LCA Curricular Applications for Battery, Semiconductor and Transportation Workforce *

Integrating LCA into the Curriculum

Project Goal:

To build curriculum that can be integrated into courses.

Approach

Develop LCA applications related to the energy, semiconductor and transportation/aviation certificates and curriculum

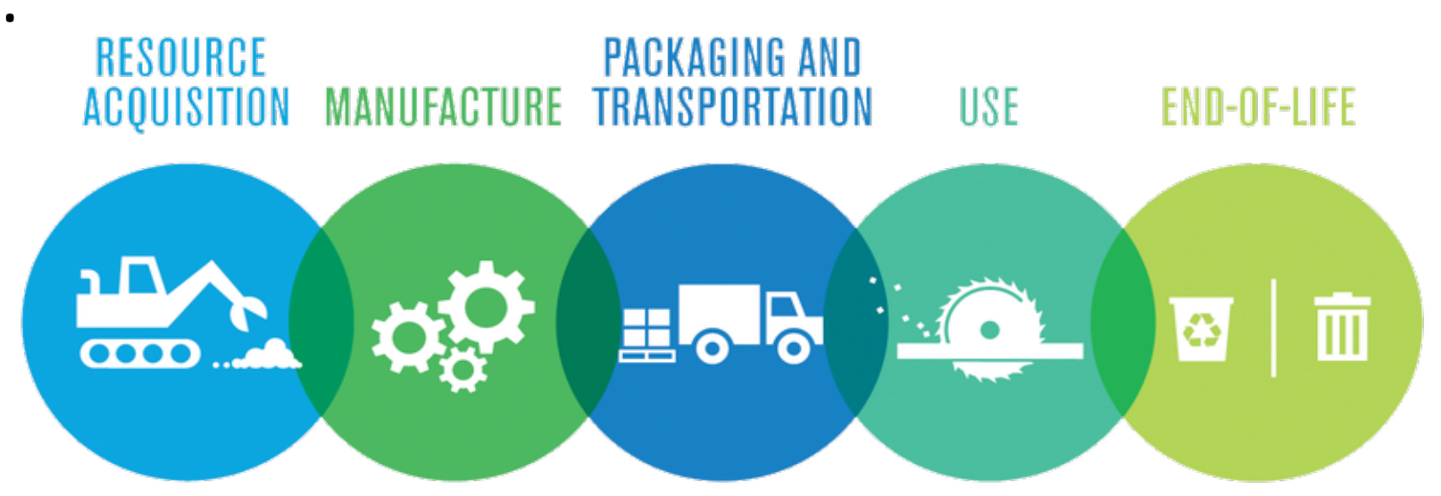
Module 1: ABET EAC SO 2 AND 4

The value proposition for Life Cycle Analysis in engineering?

Life Cycle Analysis (LCA) is a systematic method for evaluating the environmental impact of a product or material throughout its lifecycle. From resource acquisition to manufacturing, transportation, usage, and end-of-life disposal, LCA provides a cradle-to-grave assessment of environmental effects. By identifying hotspots of energy consumption, greenhouse gas emissions, and waste, LCA empowers researchers and industries to design more sustainable solutions.

Why is LCA Important?

In an era defined by environmental challenges, LCA is critical for quantifying and reducing the ecological footprint of materials and processes. Traditional materials like petroleum-based resins have enabled technological progress but come with significant environmental costs, such as high carbon emissions and resource depletion. Integrating LCA ensures that advancements in fields like semiconductors, drone manufacturing, and battery systems prioritize both performance and sustainability.



Materials Selection for Design: Contemporary applications.

LCA serves as a unifying framework for evaluating the innovative materials explored in this work. High volume applications such as computer circuit boards have epoxy resin and ceramic fillers. New applications in batteries are requiring additional criteria such as thermal conductivity and dielectric strength. Unmanned aerial vehicles present an opportunity to deliver goods to rural communities or reach hazardous environments for monitoring. Thus we developed curriculum that can lay the foundation for a future workforce that can consider new material alternatives as well as add measurements to support the attainment of high performance required for reliable performance. Whether optimizing bio-based epoxy composites for mold compounds, designing drone components with PLA and recycled PET, or improving thermal and dielectric properties in EV batteries, the insights from LCA guide decision-making and material selection.

