DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

2.5.6.105 Bioderived Materials for Large-Scale Additive Manufacturing

March 4-8, 2019

Erin Webb, Soydan Ozcan,
Andy Zhao, Halil Tekinalp

Oak Ridge National Laboratory

ORNL is managed by UT-Battelle, LLC
for the US Department of Energy

Goal Statement

Improve economic viability of biomass supply chains with integration of materials coproducts

Research questions:

1. Is biomass a suitable replacement for carbon fiber in bioderived composites for large-scale 3D printing?

2. Can we design integrated biomass supply chains for fuels and materials to reduce biofuel feedstock costs?

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Quad Chart

Timeline

- 10/1/2017
- 9/30/2020
- 45%

	Total Costs Pre FY17**	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded			$346K	$692K
Project Cost Share*				

Barriers addressed

- Ct-J. Identification and Evaluation of Potential Bioproducts
- Ot-B. Cost of Production
- ADO-A. Process Integration

Objective

To improve the economic viability of the biofuels industry by adding a new high-value revenue stream for biomass supply chains - bioderived composites for the rapidly expanding large-scale additive manufacturing industry

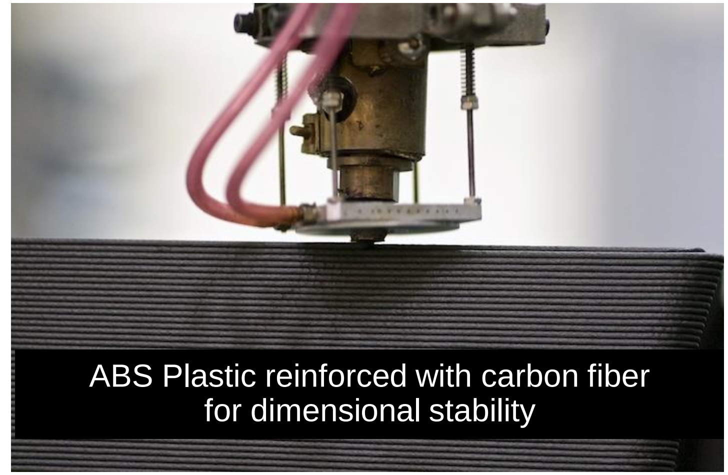
End of Project Goal

To resolve technical challenges of scale up in biomass preprocessing and biocomposites compounding operations to supply >500 lb of a bioderived material with biofiber reinforcement for a joint BETO/AMO large-scale printing demonstration

