

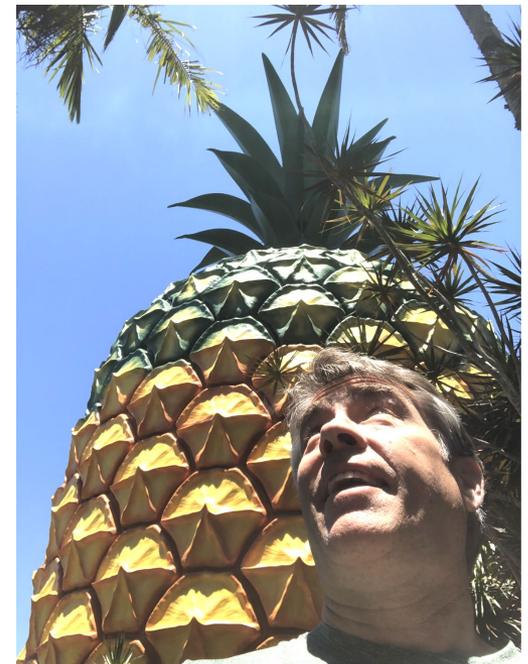
# Biobased Resins for Manufacturing in the Circular Economy



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John Dorgan &  
*The Big Pineapple*

# Topics

- *Composites (and now countertops)*
  - Wind turbines: More and bigger - lots of material used.
  - What's needed for resin systems.
- *Sustainable and Circular Resins*
  - Biorenewable content (lower embedded energy).
  - **Proof of circularity.**
  - Triggered degradation gives other end-of-cycle options.
- *No time for Discussion*
- *Details Available Upon Request*
  - Chemistry, rheology, spectroscopy, materials properties, etc.

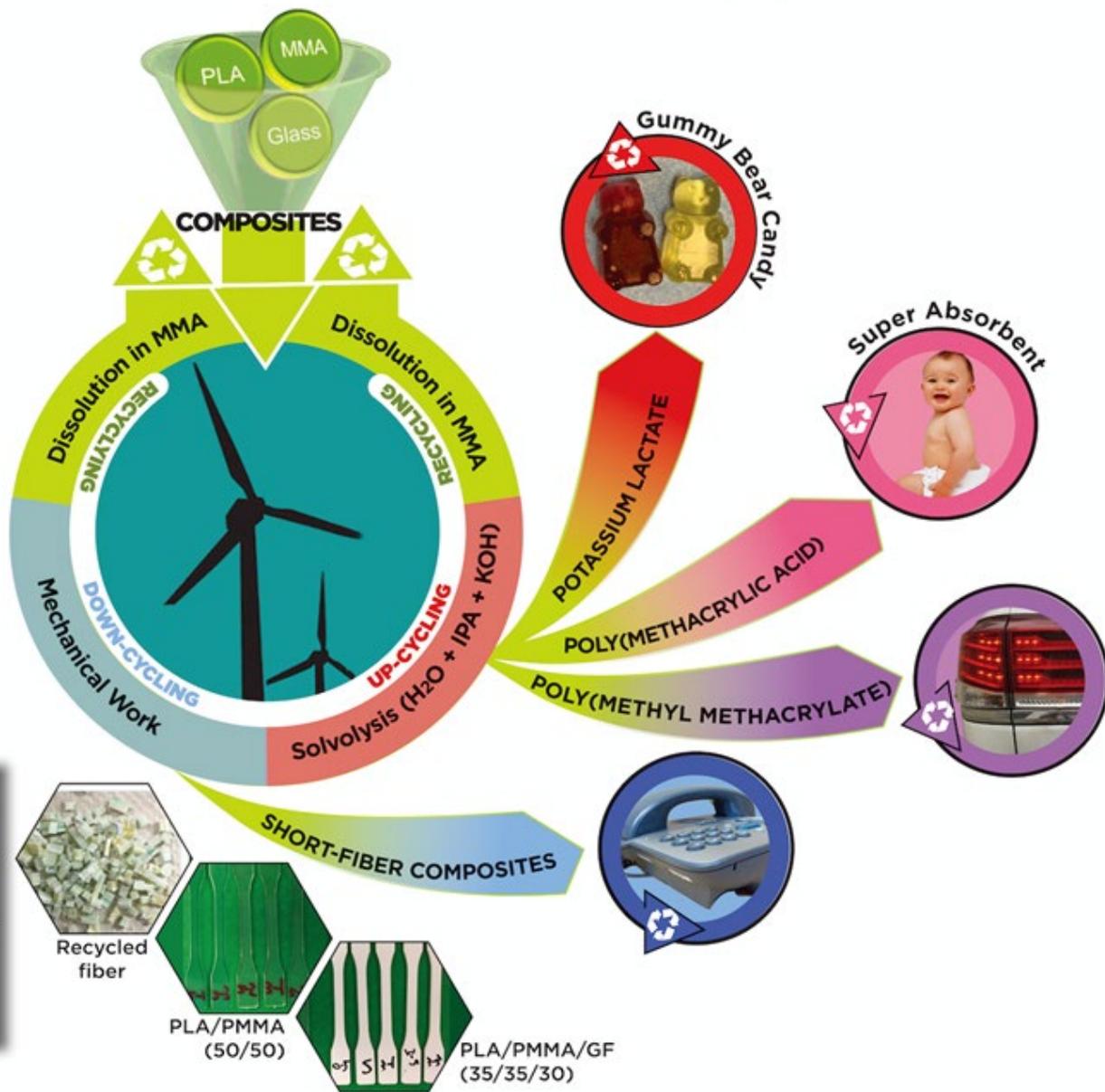
# Demonstrating what's possible



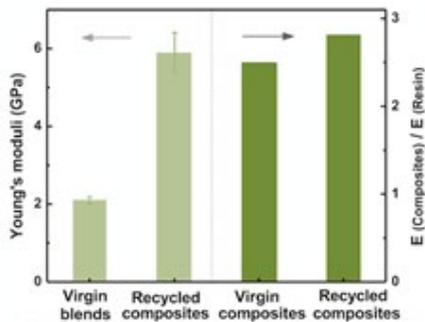
**UP-CYCLING:**  
higher value components

**RECYCLING:**  
blade-to-blade

**DOWN-CYCLING:**  
lower value components



Recycled fiber from composite feedstock



Recycled fiber



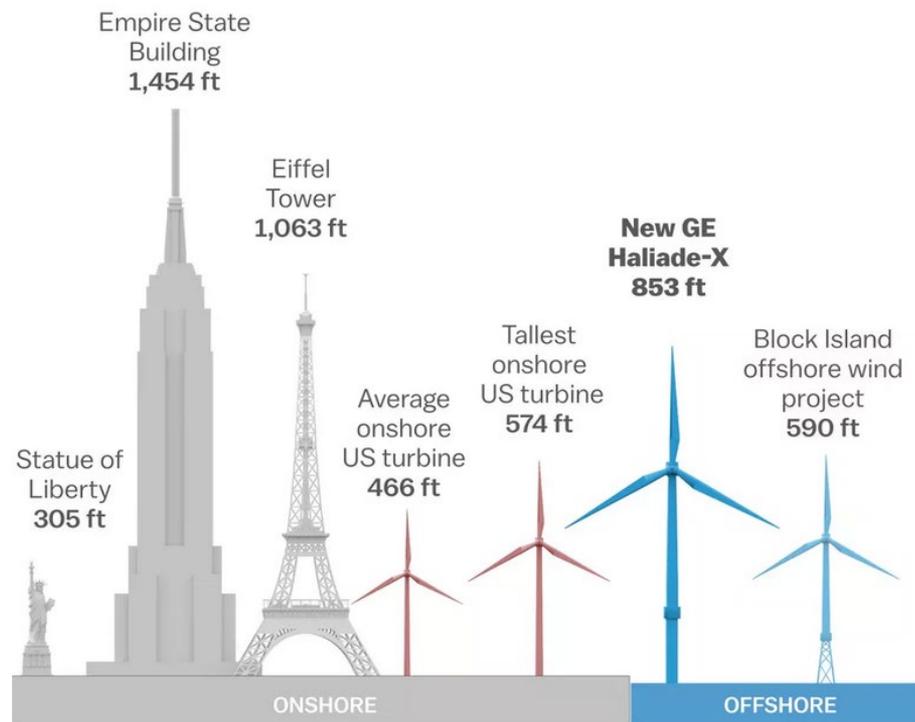
PLA/PMMA (50/50)