Insights from Our Work

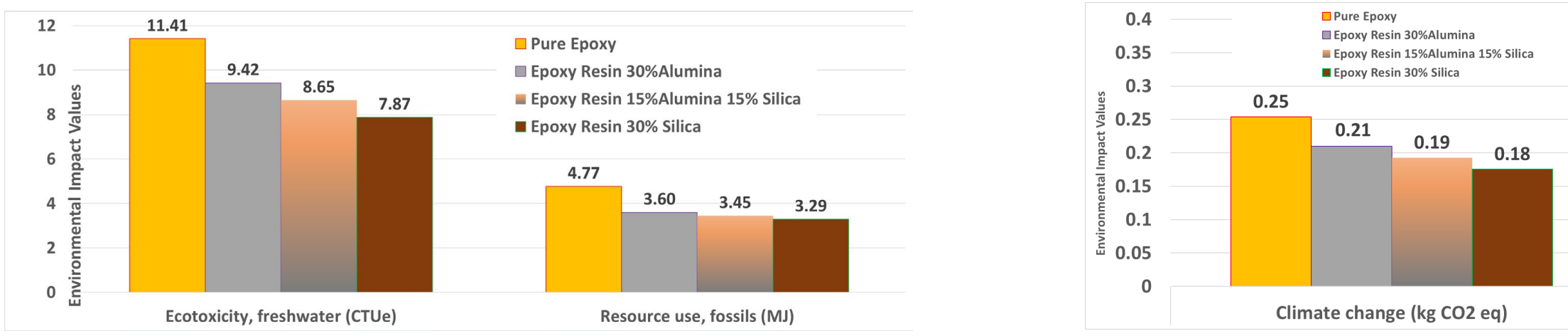
Environmental Hotspots: Material production consistently emerged as the most energy-intensive phase, emphasizing the importance of sustainable raw materials like PLA and recycled PET.

Sustainability Gains: The incorporation of bio-based materials, natural fibers, and recycled components demonstrated measurable reductions in greenhouse gas emissions and resource consumption.

Performance-Sustainability Balance: LCA underscores the trade-offs between functional performance (e.g., thermal conductivity, dielectric strength) and environmental impact, enabling informed optimization.

A Path Toward Sustainable Engineering

LCA transforms how we approach material design by quantifying environmental impact and integrating sustainability into innovation. By applying this framework, our work not only advances the development of high-performance materials but also contributes to the broader mission of mitigating climate change and promoting resource efficiency.



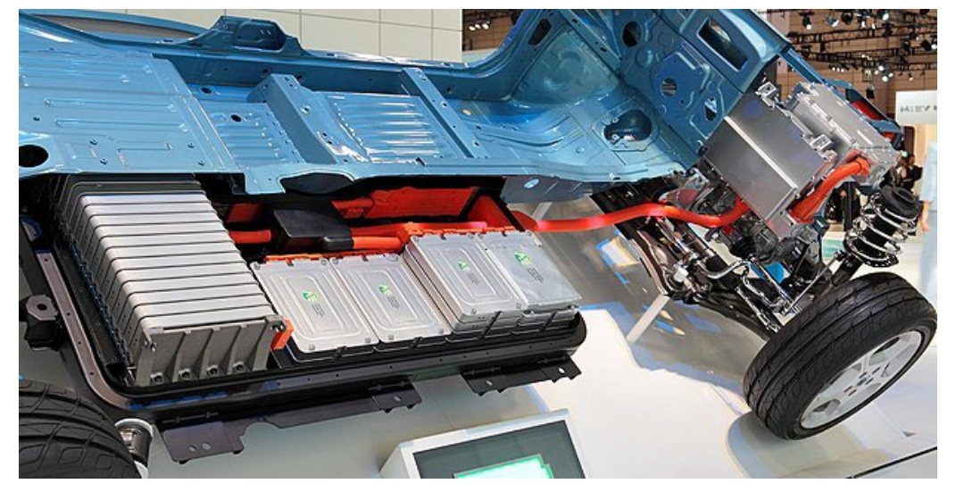
Adding ceramics to epoxy decreases the carbon footprint. LCA indicates silica contributes more than alumina [1]

Advancing Sustainable Materials for EV Battery Applications

Energy Certificate

The Need for Innovation

Electric vehicles (EVs) are at the forefront of reducing carbon emissions in transportation, but their success hinges on efficient and sustainable battery systems. These batteries must dissipate heat effectively, operate safely under high voltages, and minimize their environmental footprint. To address these challenges, our research explores bio-based epoxy composites reinforced with Boron Nitride (BN) and Silicon Dioxide (SiO_2) as transformative materials for EV battery systems.



