Oak Ridge National Laboratory

Enabling the Circular Economy

"Develop Value Added Recycled Feedstocks for Composite Manufacturing"

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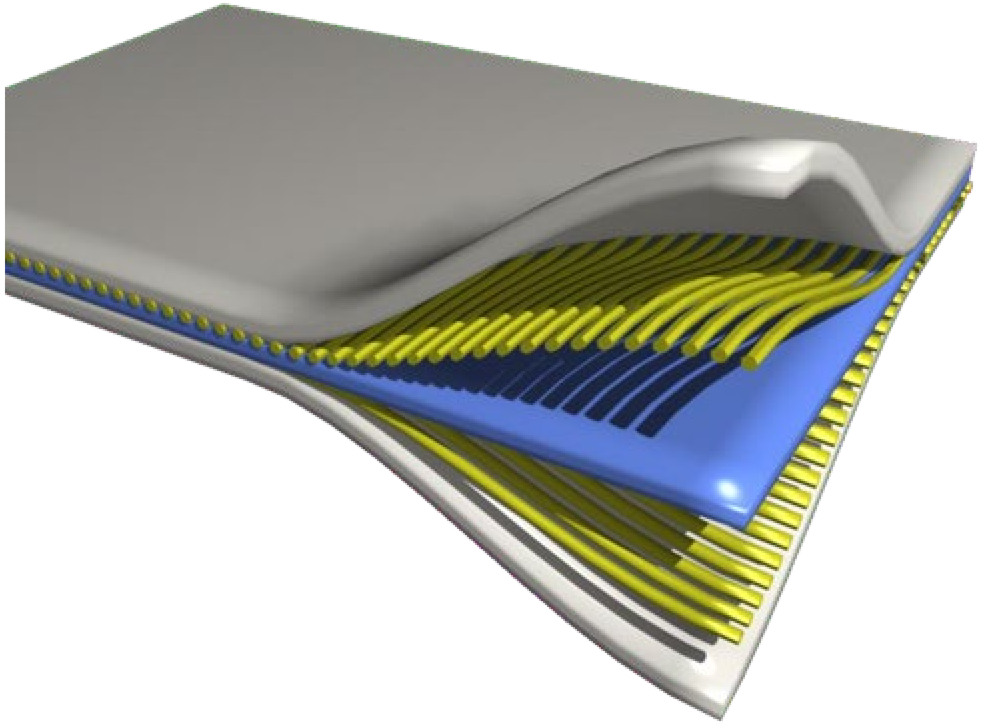
May 26, 2022

What are FRPCs?



Fiber Reinforced Polymer Composite (FRPC)

•Polymer phase:
–lightweight, easy to process/handle, chemically resistant
–Ex. Epoxy, Unsaturated polyester, vinyl ester,

•Fiber phase:
–still relatively lightweight, exhibits high mechanical property performance
–Ex. E-glass fiber (GF), carbon fiber (CF)

•Combined for high specific modulus & strength materials

H_2 Tanks

Tanks made from **composite material**, **fiberglass/aramid or carbon fiber with a metal liner (aluminum or steel)** Approximate maximum pressure 300 bars to 700 bars

Filament Winding has the potential to make the lightest, strongest, safest, uv resistant, corrosion resistant and impact resistant tanks for hydrogen powered vehicles

Waste Stream for Composite and Additive Manufacturing

Waste Stream	Recovered Commodities	Value-added Recycled Products
<u>Example Thermosets</u> • Compressed Gas vessel • Wind Turbine Blades • Aerospace Components • Automotive Paneling • Marine • Construction Industry • Bicycle Industry • High End Sports Equipment (e.g. CF Kayak paddles)	Thermoset Composites → Energy & Chemicals → Reclaimed Valuables, e.g. fibers, carbon black	• Additively manufactured parts and industrial molds (e.g., precast concrete for construction) • Compression and/or injection molded components for vehicle lightweighting (e.g., automotive body paneling) • Composite extrusion for infrastructure components (e.g., composite decking)
<u>Example Thermoplastics</u> • Bottles • Packaging Materials • End of Life AM parts • Automotive Trim • Elastomers (Rubber) • Water Sports Equipment	Thermoplastic → High Value Plastics for AM → Low value plastics for composite upcycling	

Recycling Options

Mechanical
- cutting and shredding to produce filler reinforcement
- simple on paper but typically economically viable

