United States Wind Turbine Blade Recycling Assessment

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Sandia Blade Workshop

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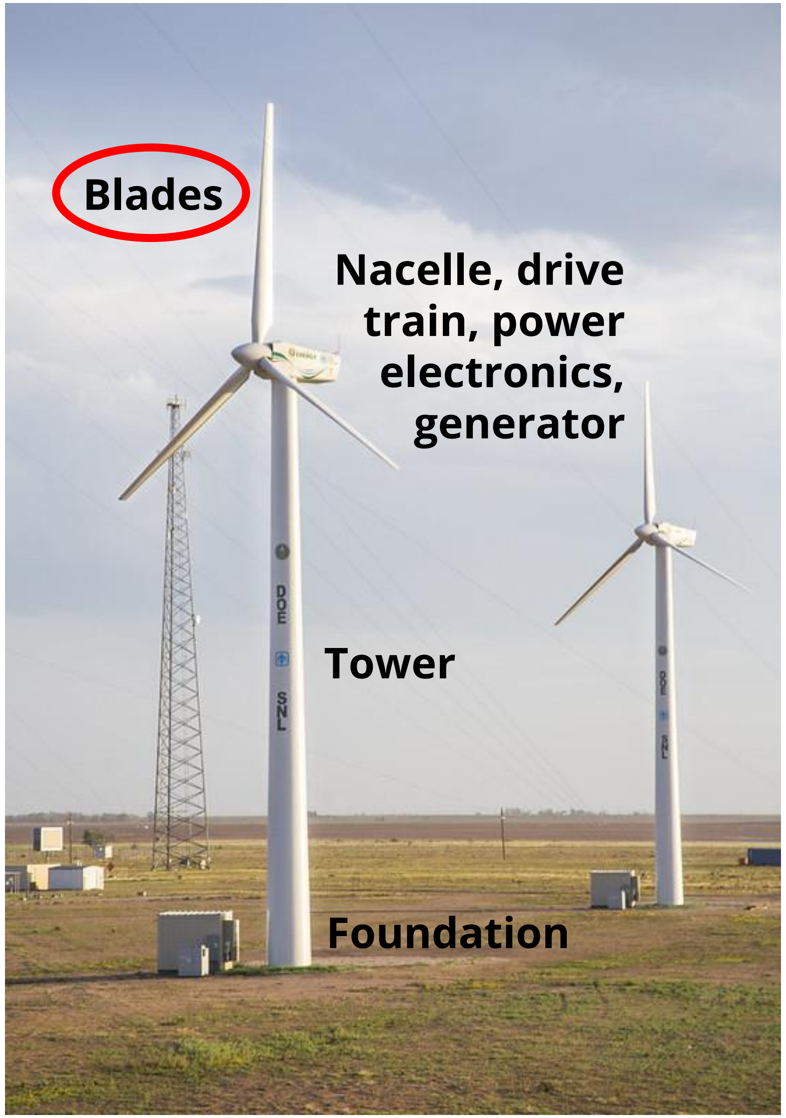
Multi-Lab Assessment of Wind Recycling



Blade Recycling Assessment Team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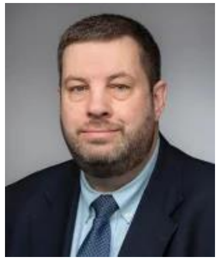
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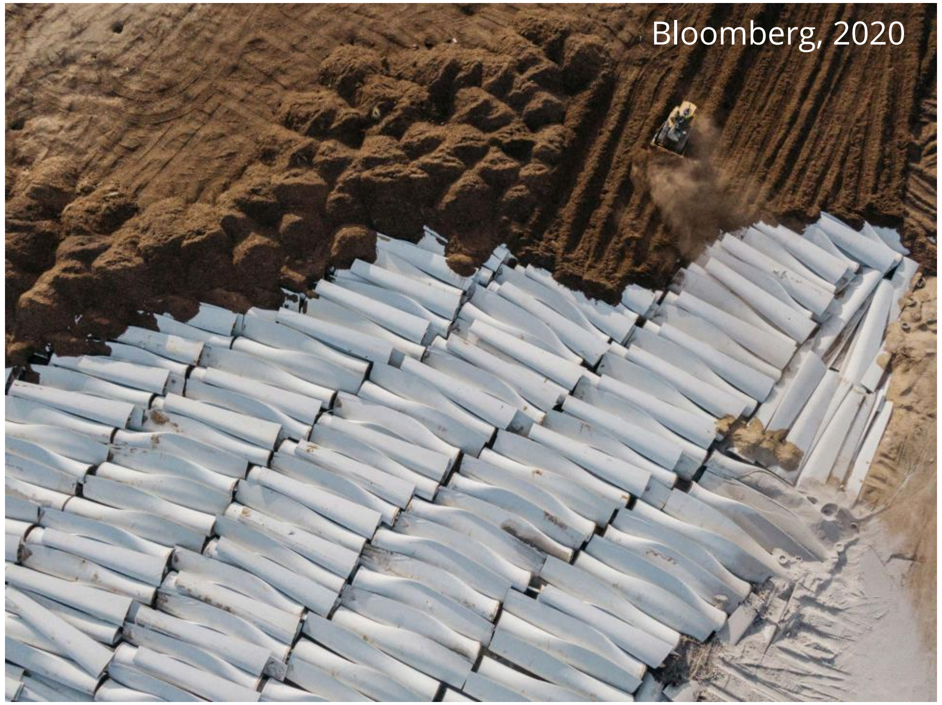
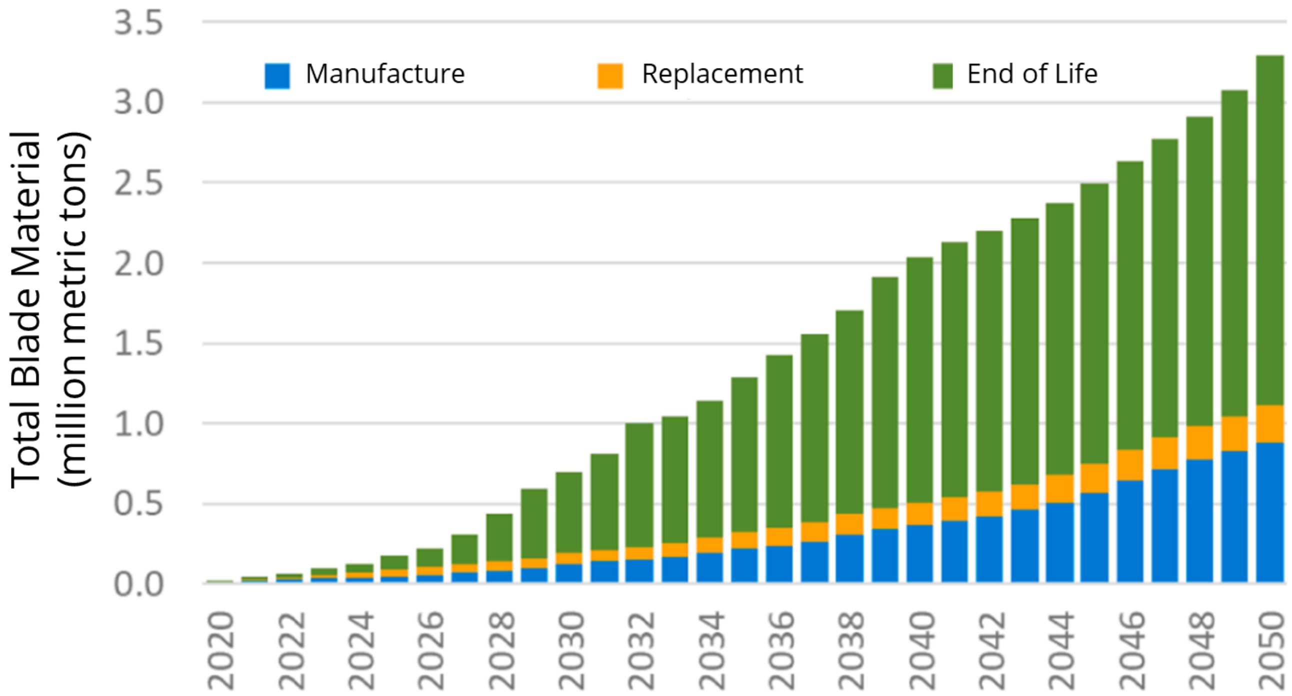
End of Life Wind Turbine Blades

