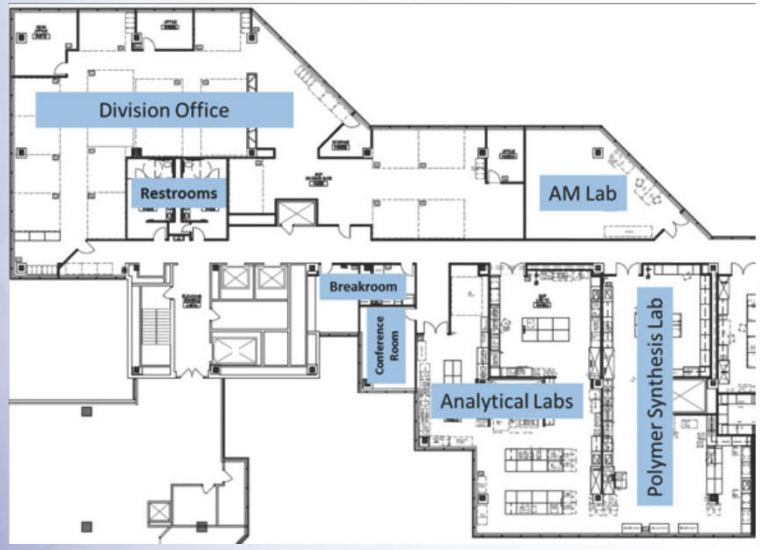
- 12” PREPREGGER
- 3 AUTOCLAVES
- 7 HYDRAULIC PRESSES
- RTM
- VARTM
- FILAMENT WINDING
- PULTRUSION
- INJECTION MOLDING
- 60” TACKIFIER
- 3D PRINTERS
- HAND LAY-UP
- RESIN FILM INFUSION
- LARGE OVENS

UDRI Facility

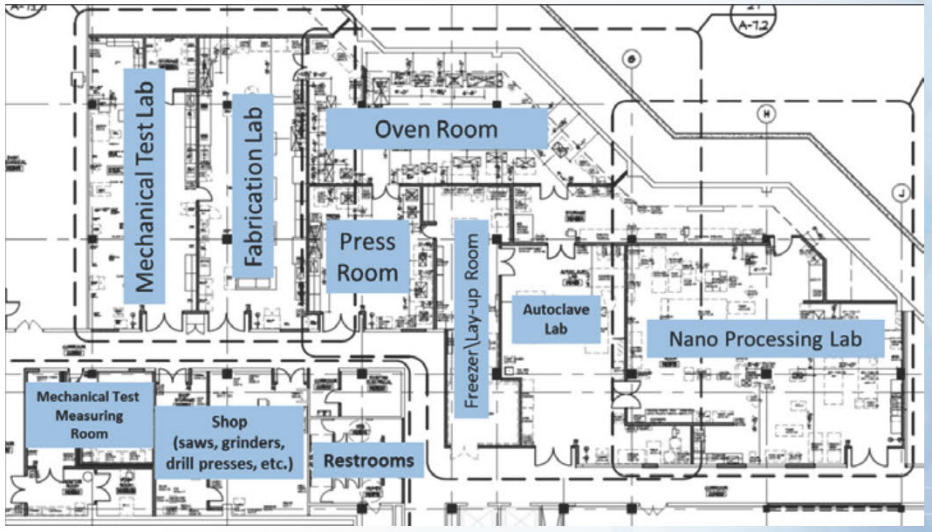
UDRI
UNIVERSITY of DAYTON RESEARCH INSTITUTE



MCP 4th Floor Labs and Office ~13,000 square feet



MCP Basement Labs ~13,000 square feet



UDRI Facility

Analytical Lab

Environmental Conditioning Lab

UDRI Facility

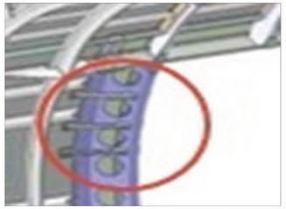
Film Line

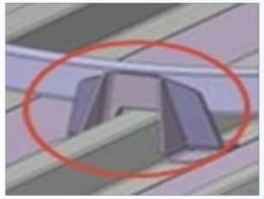
Hot Press Lab

Net shape preforming

Complex shaped CFRP parts:

- load detour
- load introduction
- stiffening function



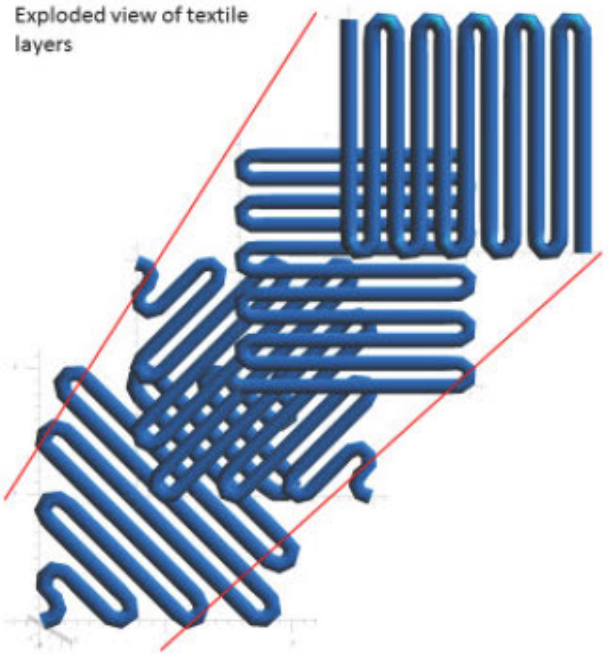


Potential applications:

- Cleats, clips, brackets
- Window frames
- Frame elements

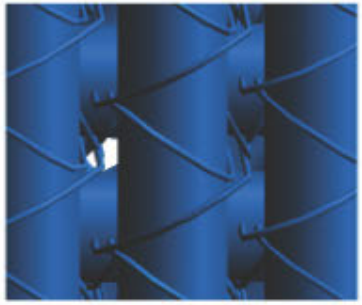
Net Shape Preforming

Simulation and fabrication of quasi-isotropic preform

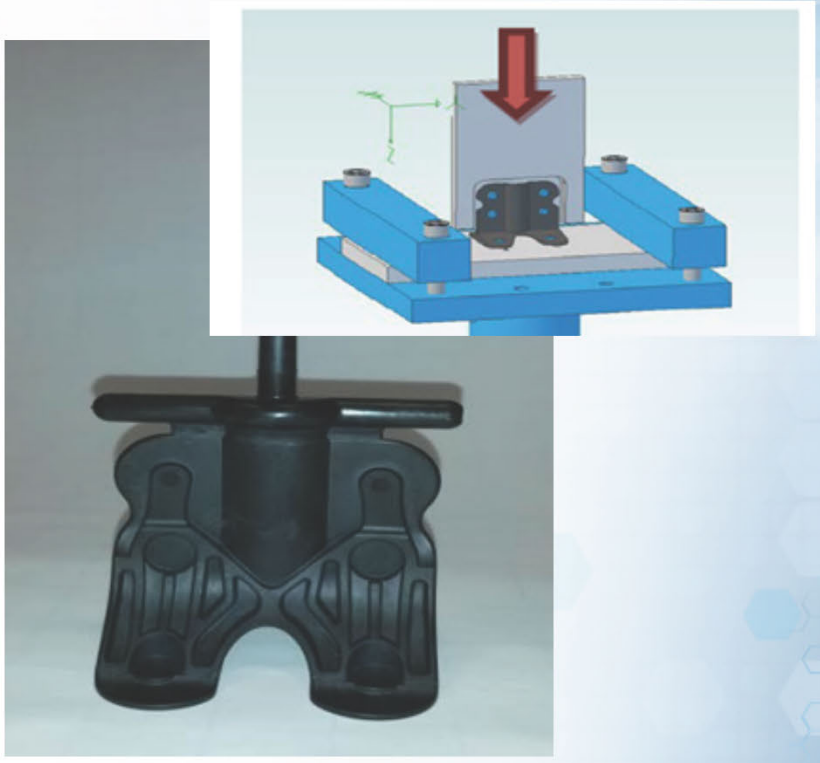


Back Side – Quasi-Isotropic Laystitch preform.
Differential amount of stitching is an artifact of the number of layers printed to show the quasi-isotropic nature of the preform.