Advancing Sustainable Materials for EV Batteries

Reimagining Battery Materials

Petroleum-based epoxy resins have traditionally dominated battery systems, but their high carbon emissions and resource depletion demand sustainable alternatives. This research introduces soy-based epoxy resins reinforced with Boron Nitride (BN) and Silicon Dioxide (SiO_2) as a transformative solution. These composites achieve a crucial balance between sustainability and performance, paving the way for next-generation EV batteries.

Thermal Management and Electrical Safety

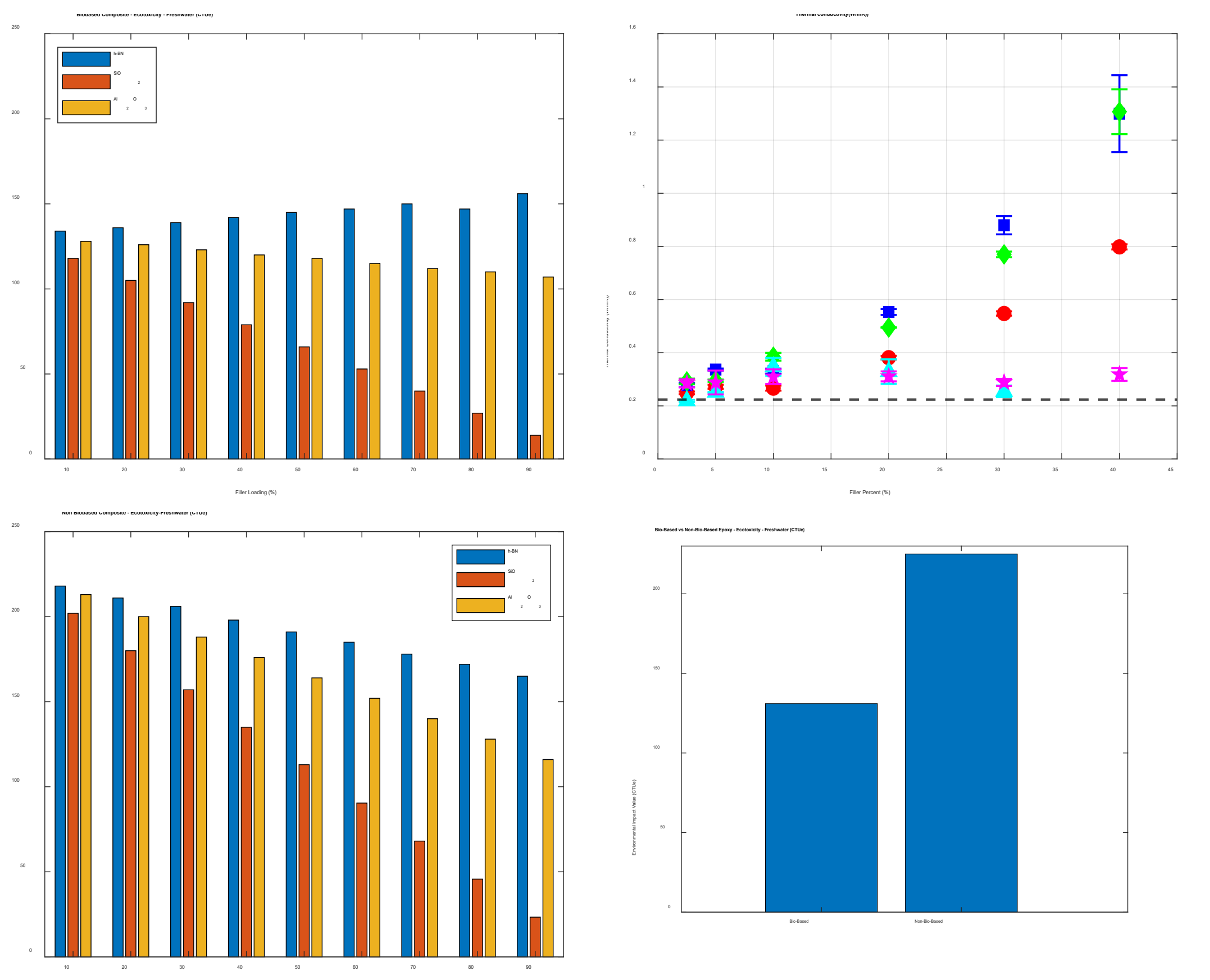
Efficient heat dissipation and electrical insulation are critical to battery performance and safety. BN fillers significantly enhance thermal conductivity, enabling batteries to operate at cooler temperatures, extend lifespan, and remain stable under high-power demands. Additionally, BN's superior dielectric breakdown strength ensures safe operation under high voltages, preventing failures and improving system reliability.