Project Overview
Large-scale polymer additive manufacturing

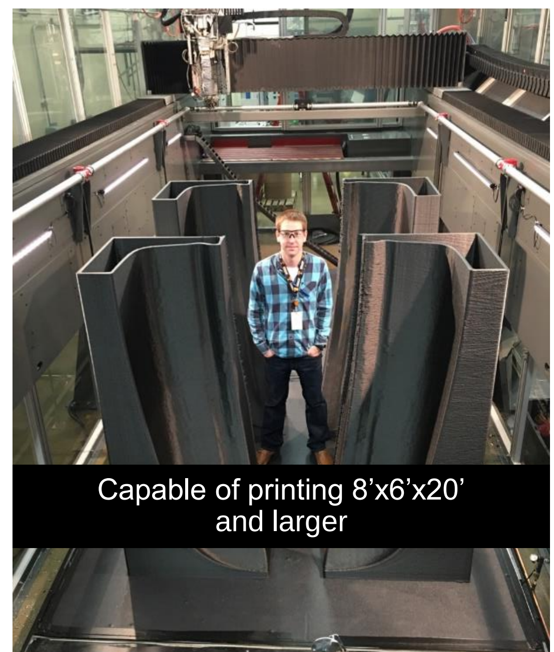
Bigger, faster, cheaper, smarter

Extruder attached to gantry system



ABS Plastic reinforced with carbon fiber
for dimensional stability

Pelletized feed replaces filament



Capable of printing 8’x6’x20’
and larger

Project Overview

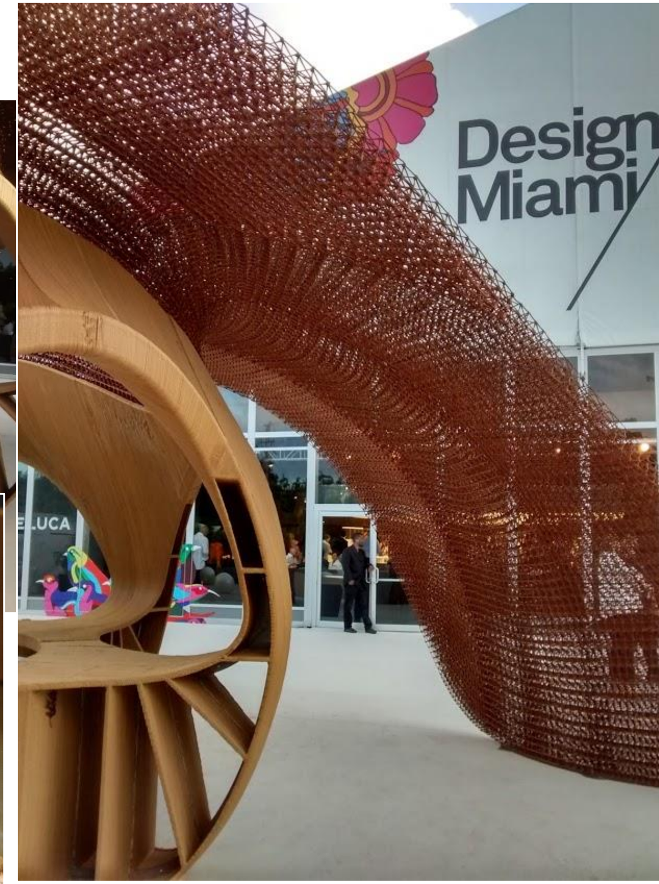
Advantages of Biomaterials

Enhancing the Clean Energy Economy

- ✓ 100% renewable product
- ✓ Rural economic development
- ✓ Lower cost and environmental impact than petroleum-derived products
- ✓ Increased pathways for recycling
- ✓ Sustainable manufacturing practices
- ✓ Improves economics of biofuel production

Project Overview
Prior experience with bioderived materials for 3D printing

Design Miami, December 2016
Pavilion designed by Shop Architects of NYC
20% bamboo, 80% PLA



Can we produce biocomposites from domestic feedstocks in a way that complements the biofuel industry?

Management Approach

- Team
  - PI: Erin Webb
  - Materials science: Soydan Ozcan, Andy Zhao, Halil Tekinalp
  - Biomass supply and processing: University of Tennessee Center for Renewable Carbon
  - Printing: ORNL Manufacturing Demonstration Facility (MDF) with financial support from the DOE Advanced Manufacturing Office (AMO)

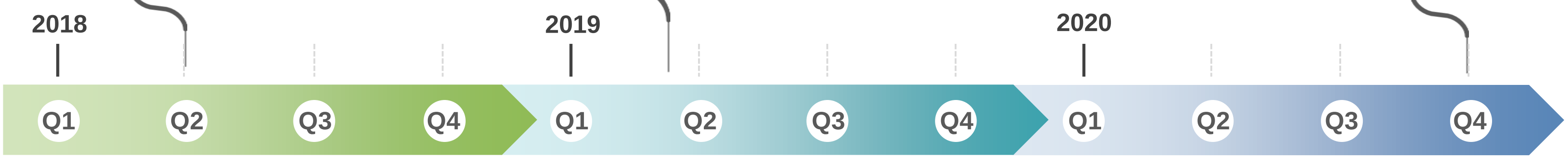
- Project management
  - Biweekly or monthly ORNL meetings
  - Quarterly meetings with UT CRC and MDF
  - Quarterly updates to BETO technology manager

Management Approach
Timeline

Podium demo
Poplar supplied and processed at UT used in printing a podium base

Now
BETO Peer Review

Project End Goal
Supply >500 lb of biomass for a joint BETO/AMO large-scale printing demonstration



Project start

Go/No Go
(1) Is poplar/PLA a suitable composite for 3D printing?

