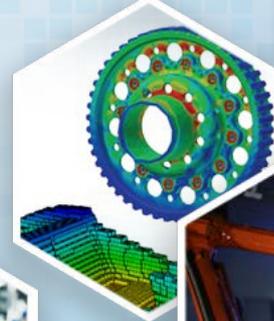


Welcome to the Wind Energy IACMI Working Group

Derek Berry, NREL

Steve Nolet, TPI Composites

October 8, 2020



IACMI Wind Working Group Meeting Agenda



Agenda Item	Speaker/Moderator	Time (EST)	Duration
Welcome and Introduction	Derek Berry	4:00-4:05 PM	5 minutes
IACMI Working Groups	Dale Brosius	4:05-4:10 PM	5 minutes
IAMCI Wind Overview	Derek Berry Steve Nolet	4:10-4:25 PM	15 minutes
Group Discussion	Steve Nolet Derek Berry	4:25-4:55 PM	30 minutes
Wrap-up	Derek Berry	4:55-5:00 PM	5 minutes

Working Group Meeting Rules/Guidelines



- ◆ **Format includes an introduction and opening presentation from the meeting leader(s)**
- ◆ **All participants will be muted once the presentation starts**
 - ◆ Remain on mute unless you wish to speak. You will need to unmute yourselves to speak. Please re-mute yourself after speaking.
 - ◆ If you are on the meeting via phone, use *6 to unmute and re-mute
- ◆ **The platform allows for live polls**
 - ◆ One poll will be for meeting frequency
 - ◆ Other polls may be created by the leaders or in live time based on input

Consortium Working Groups



- ◆ **Mission – Focus on addressing technoeconomic barriers to mass adoption of composites in partnership with similarly aligned organizations**
- ◆ **Formation**
 - ◆ Topic based, ideally formed organically from the membership
 - ◆ Members include industry, academic, national laboratory at all levels of consortium
 - ◆ Elect chair, meet at least 4x per year, more if desired by group
 - ◆ Opportunity to align with external entities (ACMA, ACC, other organizations)

◆ Principal Activities

- ◆ Identify key technical and cost challenges and possible solutions to those
- ◆ Conduct roadmapping as needed specific to topical market or technology focus
- ◆ Inform funding agencies (DOE, DOD, etc.) of priority R&D needs
- ◆ Propose projects for funding – using working group funds or IACMI pool funding
- ◆ Propose mini-conferences or other activities, possibly with outside entities
- ◆ Report activities and successes at IACMI member meetings and other forums, including trade press and conferences

IACMI Wind Working Group Outline

- 1 **Scope Definition**
- 2 **Objectives**
- 3 **Wind Overview: Composites, Manufacturing**
- 4 **Building on IACMI Research and Capabilities**
- 5 **Open Discussion: Challenges and Opportunities**
- 6 **Poll Questions (3 Total)**
- 7 **Wrap-up and Path Forward**

Scope of IACMI Wind Working Group



Source: NREL



- Wind turbine composite structures
- Focus on wind turbine blades
- Other existing and potential composite wind turbine structures
- Potential application to other renewable energy composite structures (e.g., MHK)
- Focus on materials and manufacturing challenges at scale
- Address both technical and economic challenges
- Informed by industry needs / path to commercialization



IACMI Wind Working Group Objectives



Source: NREL

- Identify key composite materials and manufacturing challenges in the wind industry that can potentially be addressed through IACMI (Industry, Universities, National Labs) capabilities
- Engage a broader part of the wind industry to provide more insight into current and future challenges
 - OEMs
 - Blade suppliers
 - Material supply chain
 - End users / owner operators
 - Laboratories
 - Certification and standardization bodies
- Develop new guidelines and standards
- Identify research demonstrations at scale to drive a path towards commercialization