- reduced properties after several cycle of recycling

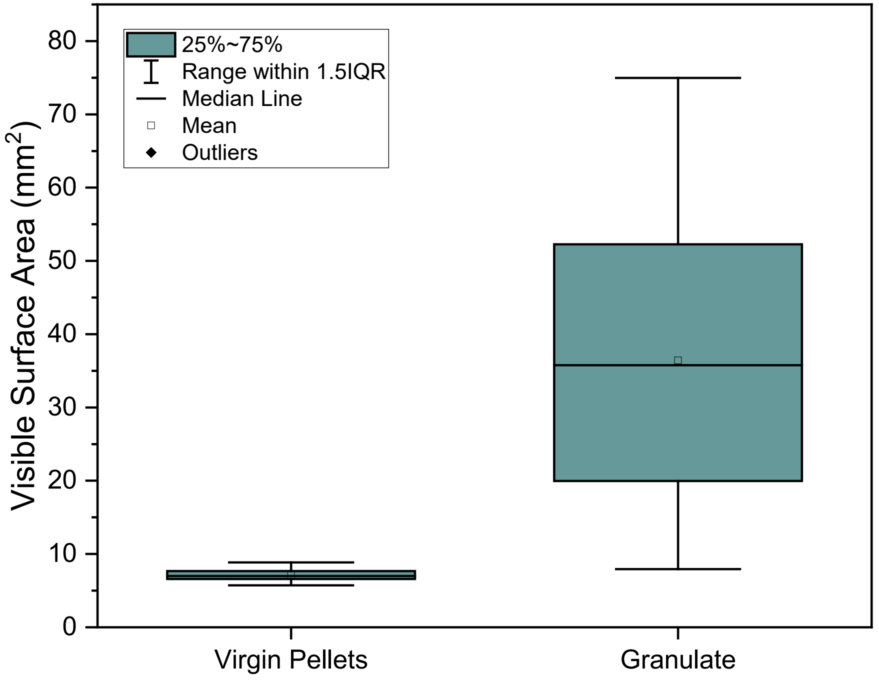
Solvolysis
- solvolysis dissolves the resin, leaving behind fiber for reuse
- can be effective but could produce chemical waste and can be comparatively expensive to setup

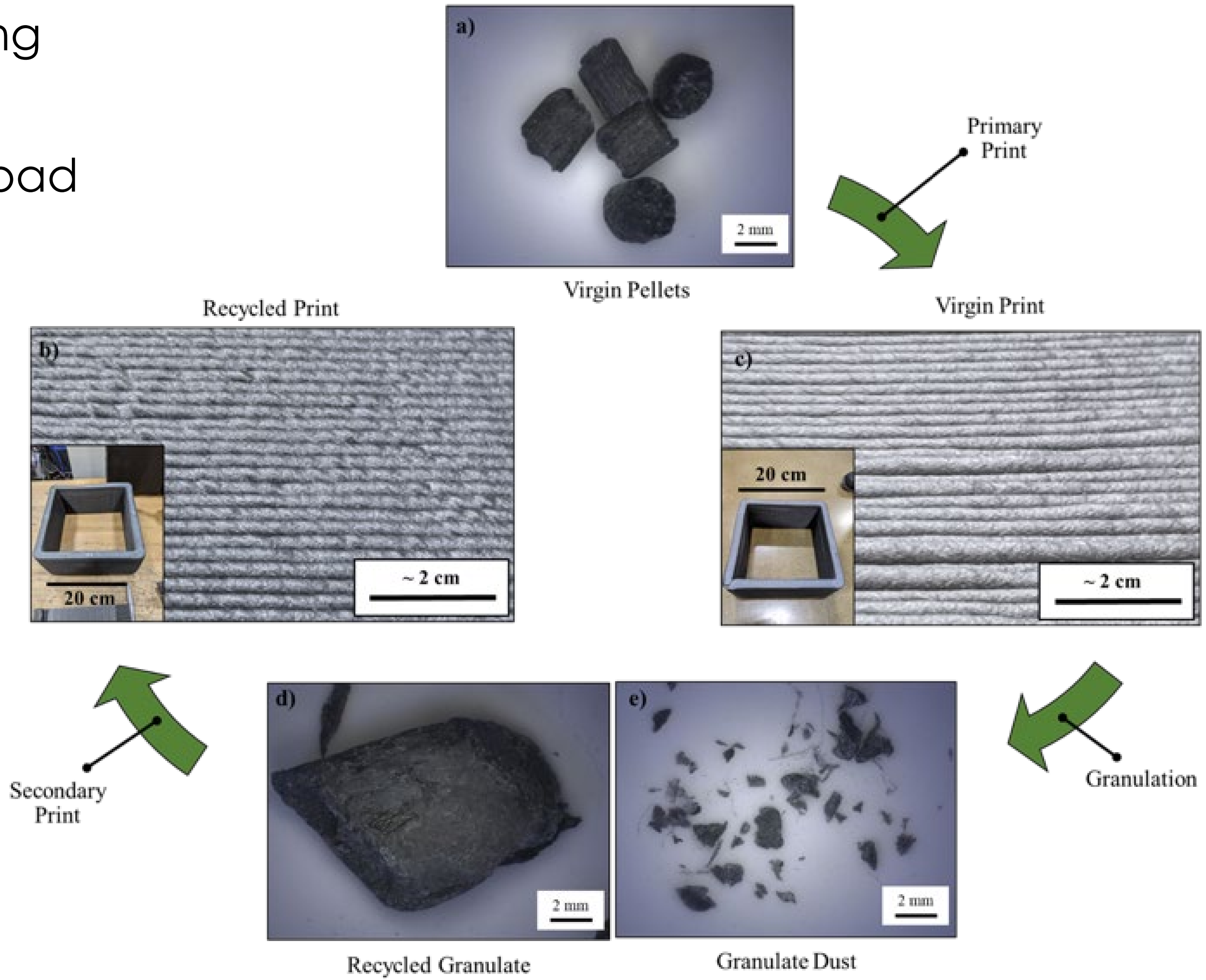
- Active efforts to scale for CF uncured production scrap, several commercial products available so far, significant amount of CF prepreg scrap available in the market