Sustainability at the Core

Life Cycle Analysis highlights the environmental benefits of bio-based materials. Compared to traditional resins, BN and SiO_2 composites dramatically reduce CO_2 emissions and fossil fuel dependency, making them essential for the future of sustainable EV technology.

A Cleaner Future for Transportation

The versatility of these bio-based composites allows them to play pivotal roles as structural components or thermal interfaces in EV batteries. By integrating advanced materials with sustainability principles, this research contributes to a cleaner, greener future for transportation.



Comparing a biobased epoxy (soy) to a non biobased epoxy, benefits to LCA are obtained as ceramics are added. For battery applications, high ceramics are needed for heat dissipation so functional and LCA beimpacts are obtained through critical thinking and design. (Software: Excel and Ecoinvent database) [1]

Machine Learning and Design of Experiments Application for Mold Compounds with Data-Driven Insights (ABET EAC SO1)

Epoxy molding compounds are critical to semiconductor packaging, providing thermal management and structural stability under challenging conditions. Our work focuses on reimagining these compounds through sustainable bio-based epoxy matrices and strategic filler additions. By leveraging fillers such as Boron Nitride (BN) and Silicon Dioxide (SiO_2), we aim to create materials that meet both performance demands and environmental objectives. Advanced analytical techniques like Design of Experiments (DOE) and machine learning enabled us to identify the ideal combinations of fillers and compositions.