Early Utility Scale Wind Power: Composites

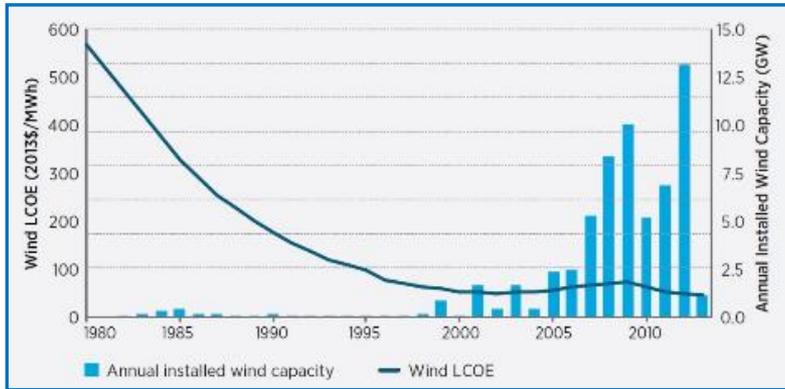


Source: Derek Berry, NREL/TPI Composites

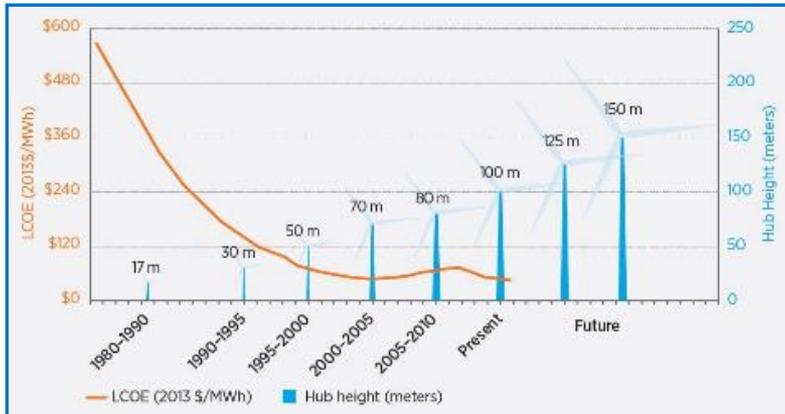


Source: Derek Berry, NREL/TPI Composites

Drivers of Wind Capacity Growth



Average wind LCOE and US annual installed wind capacity

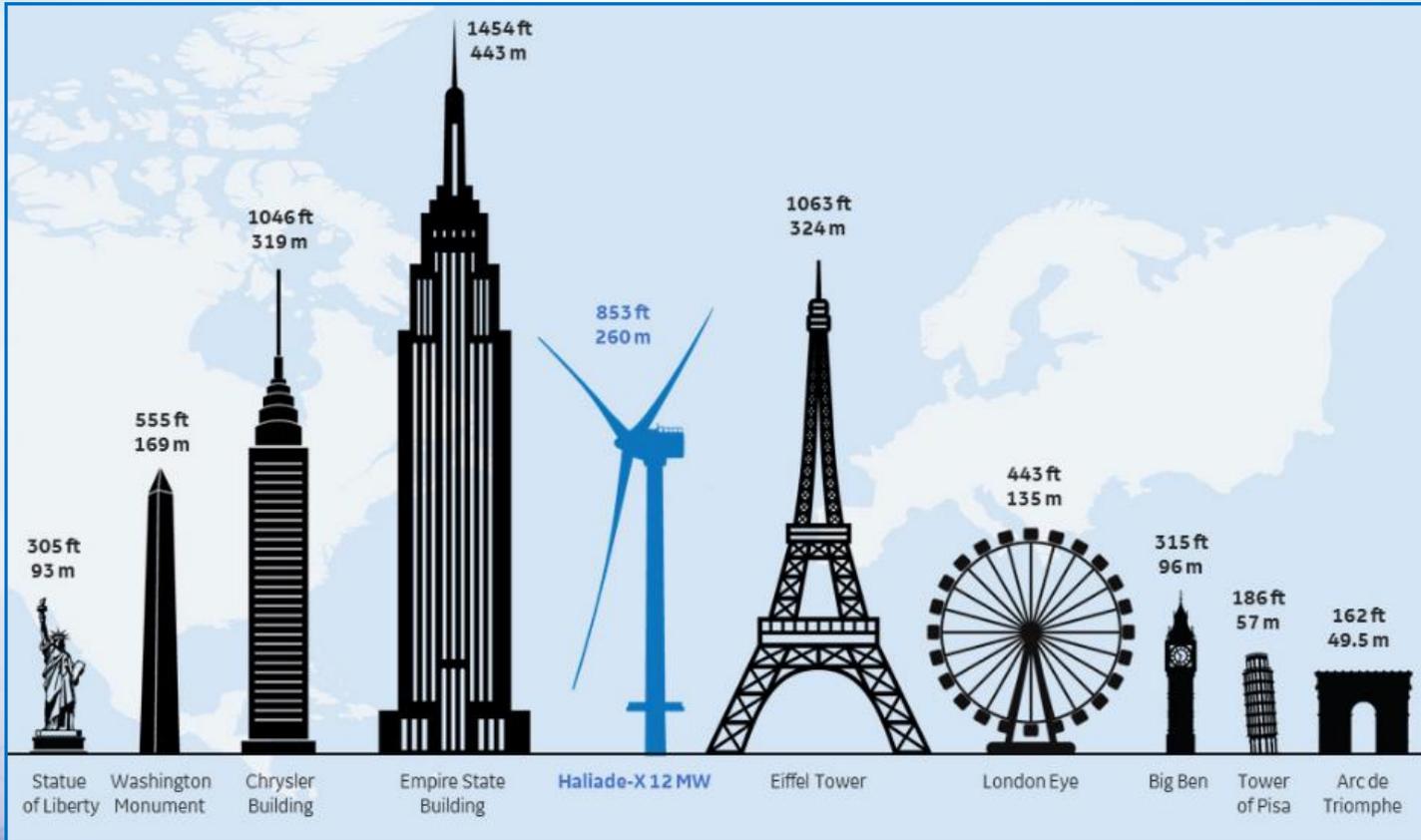


Average wind LCOE and wind technology scale-up trends

- Average wind levelized cost of energy (LCOE) is a major factor in driving installed wind capacity in the United States
- Ability to scale wind turbine technology is a driving force in reducing the average wind LCOE in the United States

Source: Wind Vision: A New Era for Wind Power in the United States, US Department of Energy 2015

Wind Turbine Scaling



Courtesy of GE
Renewables

Wind Composite Manufacturing Challenges



Source: GE Renewable Energy / LM Wind Power

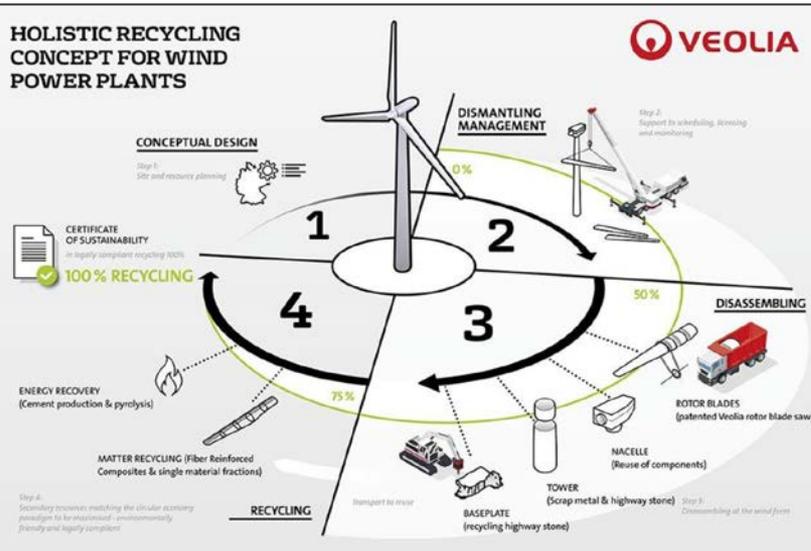
Wind Turbine Recycling – Blades Are The Challenge

Wind turbines are between 75% and 90% recyclable (without the foundation)