Pyrolysis
- Pyrolysis breaks down resin using thermal energy, releasing hydrocarbons that can fuel the ongoing process and provide surplus energy while leaving behind fiber
- mature technology with reactors already designed for materials like e-waste
- rCF commercially available; rGF is not, despite making up +90% of the market

Mechanical Recycling Pathway: Directly Using Regrind

- Successfully able to print regrind using BAAM system without clogging
- Mechanical recycling generates broad size distribution regrind





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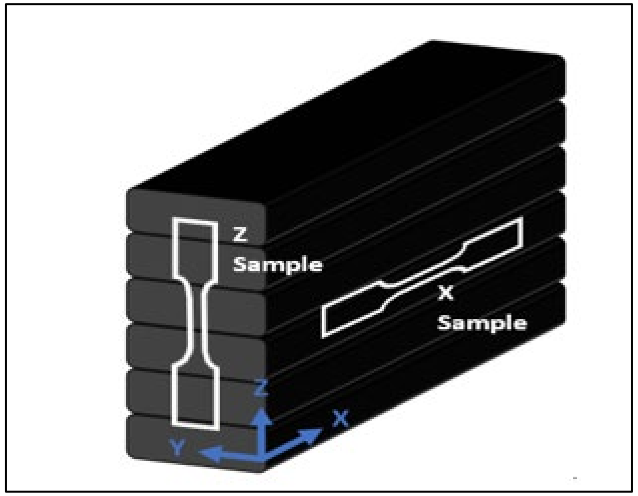
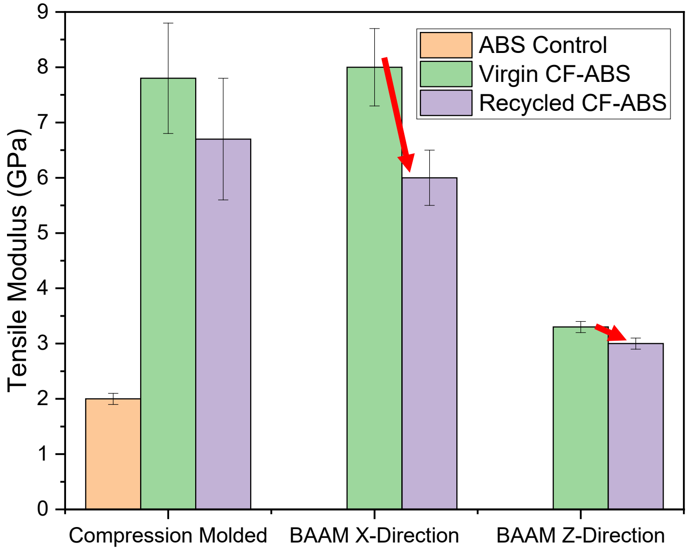
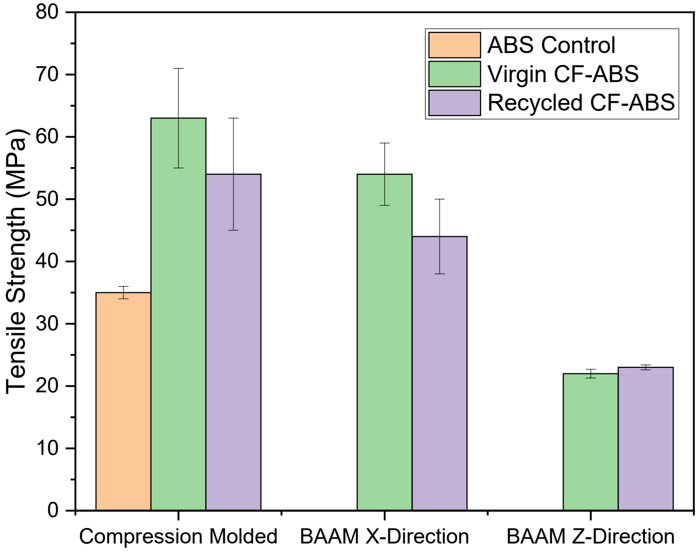
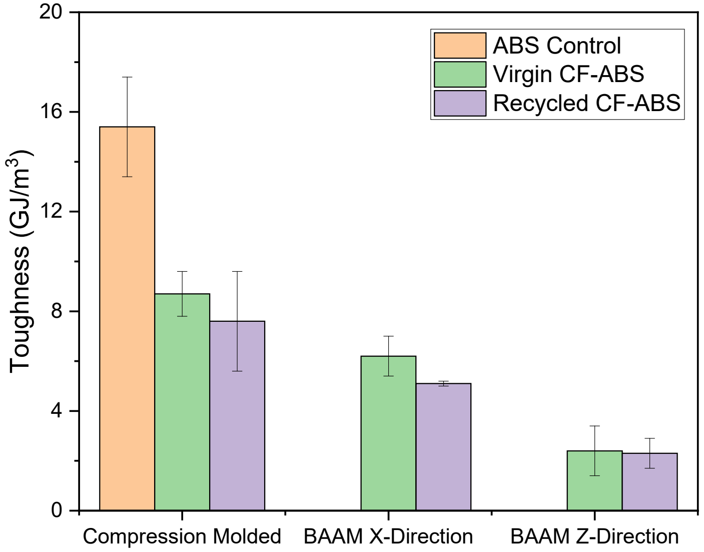
Mechanical Recycling Impacts Material Properties

- Compression molding regrind did not significantly impact mechanical properties
- BAAM did impact stiffness and toughness, but not overall strength of the material
- What could be causing this change in properties in recycling?

