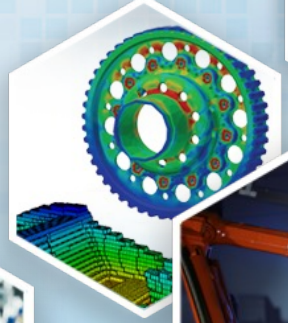
IACMI Wind Energy WG Report to Members Meeting

Steve Nolet, TPI Composites

Derek Berry, NREL

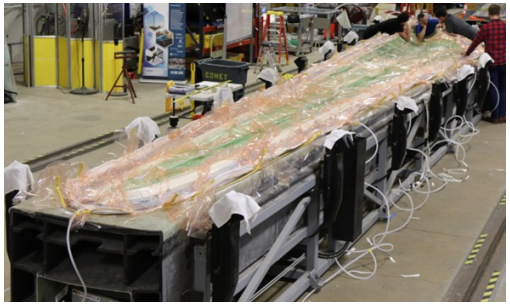
June 21, 2023

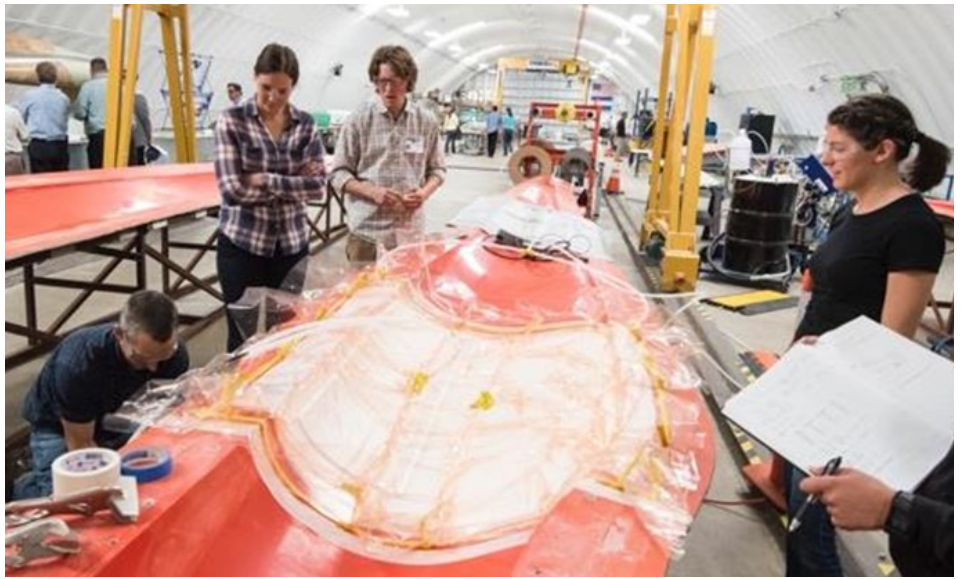


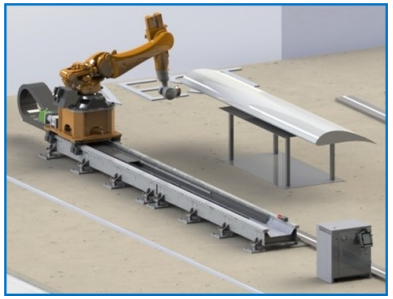
Reviewed Goals of IACMI Wind Energy WG

- Develop wind composite material and manufacturing research projects in alignment with DOE priorities
- Focus on offshore and land-based wind
- Cross-cutting developments in circular economy, digitalization, and composites manufacturing
- LCOE, recyclability, automation, cycle times
- Longer, lighter weight blades
- Decarbonizing the electricity sector
- CE for blades, modular blades, transportation costs, thermal welding / thermoforming, TEM and LCA

CoMET







Wind Composite Manufacturing Challenges at Scale

Source: GE Renewable Energy / LM Wind Power

Wind Composite Manufacturing Challenges at Scale

Source: GE Renewable Energy / LM Wind Power

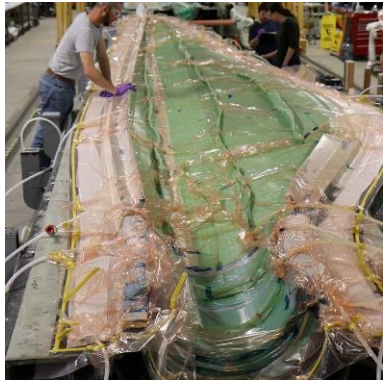
IACMI and NREL Research Leads to Wind Industry Adoption

