IACMI Wind Energy WG Report to Members Meeting

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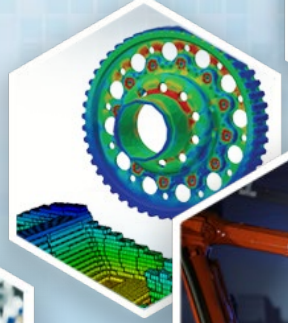
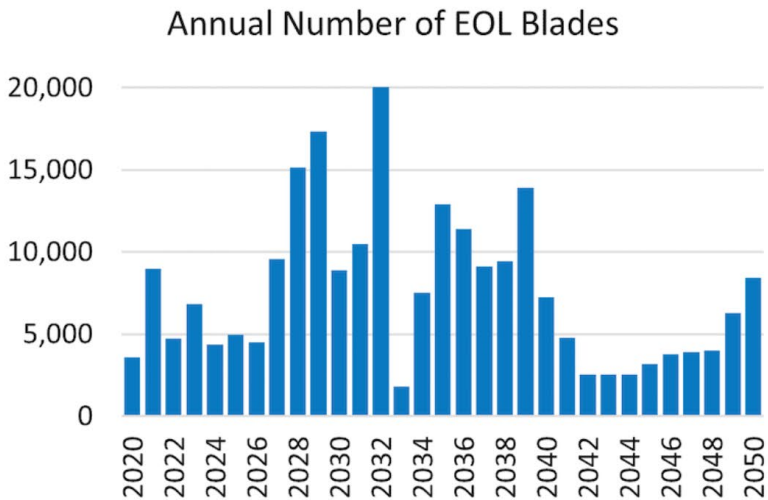


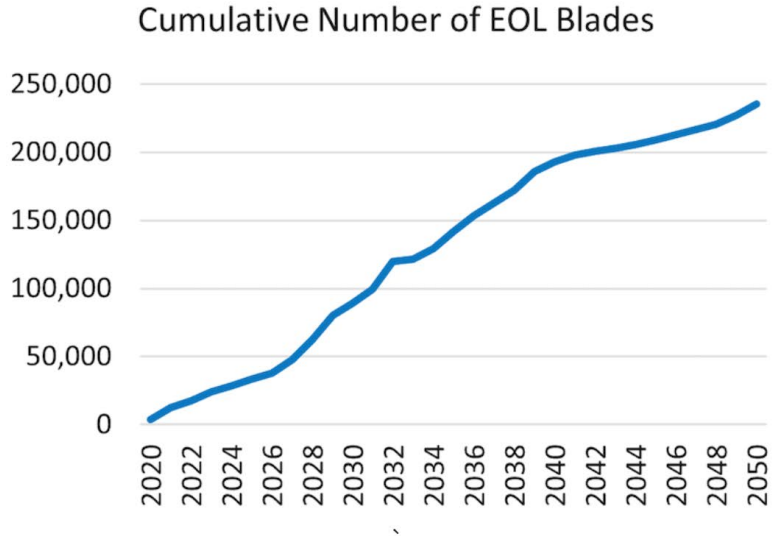
Challenges for US Wind Composite Materials and Manufacturing

- Blade quality
- NDE
- Operation and maintenance costs
  - LE erosion
- Field service and repair
- Blade cost
- Cycle time
- Decarbonization
- Recycling / sustainability
- Manufacturing waste
- Training / workforce development
- TEM [TEA] / LCA

Blade Waste Estimates

- On average, **3,000–9,000 blades are being taken out of service per year in the United States** and that number is expected to increase to 10,000–20,000 blades per year by 2040.[7]