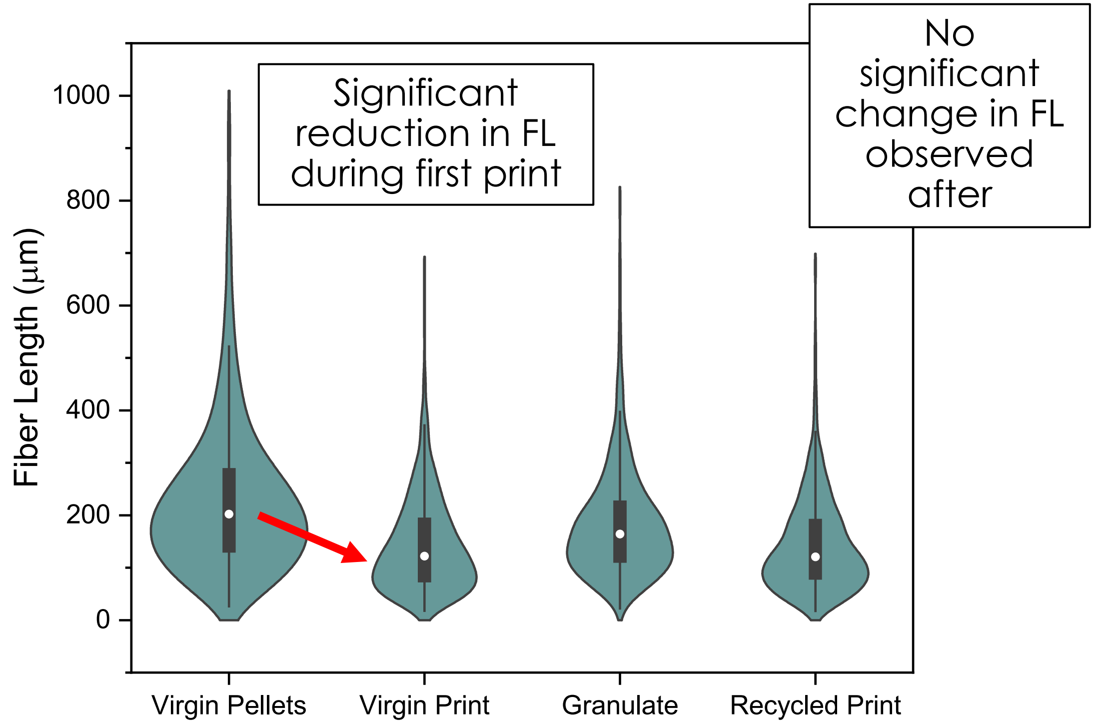


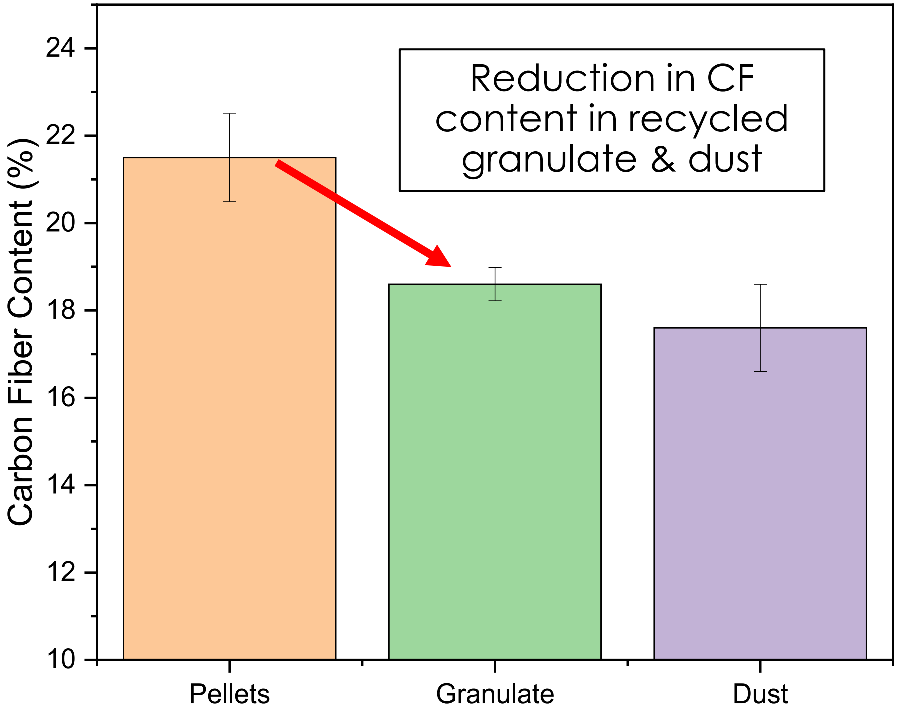




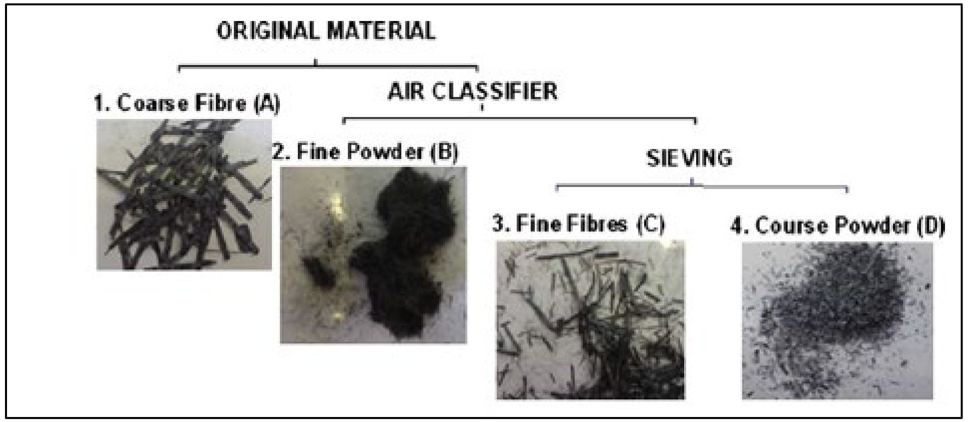


Although fiber length did not change during recycling, CF is lost in cyclonic separator





