Modeling and Simulation Technology Area

R. Byron Pipes
Director, Modeling & Simulation
Technology Area
IACMI

Design, Modeling and Simulation Technology Area
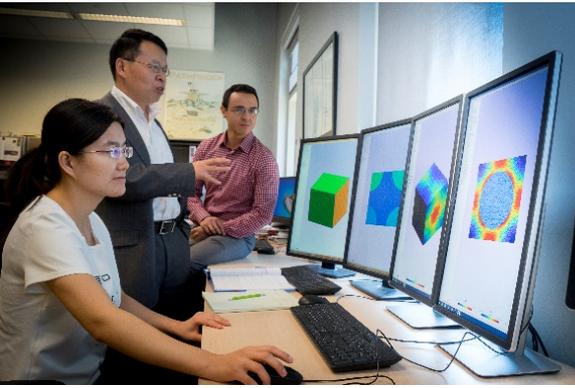
R. Byron Pipes

Director

January 14, 2016

Institute for ADVANCED
**Composites Manufacturing**
INNOVATION

Outline

- The Vision
- The Organization
- The Simulation Tools
- The Indiana Manufacturing Institute
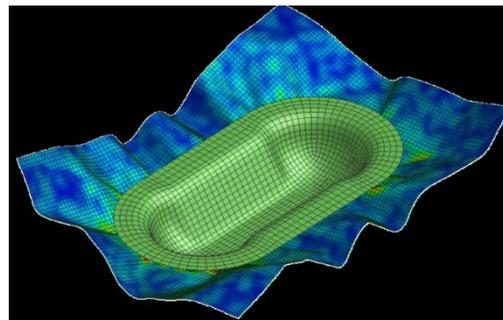- The Validation Facilities
- The Timeline

Why Simulation?

Virtual Twins of composites manufacturing processes allow for rapid optimization

- Prepreg stamping
- Injection over-molding
- High pressure resin transfer molding
- Additive 3D printing

Additive Manufacturing

HPRTM
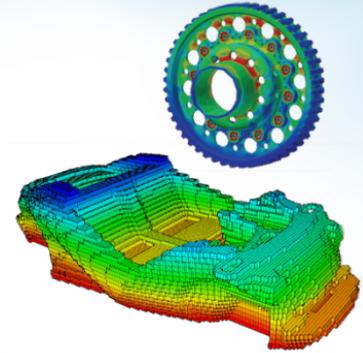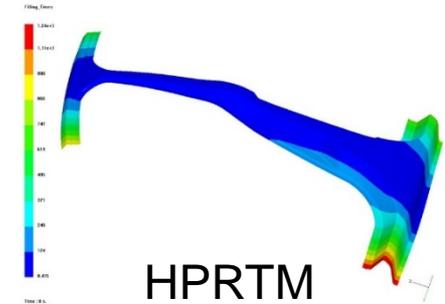
Prepreg Molding
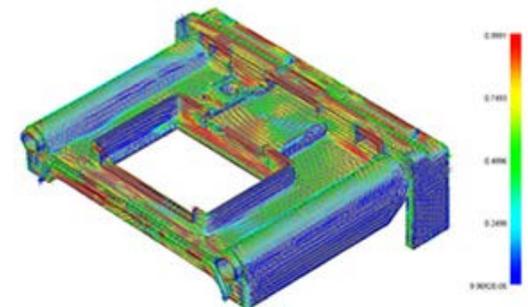
Injection Over-Molding

What More Can Simulation Do?