Front Side – Quasi- Isotropic Laystitch preform (0, +/- 45, 90 Degree Layers all visible).



UDRI Facility – Injection Over Molding



High Temperature Tooling by Additive Manufacturing

- Collaborative effort with Cincinnati, Inc (1 hour from UDRI)
- Focus on single sided tooling capable of 350F and 100 psi cure (autoclave, Rapidclave, e.g.)
- Focus material is specially formulated carbon fiber filled polysulfone. Other materials, such as PPS and PEI have also been trialed.

THE COMPOSITES iacmi INSTITUTE

Vehicles

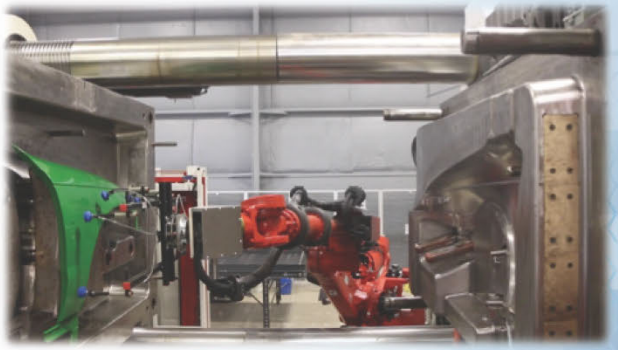
MICHIGAN STATE UNIVERSITY

Vehicles

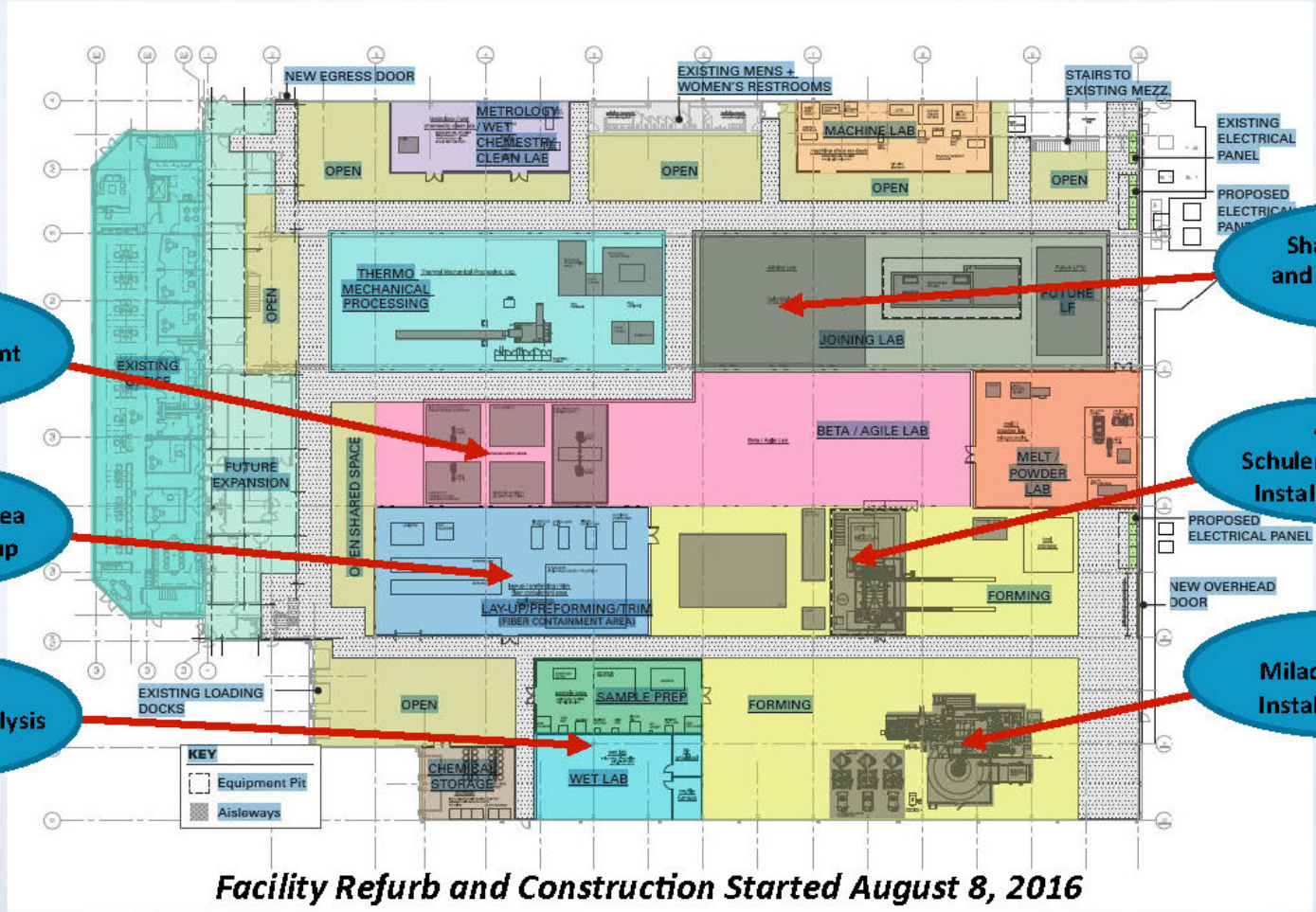
- Vehicles Technology Area includes two locations
- Michigan State University
  - East Lansing
  - Detroit (“Corktown”)