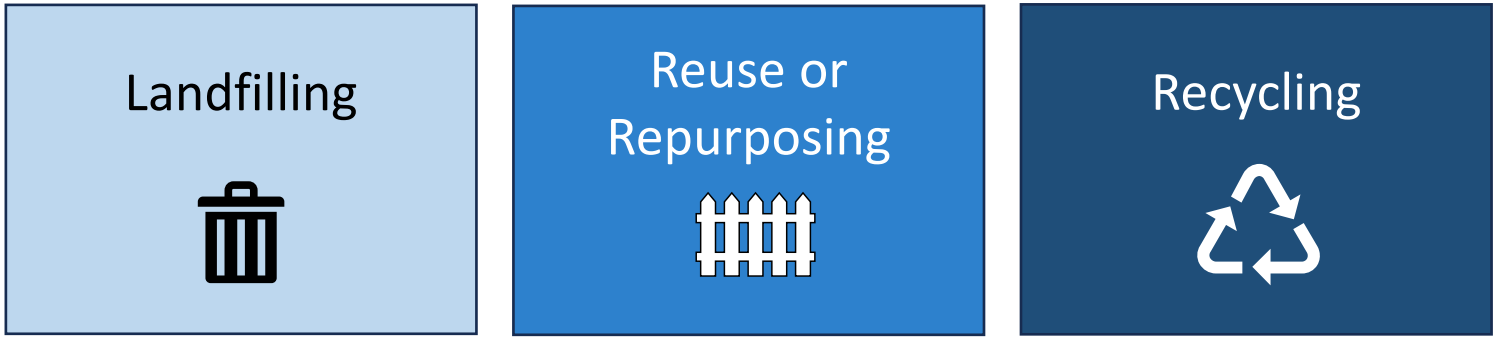


Estimates of end-of-life wind turbine blades projected to be taken out of service each year (left) and total (right).
Figures from Cooperman, Eberle, and Lantz (2021)

[7] Cooperman, A., A. Eberle, and E. Lantz. 2021. Wind Turbine Blade Material in the United States: Quantities, Costs, and End-of-Life Options. *Resources, Conservation and Recycling* 18: 105439. https://doi.org/10.1016/j.resconrec.2021.105439.

Component Processing

- Three major options for processing:



- Decisions are influenced by factors like:
  - Cost
  - Accessibility/transportation
  - Capacity of processing
  - Laws and regulations
  - Sustainability goals.

Landfilling

Wind turbine blades being buried at a landfill in Casper, Wyoming.
Photos from Brendan Lachance, Oil City News

- Most wind turbine blades are currently disposed of in landfills
  - Landfilling is generally an easier option than recycling currently (e.g., lower cost, more proximate to project site, more processing capacity)
- In 2018, about 50,000 tons of blade waste were managed at U.S. landfills[3]
  - This was about 0.017% of combined municipal solid waste and construction and demolition waste managed by landfills that year (~291.1 million tons)[3]
- Landfilling blades can present challenges for landfill operators and communities, as they may **take up a large amount of landfill space** and can **require specialized equipment, capacity, and personnel**
  - Some communities have enacted landfill bans, and some landfill operators may not accept blades
  - Several countries have banned landfilling of blades (e.g., Austria, Germany, Finland, and the Netherlands).

[3] Oteri, Frank, Heidi Tinnesand, Chloe Constant, and Matilda Kreider. 2023. Wind Energy End-of-Service Guide. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. https://windexchange.energy.gov/end-of-service-guide.

Reuse or Repurposing

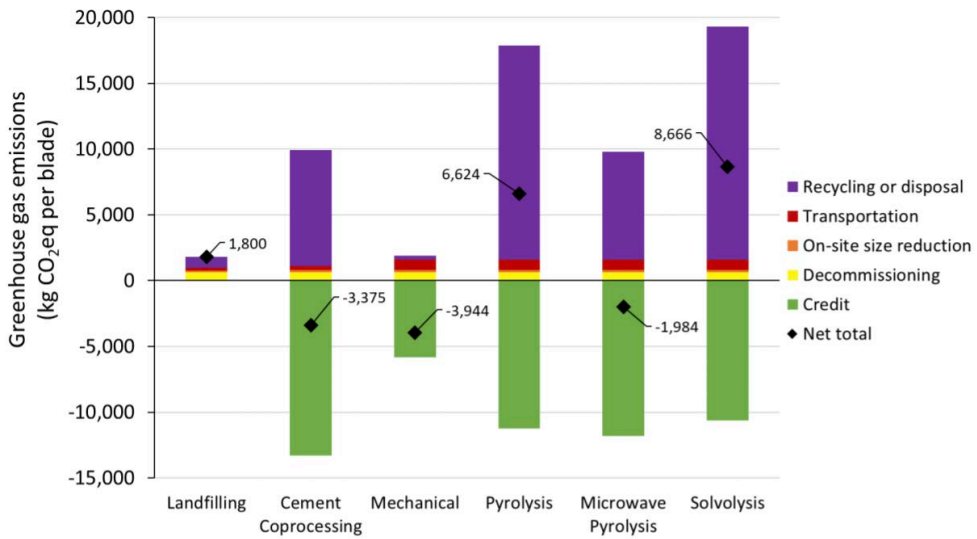
- **Reuse** of components as replacement parts in other wind turbines
    - It is relatively uncommon in the United States to sell components between project owners, but owners may move parts around within their portfolio of projects
- **Repurposing** involves the direct use of the decommissioned component to create new products like pedestrian bridges, playgrounds, benches, bike shelters, fences, and noise barriers.

