NREL
Transforming ENERGY

Thermoplastic Wind Turbine Blades and Recyclable-by-Design Materials

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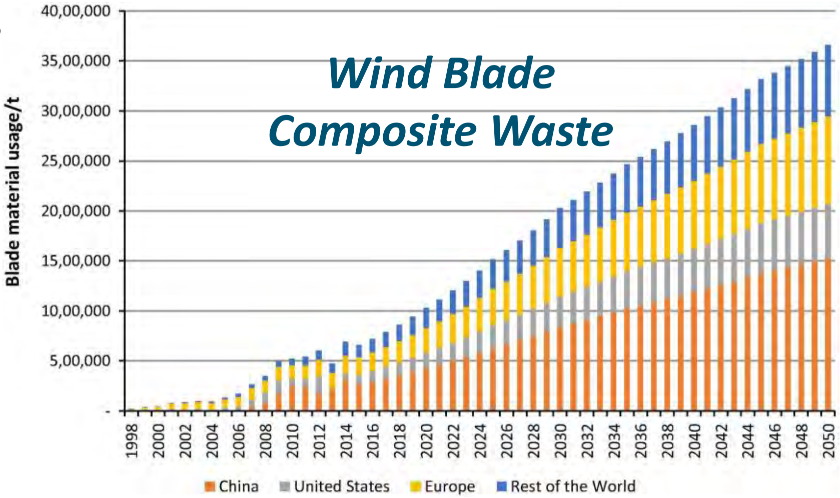
Introduction

Problem: Large composite structures like wind turbine blades have traditionally been made of materials that are costly and challenging to recycle

Impact for wind turbines: Could be over 50 million metric tons of waste by 2050 from blades

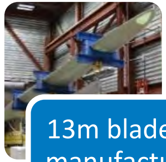
https://www.bloomberg.com/news/features/2020-02-05/wind-turbine-blades-can-t-be-recycled-so-they-re-piling-up-in-landfills



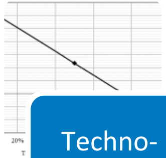
Source: Elsevier /University of Cambridge

Today's talk:

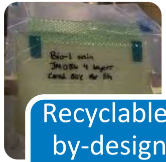
Thermoplastic blade materials



13m blade manufacturing and validation



Techno-economic analysis



Recyclable-by-design anhydride development

Thermoplastic materials

- NREL has been researching thermoplastic composites (using Elium resin) as well as novel recyclable-by-design materials to address this challenge
- Thermoplastic composites gaining interest in wind industry