National Capabilities-Michigan
Vehicle Scale Up Facility in Corktown, Detroit

- Co-located with LIFT, 9300 m^2 total
- Capitalization underway >$15M
- Construction complete
- Equipment coming online



IACMI/LIFT VTA-SUF Facility Layout



Shared Joining and Pretreatment Area

Shared Joining and Pretreatment Area

Carbon Fiber Containment Area Pre-Preg, Lay-up Etc.

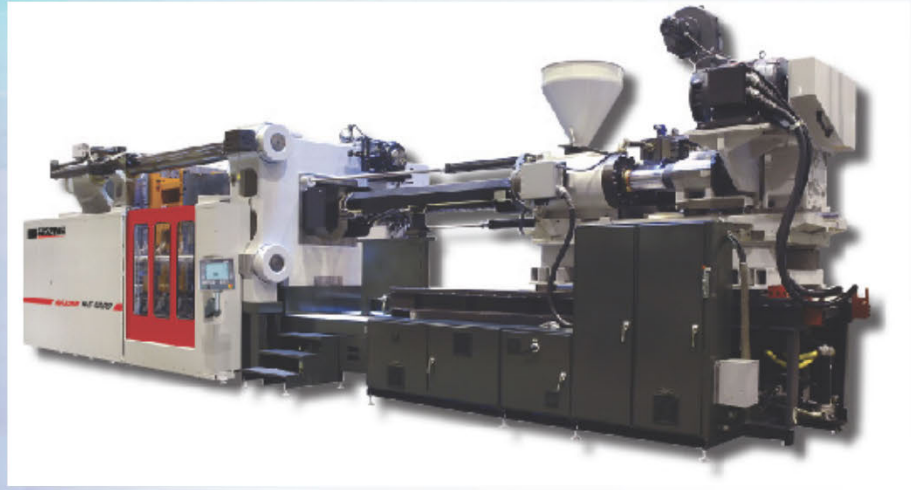
4000 T Schuler Comp. Press Installed 2Q 2017