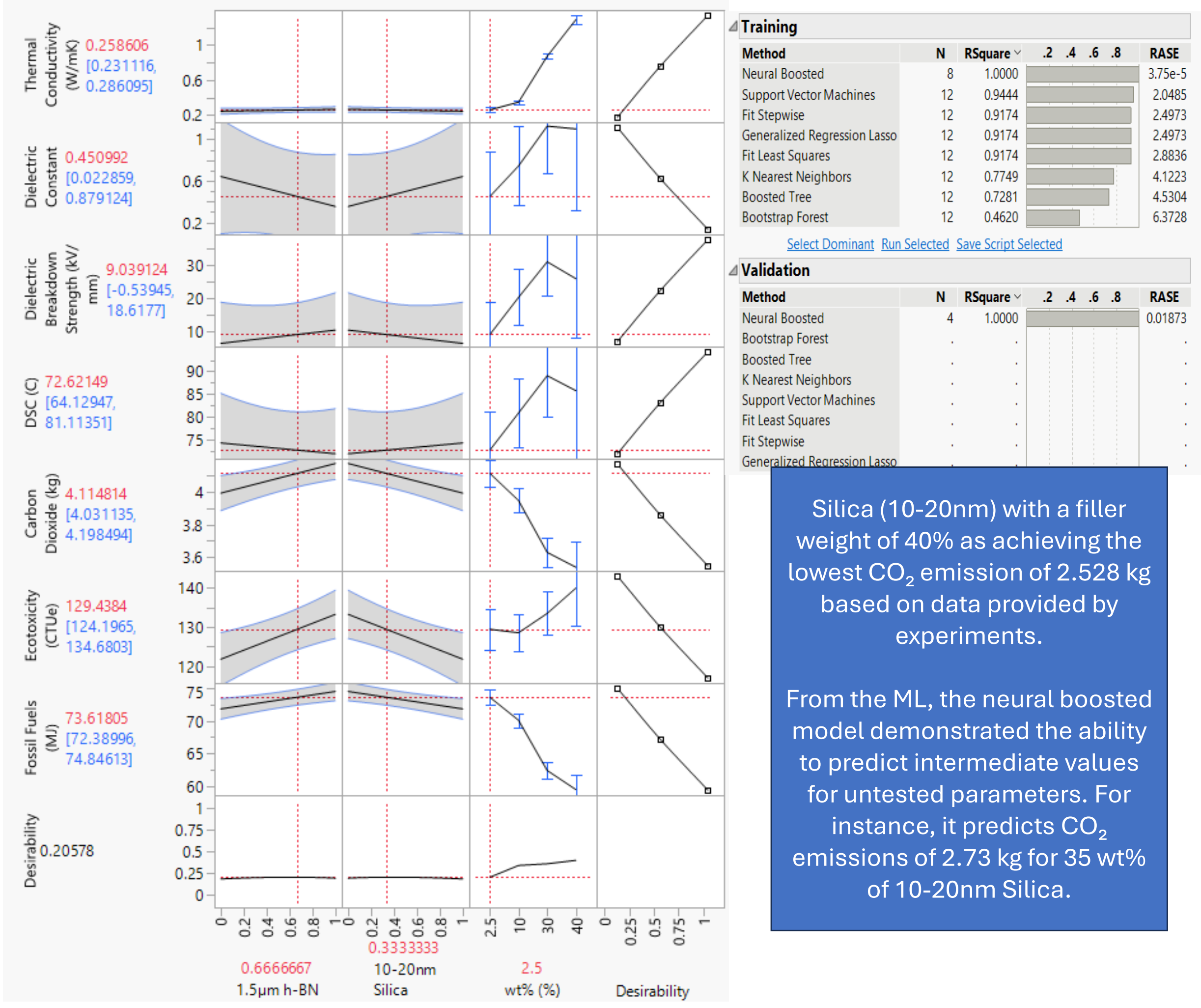
Harnessing DOE and Machine Learning

To optimize filler compositions, we employed a systematic approach combining DOE and machine learning. By analyzing the relationships between filler type, loading, and performance metrics, we uncovered trends that would be challenging to discern through experimentation alone.

Using JMP Pro, we developed a custom DOE to evaluate the effects of filler type (e.g., h-BN, Silica) and weight percentage (wt%) on both functional properties (e.g., thermal conductivity, dielectric strength) and environmental impacts (e.g., CO_2 emissions, fossil fuel usage). This enabled us to predict values across a wide parameter space, optimizing material formulations for performance and sustainability.

Predictive Modeling and Machine Learning

JMP Pro's predictive modeling tools allowed us to screen various machine learning methods to identify the best predictors for our data. Neural Boosted Trees provided the most accurate predictions overall.



Training

Method	N	RSquare	.2 .4 .6 .8	RASE
Neural Boosted	8	1.0000		3.75e-5
Support Vector Machines	12	0.9444		2.0485
Fit Stepwise	12	0.9174		2.4973
Generalized Regression Lasso	12	0.9174		2.4973
Fit Least Squares	12	0.9174		2.8836
K Nearest Neighbors	12	0.7749		4.1223
Boosted Tree	12	0.7281		4.5304
Bootstrap Forest	12	0.4620		6.3728

Select Dominant Run Selected Save Script Selected

Validation

Method	N	RSquare	.2 .4 .6 .8	RASE
Neural Boosted	4	1.0000		0.01873
Bootstrap Forest	.	.		.
Boosted Tree	.	.		.
K Nearest Neighbors	.	.		.
Support Vector Machines	.	.		.
Fit Least Squares	.	.		.
Fit Stepwise	.	.		.
Generalized Regression Lasso	.	.		.

Silica (10-20nm) with a filler weight of 40% as achieving the lowest CO_2 emission of 2.528 kg based on data provided by experiments.

From the ML, the neural boosted model demonstrated the ability to predict intermediate values for untested parameters. For instance, it predicts CO_2 emissions of 2.73 kg for 35 wt% of 10-20nm Silica.