(2) Does addition of biomaterial feedstock coproduct have potential to help biofuel feedstock meet cost targets?

Focus:
- Assess poplar as replacement for carbon fiber in composites for large-scale 3D printing
- Cost analysis of biomass for biofuels AND biomaterials

Focus :
- Test additional feedstocks (tentatively pine and switchgrass)
- Optimize and scale-up biomass preprocessing operations for integrated fuel and materials supply chains

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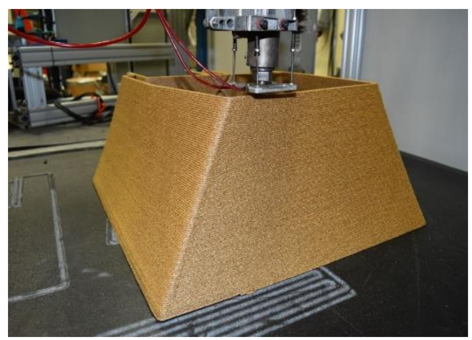
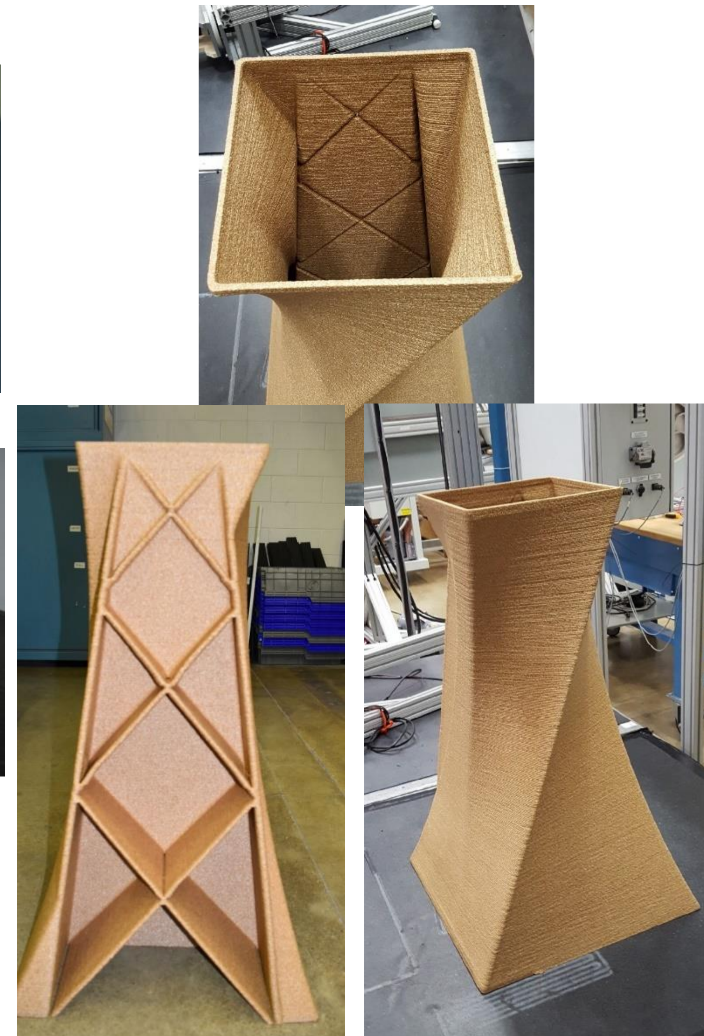
Technical Approach
Preliminary demonstration

Test print in February, 2018
Podium base with PLA + 20% poplar

425-850 µm screen





Technical Approach

Research questions:

1. Is biomass a suitable replacement for carbon fiber in bioderived composites for large-scale 3D printing?
2. Can we design integrated biomass supply chains for fuels and materials to reduce biofuel feedstock costs?