Award-winning Thermoplastic Blade Research Demonstrates Performance and Economics

2016: 9-meter Blade Technology Demonstration at NREL CoMET

R&D 100 CONFERENCE & AWARDS

2018: 13-meter Blade Fabrication at NREL CoMET



2019: 13-meter Blade Validation at NREL STL

ZEBRA Consortium

2022: Industry Adoption – LM Wind Power 62-meter Blade Fabrication

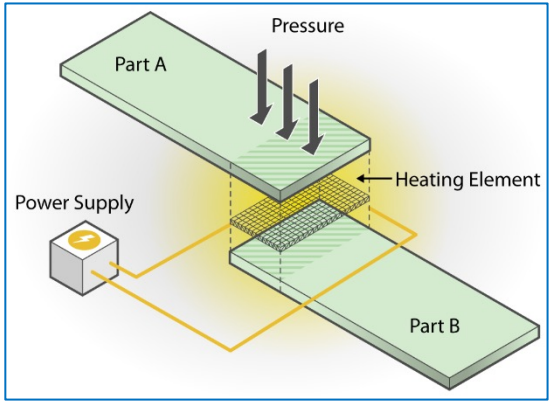
Innovative Modeling, Research, Scaling and Validation at NREL

- Thermoplastic material property database developed through coupon characterization
- 9-meter advanced technology demonstration blade
- Techno-economic analysis demonstrates lower cost
- Fabrication and structural validation of 13-meter wind blade

ZEBRA (Zero wastE Blade ReseArch) Consortium

- 62-meter recyclable wind blades produced at LM Wind Power

IACMI Project 4.3: Thermoplastic Thermal Welding



ARKEMA INNOVATIVE CHEMISTRY

GE Renewable Energy

LM WIND POWER a GE Renewable Energy business

tpi DELIVERING COMPOSITE SOLUTIONS

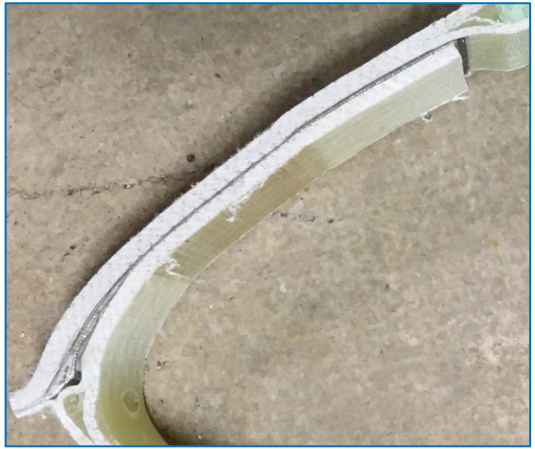
Nippon Electric Glass

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THE UNIVERSITY OF TENNESSEE KNOXVILLE

