Assessing the Performance of a Circular Economy for Wind Energy Technologies: A Summary of Three Analytical Tools

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Renewable Energy Materials Properties Database (REMPD)

National Renewable Energy Laboratory. (Under Review). "Renewable Energy Materials Properties Database." Version 1.0. Washington, D.C.: U.S. Department of Energy.

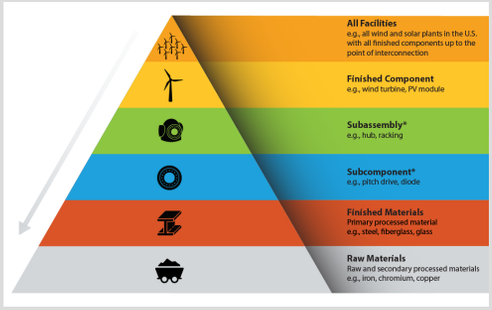
Goal: To develop a comprehensive database of materials used in wind and solar plants, including material quantities and physical materials availability.

Database overview:

- Six-tiered data structure: raw materials, finished materials, subcomponent, subassembly, finished component, all facilities
- Seven types of information: country of origin, source, significant uses, projected availability, physical properties, type, and quantity

Key takeaways:

- Annual U.S. wind energy demand for materials anticipated to be <5% of 2020 global production of most materials through 2050
- REMPD's material intensities and scenario analysis capabilities could inform circular economy opportunities



Taxonomy used to organize data in the REMPD.
*Not all components in the database have data at the subassembly and subcomponent levels.
Source: NREL 2023 (Illustration by Nicole Leon, NREL)

Wind Blade Circular Economy Agent Based Model

Walzberg, J., Cooperman, A., Watts, L., Eberle, A. L., Carpenter, A., & Heath, G. A. (2022). *iScience*, *25*(8), 104734.

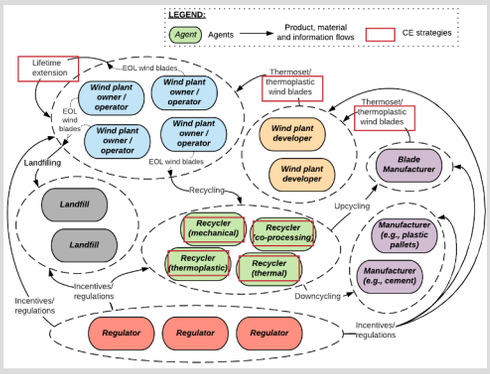
Goal: To understand how wind stakeholders' end-of-life behaviors influence wind blade circularity and evaluate the impact of regional variables (e.g., logistics and transportation).

Model overview:

- Six types of agents: manufacturers, wind plant developers, wind plant owners, recyclers, regulators, landfills
- Three end-of-life (EOL) options: lifetime extension, recycling, landfill
- Two manufacturing options: thermoset blades, thermoplastic blades
- EOL option chosen via extended version of the Theory of Planned Behavior

Key takeaways:

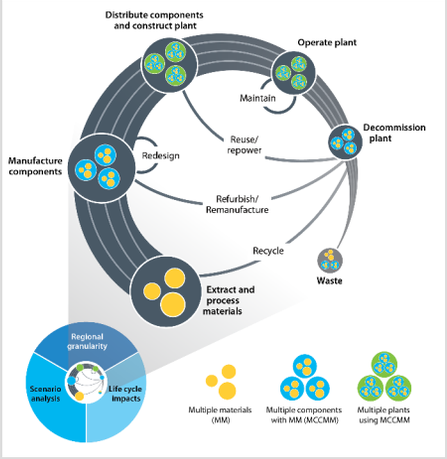
- Recycling early adopters incite new social norms speeding up circularity transition
- Logistical barriers (e.g., permits) and transportation costs significantly affect results



An agent-based model of circular economy (CE) strategies for wind blade.
Source: Modified from Walzberg *et al.* 2022

Circular Economy Lifecycle Assessment and Visualization (CELAVI)

Hanes, R., Ghosh, T., Key, A., & Eberle, A. (2021). *Frontiers in Sustainability*, *2*, 671979.
Ghosh, T., Hanes, R., Key, A., Walzberg, J., & Eberle, A. (2022). *Resources, Conservation and Recycling*, *185*, 106531.



Supply chain structure and material flows in the CELAVI framework.
Source: Modified from Hanes *et al.* 2021

Goal: To create a modular framework that can be used to evaluate the impacts associated with circular economy transitions and to demonstrate the capabilities of the framework by executing a case study on wind blades.

Framework overview:

- Three integrated modeling methods: discrete event simulation, life cycle assessment, network analysis
- Six modules: cost, transportation routing, discrete event simulation, lifecycle analysis impact assessment, supply chain network, visualization
- Data-driven structure accommodates multiple scales (material to component to supply chain) and resolutions (e.g., country, state, county)

Key takeaways:

- CELAVI hybridizes existing methods to meet the demands of modeling circularity transitions and associated impacts, including modeling spatial and temporal dynamics.
- Wind blade case study demonstrates CELAVI's capabilities to evaluate tradeoffs associated circular economy transitions.

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Wind Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Japan-America Frontiers of Engineering Symposia
Tokyo, Japan
July 17-20, 2023
NREL/PO-6A20-86358