Sample Prep Wet Lab and Analysis Area

3000 T Milacron Inj Press Installed 4Q 2016

Facility Refurb and Construction Started August 8, 2016

Injection molding press

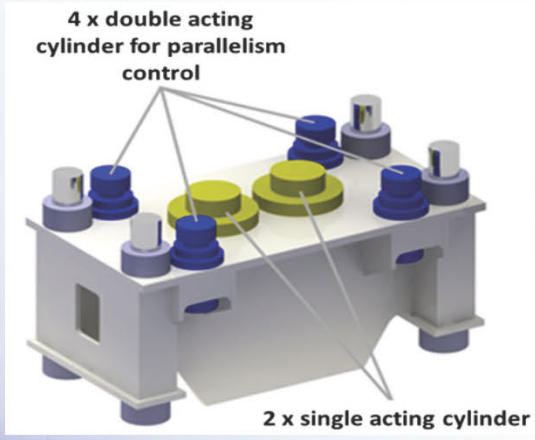


MILACRON®

- Built by Milacron
- Specifications
  - 29,500kN (3,315T)
  - Platen: 3m x 2.5m (~10ft x 8ft)
  - 413 oz. max shot size (multiple screw sizes)
- Operational since February 2017

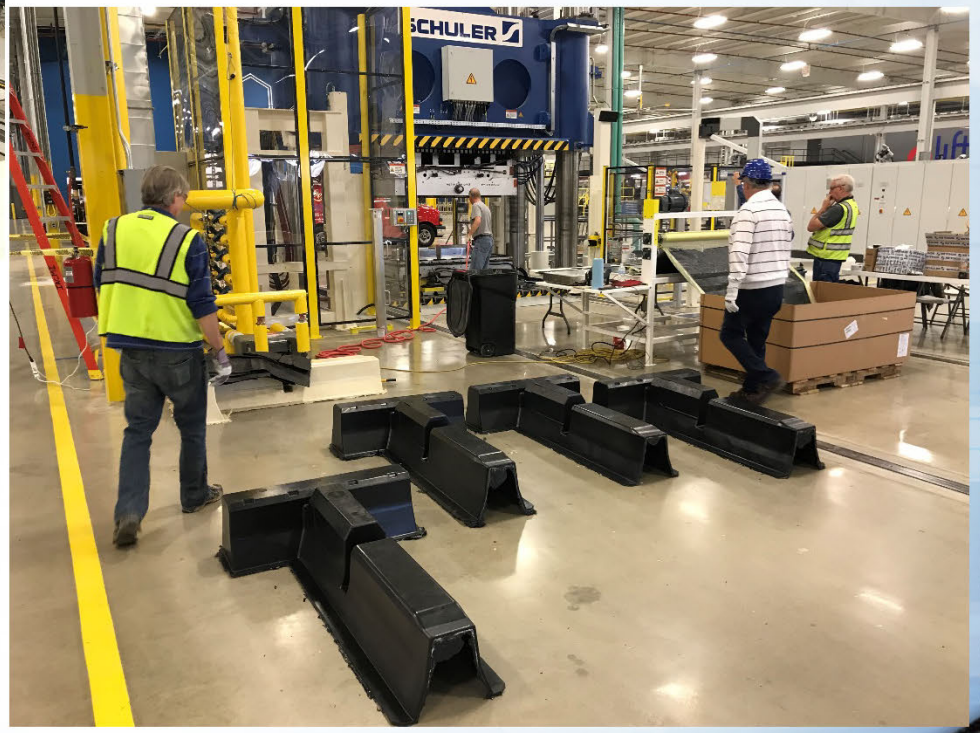
Compression press

- Manufactured by Schuler
- Short-stroke design
- Multi-process capable
  - “Closed mold” infusion
  - Compression molding
  - Thermoplastic forming, etc.
- Specifications
  - 36,000kN (4,000T)
  - Platen: 3.6m x 2.4m (~12ft x 8ft)
- Operational since October 2017



SCHULER
FORMING THE FUTURE

Compression press



Laboratories

- Analytical-wet lab & sample prep (340 m^2)
  - Material preparation (e.g., mixing)
  - Materials Characterization
    - FTIR, DSC/DMA, Microscopy, etc
  - Trimming, cutting, grinding, etc.