But the vast majority of EOL blades currently end up in landfills



Source: Bloomberg

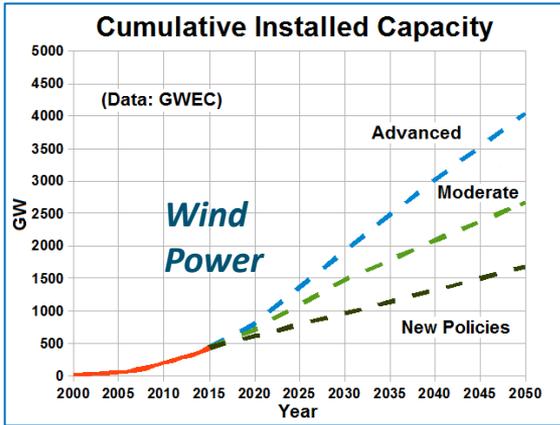


Source: Veolia, ACMA Composites Recycling Conference, 20 May 2020

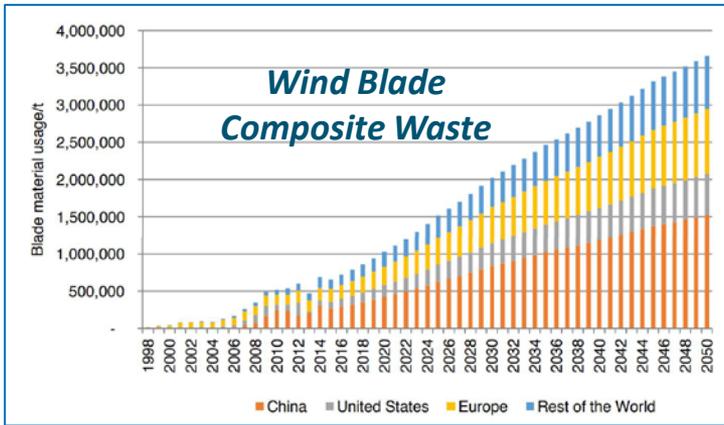
Materials	Treatment
Steel	90% recycled + 10 % landfill
Al	90% recycled + 10 % landfill
Cu	90% recycled + 10 % landfill
Polymer materials	50% incinerated + 50% landfill
Lubricants	100% incinerated
All other materials (including concrete)	100% landfill

Source: Waste and Material Flow Analysis in the End-of-Life Wind Energy System, Tazi et. Al., Resources, Conservation and Recycling, Volume 145, June 2019, pages 199-207

Wind Turbine Blade Composites Waste



Source: Global Wind Energy Council



Source: *Wind Turbine Blade Waste in 2050*, Pu Liu and Claire Y. Barlow, University of Cambridge Institute for Manufacturing



Source: Bloomberg



Source: Derek Berry, NREL



Source: Hammel Recyclingtechnik Equipment

Over 50 million metric tons of waste by 2050

Challenges of Wind Turbine Blade Composite Recycling

Two Challenges

Existing Thermoset Blades

Advanced Material Recyclable Blades

- Vast majority of blades end up in a landfill at end of life
- Few feasible methods to recycle existing blades
- Lack of design for recycling and reuse



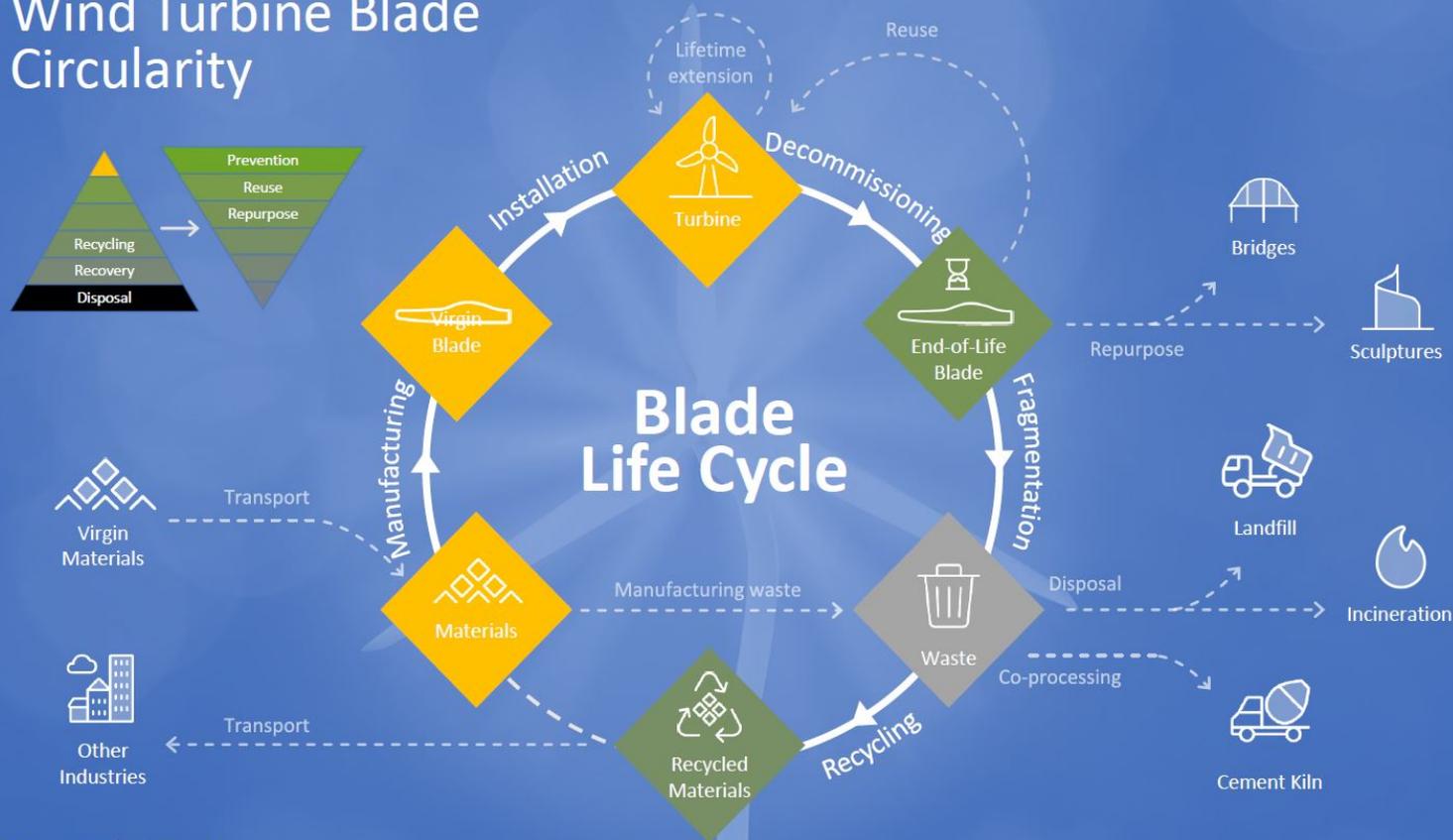
Source: ShareAmerica - U.S. Department of State