PLA/PMMA/GF (35/35/30)

# Wind Turbines - More and Bigger

Cumulative U.S. Wind Capacity



Source: GE, Vox research

Vox

***A 60m blade weighs 20 tons and is 30 wt% polymer resin.  
( 6 tons per blade, ~2000 blades per GW, 5 GW/yr  
~ 60 million kilograms of polymer resin annually )***

# The Downside of the Upside



# 12 Principles of Green Chemistry\*



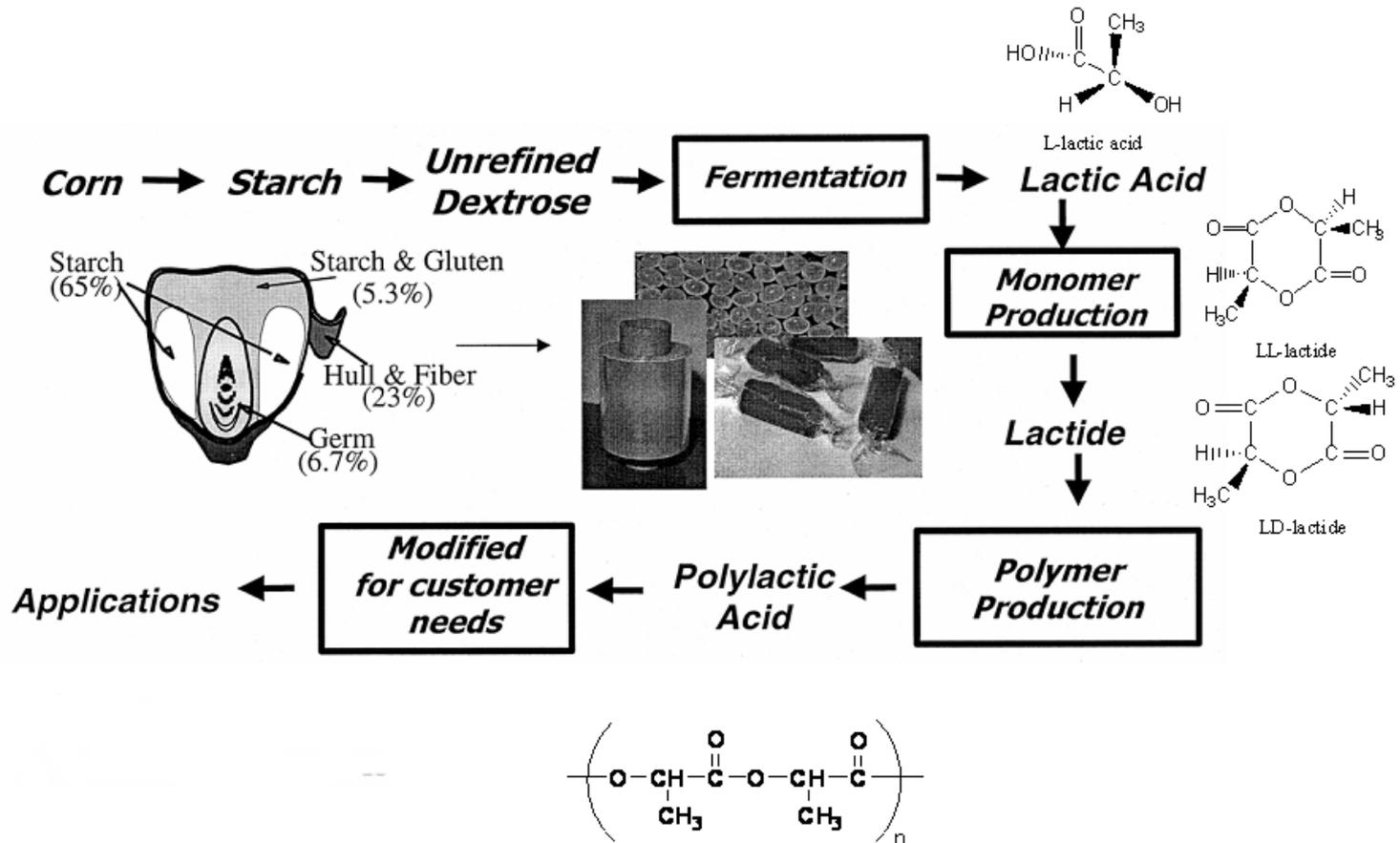
#4) Use **renewable feedstocks**: Use raw materials and feedstocks that are renewable rather than depleting.

#10) Design chemicals and products to **degrade after use**: Design chemical products to break down to *innocuous substances* after use so that they do not accumulate in the environment

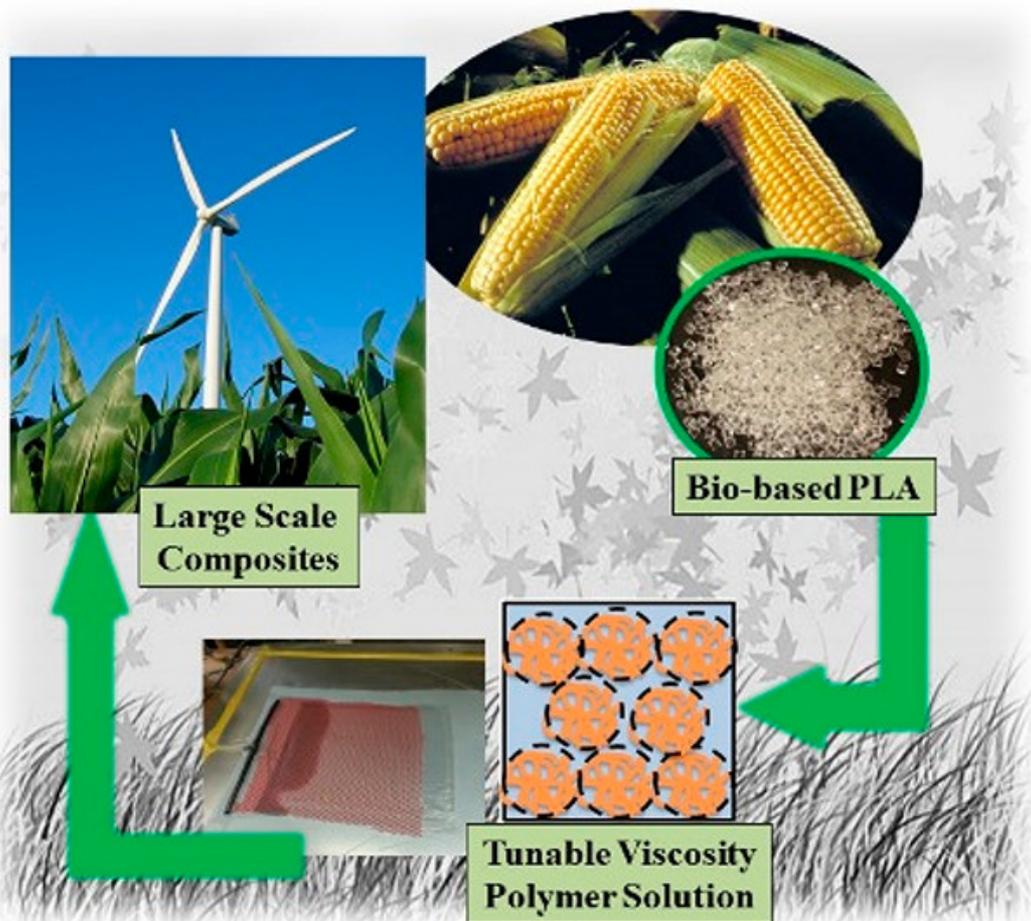
\**Green Chemistry: Theory and Practice*, Anastas, P. T.; Warner, J. C. Oxford University Press, New York (1998)

# Polylactide (PLA) – renewable and degradable.

Working with Natureworks since 1995, I've been intimately involved in the commercial developments of biobased PLA.



# Polymer science and engineering unleashed



**See our samples!**

Developed **biobased resins** suitable for **composites**, making **cultured stone**, and for **3D-printing**.