- Controlled process lab (450 m^2)
  - Temperature & humidity controlled
  - Negative pressure & filtered return (carbon containment)
  - Space for pre-preg & tape lay-up lines

12” prepreg line

LITZLER
DRIVEN BY RIGHT

Resin mixing unit for HPRTM and wet pressing

- Ordered from Hennecke
- Capable of processing epoxies and polyurethane systems
- High pressure (120 bar) capability
- Arrives late January
- In operation March 2018

Hennecke
Polyurethane Technology

Consigned Equipment

plasmatreat
solutions on top

Plasma cleaning & coating
(2 systems via LIFT)

ROCTOOL
MOLDING MATTERS.

Systems for rapid (induction) heat-cool for injection & compression molding

Tools currently available for project use

Saturn Fender

Tonneau cover (inner & outer)
Ford Sport Trac

Chevy Volt Battery Box

Technology Partner Facilities

Composite Prototyping Center

Composite Recycling Technology Center

Composite Prototyping Center

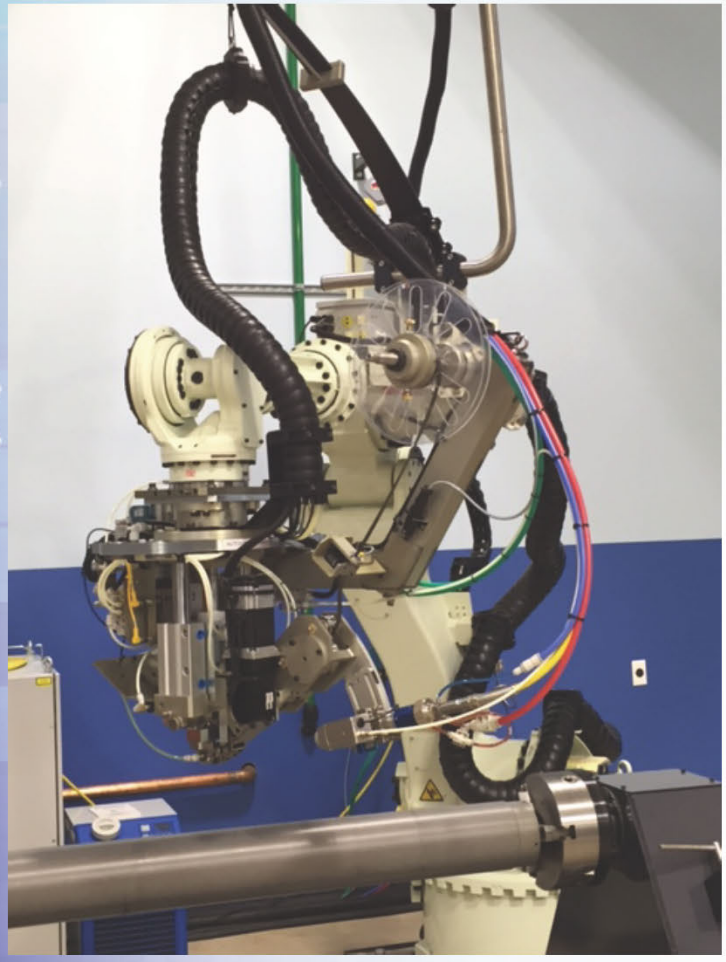
- Composite Prototyping Center
- Plainfield, NY (Long Island)