- Predict material architecture from process conditions

Molding Flows

Fiber Orientation State

$$a_{ij} = \begin{bmatrix} 0.17 & 0.09 & 0 \\ 0.09 & 0.45 & -0.01 \\ 0 & -0.01 & 0.38 \end{bmatrix}$$
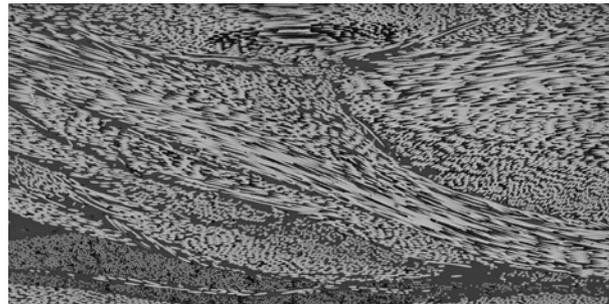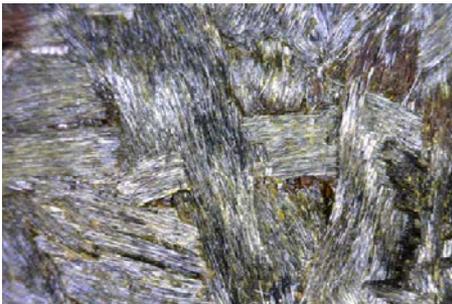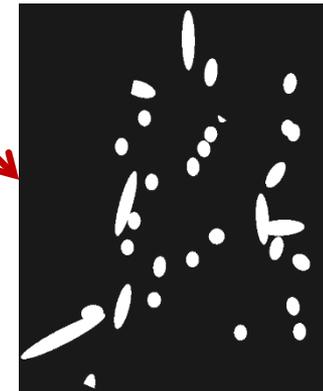
Simulation Can Predict Performance from Manufactured Architecture

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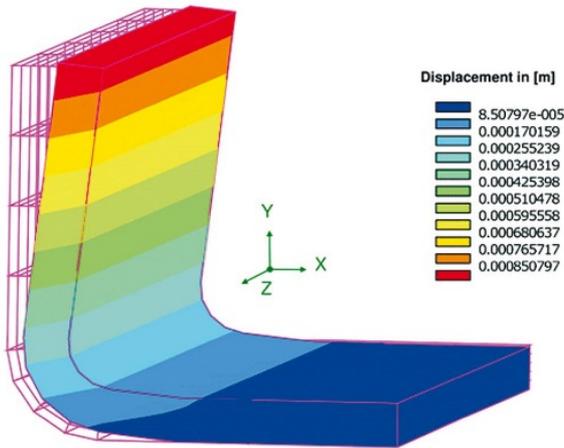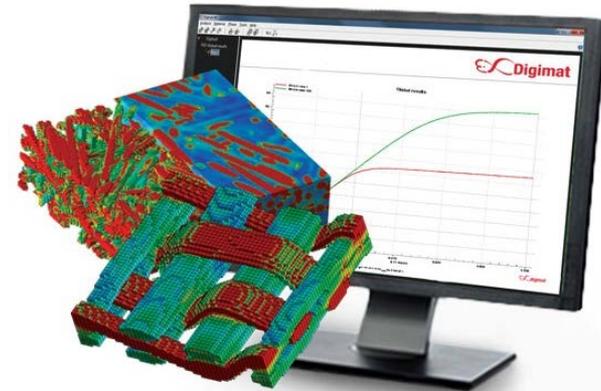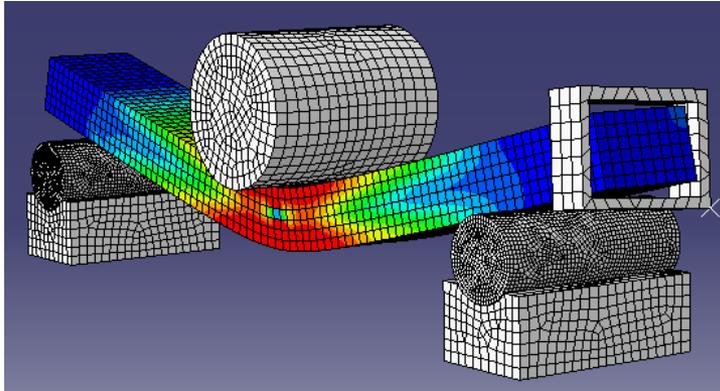
Leverage Computing Power to Enhance Confidence