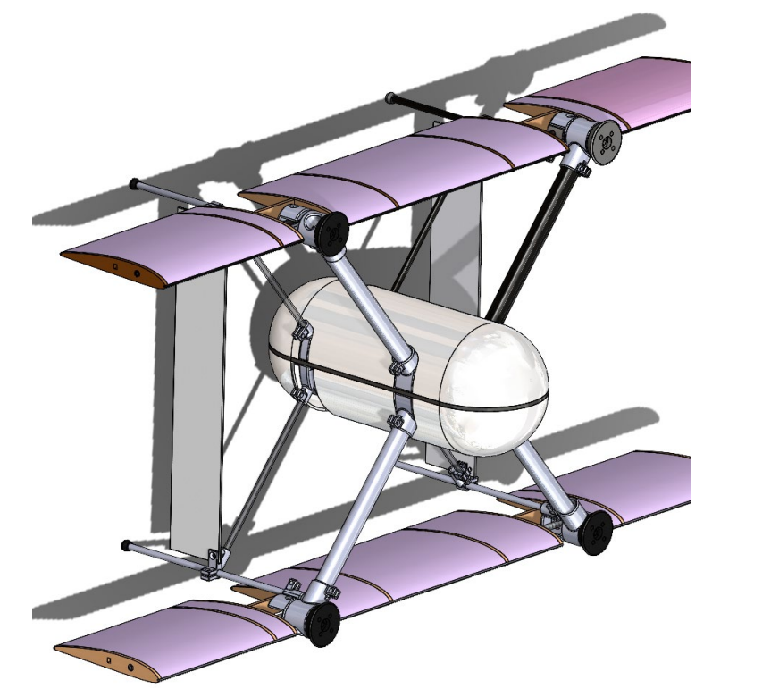
Thermal conductivity and CO_2 emissions emerged as the most predictable properties, with excellent model accuracy. This allowed us to confidently prioritize Boron Nitride in formulations targeting heat dissipation and sustainability. Dielectric breakdown strength showed non-linear behavior, emphasizing the importance of exploring a wider range of compositions to refine predictions further.

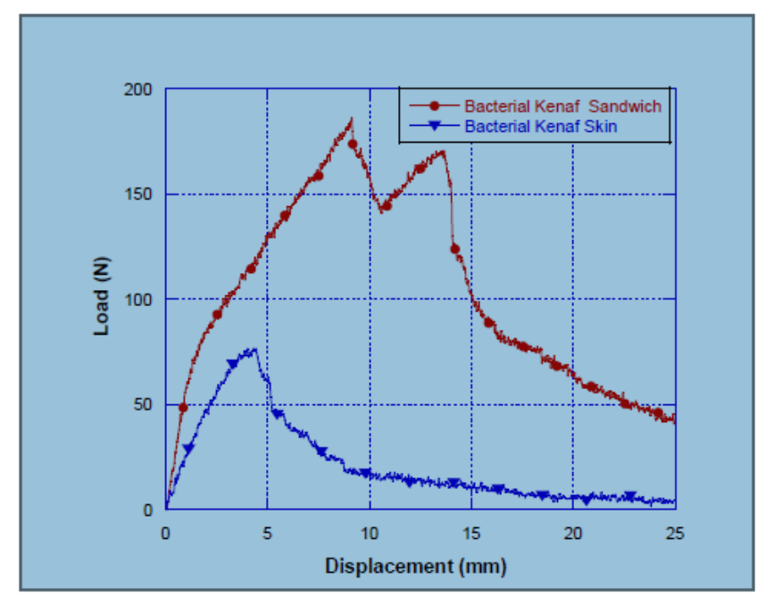
Machine learning revealed the delicate balance between environmental impact and performance, guiding the development of hybrid systems that integrate the strengths of both BN and SiO_2.

Future plans: Work with the the UTD Jindal School of Management, Natural Science and Mathematics, Jonsson School of Engineering and Computer Science to add an Engineered Sustainable Product Module or Course to a Sustainability Microcredential.

Sustainable Materials for Drone Manufacturing

Drones demand lightweight, high-performance materials that are also environmentally sustainable. The wing of a drone is designed using a sandwich composite which comprises a core and a skin. The benefits from using sandwich design is that for very minimal increase in weight (light foam core) a significant boost in force carrying ability is obtained