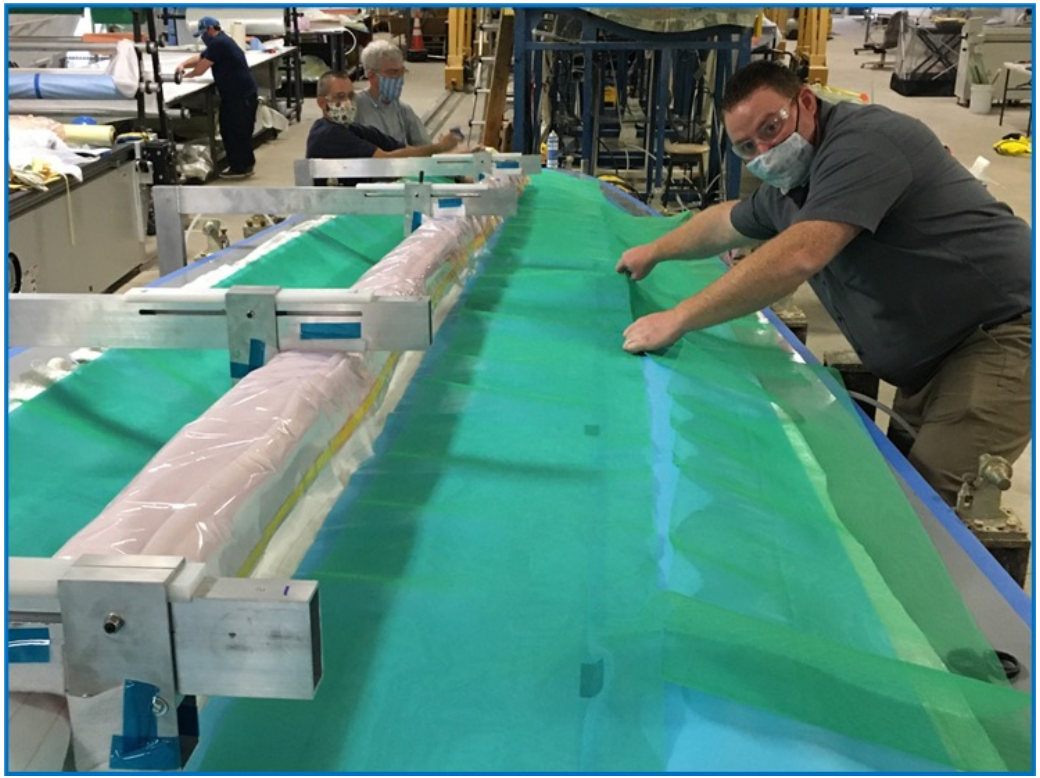
MINES

- 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

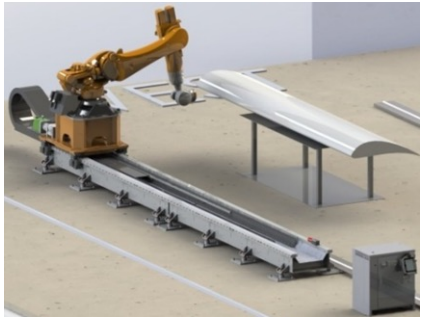


IACMI Project 4.8: Techno-Economic Wind Blade Manufacturing Model to Identify Opportunities for Cost Improvements

Manufactured three GE 56.9-meter blade tips at NREL's COMET facility



Follow-on Research Automating and Decarbonizing Composite Technology

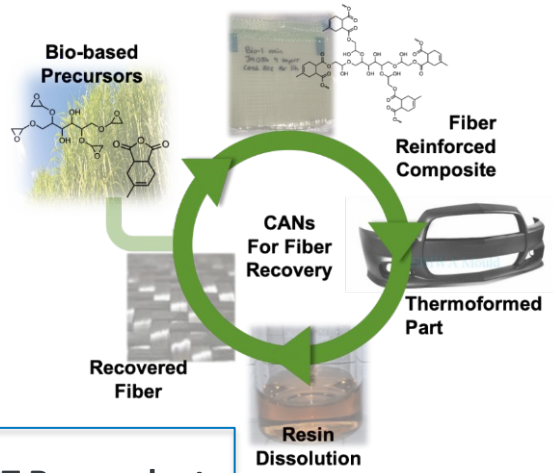


NREL | GE Renewable Energy | LM WIND POWER a GE Renewable Energy business

Advanced Automation for Wind Blade Finishing

- DOE AMO funded research at the CoMET facility
- Robotic blade trimming, grinding and sanding
- Reduce labor cost and cycle time; increase blade quality
- Collaboration with key US wind industry partners
- Demonstrated at LM blade production facility in North Dakota

CoMET Research at Scale for Renewable Energy Applications



Bio-Based Resins to Enable Decarbonization and Recycling

- CFRCs can light-weight vehicle parts up to 60%–70%
- By developing resins that can undergo exchange reactions, CFs can be recycled
- Bio-based starting blocks have the potential to decarbonize vehicle part manufacturing
- Bio-derivable epoxy-anhydride covalently adaptable network (CAN) enable recyclable-by-design CFRCs

Nicholas Rorrer: 2022 DOE VTO Annual Merit Review

NREL | VERDANT POWER

Renewable Tidal Marine Energy

- WPTO funding for advanced material and manufacturing research
- NREL CoMET team designed and manufactured low embodied energy, recyclable-by-design thermoplastic tidal energy blades
- Improved seawater performance and robustness
- Deployed for operational validation in East River, NYC

Discussed IACMI Wind Projects: Scope and Structure

- Approximate wind budget over five years: $8.2M
  - Only first year allotted ($1.64M)
  - Includes both federal and state funds
  - Additional wind research projects and funding may come from other IACMI areas
- Developing wind project ideas in conjunction with SOPOs and budgets
- One year research projects vs. multi-year with yearly deliverables
- Research priorities identified by wind industry
- Continue to coordinate with IACMI Wind Working Group