- Create Composites Virtual Factory HUB (cvfHUB)

- Develop platform for hosting and integration of commercial software tools for composites

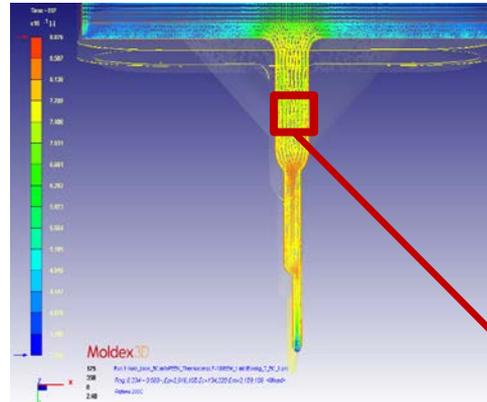- Provide end-to-end simulation for composites

- Correlate at multiple scales prediction and reality

- Make tools and knowledge available to entire value chain to enhance confidence and reduce cost

COMPOSITES DESIGN & MANUFACTURING HUB
- Tool training
- Tool evaluator (TML)
- New tool development

COMPOSITES VIRTUAL FACTORY HUB
- Commercial tools
- Browser-based Platform
- Secure Environment

- Vehicle teams
- Wind teams
- CGS teams
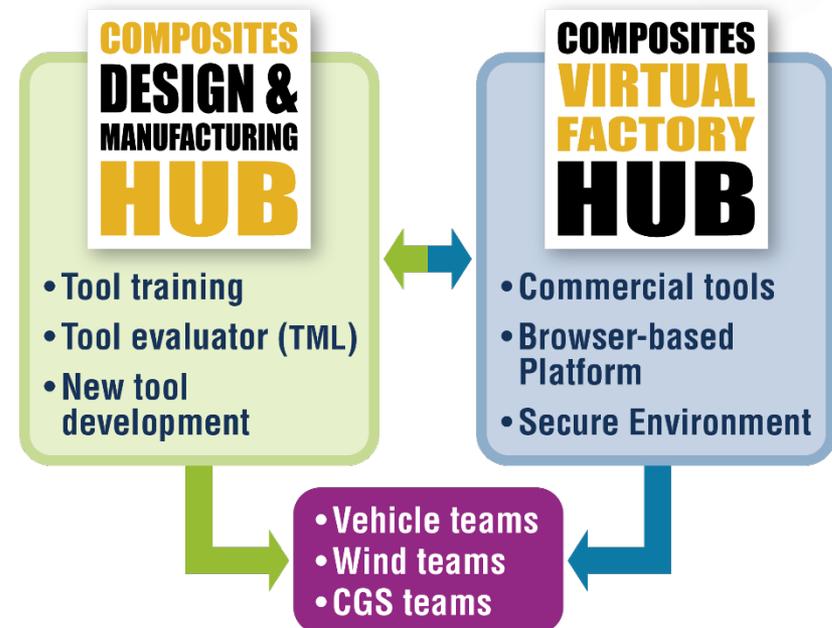
Vision: To Leverage Computing Power to Enhance Confidence

- The Design, Modeling and Simulation TA will host simulation tools and tool experts.

- By 2020, the Composites Virtual Factory HUB (cvfHUB) will become **THE** source where the composites industry looks for help with product and process design, modeling and simulation.

- The cvfHUB will have access to all the major composite tools, integrated and validated, and its personnel will possess the needed knowledge to provide simulation, consulting and training.