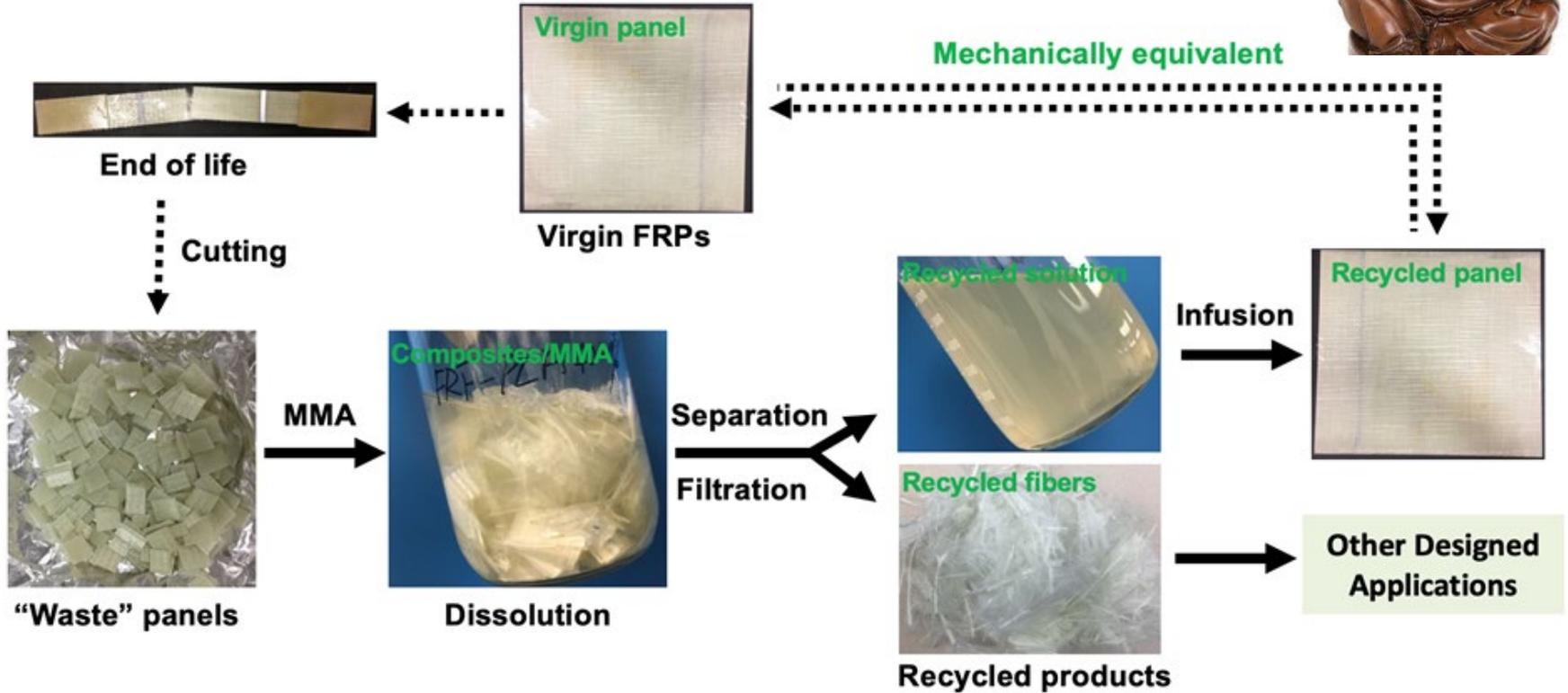
**Extensive study** using light scattering and dilute solution property studies. Rheometry and curing kinetics; exotherm management.

*Styrene-Free, Partially Biobased Resin System for Thermoplastic Composites.*  
*I. Rheological Properties and Preliminary Panel Fabrication ACS Sustainable Chemistry & Engineering, (2019)*

# Circularity of resin confirmed

Recovered resin is *reincarnated* as a new panel !

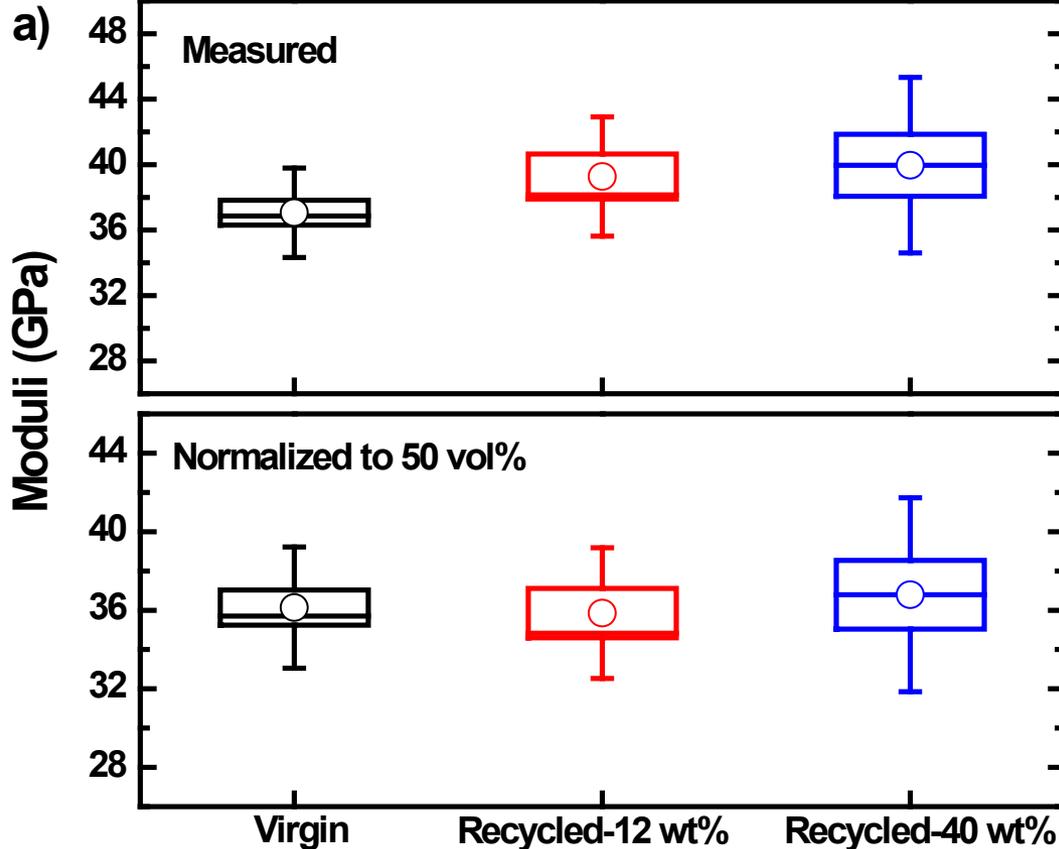
circularity  
is divine!



Upon end-of-cycle use, thermoplastic version can be dissolved in monomer.

Glass settles and is easily removed for recycling.

# Circularity confirmed



Excellent fiber wetting!

Tensile moduli of fiberglass composites in fiber direction give typical values of **40 GPa**

“Turbine-to-Turbine”