Left: A repurposed blade that has been used to create outdoor seating. Photo from Anmet

Below: Construction workers install a footbridge across the Szprotawa River in Poland. Photo from Anmet

Life Cycle Analysis for Blade Processing Options

- Recycling processes tend to be energy intensive and produce greenhouse gas emissions
  - For some processes, these emissions may outweigh the benefits of the recycled product they create
- Emissions of all recycling approaches are many times less than the total blade manufacturing emissions[9]
  - Blade recycling is thus an opportunity to **reduce life cycle emissions of blade materials** if it becomes technically and economically feasible to reuse materials to make new blades or other products.[9]



Life cycle greenhouse gas emissions of recycling approaches compared with landfilling.
Figure from U.S. Department of Energy *Road Map for Recycling Energy Systems in the United States*

[9] Christoffel, Tyler et al. Forthcoming. *Road Map for Recycling Wind Energy Systems in the United States Part 1: Providing a Baseline for America's Wind Energy Recycling Infrastructure for Wind Turbines and Systems.* U.S. Department of Energy.

Blade Design

- Research is being conducted to develop wind turbine **blades that are specifically designed to be recycled**
  - Several blade manufacturers, as well as NREL, have developed prototypes
  - One manufacturer, Siemens Gamesa, has set goals of producing fully recyclable blades by 2030 and fully recyclable turbines by 2040[9]
- Replacing traditional thermoset epoxy resin, which is currently used in most blades, with either **thermoplastic resin** or **reversable thermoset resin** could enable more complete recycling.

Construction of a revolutionary 13-meter thermoplastic blade at NREL. A vacuum bag covers the laminate and mold, which is infused with resin.
Photo by Ryan Beach, NREL 62034

[9] State of Green. 2023. "The world's first recyclable offshore wind turbine blades." https://stateofgreen.com/en/solutions/the-worlds-first-recyclable-offshore-wind-turbine-blades/.

State of the Blade Recycling Industry

- There is **no standardized process** or commercial application for recycling blades
- The blade recycling industry, while increasing in size, still has a limited capacity
- As of 2022, blade recyclers in the United States had the **capacity to recycle more than 3,000 blades per year**[10]
    - 3,000-9,000 blades being taken out of service per year currently and 10,000-20,000 per year by 2040[11]
- As new processing methods mature and secondary supply chains are developed, opportunities for blade recycling and repurposing are expected to become more widely available.

Final product that is realized when the mechanical recycling process is complete in Veolia's blade recycling process.
Photo from Veolia

[10] Farzan, S. 2022. "How to Recycle a 150-Foot Wind Turbine Blade? Haul It to Louisiana, MO." *St. Louis Public Radio*. May 27, 2022. https://news.stlpublicradio.org/health-science-environment/2022-05-27/how-to-recycle-a-150-foot-wind-turbine-blade-haul-it-to-louisiana-mo.

[11] Cooperman, A., A. Eberle, and E. Lantz. 2021. Wind Turbine Blade Material in the United States: Quantities, Costs, and End-of-Life Options. *Resources, Conservation and Recycling* 18: 105439. https://doi.org/10.1016/j.resconrec.2021.105439.