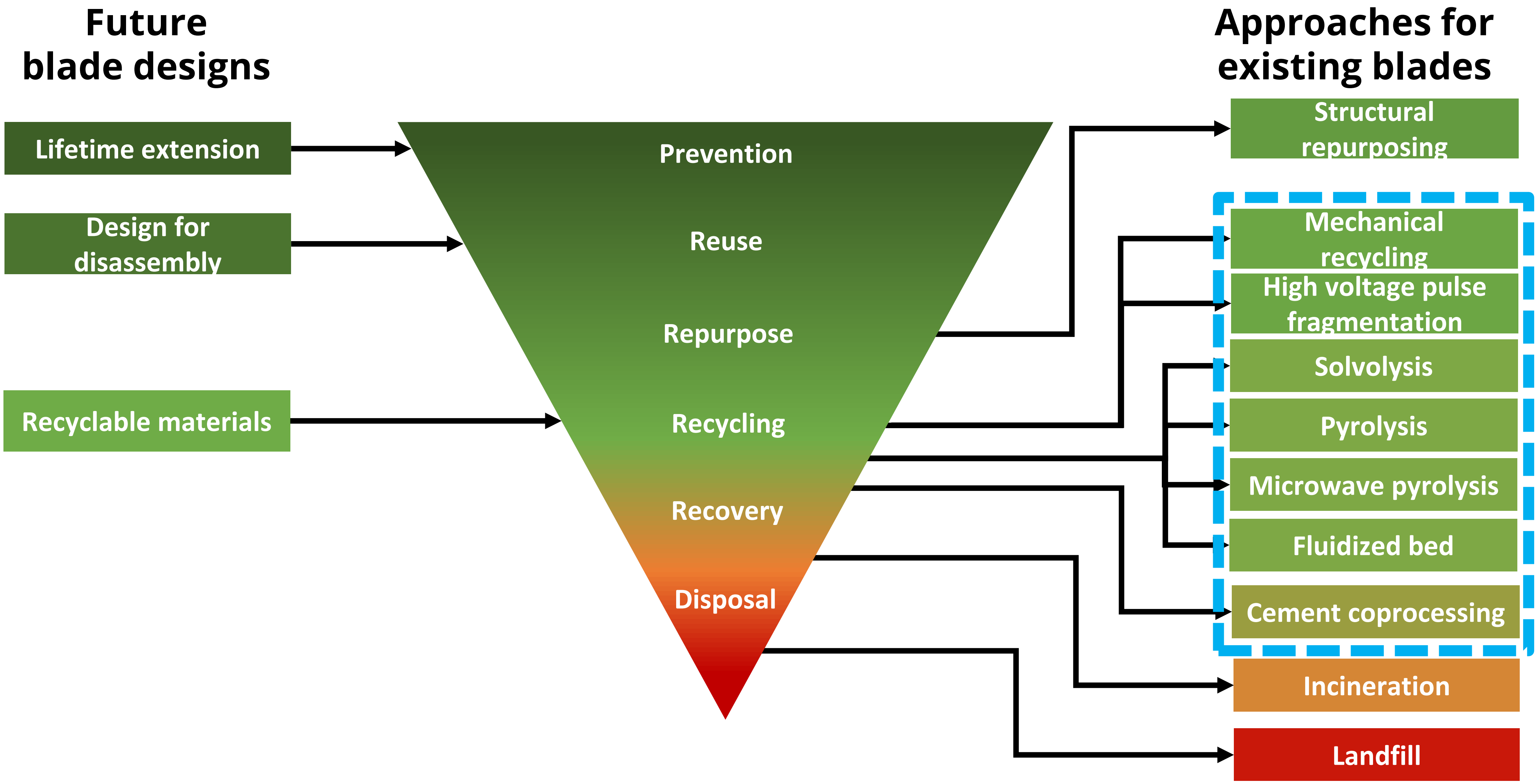




Cooperman et al. 2021

Over two million metric tons of end of life material in U.S. by 2050

Blade Recycling and End of Life Approaches



Blade Recycling and End of Life Approaches

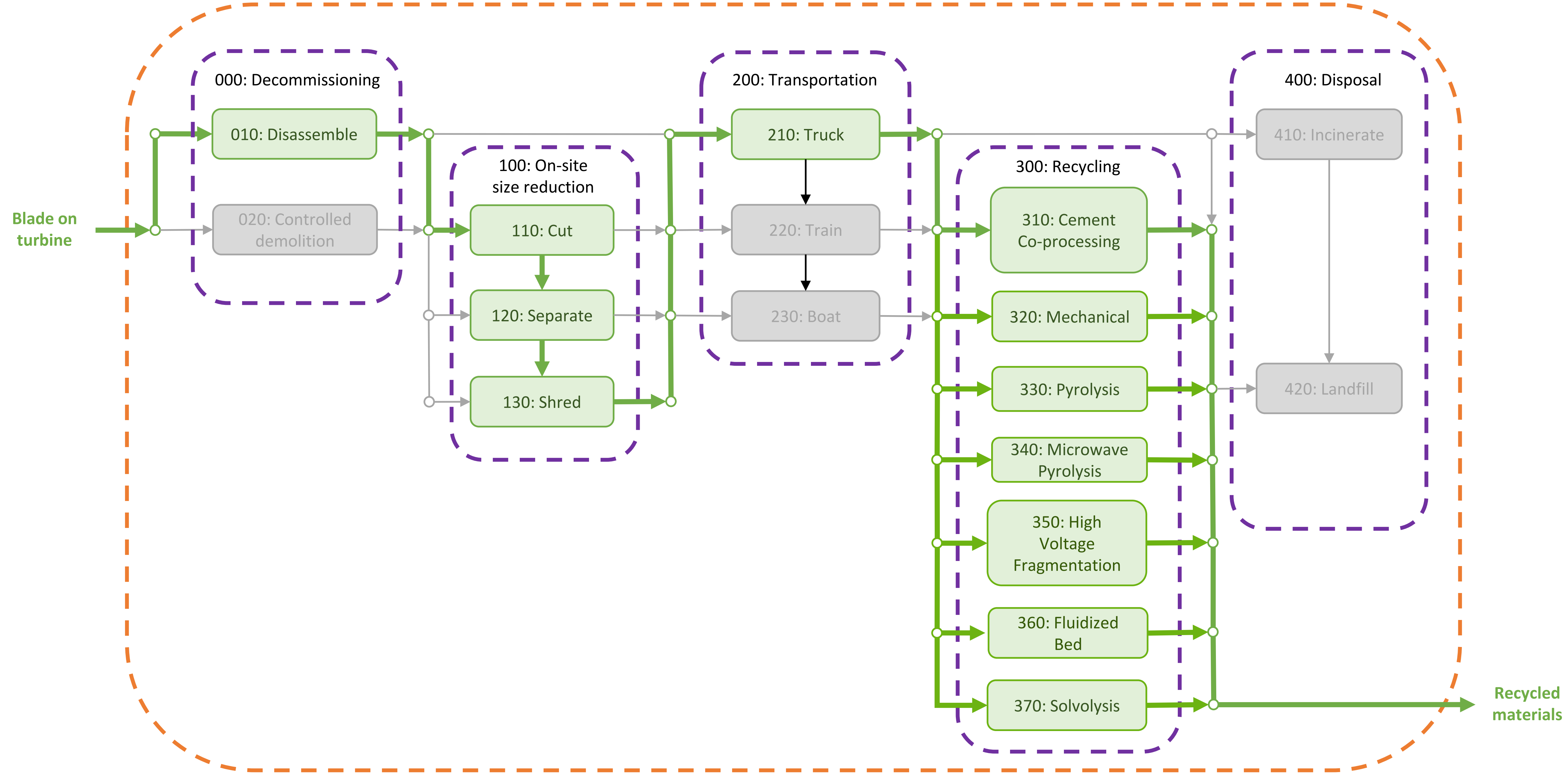