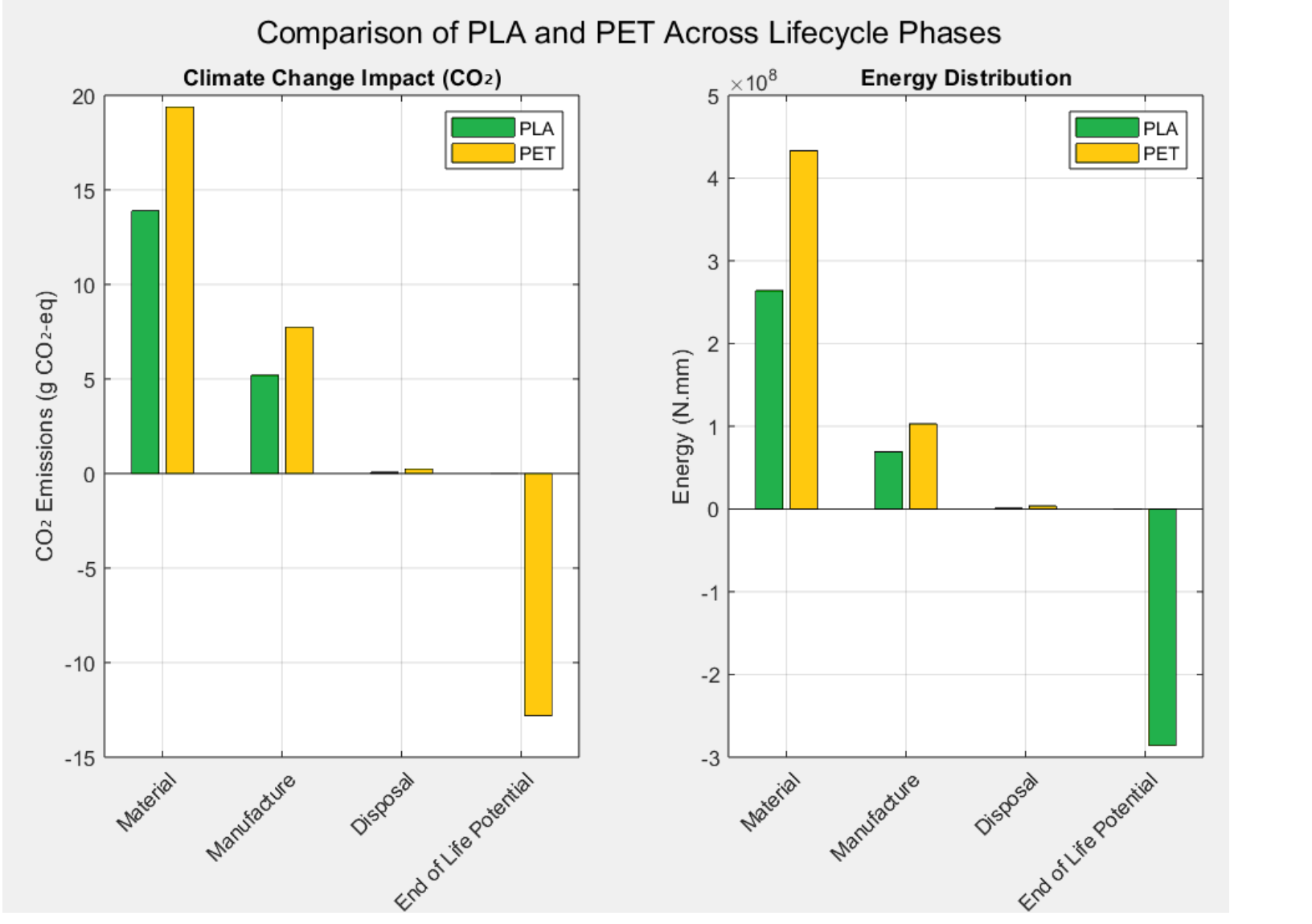


Impact of material source from fossil fuel to plant based material effect

This research explores PLA and recycled PET, combined with natural fibers and sandwich composite designs, to create components with reduced carbon footprints and enhanced strength.