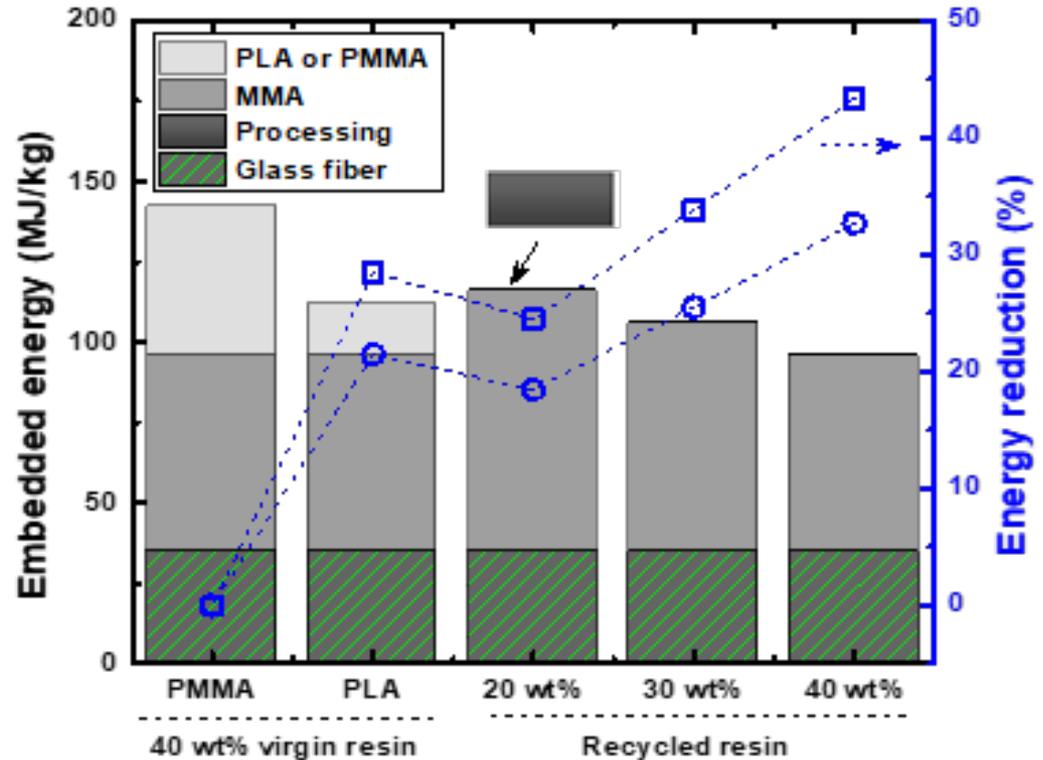
# Renewable content improves metrics

**See our samples!**

**PLA biobased** infusible thermoplastic and thermosetting resins.

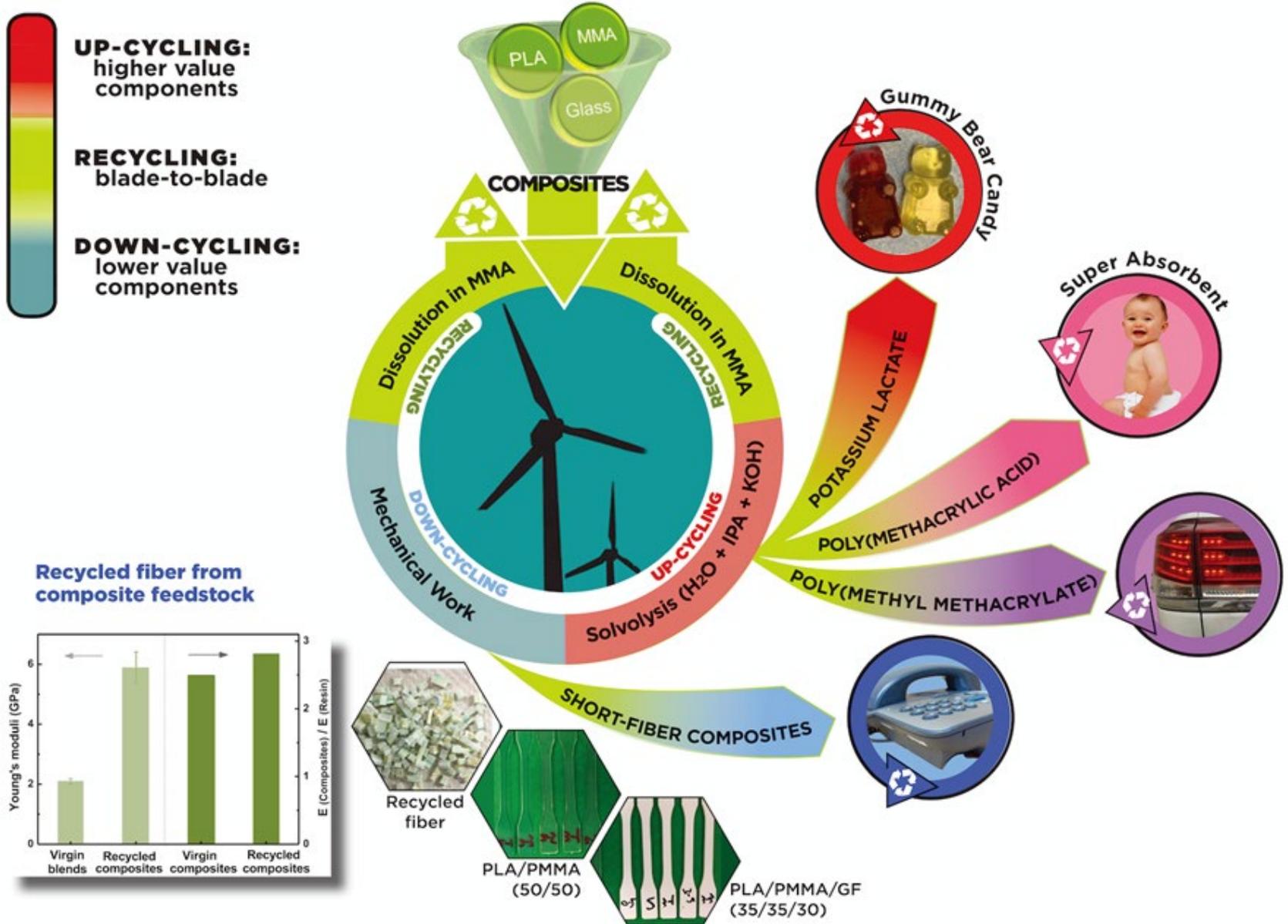
PLA has **lower GHG emissions** and **less embedded energy**.

**PLA costs less than PMMA.**

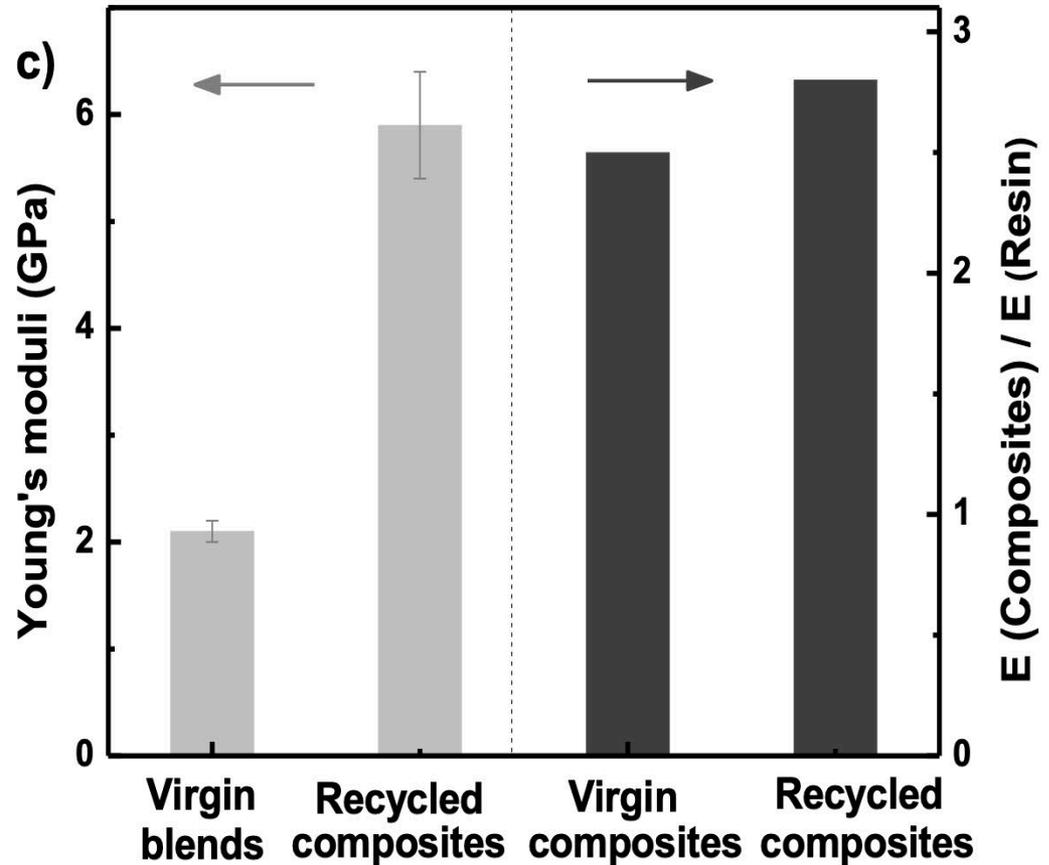
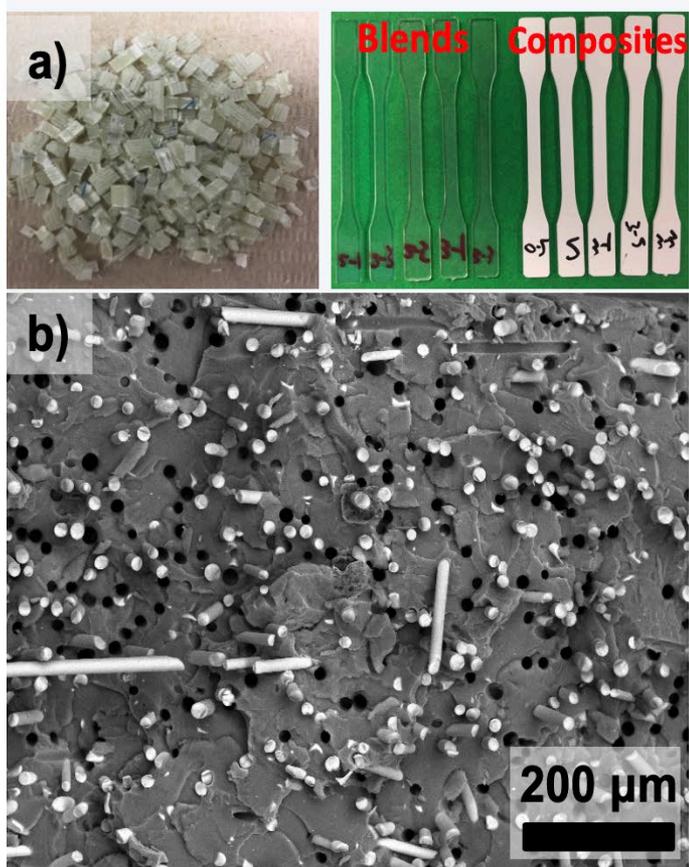