Future blade designs

Approaches for existing blades

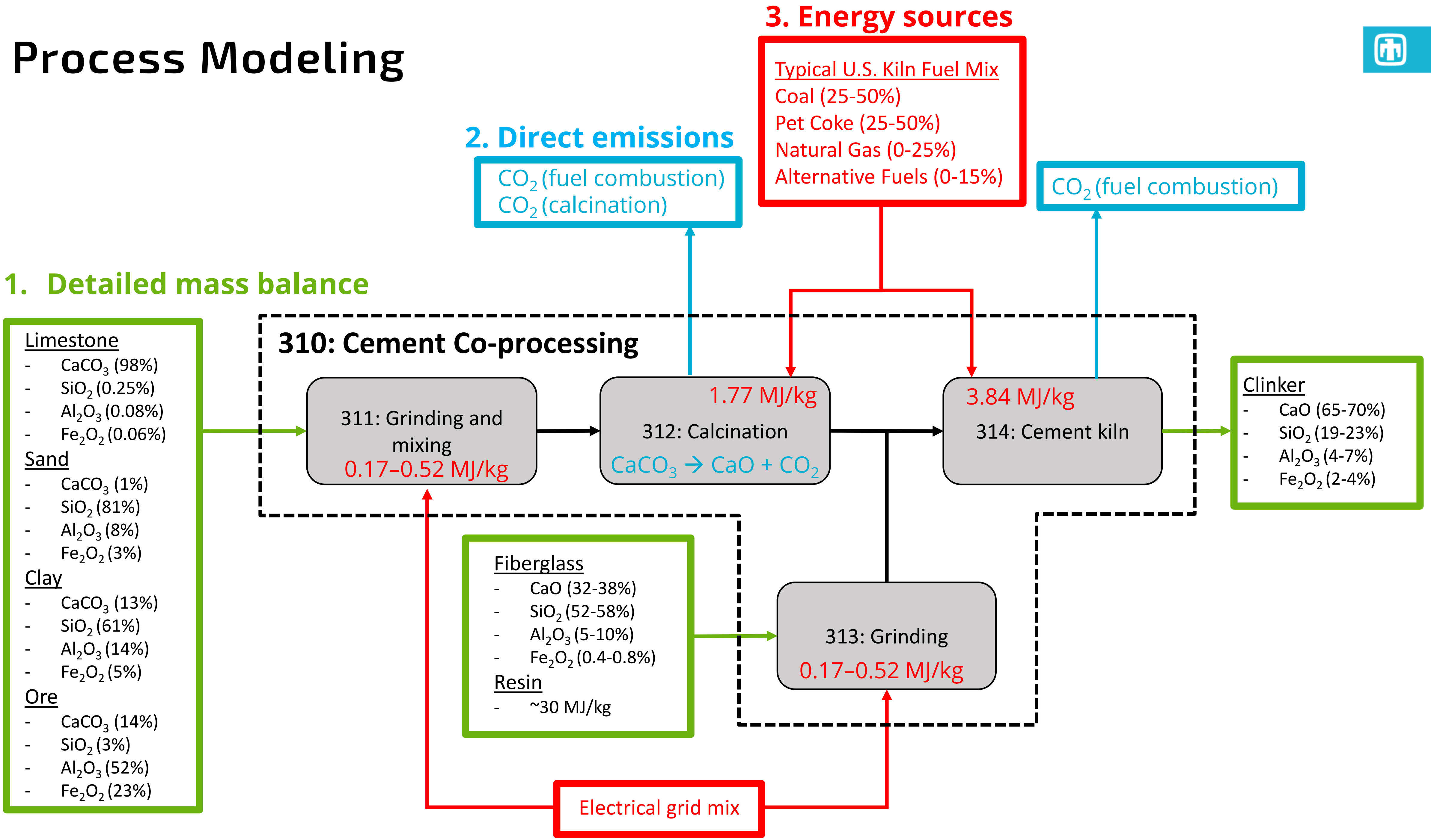
Are these approaches actually better for the environment, and what are the associated challenges?

Are there opportunities to extract higher value out of retired wind turbine blades?