Overview of “Recycling” from the Perspective of a Blade Manufacturer

- TPI Composites is committed to finding end-of-life solutions that avoid landfill.
- The need is IMMEDIATE!
  - 8,000 wind blades de-commissioned in N. America alone, in 2021.
  - The EU will be decommissioning over 25,000 tonnes annually by 2025.
- Re-capture embodied energy of the blade providing power for other industrial processes, reclaim materials for other uses.
- Viable solutions are currently available.
  - Challenge is to make them economically viable.
- Targeting solutions with economic business cases within next 18-24 months.
  - Scaling with increasing volume will reduce cost.
  - Actively partnering with industry for post process by-products (glass fiber & resins).
  - Carbon is already being reclaimed and used in new products.

Moving toward Higher TRLs

Technology	Current Status	Current TRL	Target TRL for IACMI 2.0 Project	What's Needed?
REC RiversEdge Composites	4 x 4 panels made at REC with phenolic resin	4	7-8	Scale-up to 4 x 8, Technoeconomic analysis, Mechanical & FR properties
GreenTex Solutions, LLC	Variety of Panels made by GreenTex, higher value performance product	4	7	Identify application (truck floor?), build subcomponents for test/optimization, Build full-scale units for installation
TEXTECH Carbon Rivers EnviroLiner	CIPP liner prepared	3	7	Scale to full size liner, Identify installer, Demonstrate Installation

Opportunities for Self-heating Bond Paste Adhesives

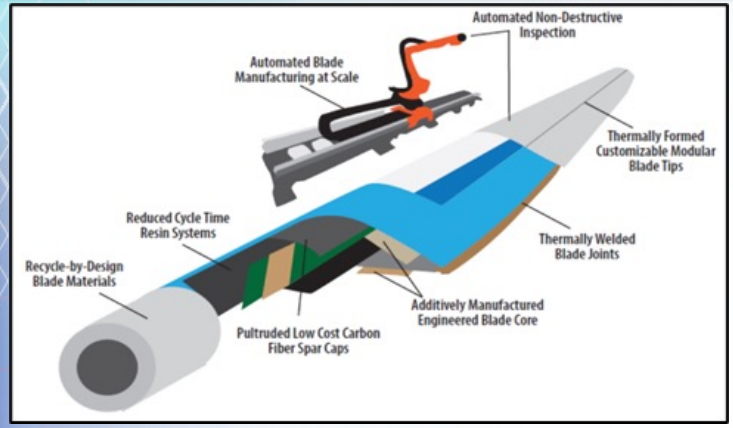
Dr. Dibyendu Mukherjee, UT Knoxville: Self-Heating Energetic Nanocomposites (SHEN)

- Reactive enthalpic components increase bond line heating rate
  - Does not rely on conduction from mold surface
  - Eliminates energy requirement from mold heating system
- Potential to minimize or eliminate thermal gradients through bond-line
  - Reducing residual stresses across adhesive joints
- Engineer total heat of reaction, enthalpy available from thermitic materials
  - Optimize cure and adhesive performance
  - Eliminate over-temperature or under-cure, full Tg development
- Cooling rate increased by heating ONLY adhesive mass rather than entire spar, blade perimeter and tooling
  - Time to demold is significantly reduced

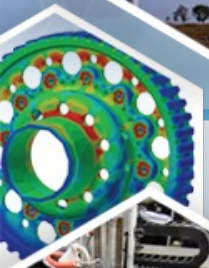
Notes from Wind Energy WG Open Discussion

- Discussion of avoiding creating silos by applications (wind, vehicle, etc.) with respect to recycling
  - Counterpoint: Focus specifically on wind turbine blade recycling – and then outlet to other groups for research efforts
- Explore the use of nano-technologies for inductive heating
- Discussion of the increase of wind turbine blade length
- Role of IACMI in standards development – repairs, O&M
- Consider research of NDE (in factory and field), vision systems, ML, AI, digital twin
- Recycling: quantify the many technologies, economics, and LCA
  - Leverage current efforts: DOE WETO (NREL, SNL, ORNL), IEA Wind Task 45

Wind Energy Working Group: Next Steps



- Organize and distribute notes from Wind Energy WG discussion
- Develop further polling of WG members
- Incorporate discussion and feedback into IACMI wind project development
- Ongoing research project topic discussion at future Wind Energy WG Meetings


Thank you

IACMI Wind Energy Working Group Meeting

snolet@tpicomposites.com
derek.berry@nrel.gov