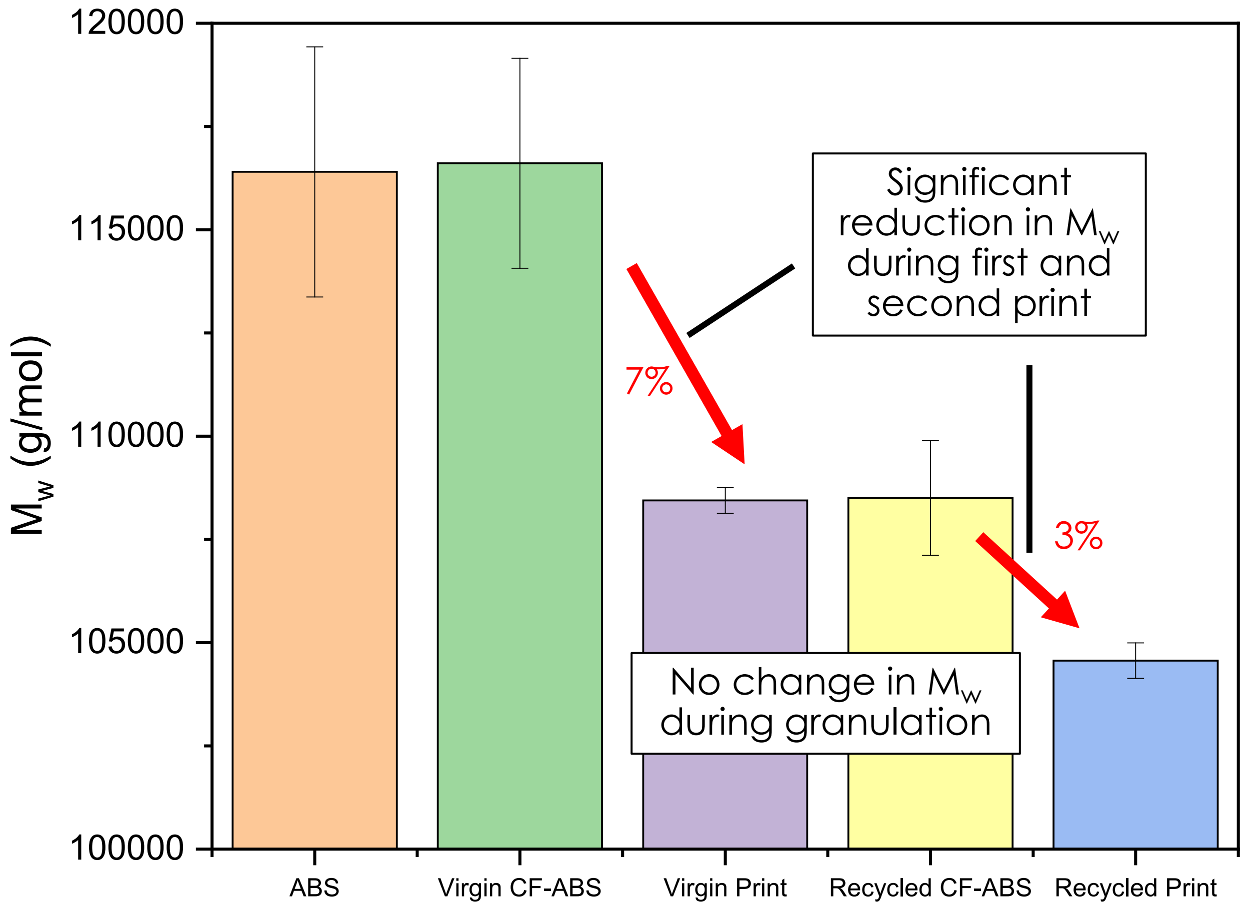
However, since CM samples did not see change in properties, it is unlikely this is the major contributor to changes in properties