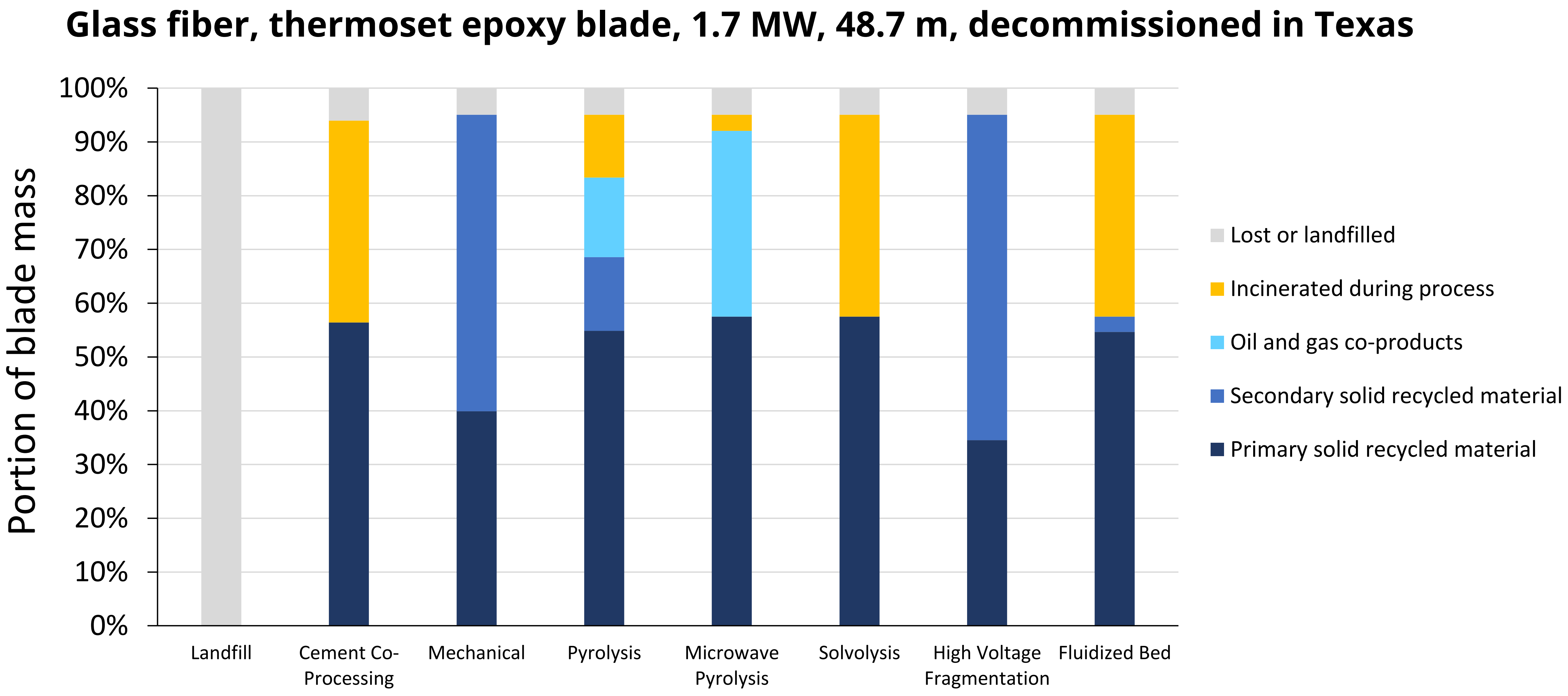
Life Cycle Inventory



Process Modeling

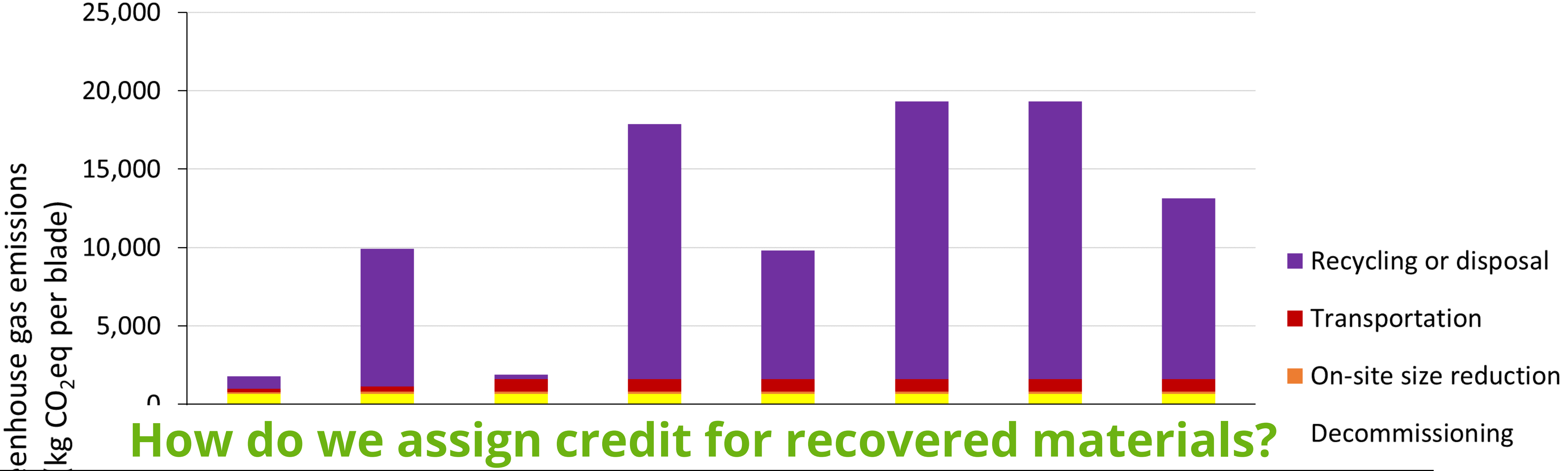


Mass Yield Results



Greenhouse Gas Emissions Results

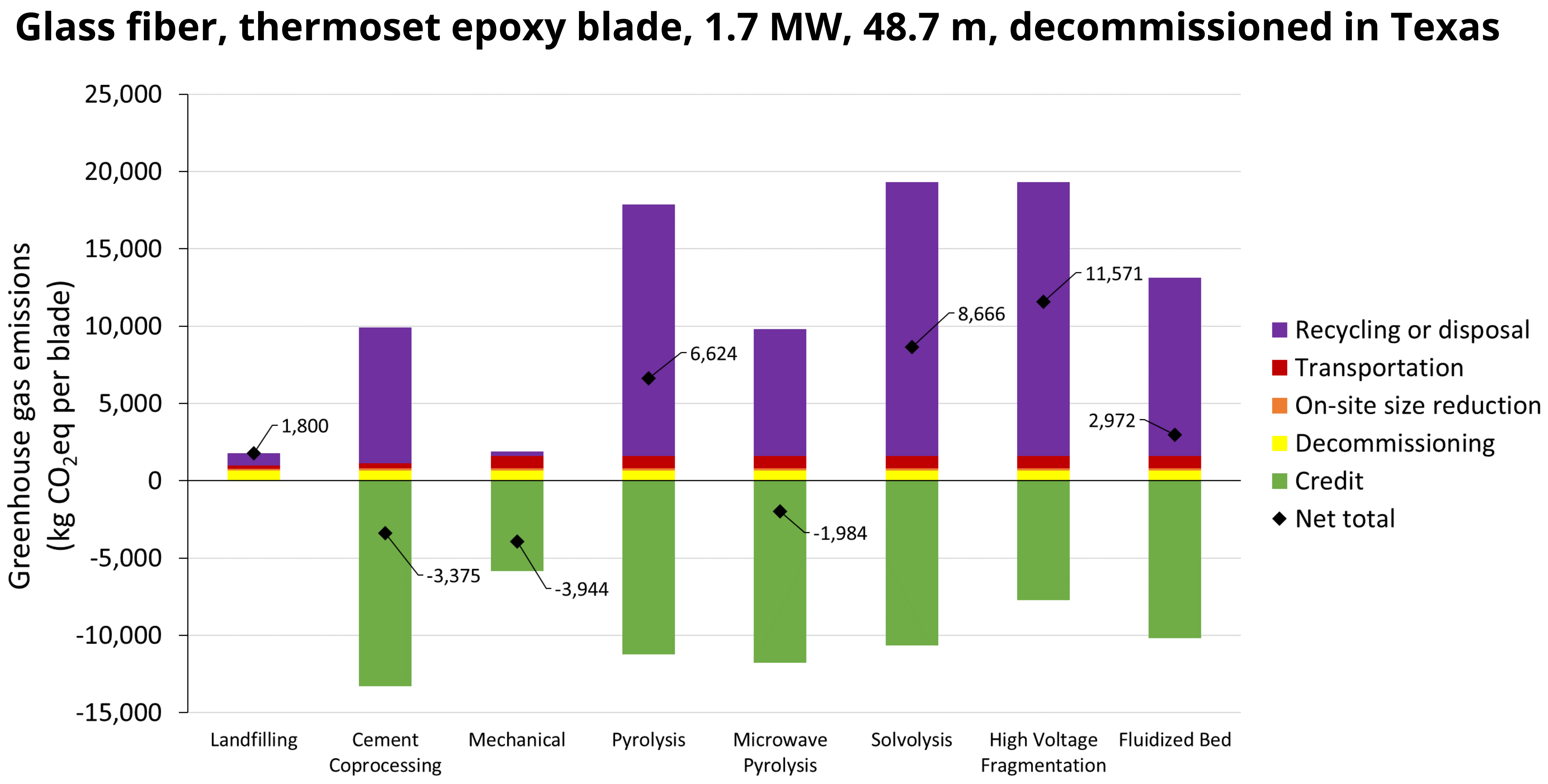
Glass fiber, thermoset epoxy blade, 1.7 MW, 48.7 m, decommissioned in Texas