Source: Hammel Recyclingtechnik Equipment

Wind Industry Approach to Wind Blade Circularity

Wind Turbine Blade Circularity

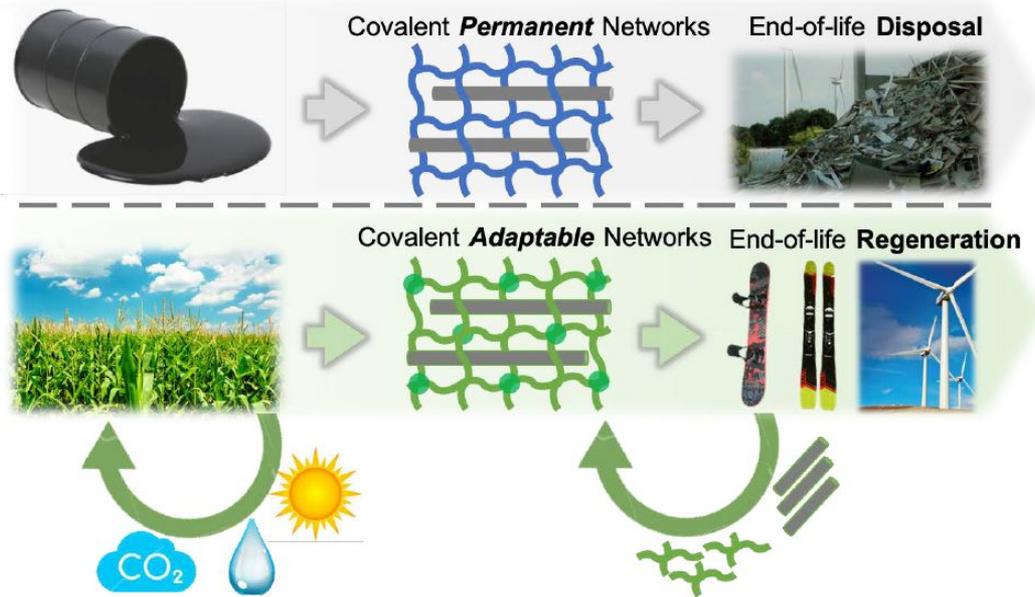


Source:
GE Renewable Energy

ACMA Composites
Recycling Conference

20 May 2020

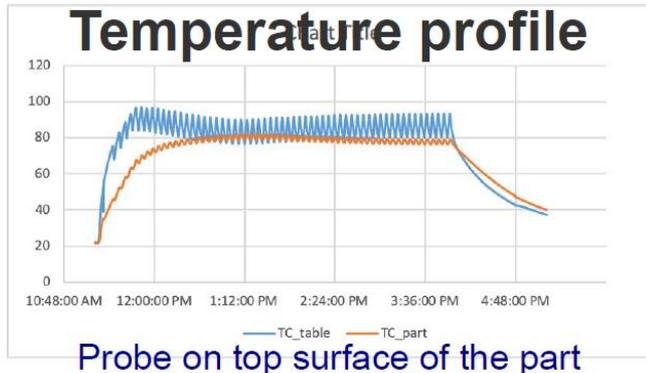
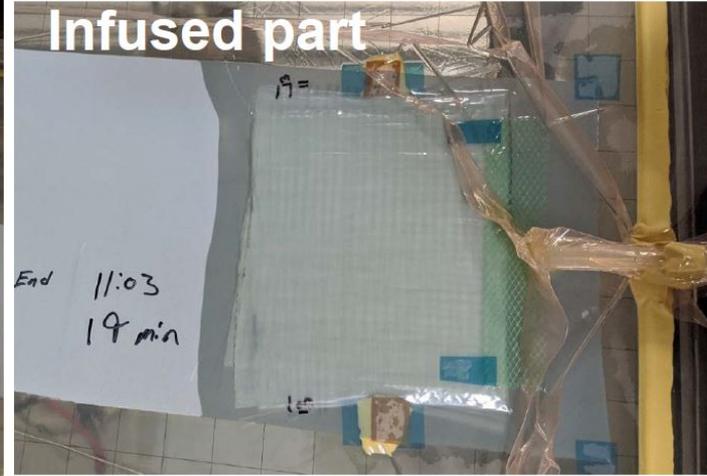
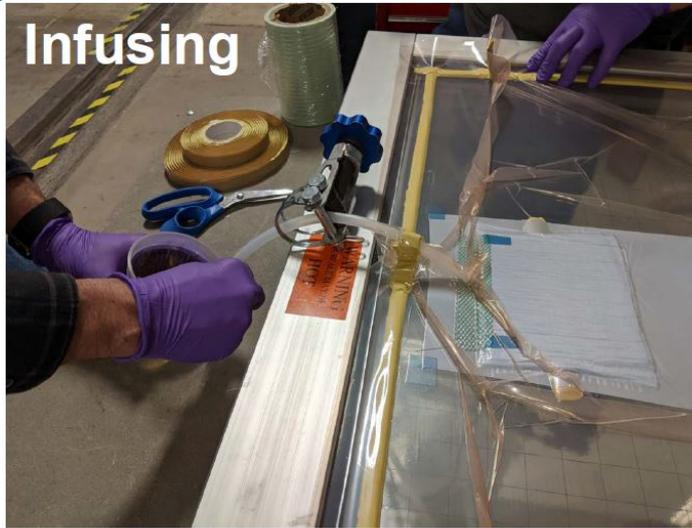
Recyclable Thermoset Resin Systems



Solution:

- Dynamic covalent chemistry enables degradation and regeneration of thermosetting polymers
- Bio-derived **scalable** monomers for applications in the field

Recyclable Thermoset Infusion Trials at the CoMET



IEA Wind TCP Task Proposal: Enabling wind turbine blade recycling



Illustration by: Marie Boye Thomsen

Justine Beauson, Technical University of Denmark (DTU)

Derek Berry, National Renewable Energy Laboratory (NREL)

IEA Wind TCP ExCo 85, Virtual Meeting

27.05.2020

IACMI Project 4.2: Thermoplastic Composite Development for Wind Blades

- This project develops new **thermoplastic** process technology and materials for wind turbine blade manufacturing. This project addresses the challenges of using thermoplastics in blades, such as: **cost** (through techno-economic modeling), **processing temperature** (through process modeling & thermal NDE), and **material properties** (through panel production & testing). The ultimate project outcome is a **structurally verified thermoplastic blade component**, which will demonstrate commercial feasibility of integrating thermoplastics in wind turbine blade production

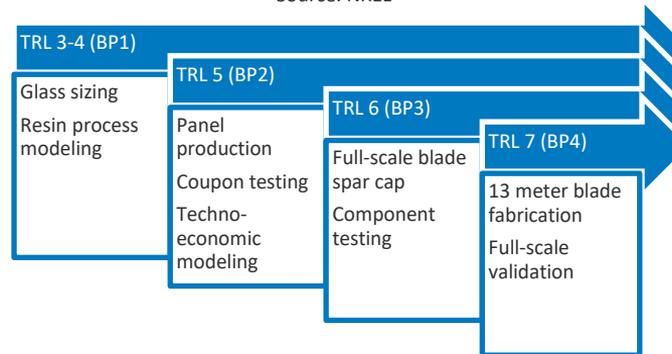
- Length of Project:**

- BP1: July 1, 2015, through January 31, 2016
- BP2: February 1, 2016, through January 31, 2017
- BP3: February 1, 2017, through March 31, 2018
- BP4: April 1, 2018, through July 31, 2019
- BP5: August 1, 2019 through May 31, 2020

- **Partners:** TPI Composites, Arkema, Johns Manville, Colorado School of Mines, NREL, Purdue University, ORNL, Vanderbilt University, University of Tennessee

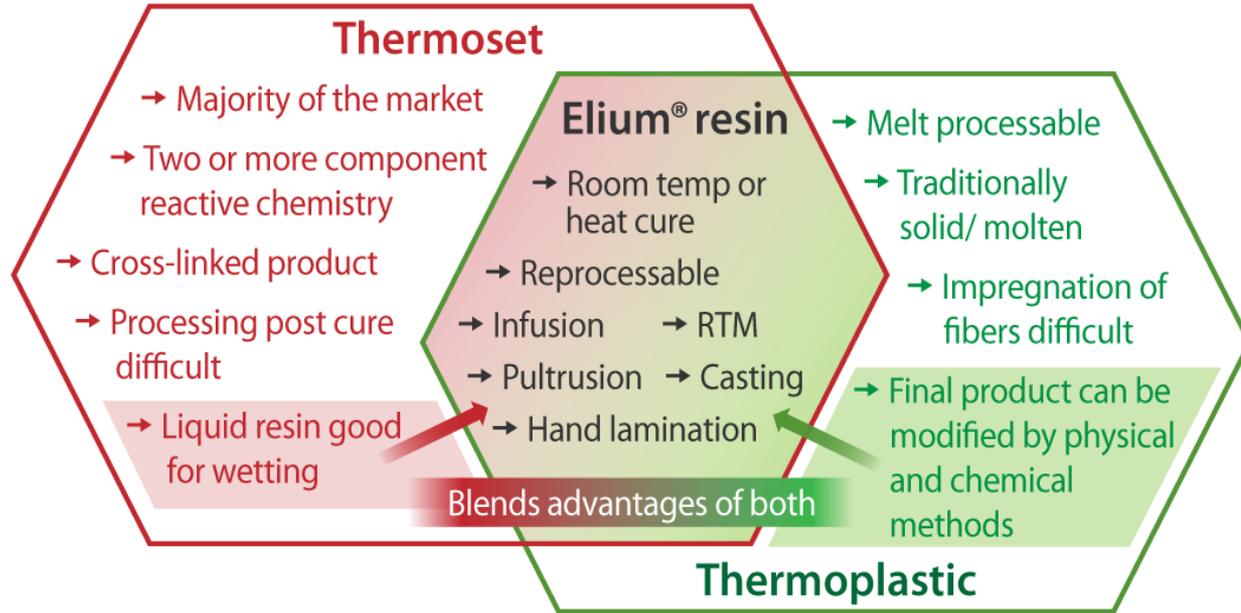


Source: NREL



- **Innovation:** Development of in-situ polymerized thermoplastic resin system for megawatt scale wind turbine blade production:
 - Cycle time
 - Recyclability
 - Thermal welding

IACMI Project 4.2: Thermoplastic Resin System

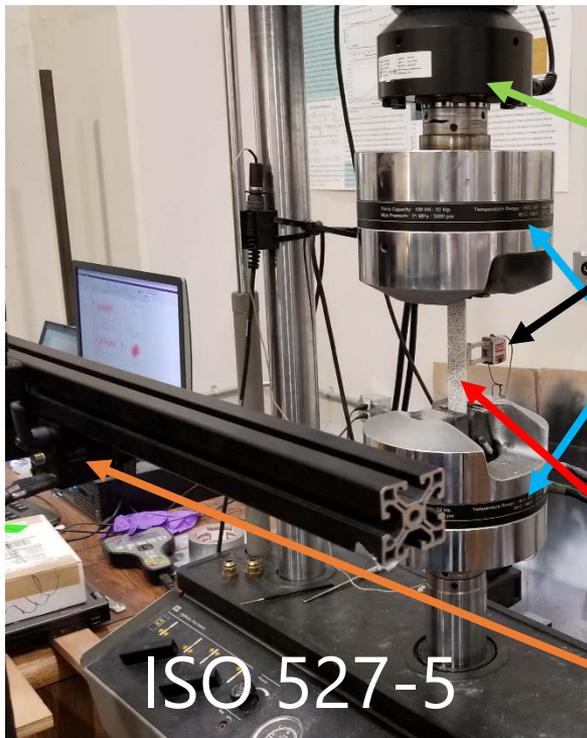


- Johns Manville UD and $\pm 45^\circ$ non-crimp fabrics were produced with StarRov® 086