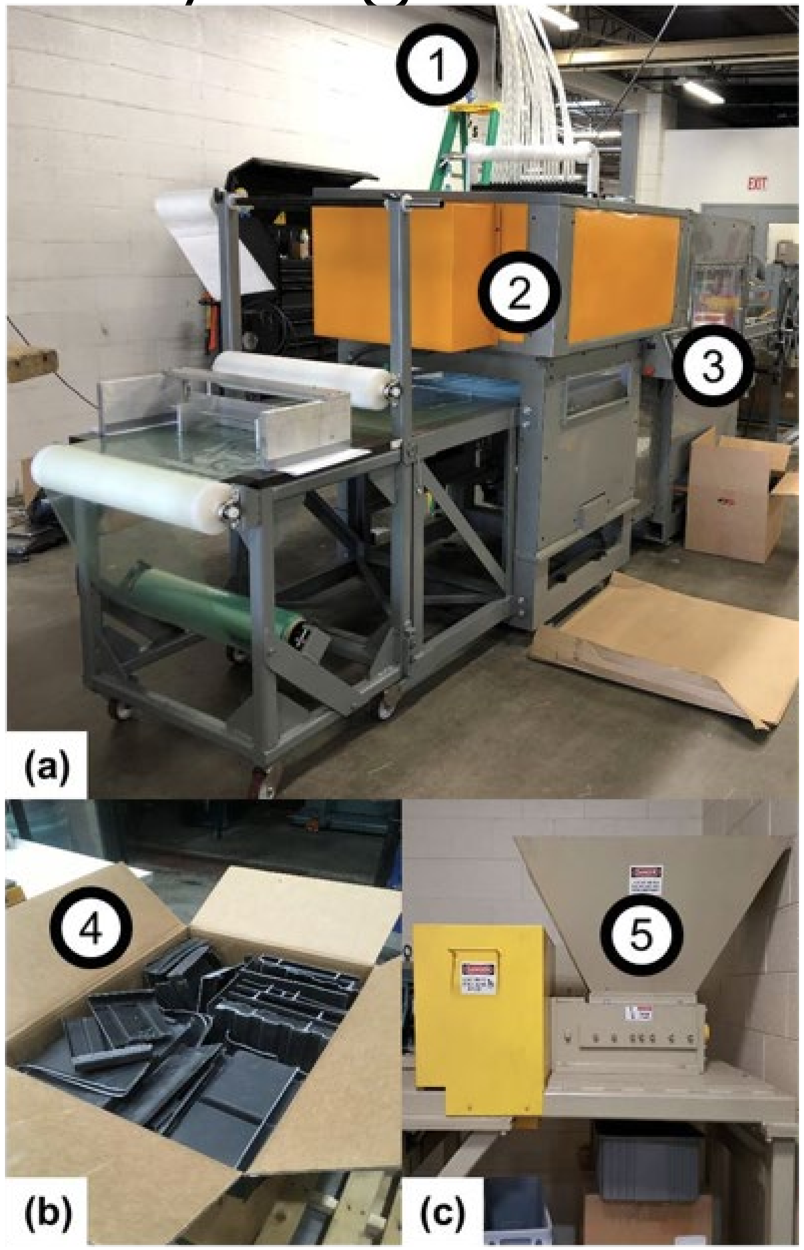
Palmer, J.; Savage, L.; Ghita, O. R.; Evans, K. E., Sheet moulding compound (SMC) from carbon fibre recyclate. Composites Part A: Applied Science and Manufacturing 2010, 41 (9), 1232-1237.

BAAM Damages Resin Molecular Weight

- BAAM significantly impacts molecular weight of resin
- Literature suggests this is caused by chain-scission reactions from the presence of impurities such as water in the recycled feedstock
- However, impurities would also have been present during initial compounding step, but no change to M_w
- What is happening?