How do we assign credit for recovered materials?

Recovered material	Virgin material credit	Property of interest	Portion of credit
Cement Clinker	Cement Clinker	All properties	100%
Fiberglass	Fiberglass	Tensile strength	50-80%
Powder	Mortar	All properties	100%
Oil	Light Fuel Oil	Heating value	82%
Gas	Natural Gas	Heating value	72%

Greenhouse Gas Emissions Results



Greenhouse Gas Emissions Results

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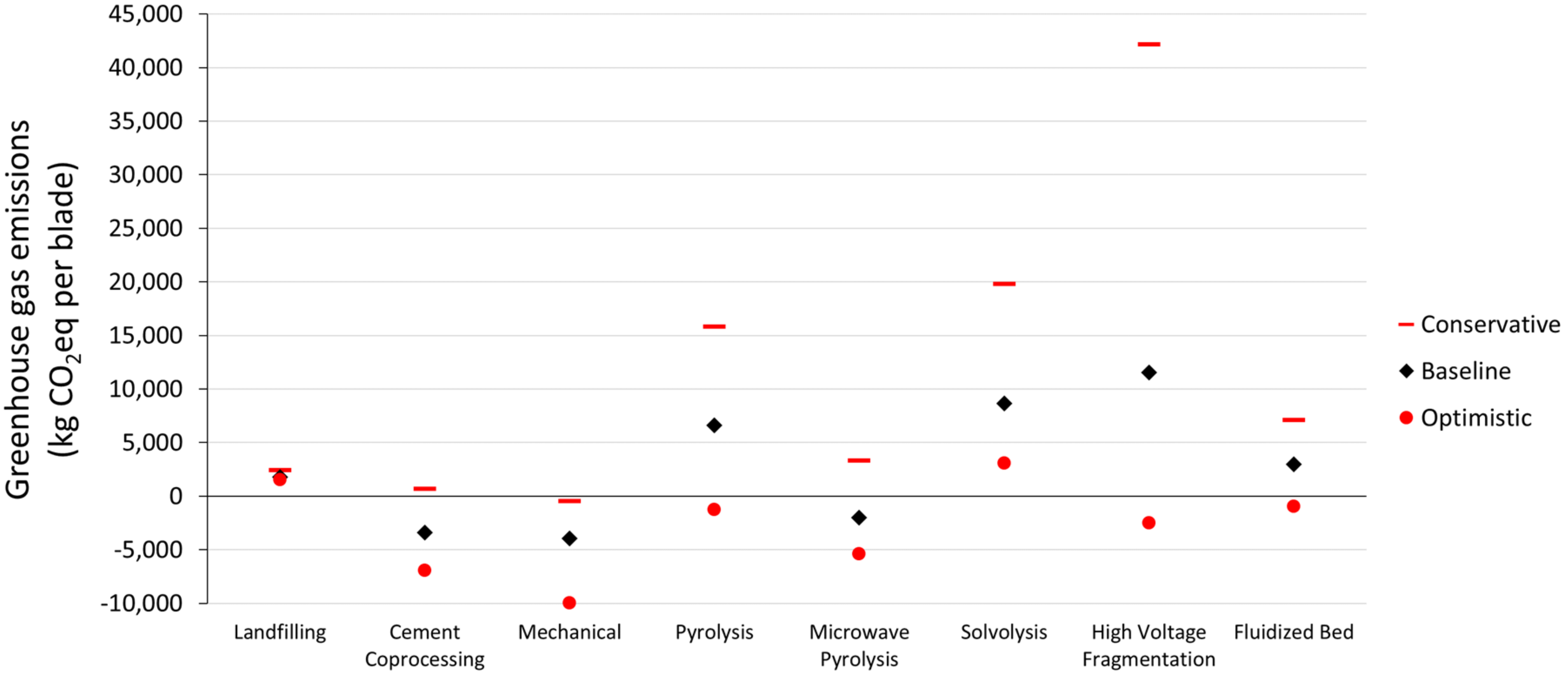