**BETTER ENVIRO METRICS AT REDUCED COST!**

# Turbine-to-Turbine Material Circularity

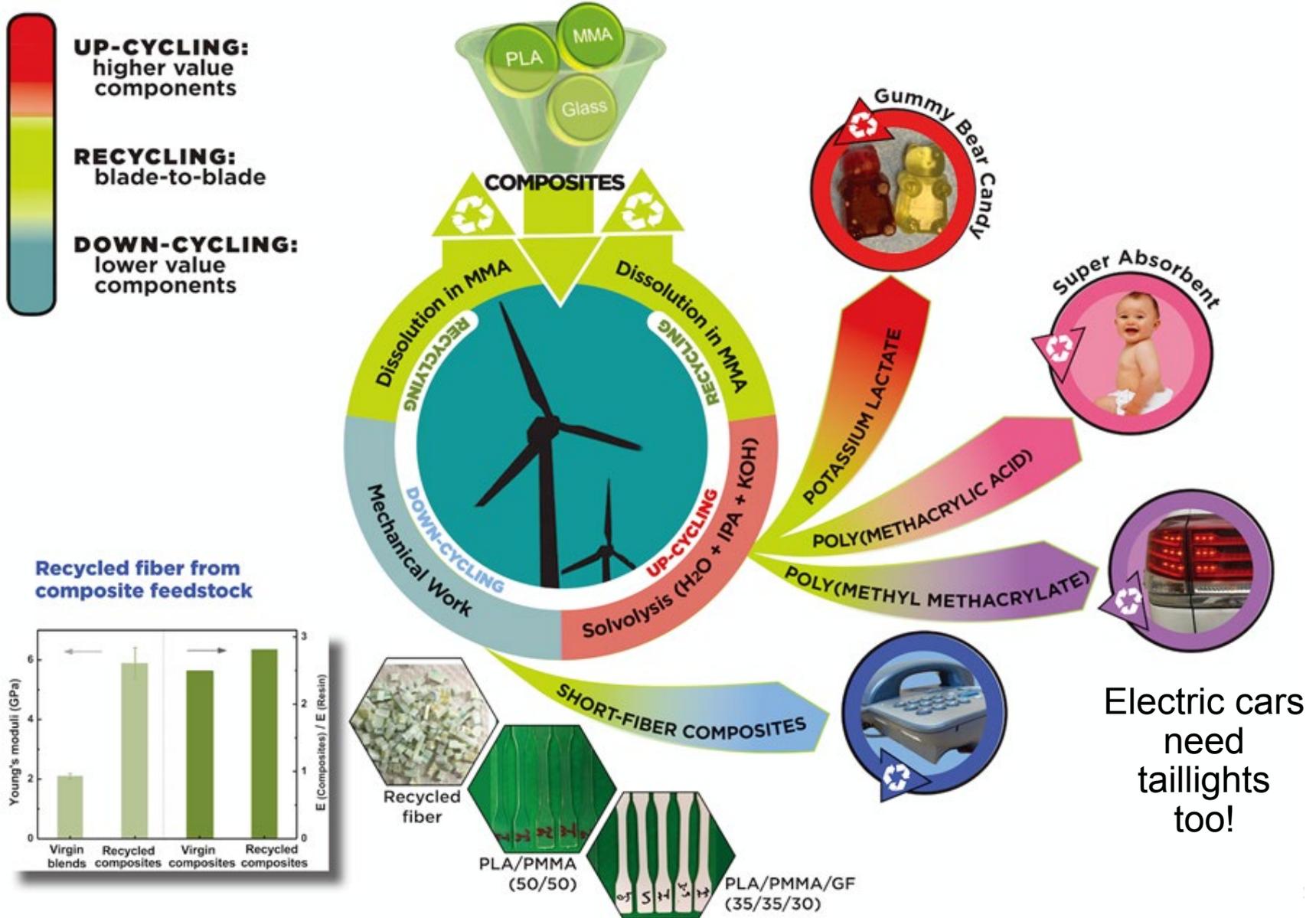


# Ground panels for injection molding

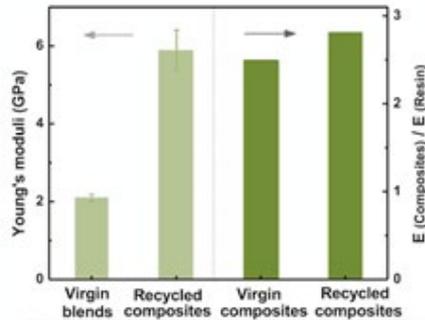


- a) Shredded panels (left) and molded recycled short fiber tensile bars
- b) Morphology of tensile fracture surface of composites
- c) Moduli of virgin blends and recycled composites

# Turbine-to-Turbine Material Circularity



Recycled fiber from composite feedstock

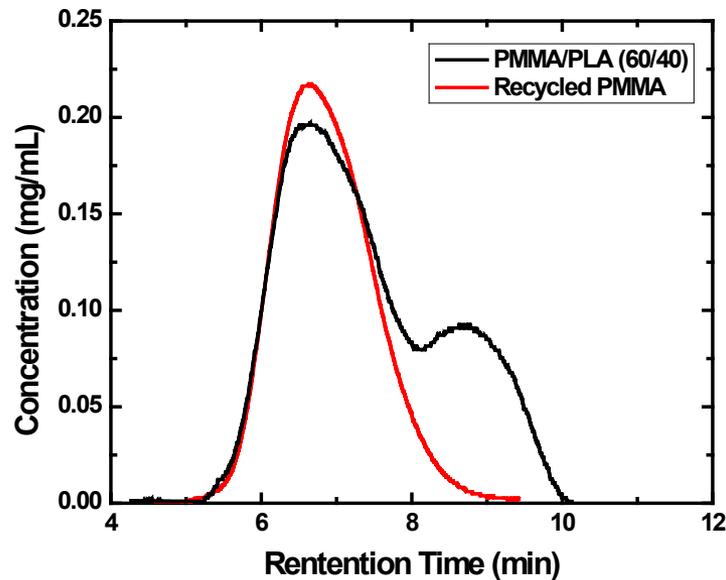


# Recovering PMMA

1) Solvolysis by alkaline solution.