- The Design, Modeling and Simulation TA will build confidence in composites manufacturing simulation by validation. The validation capabilities will serve the following primary functions:

  - Measurement of input data requirements for simulation tools

  - Validation of simulation tool predictions with lab scale experiments

  - Prototyping of manufacturing processes and composite products at the laboratory scale
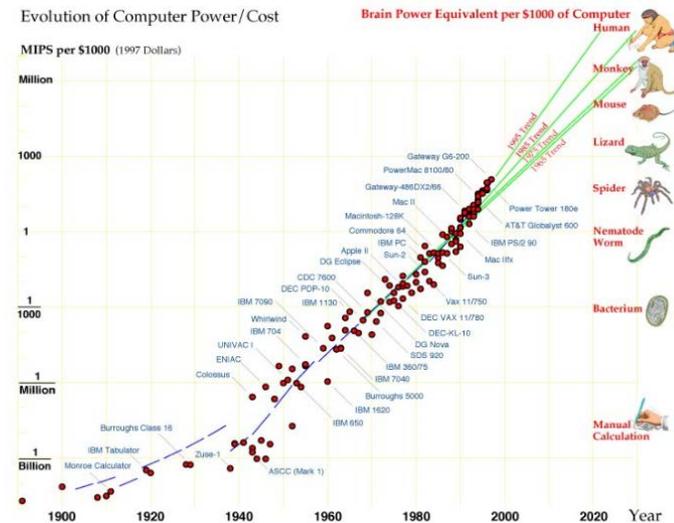
Organization of the DMS TA

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Director, DMS TA
Director, cdmHUB

Ron Steuterman
Managing Director

Christine Cowden
Operations Assistant

Graduate Students
Bastian Brenken
Justin D. Miller (co- with Yu)
Nicholas DeNardo
To Be Named (co- with Yu)

Johnathan Goodsell
Director,
Validation Lab
Assistant Director,
cdmHUB
Associate Director,
cvfHUB

Faculty Collaborators

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Information Technology

Ronald Sterkenburg
Professor, Purdue
Aviation Technology

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Associate Director,
cdmHUB

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MD & UQ
Professor, Purdue
Materials Engineering

Michael Bogdanor
Senior Software
Application Engineer

Nathan Sharp
Validation
Engineer

Graduate Students
Garam Kim
Tyler Futch

Ben Haley
Software
Engineer
(0.50 FTE)

Graduate Students
Saaketh Desai
Tongtong Shen

Open

Open
Validation Engineer

Open

Tian Tang
Software
Engineer

Add'l Faculty Collaborators
To Be Determined; possibly
Mechanical & Chemical
Engineering

Open
Lab Technician

Graduate Students
Bo Peng
Yufei Long
Justin D. Miller (co- with Pipes)
To Be Named (co- with Pipes)