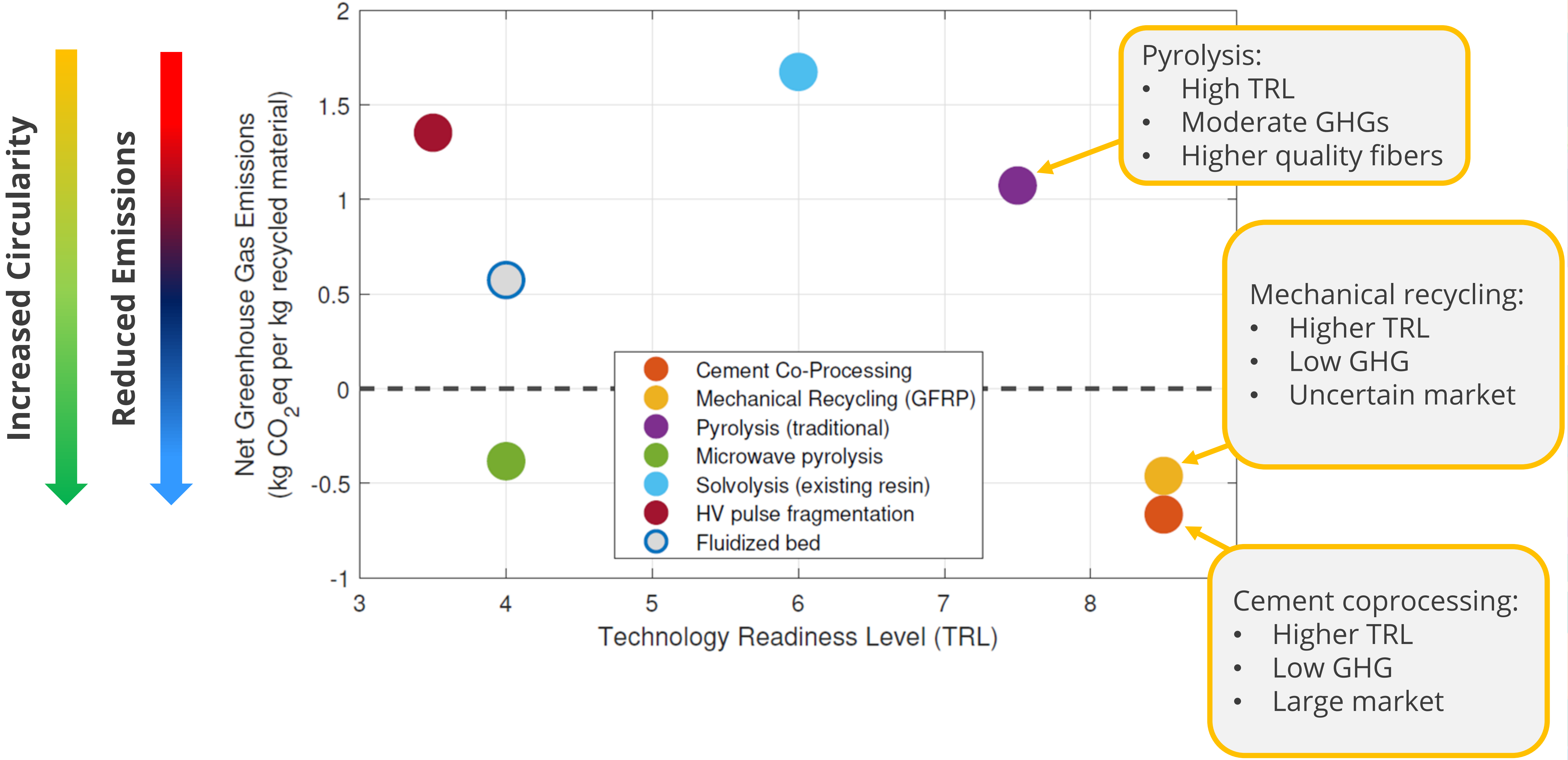
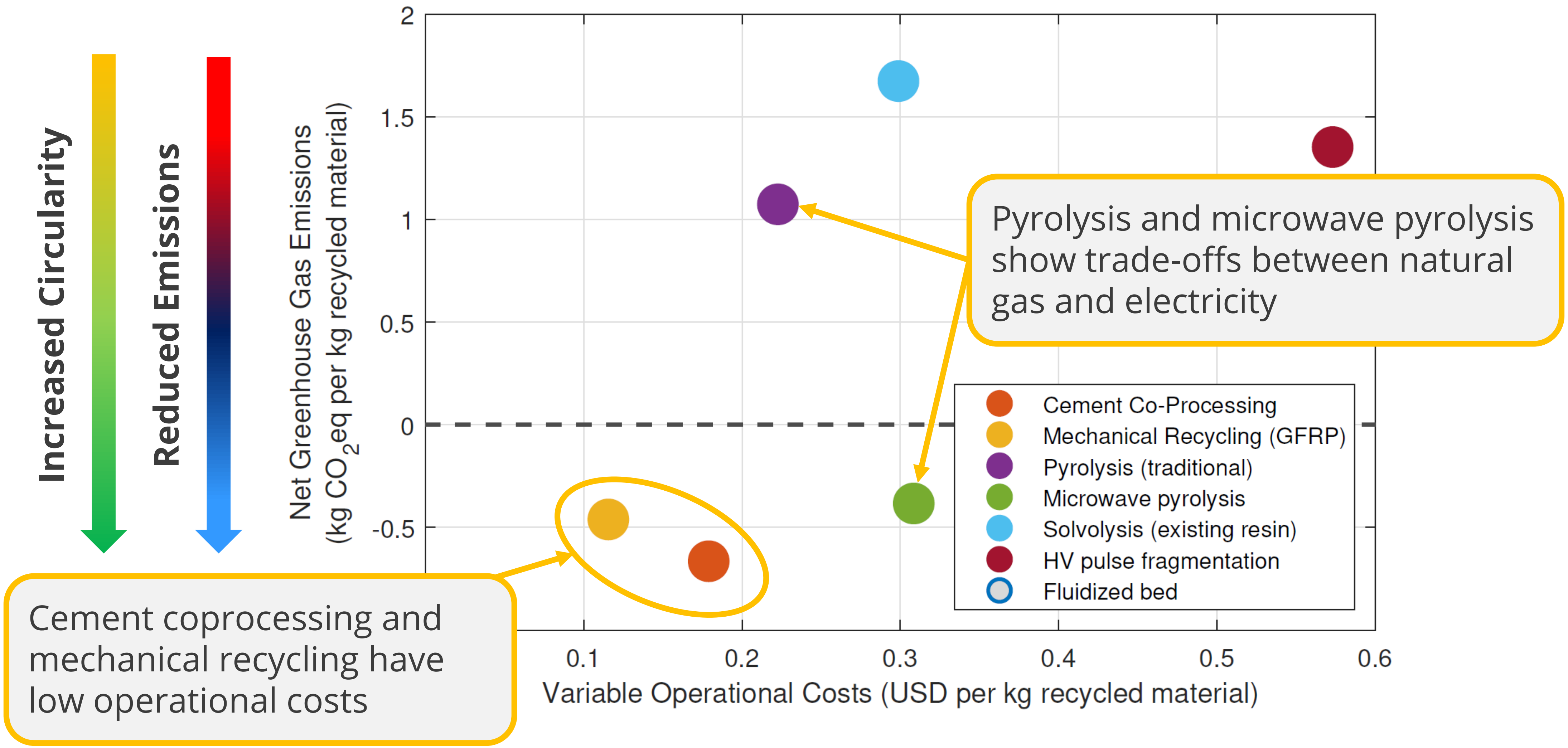


Multi-Metric Results



Multi-Metric Results



Alternative Materials

Materials	Glass fiber with Thermoset Epoxy (kg)	Blades with Alternative Materials	
		Carbon-Fiber Spar (kg)	Recyclable Resin (kg)
Glass fiber	5,283		
Carbon fiber	0		
Thermoset epoxy resin	2,401		
Separable thermoset resin	0		
Balsa	416		
Gelcoat	180		
Adhesive	450		
Steel	270		
Total mass	**9,000**		