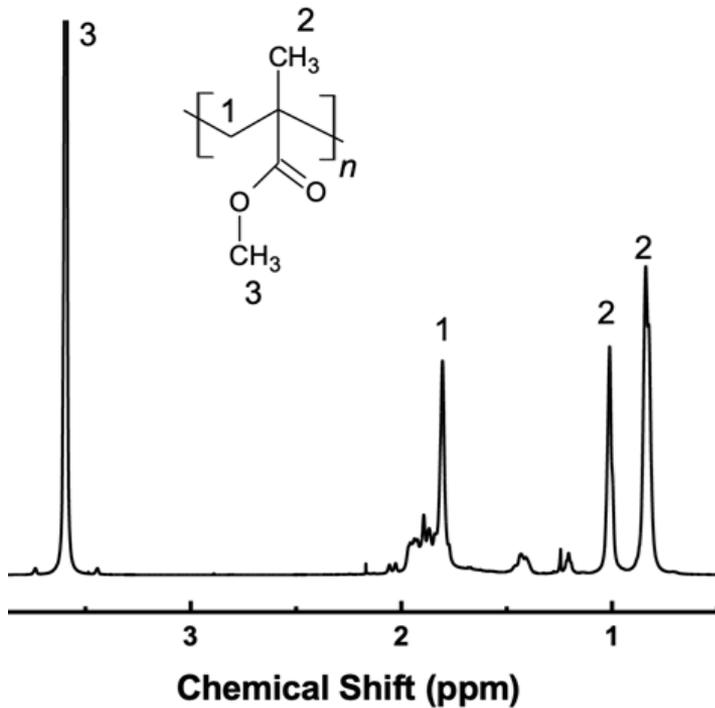
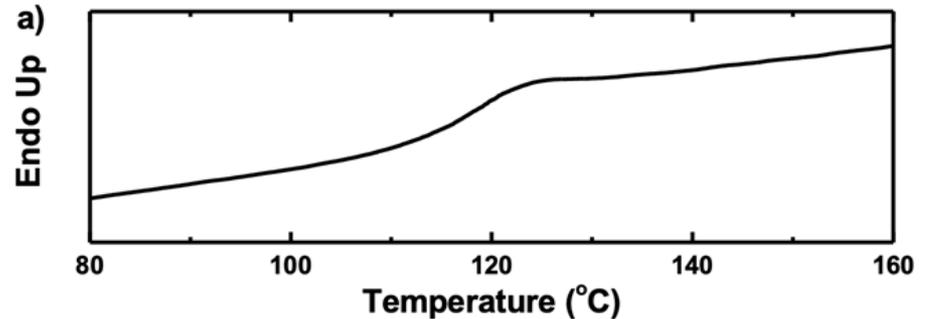


2) Solution cooled to room temperature and precipitated PMMA removed by vacuum filtration.



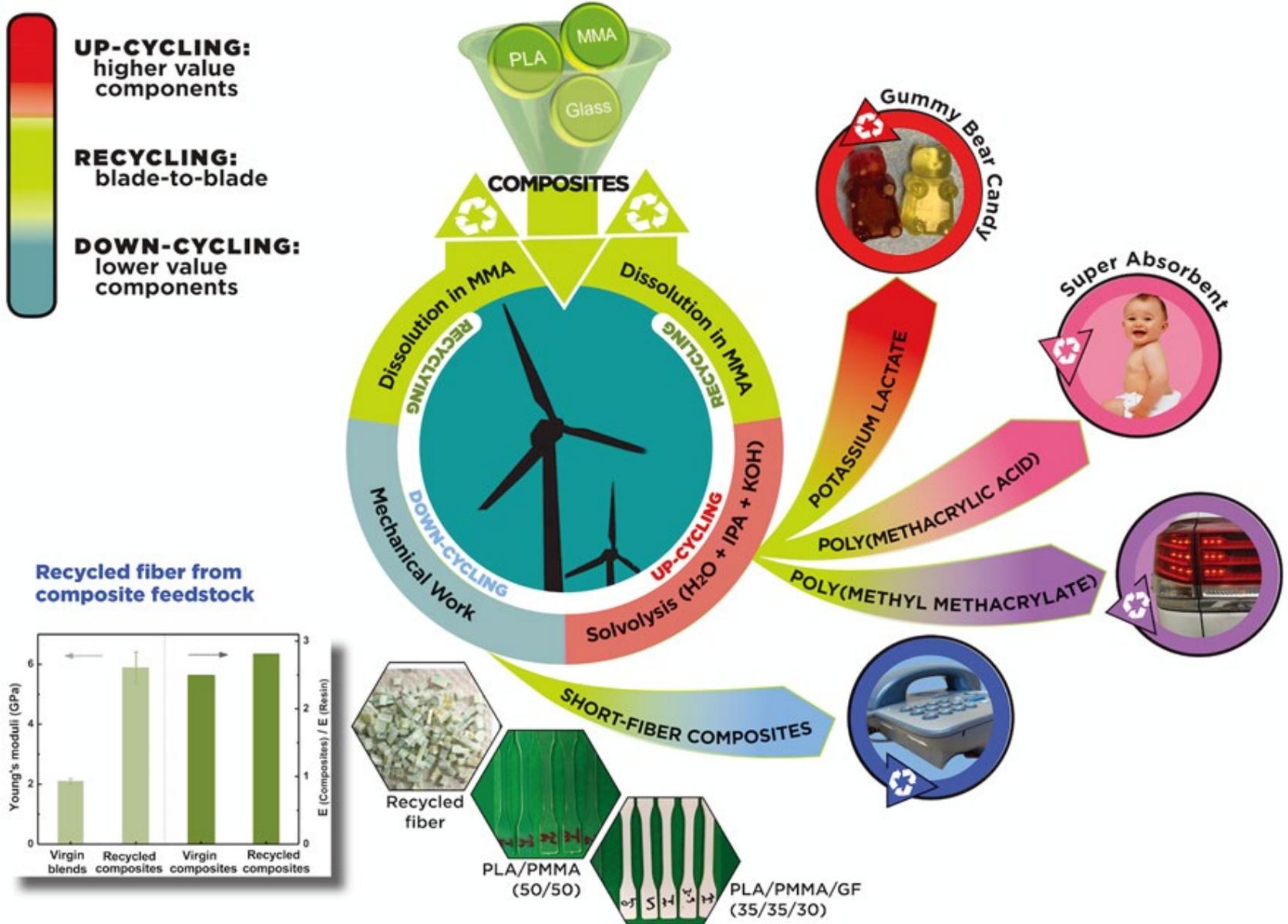
# Recovering PMMA after PLA hydrolysis

PMMA glass transition temperature observed.



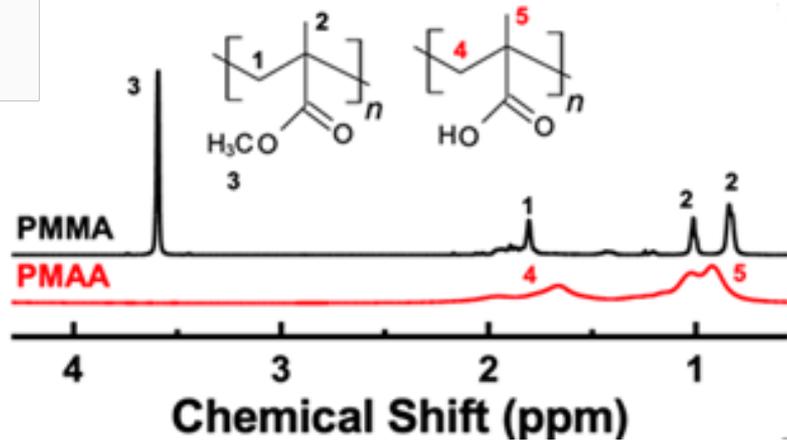
PMMA structure confirmed by proton NMR.