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Simulation Software

Integration of many major commercial simulation tools

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

CATIA
ABAQUS
ACCELRYS
ENOVIA
DELMIA

HYPERWORKS
MDS

SwiftComp
VABS

MF, FE, MX, CAE, MAP, HC, RP, VA

eDesign
Professional
Advanced

COMPRO
RAVEN

Example: Prepreg Laminate Molding
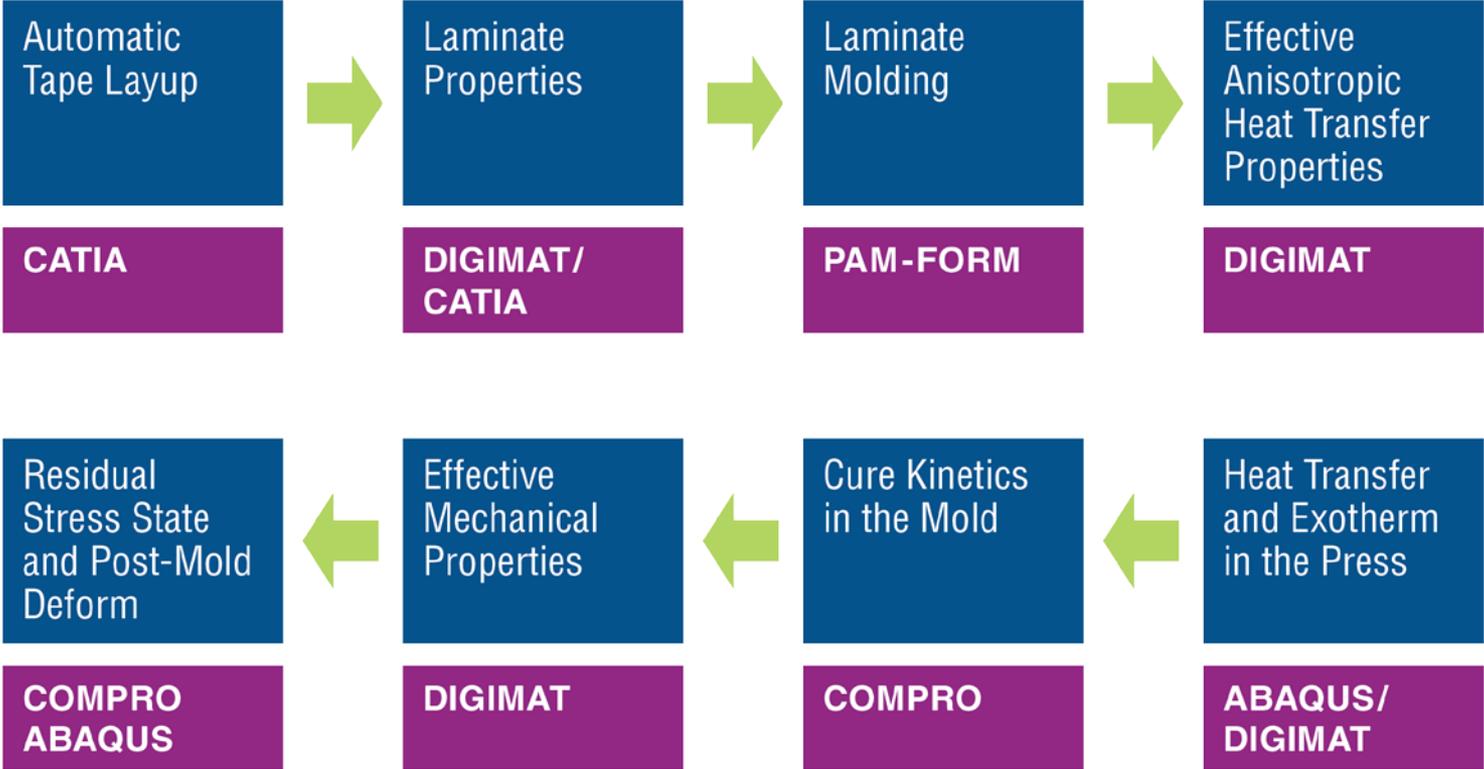
Automatic Tape Layup	→	Laminate Properties	→	Laminate Molding	→	Effective Anisotropic Heat Transfer Properties
CATIA		**DIGIMAT/ CATIA**		**PAM-FORM**		**DIGIMAT**

Residual Stress State and Post-Mold Deform	←	Effective Mechanical Properties	←	Cure Kinetics in the Mold	←	Heat Transfer and Exotherm in the Press
COMPRO ABAQUS		**DIGIMAT**		**COMPRO**		**ABAQUS/ DIGIMAT**

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Automatic Tape Layup

- **Function:** Geometric control of tape lay stacking sequence, thickness position and fiber orientation

- **Software Code:** CATIA (Dassault Systemes)

Laminate Properties

- Function: Prediction of laminate forming properties

- Computer Code: Digimat/MSC and/or SwiftComp

- Micromechanical analyses to predict input properties for forming analysis

- Micromechanical analysis to predict final properties of the formed prepreg tape laminate

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Laminate Molding

- **Function:** Prediction of the forming behavior of the prepreg laminate

- **Software Code:** PAM-FORM (ESI)

- PAMFORM will predict the force necessary to fully form the prepreg laminate

- PAMFORM will predict the fiber orientation field within the formed geometry

- PAMFORM will predict the formation and location of wrinkles on the prepreg laminate after forming

Heat Transfer of Prepreg Laminates

- **Function:** Heat transfer for thermoset polymer prepreg laminates

- **Software Codes:** Digimat/MSC or SwiftComp and Abaqus (DS)