Reduce cycle time and energy consumption

Can be thermally joined

- Eliminates adhesive bonds, increasing strength and reliability

Can be reformed

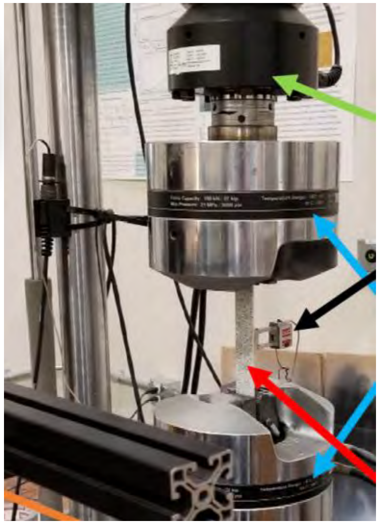
- Enables easier repair and maintenance

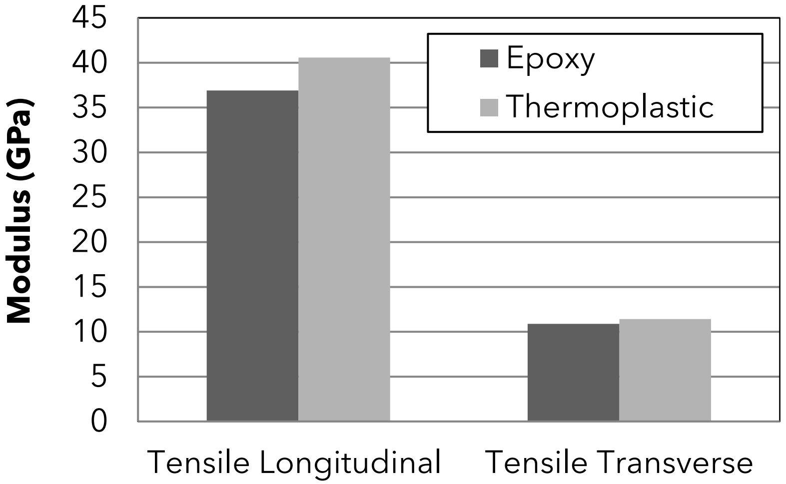
Can be recycled at the end of their life span

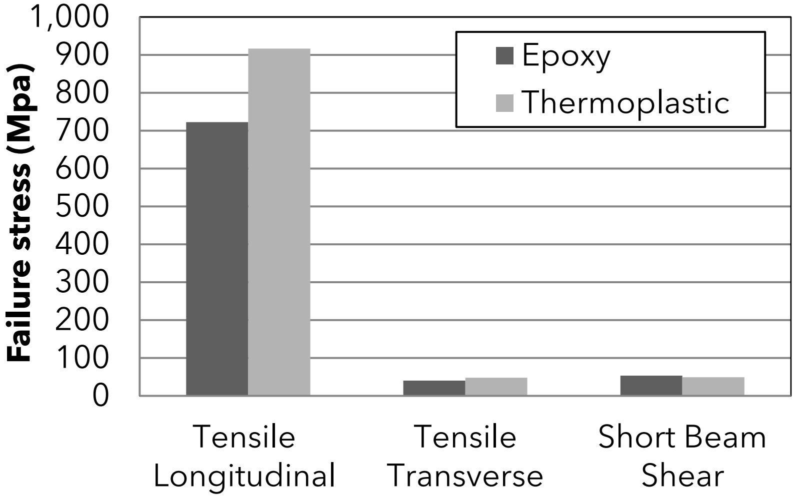
On-site manufacturing becomes a viable option

Coupon-scale validation

- Thermoplastic composites compared to thermoset composite materials at a coupon scale
- Thermoplastics are within 5% strength and modulus compared to epoxy








13 m blade manufacturing
and validation
OVERHEAD DOOR

13-m Epoxy blade

- DOE WETO Project: National Rotor Testbed (NRT)
  - 13-m blades made using traditional epoxy resin and fiberglass to go on SNL SWiFT turbine
  - ORNL 3D printed molds
  - TPI Composites fabricated 4 blades
    - 3 to fly at SWiFT site
    - 1 to NREL for structural validation

Sandia National Lab's SWiFT site

PhotoCredit: https://energy.sandia.gov/energy/renewable-energy/wind-power/wind_plant_opt/

13-m epoxy NRT blade

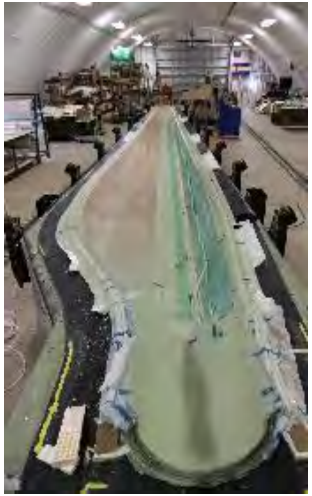
Maximum Flap Loading

Maximum Edge Loading

Photo Credit: NREL

13-m Thermoplastic blade

- Identical thermoplastic blade manufactured with Elium resin in the CoMET at NREL using the same tooling
  - Different fiberglass, adjusted layup using NuMAD to match stiffness and thickness to 5%
  - Different adhesive (PMMA adhesive chosen based on lap shear testing)