# Turbine-to-Turbine Material Circularity

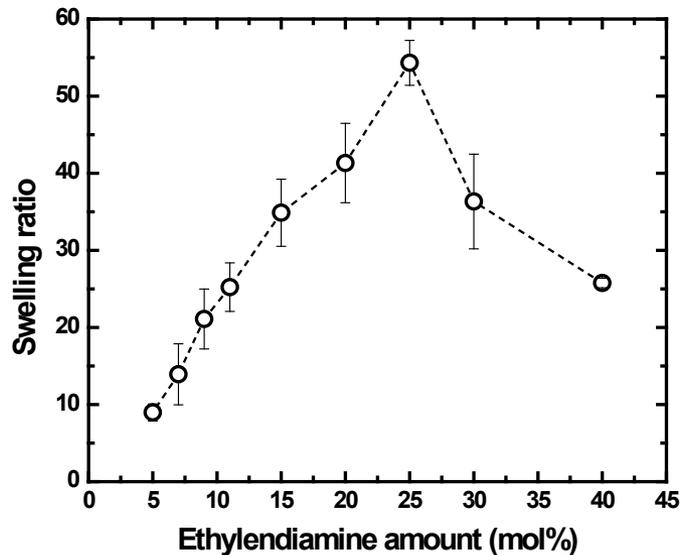


# Solvolysis to superabsorbent PMAA

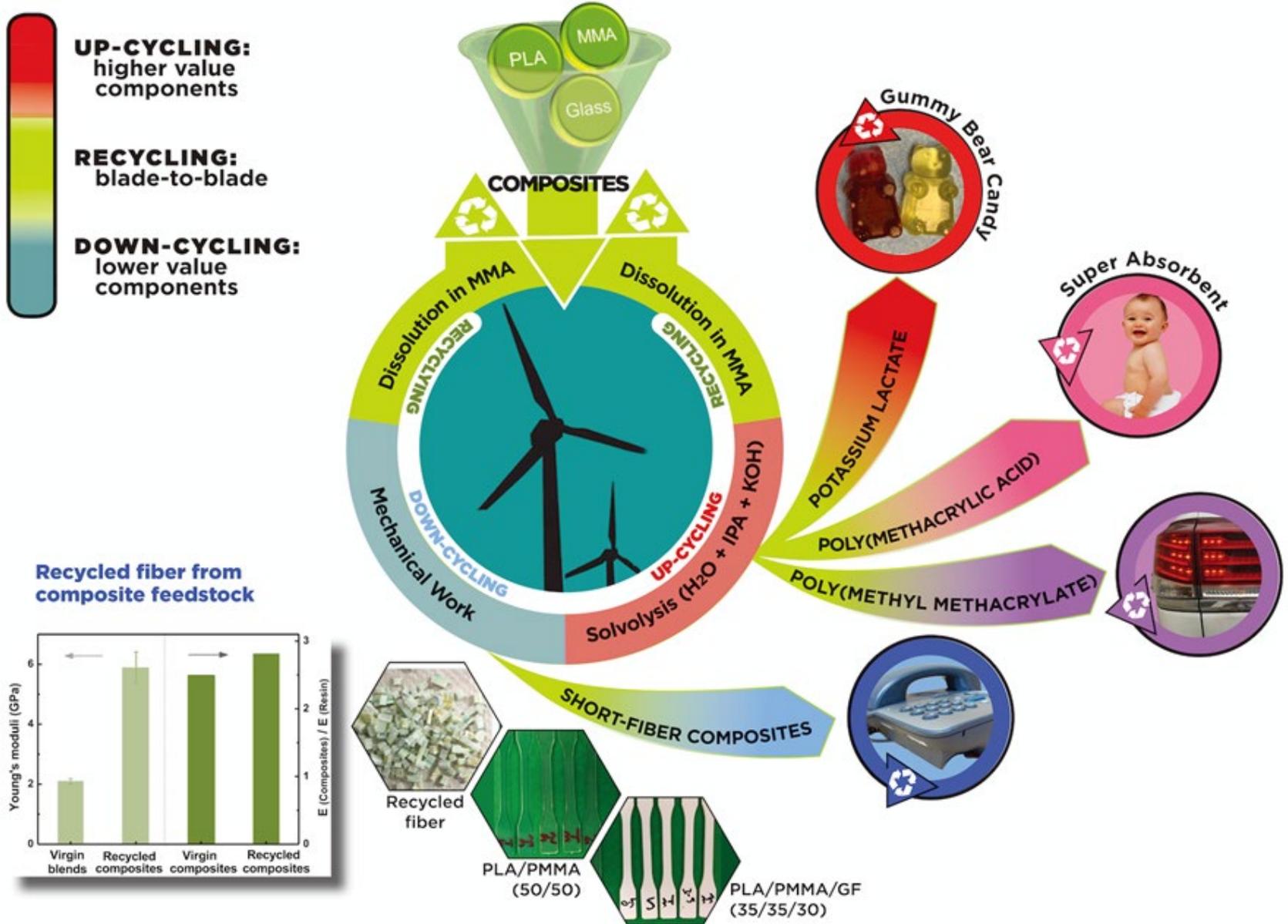
More aggressive solvolysis at **140°C** converts PMMA to PMAA.



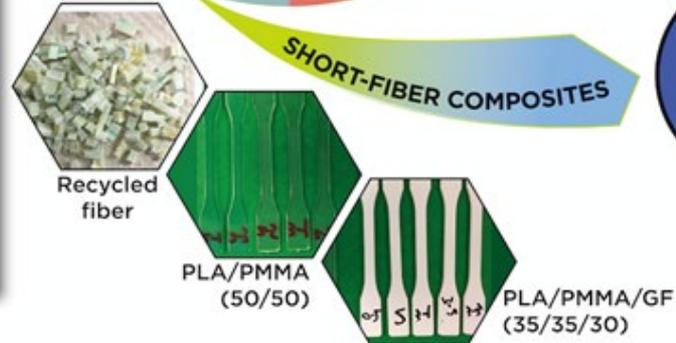
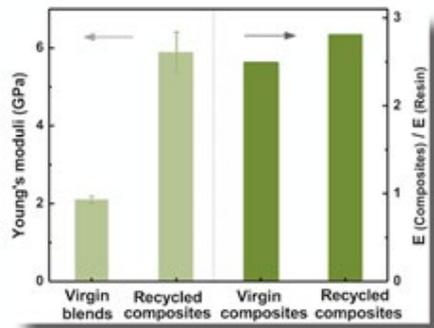
**SUPERABSORBANT**



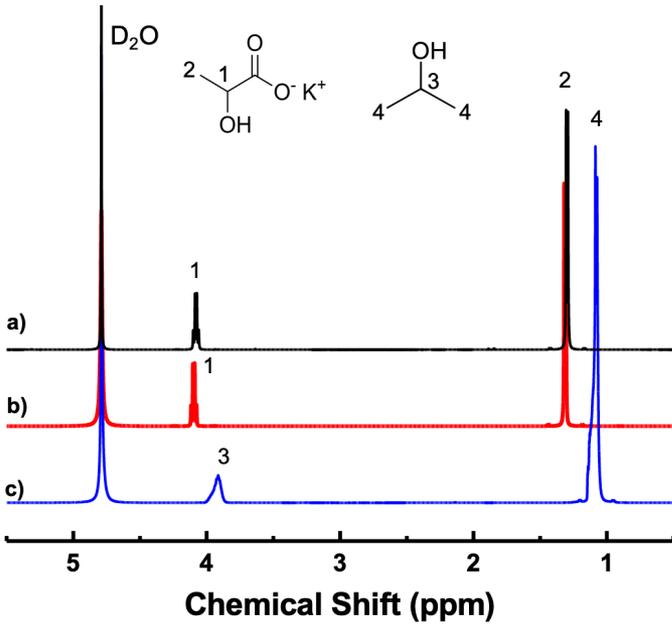
# Turbine-to-Turbine Material Circularity