- Digimat or SwiftComp will predict the heat transfer properties of pregreg and laminate

- Abaqus will predict the temperature distribution with time for the molded laminate

Cure Kinetics in the Mold

- **Function:** Predict the state of cure of the thermoset polymer as a function of time

- **Software Code:** COMPRO (Convergent)

- COMPRO will predict the exotherm of the cure reaction

- COMPRO will predict the state of the cure of the thermoset polymer prepreg

- COMPRO will predict the cure and thermal shrinkage

Properties of the Cured Prepreg

- **Function:** Predict the physical properties and the formed prepreg

- **Software Codes:** Digimat-MF or SwiftComp and Abaqus

- Digimat will predict cure and thermal shrinkage

Residual Stress State and Post-Mold Deformation

- COMPRO and Abaqus will predict residual stresses and post mold deformations

Indiana Manufacturing Institute (IMI)

Indiana Manufacturing Institute
Located in Purdue Research Park
West Lafayette, IN
PURDUE UNIVERSITY

- Preparation Lab
- Equipment Room
- Compression/Injection Molding Labs
- 3, 4, Polymer Lab, 5, 6, Validation Lab, 7, 8
- 17 Research Team Member Offices, 14, Virtual Display Area
- 2 Composites Mfg and Validation Labs
- Autoclave/Oven Lab, Raisbeck Technology and Engineering Lab, 12 Additive Mfg Lab, 15 Lobby
- 9, 10, 11, 13, Digital Enterprise Lab
- CNC Machining Lab, Additive Machining Lab
- 16 Classroom/Meeting/Training Rooms
- 1 Indiana Manufacturing Institute
- Possible Molten Metals Research Space, Labs, and Offices
- Future Industry Occupants

KEY: ● Polytechnic Labs ● College of Engineering Labs ● Shared Space

- IACMI Design, Modeling and Simulation TA to occupy 30,000 sq ft
- Over 30,000 sq ft available for location of relevant industry labs
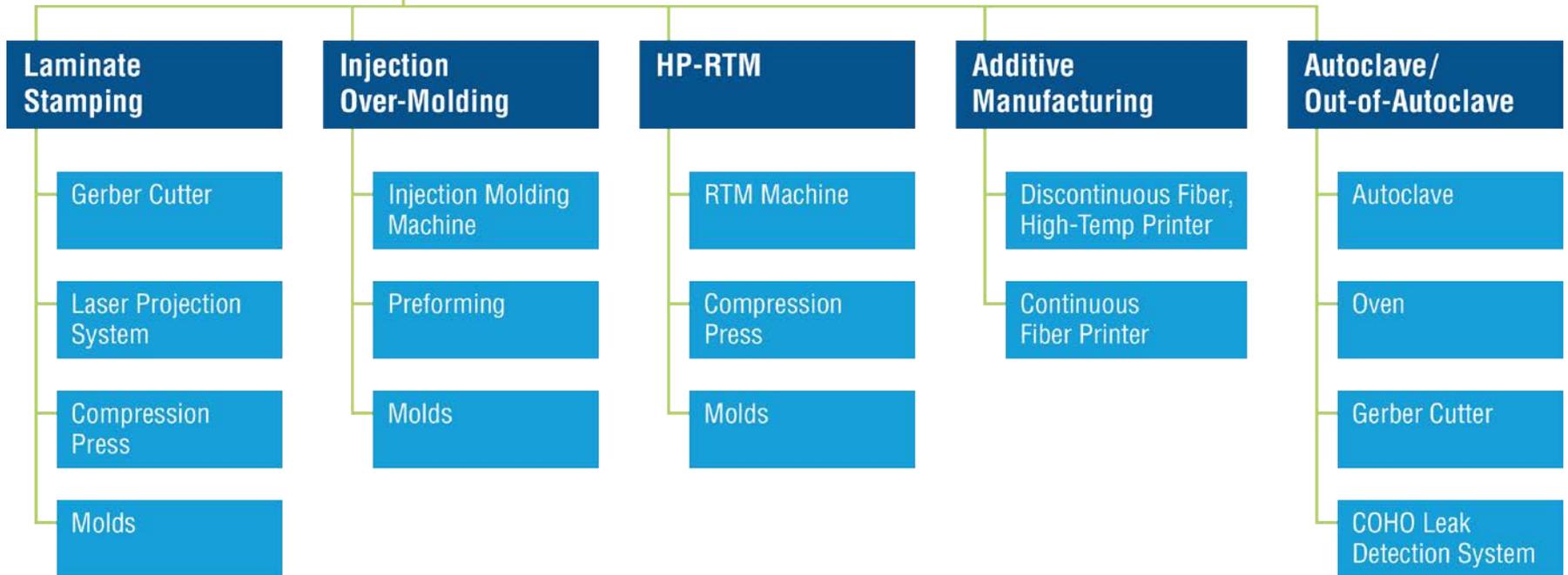- Occupancy Summer 2016