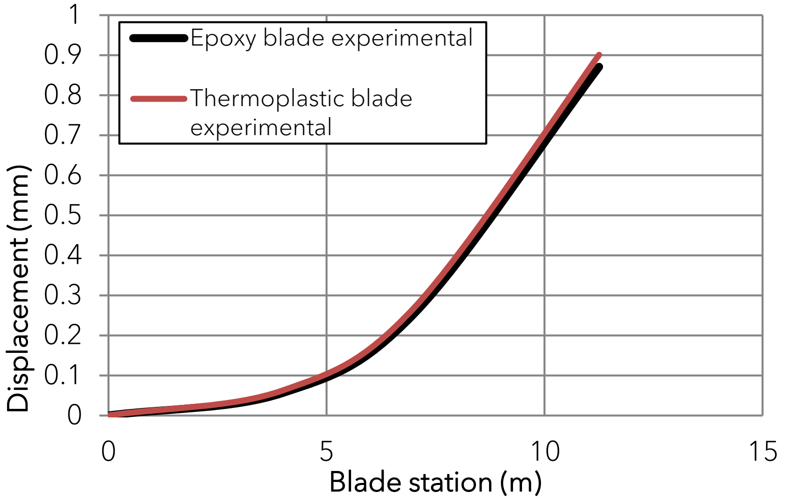
13-m TP Blade skin production (PhotoCredit: NREL)

Static load comparison

- Static strength testing
  - Flatwise displacement 3-7% higher
  - Edgewise displacement 10-15% higher
  - Strains within 10%
  - Differences attributed to differences in adhesive and fiberglass (less stiff adhesive)

13-m TP Blade static load testing at 100% design load (PhotoCredit: NREL)

	Blade Station Deflection	Thermoset Epoxy (Sandia NRT Blade)	Thermoplastic Elium (IACMI 13-m TP Blade)	Comparison (Thermoset vs. Thermoplastic)
Max Flatwise Static	7-m (54% span)	251.1 mm	265.2 mm	105.6%
	11.25-m (87% span)	865.4 mm	893.1 mm	103.2%
Min Flatwise Static	7-m (54% span)	175.1 mm	187.9 mm	107.3%
	11.25-m (87% span)	537.7 mm	563.9 mm	104.9%
Max Edgewise Static	7-m (54% span)	102.7 mm	118.8 mm	115.7%
	11.25-m (87% span)	298.8 mm	340.7 mm	114.0%
Max Edgewise Static	7-m (54% span)	114.9 mm	128.2 mm	111.6%
	11.25-m (87% span)	322.8 mm	356.6 mm	110.5%