Thermoset fiber composites and Recycling
Ex: production to recycling -SMC lifecycle



(1) Commercial E-glass rovings pass from the bobbin through plastic tubes into the SMC fabrication line

↓

(2) E-glass rovings are rotary chopped and allowed to fall onto a moving bottom resin layer

↓

(3) Uncured SMC is maturated by covering with a top layer of resin followed by compression through a series of rollers

↓

(4) Uncured SMC is compression molded and cured at temperature into a part

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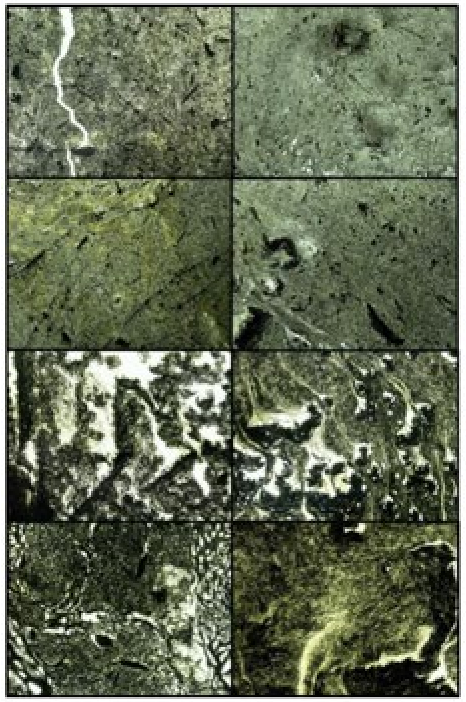
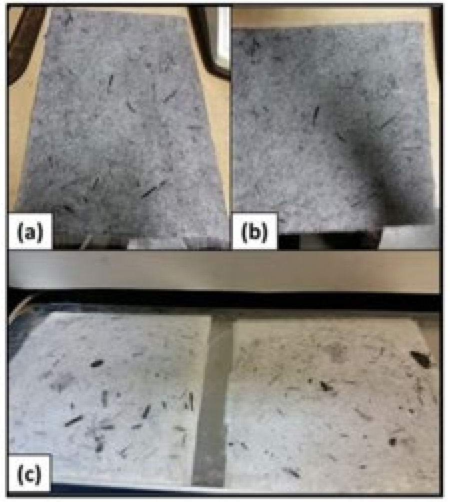
(5) Cured SMC parts are put through a shredder for size reduction

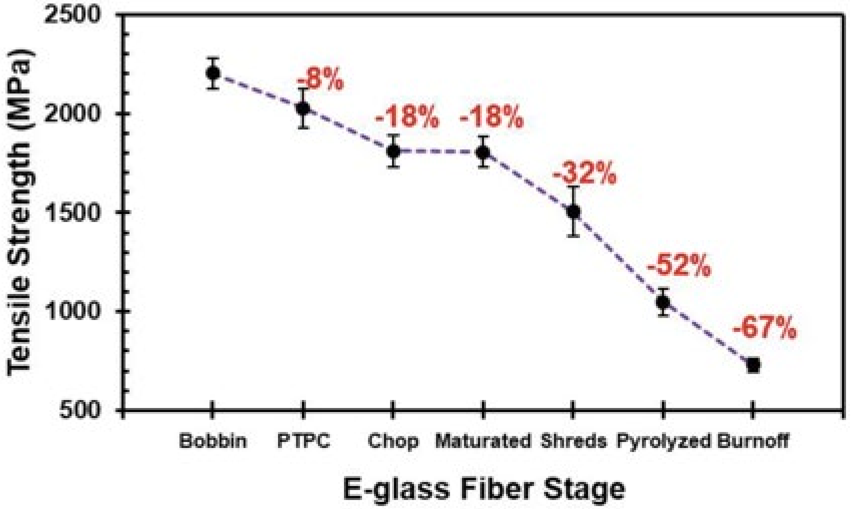
↓

(6) SMC shreds are pyrolyzed to remove resin and recover fiber

Fiber/char separation issue







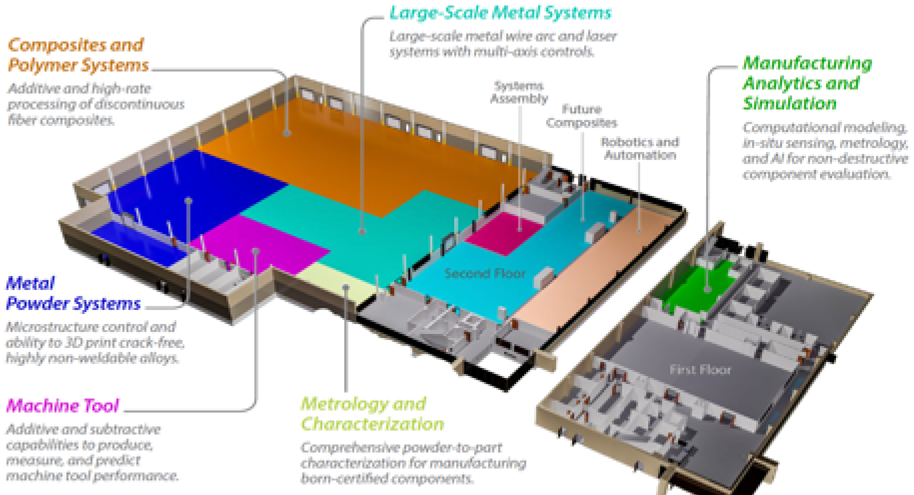
- Recovered fiber still has residual char on surface
- Char can interfere with fiber re-sizing and redispersion in new resin systems
- Burnoff possible but causes untenable further strength damage to fiber