Alternative Materials

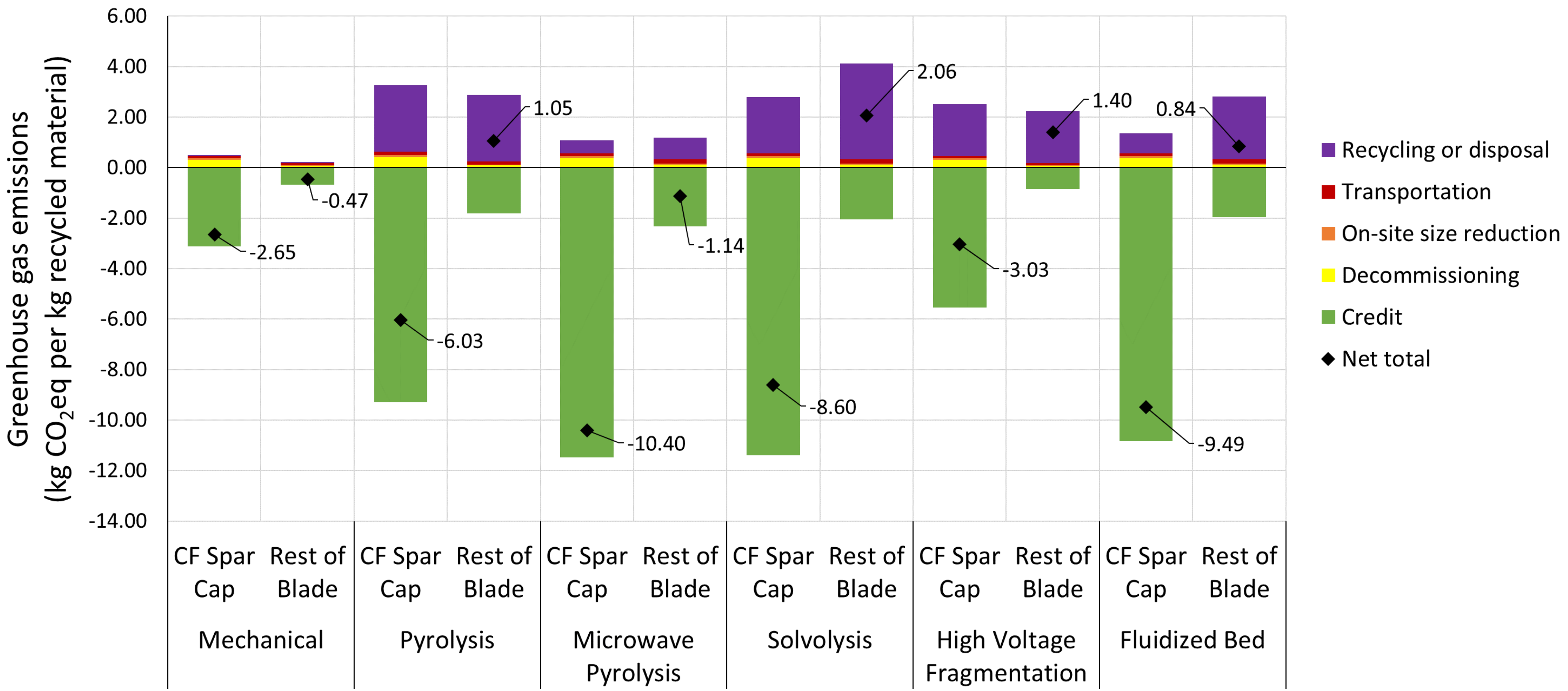
Materials	Glass fiber with Thermoset Epoxy (kg)	Blades with Alternative Materials	
		Carbon-Fiber Spar (kg)	Recyclable Resin (kg)
Glass fiber	5,283	6,224	
Carbon fiber	0	1,198	
Thermoset epoxy resin	2,401	3,685	
Separable thermoset resin	0	0	
Balsa	416	839	
Gelcoat	180	265	
Adhesive	450	664	
Steel	270	398	
Total mass	**9,000**	**13,273**	

Carbon fiber

Larger blade

Results with Carbon Fiber Spar Cap

Carbon fiber spar blade, 2.82 MW, 62.2 m, decommissioned in Texas



Alternative Materials

Materials	Glass fiber with Thermoset Epoxy (kg)	Blades with Alternative Materials	
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Glass fiber	5,283	6,224	5,283
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Gelcoat	180	265	180
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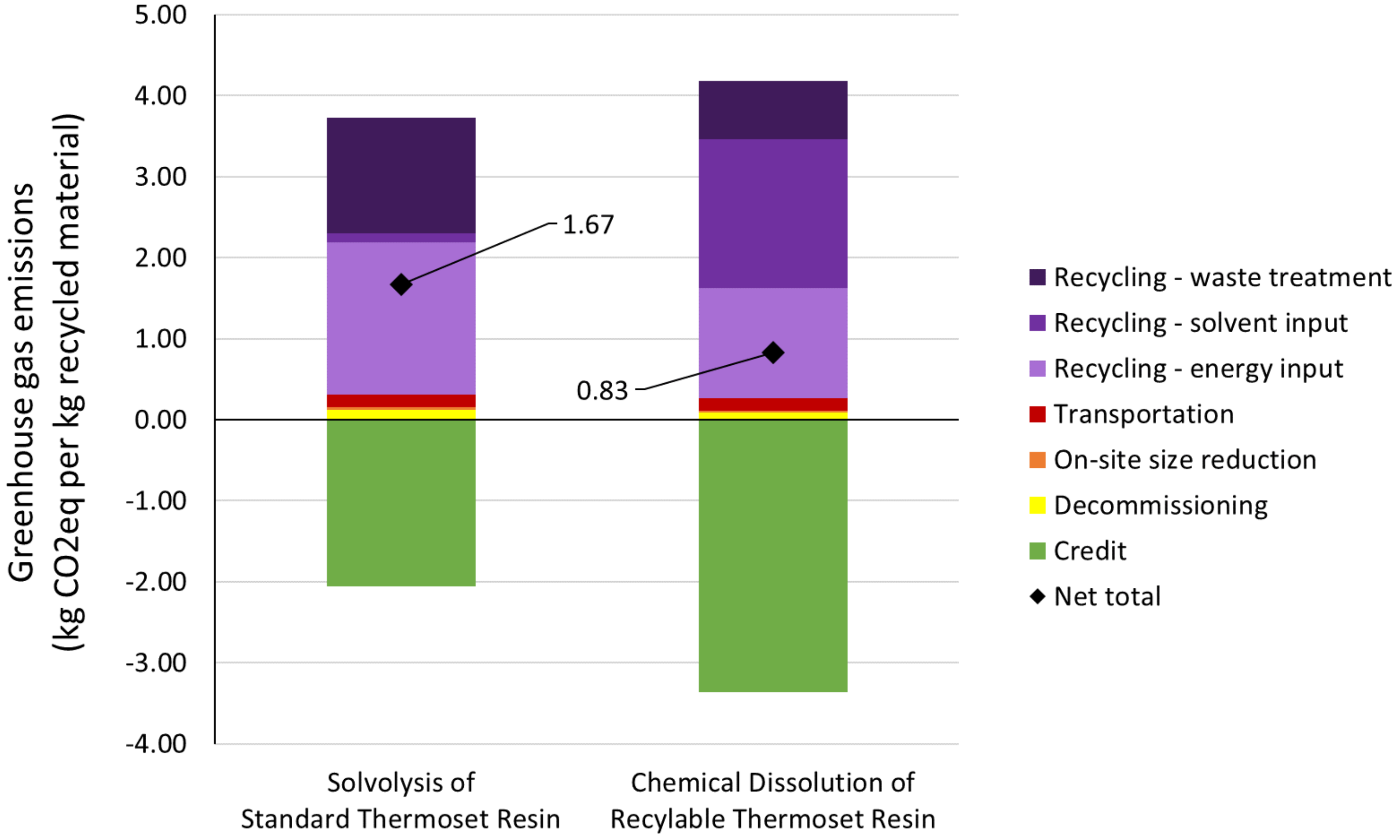
Recyclable resin