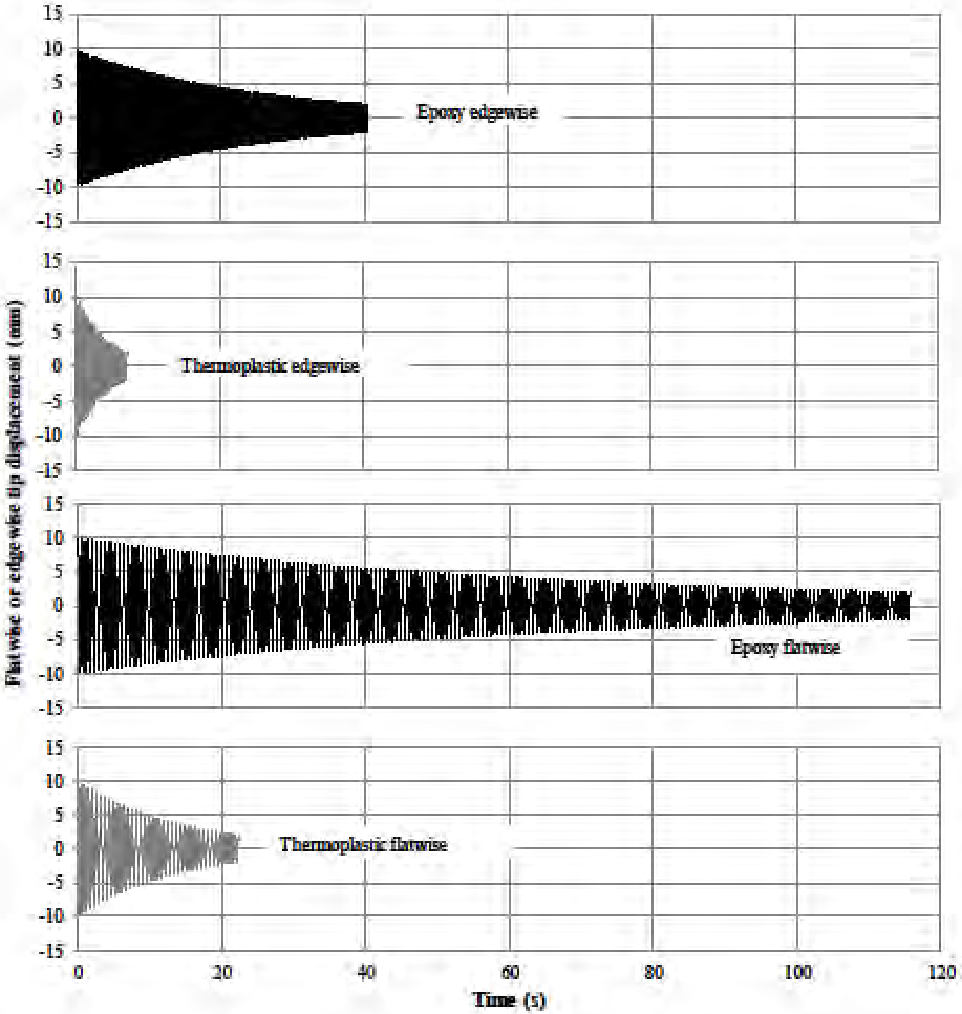
Fatigue load comparison

- Fatigue method: Damage Equivalent Load
  - Accelerated loading 1e6 (1 million) cycles using resonant fatigue testing

13-m TP Blade fatigue testing (PhotoCredit: NREL)

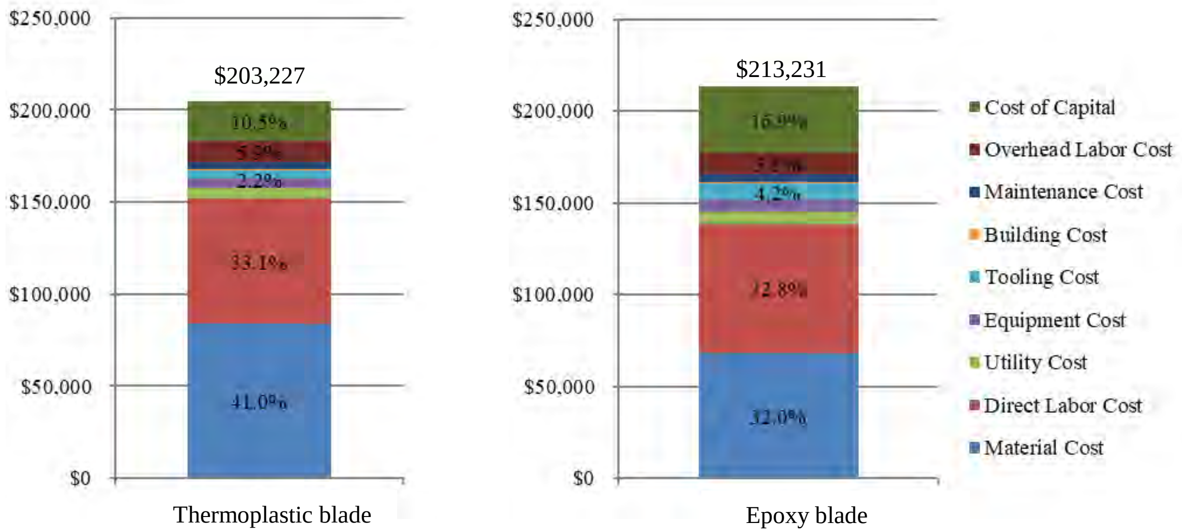
Fatigue load comparison

- Dynamic mechanical analysis (DMA) to compare damping characteristics of epoxy and thermoplastic blades
- First 3 natural frequencies within 3% of NRT
- Structural damping 5-7x higher =reduced loads in field operation
- *How does structural data impact design?*
- *Are there other tests we should be doing to better inform blade and turbine design?*