Source: NREL

Tensile, Compression and Shear testing coupled with Digital Image Correlation (DIC)



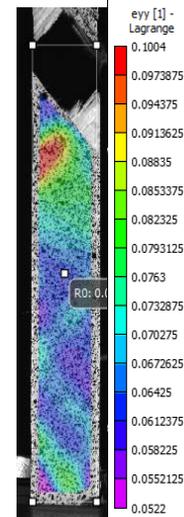
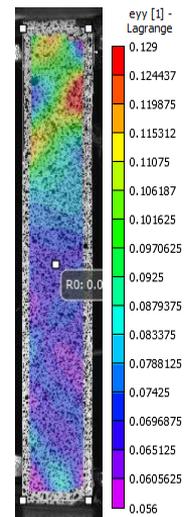
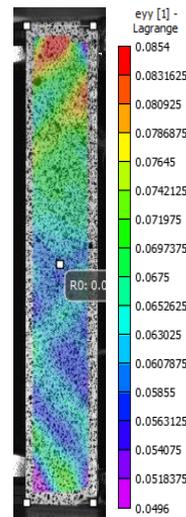
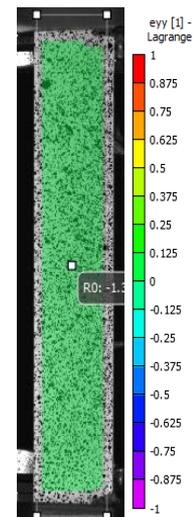
100 kN Load Cell

Extensometer

642.1 Wedge Grips

Sample with Speckle Pattern for DIC

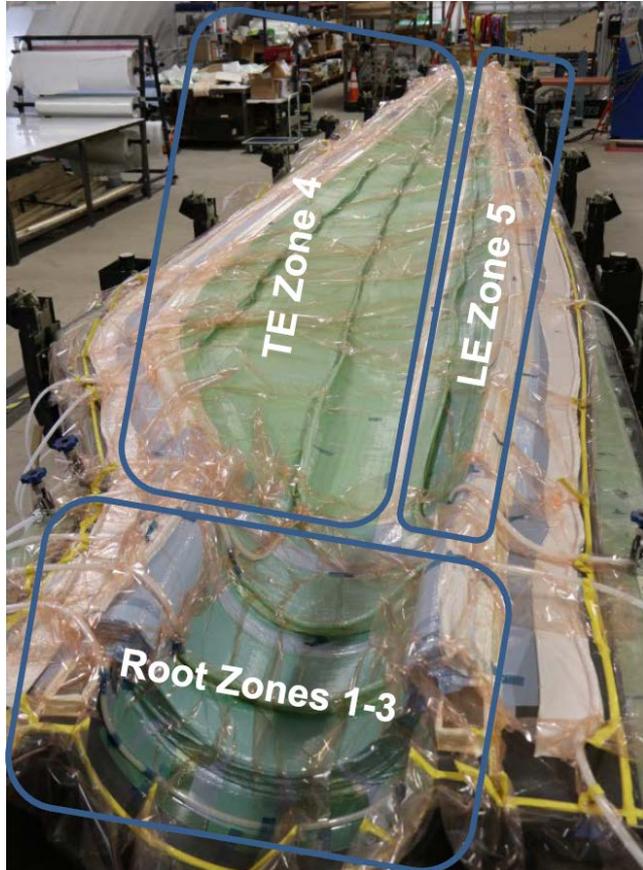
DIC Cameras



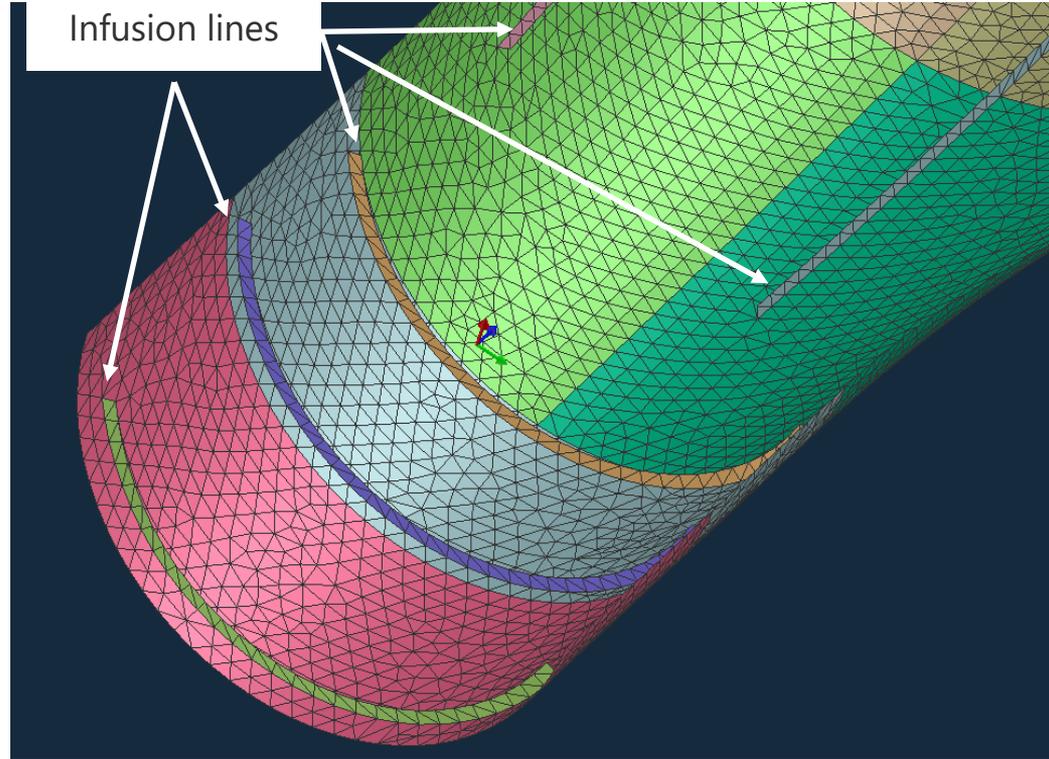
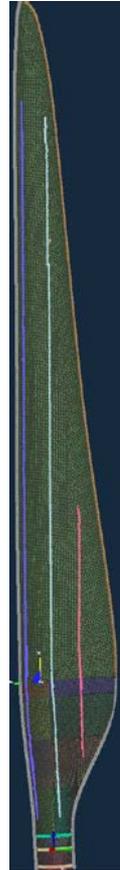
Digital Image Correlation (DIC) Strain Evolution