Recyclable Thermoset Resin Systems

Recyclable thermoset findings:

- Lower input energy
- Higher recycling credit
- Solvent recovery uncertain
- Likely to result in lower net GHGs



Key Takeaways

1. **Cement coprocessing and mechanical recycling are promising near-term solutions**
   - Decommissioning, downsizing, and transportation bottlenecks exist
   - Market for mechanically recycled products unknown

2. **Alternative materials (carbon fiber, recyclable resins) change the landscape**
   - Recycled products have higher value
   - Separation and recovery of high quality recycled materials should be prioritized
   - Advanced chemical and thermal methods become necessary

Bonus insight: Decarbonization of energy and industry has mixed impacts on results

Dissemination of Findings

To be published in 43rd Risø International Symposium on Materials Science,
IOP Conf. Series: Materials Science and Engineering (2023), IOP Publishing, doi:10.1088/1757-899X/

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United States

To be published in 43rd Risø International Symposium on Materials Science,
IOP Conf. Series: Materials Science and Engineering (2023), IOP Publishing, doi:10.1088/1757-899X/

Life cycle assessment of wind turbine blade recycling approaches in the United States

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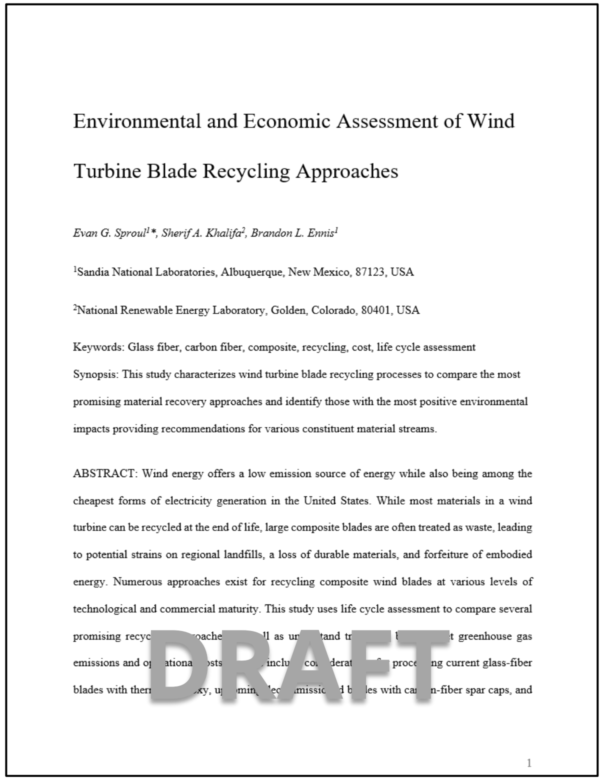
Abstract. Most wind turbine blades reaching end-of-life are sent to landfill where embedded cost, energy, and materials are lost. To avoid landfilling future blades, a broad range of recycling and material recovery approaches have been proposed as solutions in the U.S., each with benefits, challenges, and varying levels of technical maturity. The approaches include 1) cement co-processing, 2) mechanical recycling, 3) pyrolysis, 4) microwave pyrolysis and 5) solvolysis. While these approaches are all capable of recovering various forms of materials for use in secondary markets, there are trade-offs between material circularity, reducing harmful environmental emissions, and cost-effectiveness for the U.S. market. Life cycle assessment (LCA) is a critical step needed to compare these trade-offs and determine where future research and development should be focused. As a result, some previous LCA has been performed on recycling approaches. However, attempts to quantify and compare greenhouse gas emissions across a broad range of technologies have been limited, particularly within the U.S. market where landfill availability and costs do not hinder disposing of wind blades. This work addresses this limitation by presenting a detailed comparison of LCA greenhouse gas emissions and material yields from a range of wind turbine blade recycling approaches in the U.S. The LCA presented in this work includes baseline results, as well as a variety of sensitivity and scenario analyses that look at the impact of process modelling uncertainty, future energy mixes, and other critical input parameters. Overall, results show that mechanical recycling and microwave pyrolysis have the lowest net greenhouse gas emissions. However, the value of mechanically recycled materials is highly uncertain, as mechanical recycling generates a mixed feedstock that may underperform compared to virgin materials. Cement co-processing has higher net emissions than mechanical recycling or microwave pyrolysis but does generate a value-added feedstock that offsets virgin material from mining for cement production. Other advanced thermal and chemical recycling methods such as pyrolysis and solvolysis have higher net emissions due to increased energy consumption but are also highly sensitive to thermal energy sources within the model.

Published conference proceedings



Environmental and Economic Assessment of Wind Turbine Blade Recycling Approaches

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Keywords: Glass fiber, carbon fiber, composite, recycling, cost, life cycle assessment

Synopsis: This study characterizes wind turbine blade recycling processes to compare the most promising material recovery approaches and identify those with the most positive environmental impacts providing recommendations for various constituent material streams.

ABSTRACT: Wind energy offers a low emission source of energy while also being among the cheapest forms of electricity generation in the United States. While most materials in a wind turbine can be recycled at the end of life, large composite blades are often treated as waste, leading to potential strains on regional landfills, a loss of durable materials, and forfeiture of embodied energy. Numerous approaches exist for recycling composite wind blades at various levels of technological and commercial maturity. This study uses life cycle assessment to compare several

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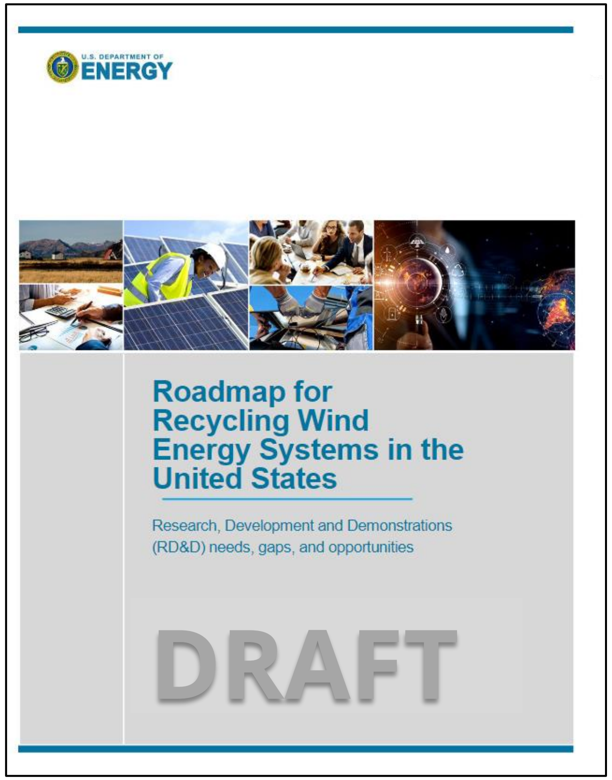
Journal article (in review)



Technical report (in review)

Sandia National Laboratories

Questions or feedback?

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