Techno-Economic Analysis

- Breakdown of blade manufacturing cost for a 61.5-m thermoplastic blade
  - Thermoplastic blade costs 4.7% less than an equivalent epoxy blade
  - Mainly driven by reduced tooling costs
  - Material costs more per kg, with economies of scale, the cost can go down further



Conclusion

- Thermoplastics can be a drop in replacement for non-recyclable epoxy resins
- Still a lot of research to do to understand the full value proposition
  - Thermal welding
  - Thermoforming
  - Repairs

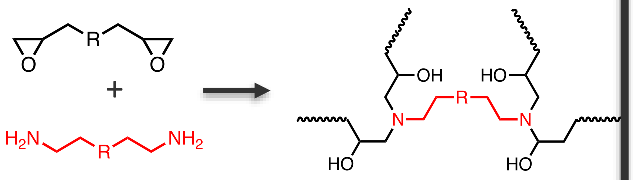
- Need to understand science and cost of recycling these blades – have not recycled the 13m thermoplastic blade

Recyclable-by-design materials at NREL

Recyclable epoxy

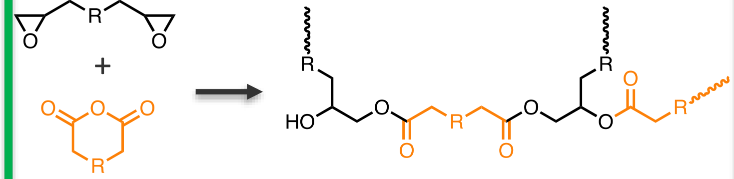
- Resins that can undergo exchange reactions -> composite materials can be recycled and thermomechanical properties modulated
- NREL developed a novel bio-derivable epoxy-anhydride resin with reversible crosslinks to enable recycling ("RBD resin")
- ROI 20-59 and patent application submitted
- Techno-economic and supply chain analysis of feedstocks shows lower GHG and potentially less expensive than traditional epoxy materials
- *NREL working on characterization and validation of this new material for wind turbine blades*