Material Mechanical Property Validation at NREL, CSM and UTK

Composite Manufacturing Process Modeling and Simulation

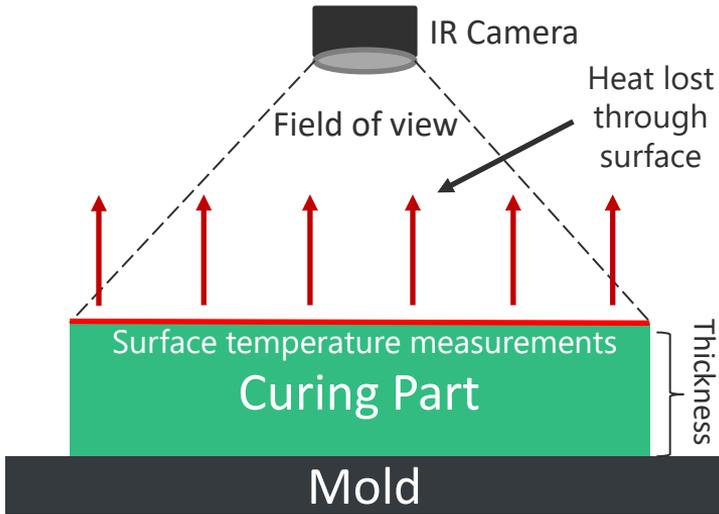


Source: Purdue University / NREL



Source: Purdue University

Flaw Identification Heat Energy Loss Outlier (HELO) Algorithm

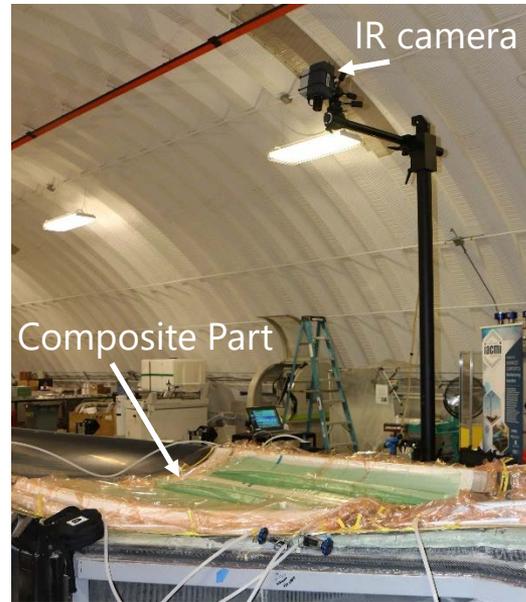


Key idea:

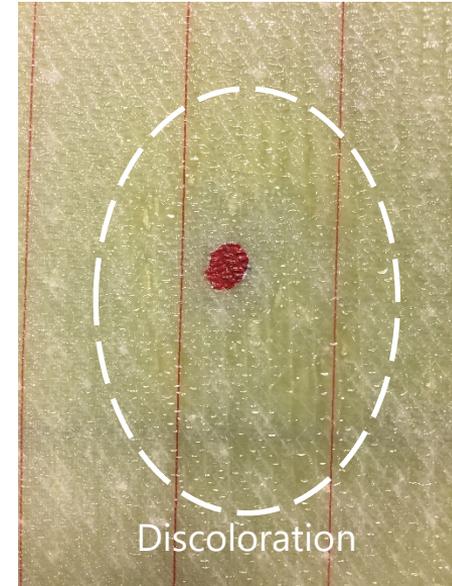
Areas that give off a different amount of heat compared to other areas are most likely to have flaws

Outlier score:

% of time during which a location's total heat output is an outlier



Experimental Setup. IR camera placed above mold to record surface temperatures



Pinhole location on finished panel (red dot). Pinhole was patched during process, so damage was limited to discoloration in circle around hole

13-meter Thermoplastic Blade Validation at NREL

- We have: 13-m blade design, 13-m blade mold set, performance data on 13-m epoxy (thermoset) blade
- Compare: 13-m thermoplastic blade to identical geometry epoxy blade
 - Thermoplastic blade manufactured with Elium resin in the CoMET
 - Different fiberglass – redesigned blade to match stiffness and thickness
 - Different adhesive (PMMA chosen based on lap shear testing)

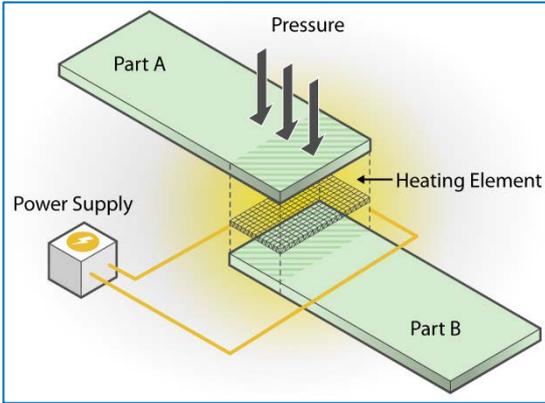


Composites Manufacturing Validation: 13m Fatigue



13-m Thermoplastic
Blade Flatwise Fatigue
Test
(Video Credit: NREL)

IACMI Project 4.3: Thermoplastic Thermal Welding



GE Renewable Energy

ARKEMA
INNOVATIVE CHEMISTRY



 **Nippon Electric Glass**



THE UNIVERSITY OF
TENNESSEE
KNOXVILLE



- Blade manufacturing using thermally welded joints
- Techno-economic model, thermal welding development, thermal weld characterization, full-scale blade component welding
- LCOE, weight reduction, cycle time, blade reliability, on-site manufacturing