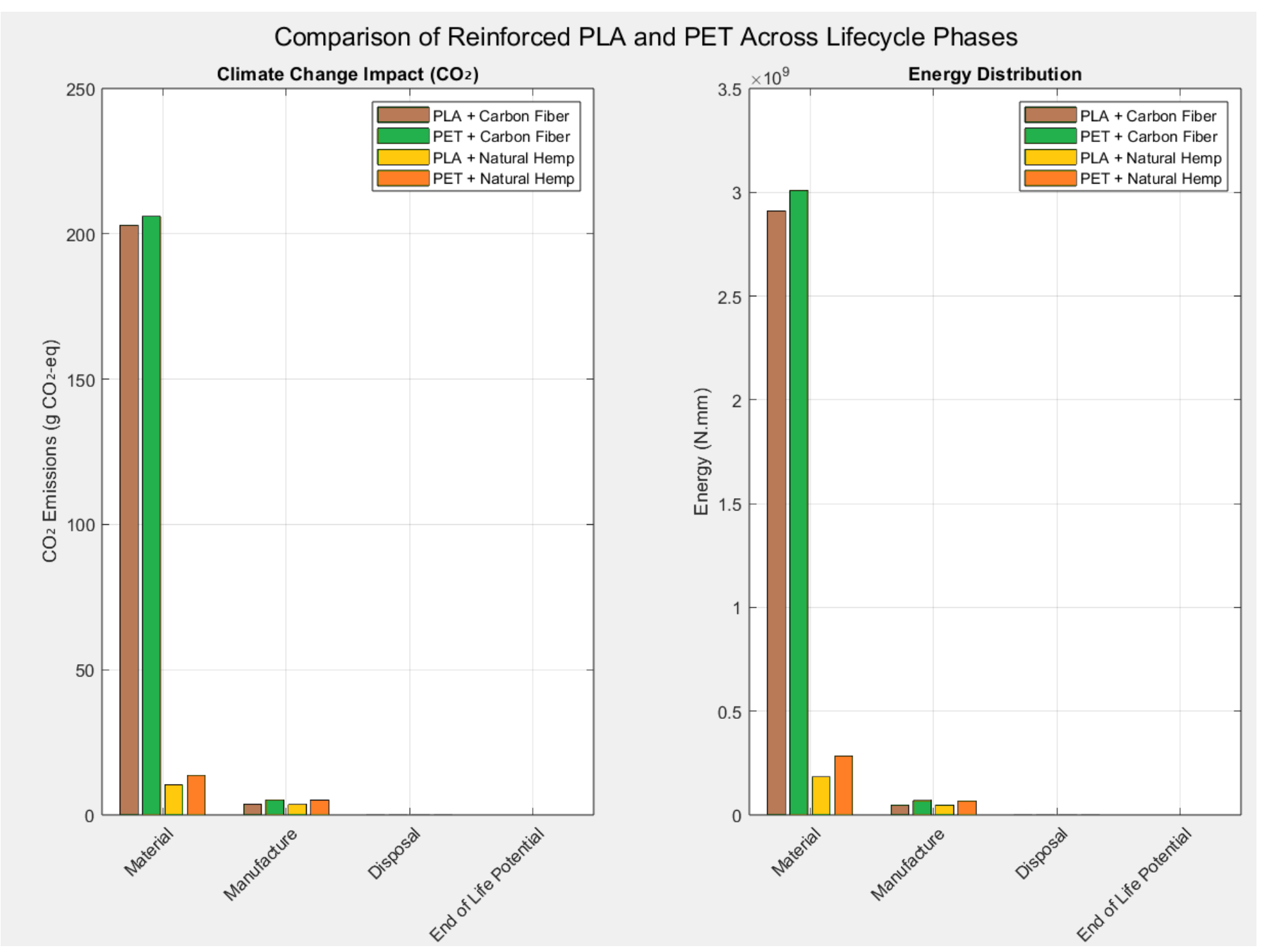
Environmental Benefits of PLA and Recycled PET

PLA, derived from renewable sources, emits significantly less CO_2 (13.9 g CO_2-eq) than PET (19.4 g CO_2-eq) during production. Recycled PET further reduces emissions with an end-of-life potential of -12.8 g CO_2-eq, highlighting the benefits of recycling. Both materials present viable alternatives to petroleum-based polymers, reducing energy use and environmental impact.



The Role of Natural Fibers

Structural components are reinforced with fibers. Natural fibers like hemp significantly lower emissions compared to carbon fiber, offering a sustainable reinforcement option. PLA + Natural Hemp composites demonstrate the lowest environmental impact, making them ideal for structural applications in drones. These materials reduce lifecycle energy consumption while maintaining strong performance.



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Reference:

[1] Visakhan, V. N., Abass, S., Gundala, K., Gopathi, B., D'Souza, N. A., Mathew, V., Terzariol, G., Fahim., A. Evaluating the Environmental and Performance Impact of Bio-Based Epoxy Composites for Semiconductor Packaging, iTherm 2025, submitted