Recycled fiber from composite feedstock

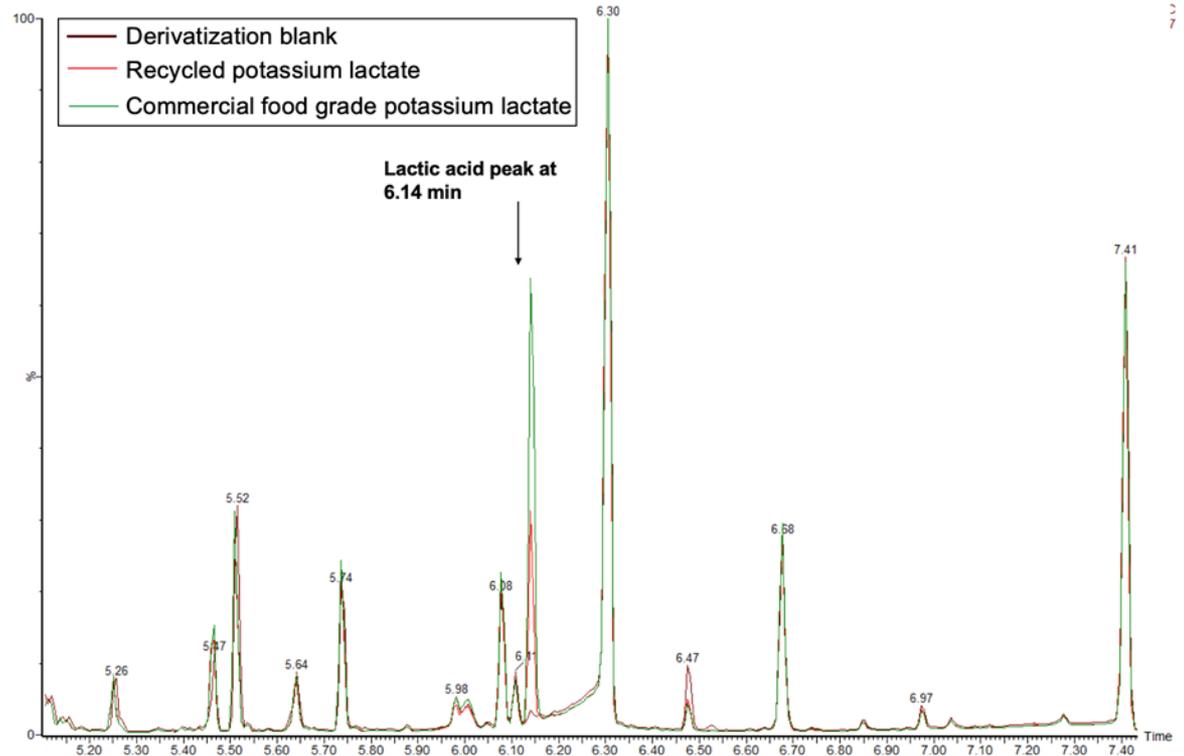


# Digestate



NMR

*Recovered potassium lactate is identical to PURASAL<sup>®</sup> HiPure P food grade from Purac.*



GCMS

# Turbines to Candy and Beyond !



*I ate these so part of me used to be a fiberglass panel!*

*Potassium lactate is found in energy drinks, leading to bad puns...*



**RE-CYCLING**  
*(get it?)*

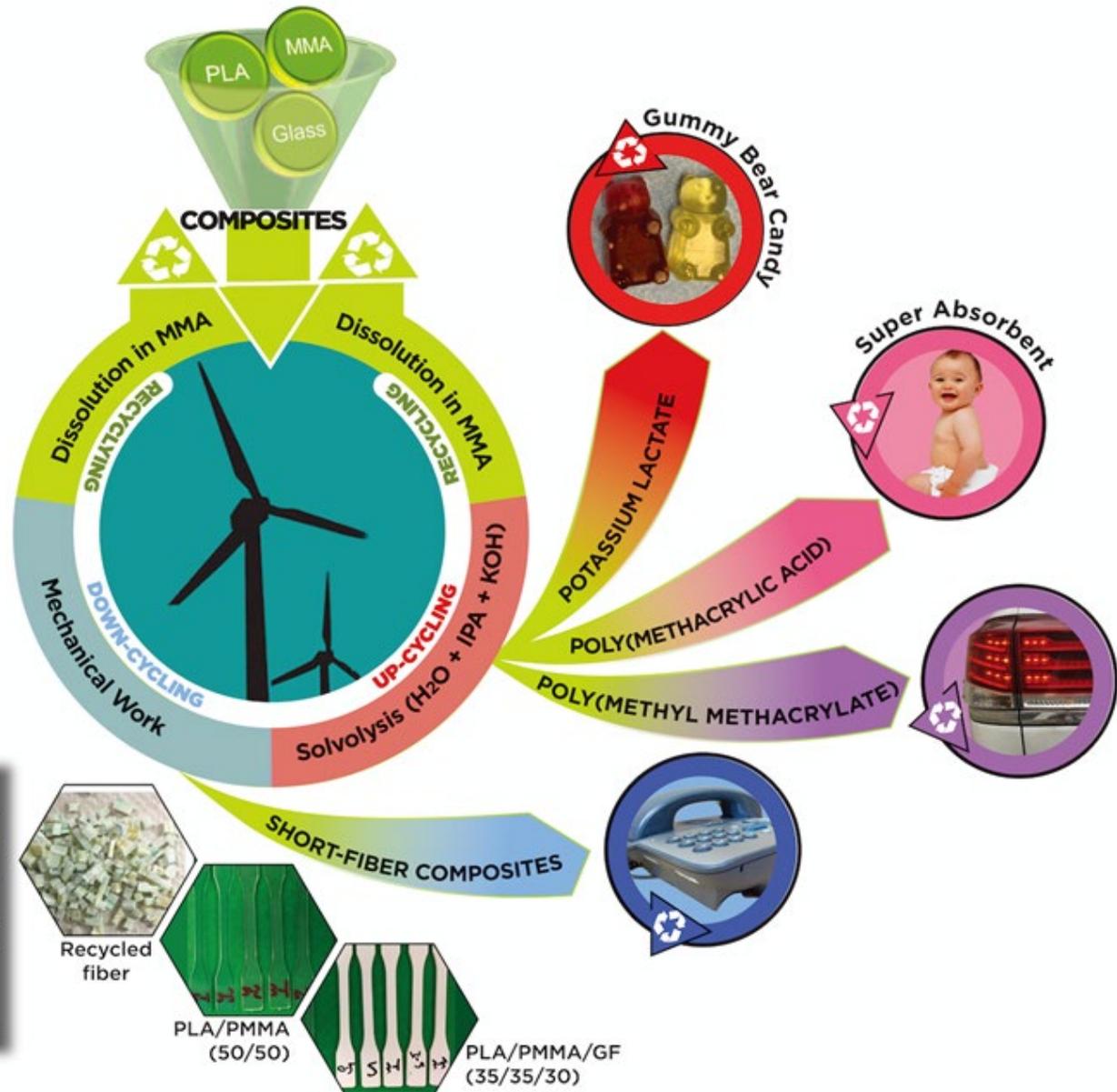
# Circularity in Composites



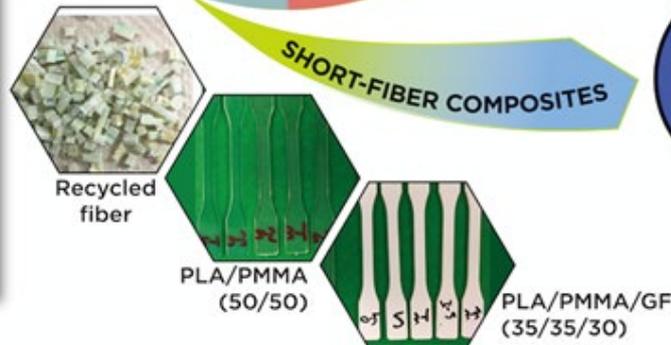
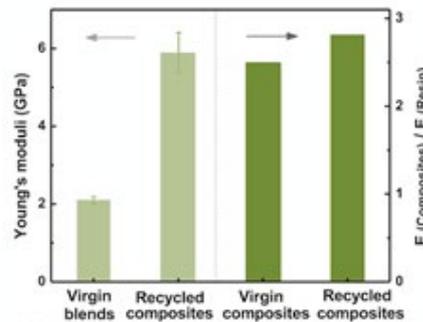
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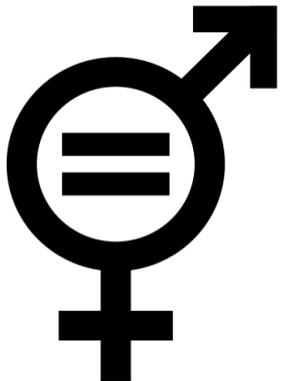


Recycled fiber from composite feedstock



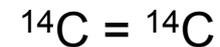
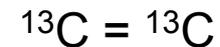
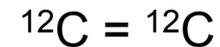
# Conclusions

- Thoughtful, quantitative, and judicious application of polymer science can **reduce costs, improve sustainability metrics, and enable the circular economy**.
- Sexism, Racism, and Carbonism are wrong; don't be a carbonist.



C = C !

well actually,



Consider: 25% of the carbon dioxide in the atmosphere was once fossil fuel so our food has already been fuel. Fiber and Food and Fuel - we need to embrace active management of the global carbon cycle by any means necessary.