Source: NREL

IACMI Project 4.5: Vertical Axis Wind Turbine (VAWT) with Thermoplastic Composite Blades



Source: Colorado State University

IACMI Project 4.7: Textile Carbon Fiber Pultruded Spar Caps



GE Renewable Energy



Source: ORNL



Source: NREL

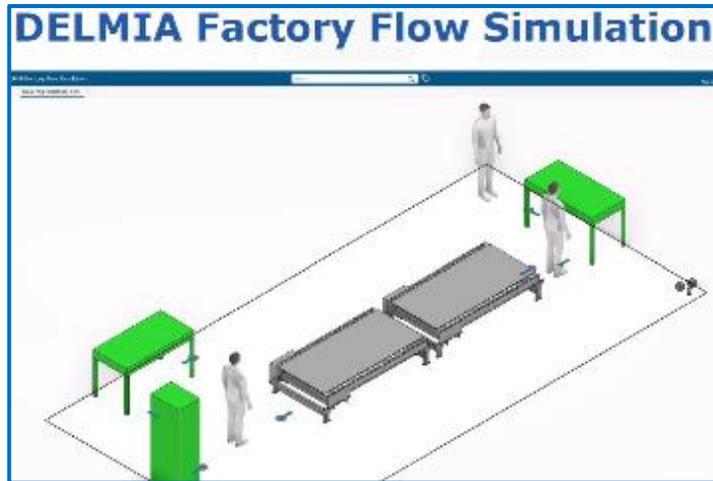
IACMI Project 4.6 / 4.8: Techno-Economic Wind Blade Manufacturing Model to Identify Opportunities for Cost Improvements



GE Renewable Energy



Source: UMass Lowell / Janicki Industries / GE Renewable Energy



Source: UMass Lowell

- Provide **an improved understanding** of the contributors to cost, and potential to implement cost reduction.
- Provide an easy to use tool that can drive cost reduction
 - ✓ Blade Designers to understand design alternatives
 - ✓ Blade Manufacturers to understand value of process alternatives and value of automation
 - ✓ Researchers understand potential value of innovation
 - ✓ Automation suppliers understand valuation of automation

IACMI Project 4.10: Innovative Wind Turbine Blade Finishing with Advanced Automated Technology

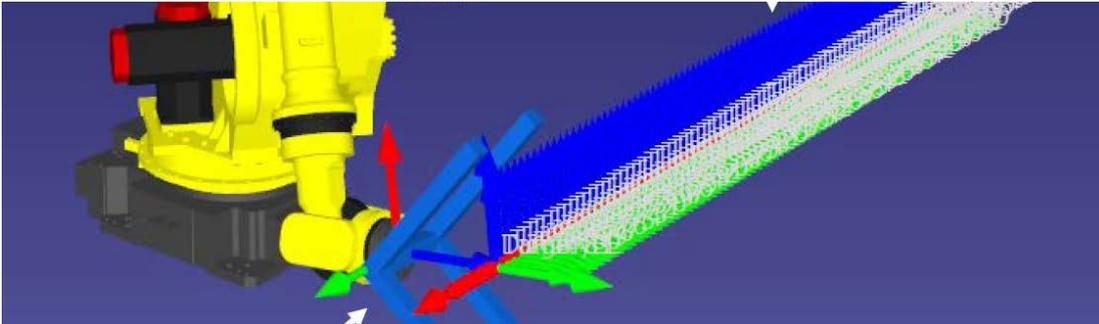
- IACMI Wind Technology Area project
- NREL lead
- Industry partner: LM Wind Power / GE
- Focus: wind turbine blade finishing automation



GE Renewable Energy

LM WIND
POWER

a GE Renewable Energy business



Potential Wind Working Group Discussion Topics



- Wind turbine blade EOL: recyclability, reuse, etc.
- Innovative composite materials: in-situ thermoplastics, reversible thermosets
- Targeted automation in blade manufacturing
- NDE/NDI in upstream blade composite manufacturing
- Development of standards
- Technology demonstration at scale
- Carbon fiber for spar caps, LE/TE stiffeners (TCF, pultrusions, etc.)
- Blade manufacturing optimization / techno-economic model
- Additive manufacturing for tooling and/or blade composite structures



Source: TPI Composites

Poll Question #1: Blade Manufacturing Challenges



What is your perception of the most challenging problem facing suppliers, manufacturers and end users of wind turbine blades?

- a. Fabrication and transportation of 100m+ blades for onshore applications
- b. Meeting cost/delivery expectations of the industry to continue reduction of LCOE
- c. Improving O&M Cost and reliability of wind blades
- d. Decommissioning/disposal/recovery of embodied energy for blades at EOL
- e. Other (identify)

Poll Question #2: Composite Recycling



What is your vision of for the future of continuous fiber composite recycling?

- a. Chemical digestion of matrix system with reclamation of reinforcements
- b. Recovery of thermal content of matrix/core materials with reclamation of reinforcements
- c. Repurposing of laminates for other structural applications
- d. Grind/pulp composite as aggregate for use in cement/asphalt or other infrastructure filler
- e. Other (identify)

Poll Question #3: Meeting Frequency

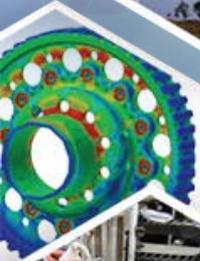


How often should the Wind Working Group meet?

- ◆ Quarterly (4x per year)
 - ◆ IACMI virtual member meeting - week of February 15, 2021
 - ◆ SAMPE Long Beach – May 24-27, 2021
 - ◆ IACMI summer meeting Detroit – week of July 19, 2021
 - ◆ CAMX Dallas – October 18-21, 2021

- ◆ Bi-monthly (6x per year)
 - ◆ Four meetings above plus two additional meetings

- ◆ Monthly (12x per year, or 11x if December skipped)
 - ◆ Four meetings above plus virtual in other months



**Thank you for
attending!!**