Challenges in Expanding Blade Recycling

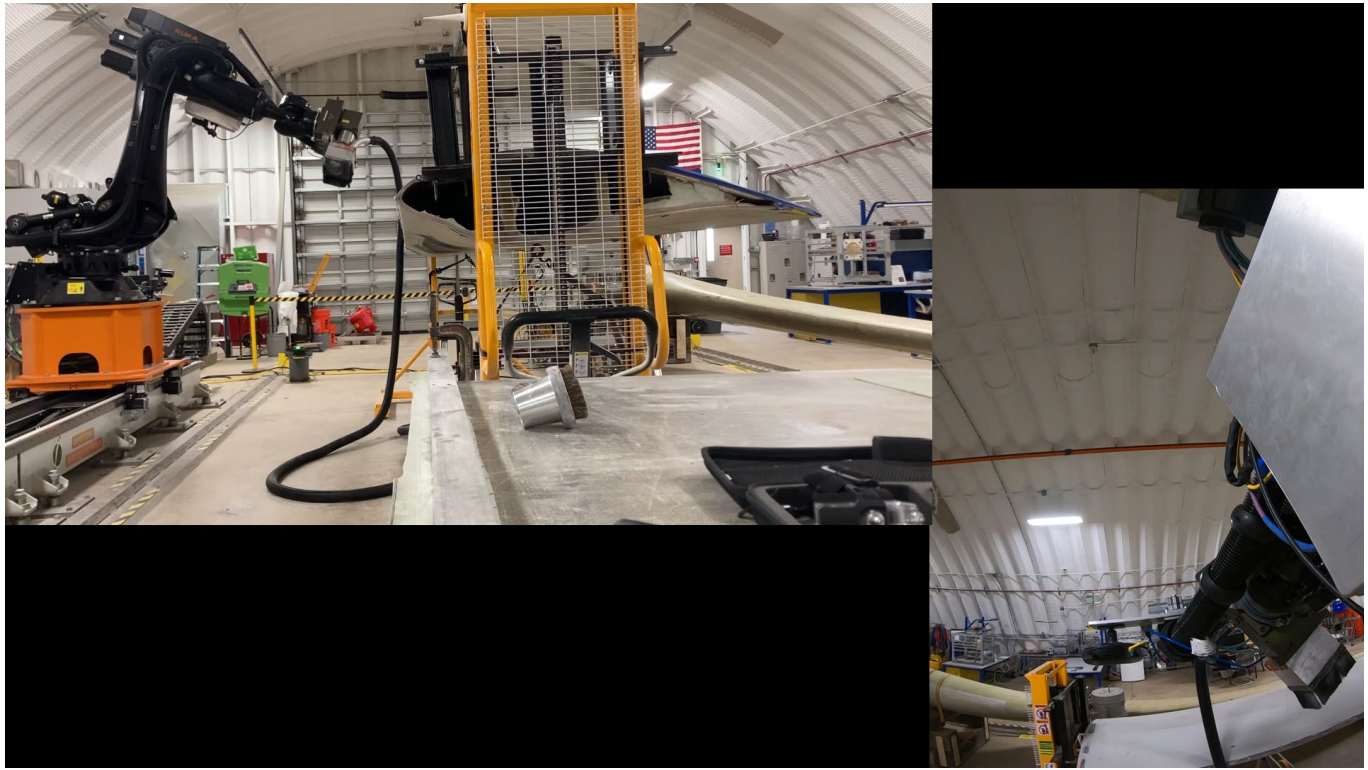
After optimizing it in the lab, the NREL team used their new PECAN resin to glue together a 9-meter wind turbine blade made with fiberglass composites and a balsawood core in NREL's Composites Manufacturing Education and Technology Facility.
Photo by Troy Boro, NREL

- Recycling is more expensive than landfilling and is not yet up to scale
- Recycling facilities likely to be farther away from wind project sites resulting in higher transportation costs for project owners compared to using local or regional landfills
- Inconsistent flow of blade waste means recyclers do not have a steady supply of waste to process, making it difficult to scale up their businesses.