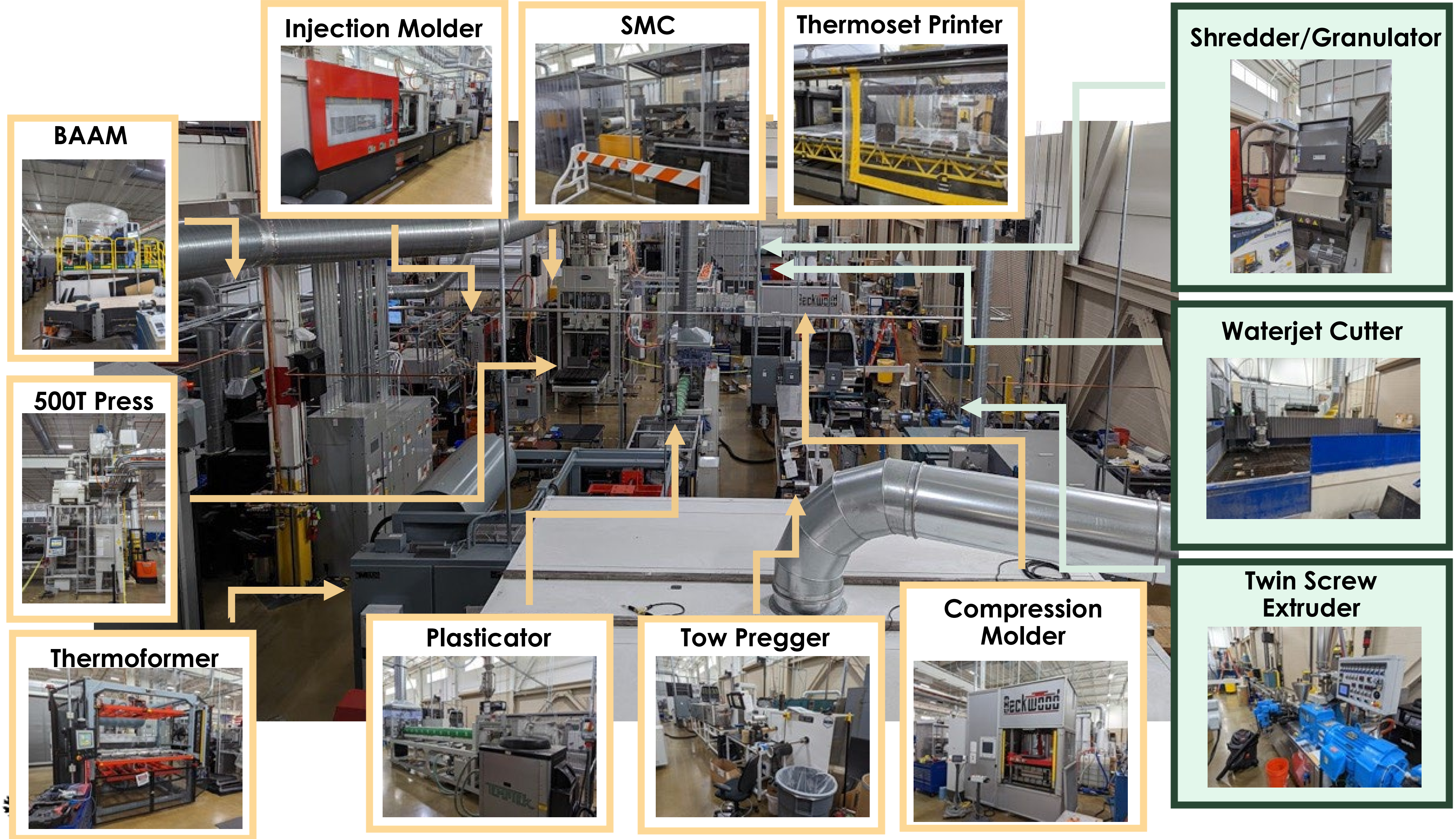
Virgin Fontinuous Fiber vs Recycled Fibers

Manufacturing Demonstration Facility

MDF by the numbers

- **>100** staff members and ~200 people total when including interns, students and co-located industry partners
- **1,000** internships from **700** unique students since 2012
- **>180** partnerships
- **>50** university collaborations
- **>130** honors/awards since inception
- **>80** advanced manufacturing systems with 60% placed at the MDF by no-cost leasing (i.e., CRADA)




Injection Molder
SMC
Thermoset Printer
Shredder/Granulator
BAAM
Waterjet Cutter
500T Press
Twin Screw
Extruder
Compression
Molder
Thermoformer
Plasticator
Tow Pregger

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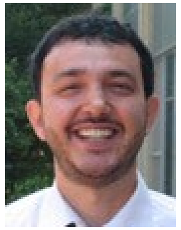



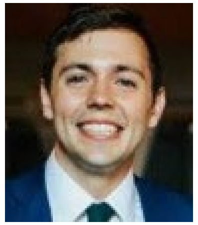



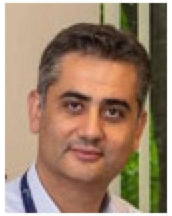

Developing scalable, sustainable materials and manufacturing technologies to enable circular economies, and to achieve carbon neutrality and energy efficiency

Thank you!

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