IMI December 2015

Lab Scale Validation Facilities

Manufacturing Processes

Laminate Stamping	Injection Over-Molding	HP-RTM	Additive Manufacturing	Autoclave/ Out-of-Autoclave
Gerber Cutter	Injection Molding Machine	RTM Machine	Discontinuous Fiber, High-Temp Printer	Autoclave
Laser Projection System	Preforming	Compression Press	Continuous Fiber Printer	Oven
Compression Press	Molds	Molds		Gerber Cutter
Molds				COHO Leak Detection System

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New Equipment Acquisition

- Resin Transfer Molding (RTM) Facility
- 250-Ton Press
- Injection Molding Machine
- Molds
- Continuous Fiber Additive Manufacturing Machine
- COHO Leak Detection System
- Leica Inverted Research Microscope
- Dynamic Mechanical Analyzer (DMA)
- Rheometer
- Laser Projection System
- Digital Image Correlation (DIC) System
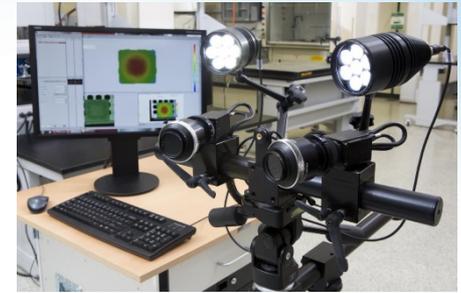
Supported by the State of Indiana

Timeline

2016

- Design, Modeling and Simulation TA engineering staff in place for code training and use

- Indiana Manufacturing Institute opens in summer

- Commercial simulation codes available

- Simulation support for Vehicle, Wind and CGS Teams

2017

- Composites Virtual Factory HUB (cvfHUB) begins delivery

- Laboratory validation facilities available
  - Prepreg molding
  - Injection over-molding
  - HPRTM
  - Composites additive manufacturing
  - Input materials property measurements
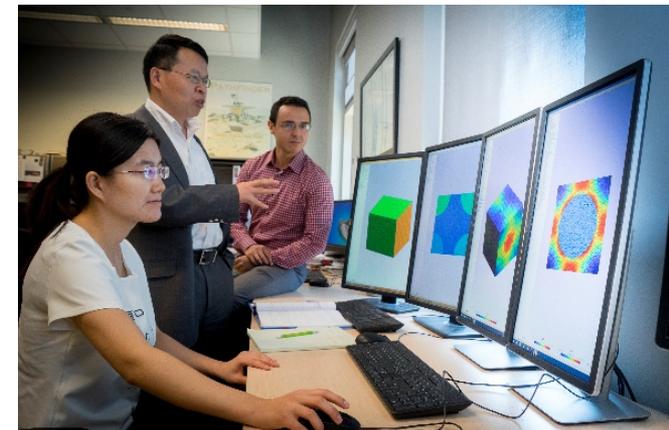
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We welcome inquiries

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