Existing and Potential IACMI Wind Projects

IACMI Automated Wind Blade Finishing

- Automated 3D scanning to autogenerate toolpath for trimming, grinding, and sanding
- Fully automated operations demonstrated to meet project metrics:
  - Sequential path programming
  - Path accuracy in chord direction
  - Cutting and grinding process flexibility
  - Cutting speed
  - Grinding speed
  - Operations compatible with (2) blade rotations
  - Operating at a working height of 5m



Potential IACMI Wind Blade Research Projects

1. [ORNL] Adhesive Deposition Optimization and Monitoring (ADOM) [TPI, LM, NREL]
2. Validation and Scale-up of Bio-Derivable Recyclable-by-Design Resins for Pultruded Spar Caps for Wind Turbine Blades (PECAN) [NREL]
3. Autonomous Wind Turbine Blade Non-Destructive Examination for Increased Manufacturing Quality [EPRI]
4. Helicoid Leading Edge Erosion Protection For Wind Blades
5. Scalable Nanomanufacturing of Nanothermite Additives for Self-heating Adhesive Formulations in Composite Joining [UTK, Miami]
6. New noise reduction composites made of rubber, functionalized graphene and powdered retired wind blades [Graphene TX]
7. [UDRI] Airborne Wind
8. Digitized NDE/NDI [TPI, Aligned Vision, NREL]
9. Workforce development

IACMI Resource Pool Funding: Wind Projects

Funded:

- Preliminary Design and Cost Assessment for the Use of Composite Reinforcements in Place of Traditional Steel Rebar for Concrete Floating Wind Turbine Foundations [UMaine]
- Spinning Chopped Fiberglass Scrap into Continuous Technical Yarns for Reuse [UTK]

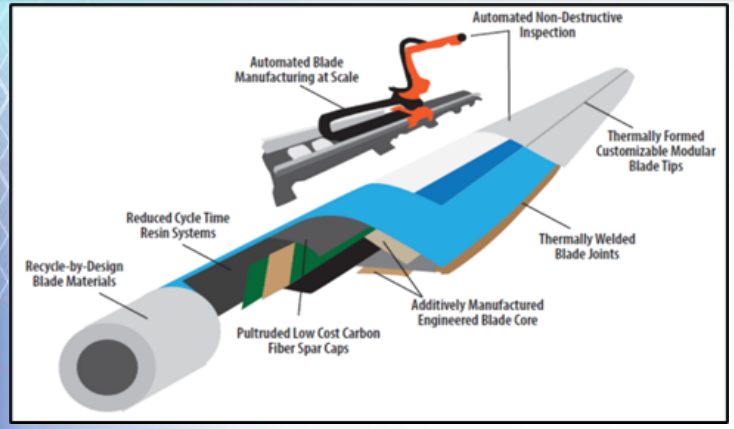
Additional Potential Projects:

- Decommissioned Composite Wind Blades, Upcycled as Structural Members [Pauer Consulting]
- Continuous molding technology for shaped FRP panels with unidirectional continuous E-glass fibers [Perseus]

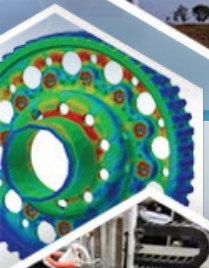
Notes from Wind Energy WG Open Discussion

- Focus on blade subcomponents to introduce new materials and mfg. processes
- Identify challenges and solutions that enable domestic blade production
- Include modular blade technology as an innovation to address challenges
- Consider non-blade composite innovation for floating offshore wind turbines
- Use of NDI/NDE, vision systems, AI - integrated in blade manufacturing process
  - Produce higher quality blades / avoid blade hospital
  - Create full digital record of layer-by-layer, infusion, etc. production process
- Assist in connecting with wind turbine OEMs and blade manufacturers
- TEMs and LCAs – before, during and after projects (NREL models)
- Consistent wind industry messaging: blades, failures, etc.

Wind WG: Action Items and Next Steps



- Discussed wind project proposal process – work with IACMI Wind TAD (Derek Berry) to develop concepts or idea papers
- Help connect IACMI members to wind industry partners
- Update Wind WG membership list
- Schedule next Wind WG: possible virtual meeting in late fall
- Informal discussions at CAMX



Thank you

IACMI Wind Energy Working Group Meeting

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