Current: Epoxy-amine resin



C-N linkages, not reversible

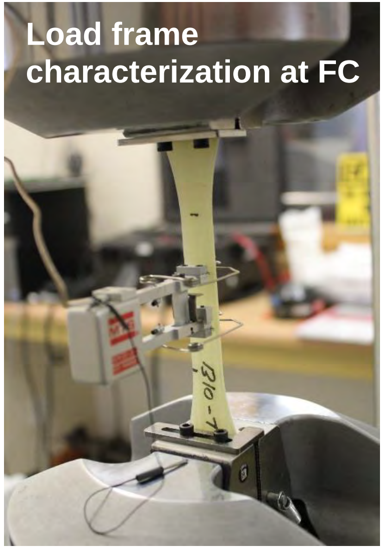
New: Epoxy-anhydride resin

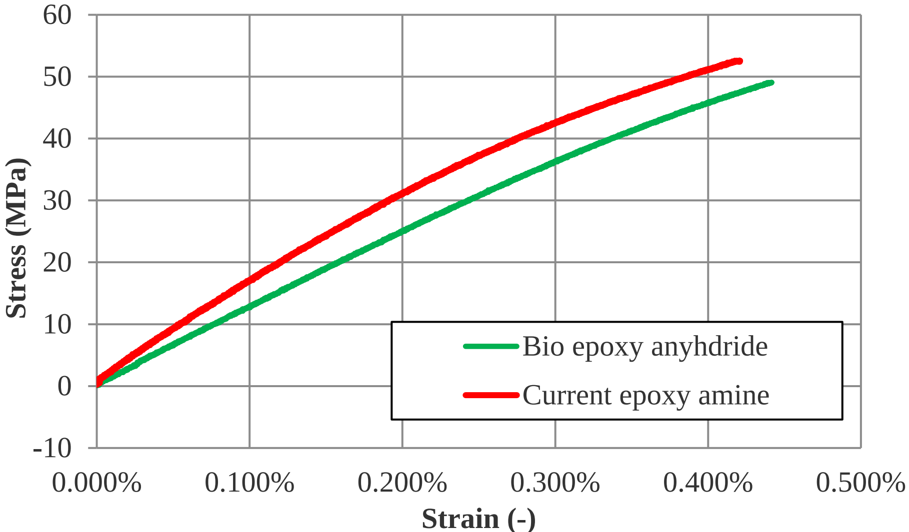


Ester linkages, reversible

Wind materials testing

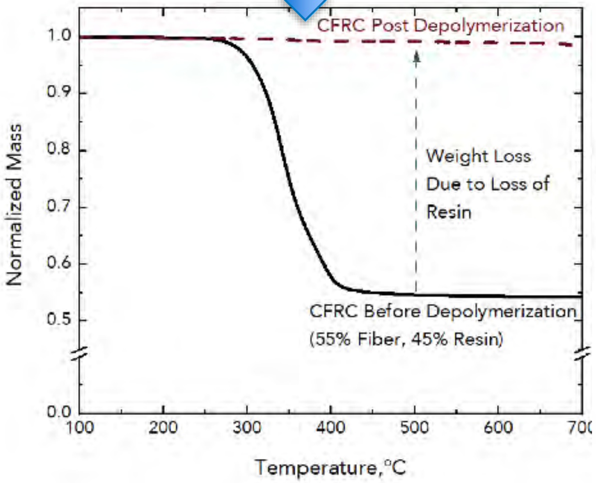
- <u>Manufacturability:</u> Infusion of RBD resin into glass and carbon fiber in the CoMET
  - Cure cycle same as traditional epoxy material
  - Similar viscosity to traditional epoxy
  - Promising! .. balance between strength and flexibility
  - SEM imaging shows possible sizing incompatibilities

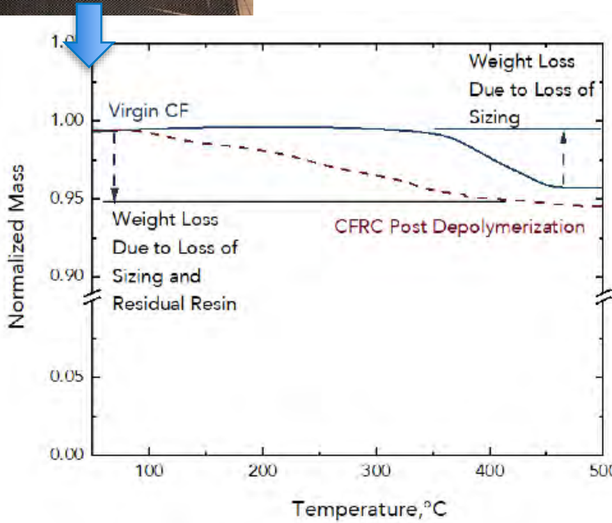


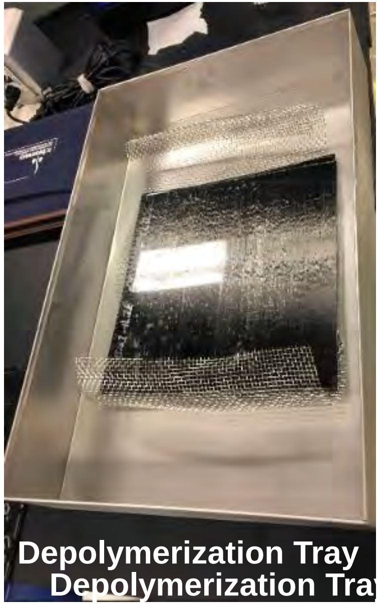


Recycling

- Currently depolymerizing panels (at room temperature and 100g+ scale)
- TGA results indicate no detrimental effect to the CF sizing post depolymerization
- Residual resin MAY further aid re-use due to exchange reactions







Depolymerization Tray
Depolymerization Tray

Thank you!

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Appendix slides

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