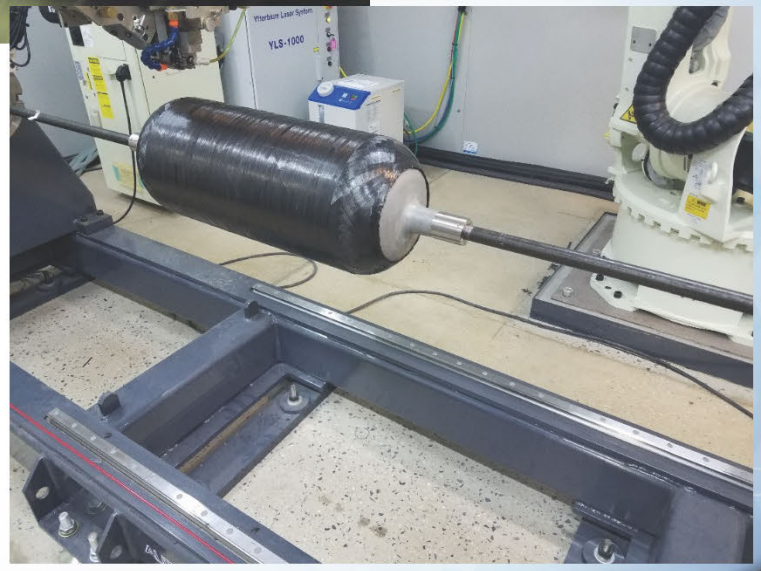
CPC Manufacturing Floor

CPC supports the following processes & functions:

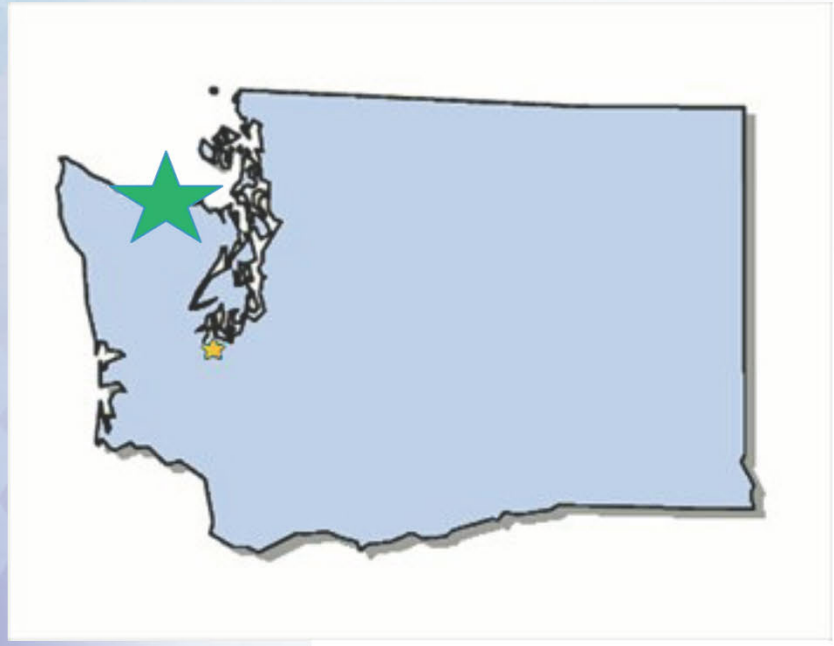
Automated Fiber Placement	RTM / VaRTM	5 Axis CNC Routing Cell
Autoclaves , Ovens	Compression Molding, Heated Press	Hand Lay-Up with Laser projection assisted templates and kitting capabilities
Clean Room (Class 100,000)	Single Ply Cutting System with nesting s/w	Test and inspection – NDT and CMM tools and instruments
3D Printer	Walk-in Freezer	

Laser Consolidation Fiber Placement





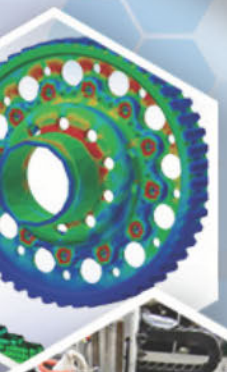
Composites Recycling Technology Center



CRTC
COMPOSITE RECYCLING TECHNOLOGY CENTER

PENINSULA COLLEGE

- CRTC, located in Port Angeles, Washington
- Objective to recycle scrap prepreg into useful parts
- Initial operations commenced



Questions?

Dale Brosius

Chief Commercialization Officer

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