Biomass Characterization

1. Composition
2. Particle size
3. Particle aspect ratio
4. Surface morphology

Material Testing

1. Material strength
2. Printability (rheology)
3. Dimensional stability of printed product

Cost Analysis

1. Biocomposite cost
2. Impact on biofuel feedstock cost

Technical Targets

Go/No Go, Due March 31, 2019

1. Material strength – 75% of CF/ABS
2. Material cost – 50% of CF/ABS
3. Reduce poplar feedstock for fuel to <$73/dry ton?

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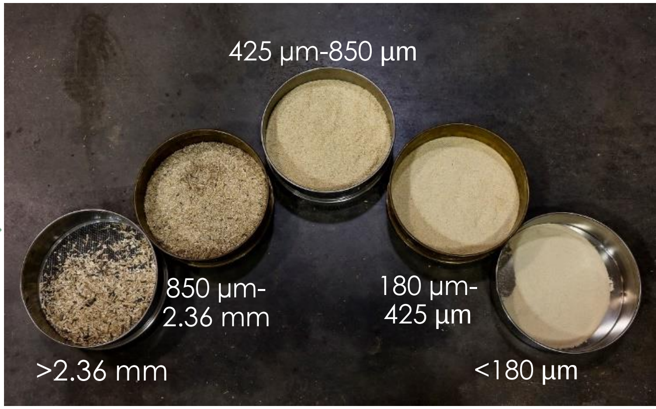
Technical Approach
Biomass Preprocessing

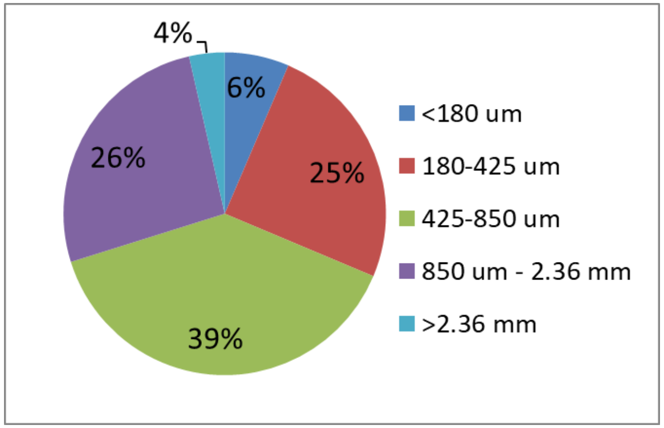
- Mechanical processing, size reduction and particle fractionation, to create feedstocks for fuels and materials
- What particle size fractions are best for materials? For biofuel conversion?

Debarked poplar logs

2-stage size reduction: chip and mill



Particle size separation by vibratory shaker



Nominal particle size for pyrolysis (NREL Design Report, 2015) = 2 mm

Which particle size is best for biomaterials?

UTIA INSTITUTE OF AGRICULTURE THE UNIVERSITY OF TENNESSEE

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Technical Approach
Cost Analysis

- Poplar for biomaterials price target
  - Current value of CF/ABS ~ $6/lb
  - At 50% of CF/ABS, biocomposite price target = $3/lb
  - At 20% fiber fill
    - Compounding process ~ $0.65/lb
    - PLA ~ $0.80/lb
    - Leaves $1.55/lb (of composite) for fiber

Poplar delivered cost

Operation	$/dry ton
Production & maintenance	100
Harvest	25
Skidding & chipping	25
Delimbing and debarking	10
Transportation	27
Hammermill	20
Particle size fractionation	10
TOTAL	217

Supply chain was designed for delivering top-quality wood. Cost estimates are conservative.

Technical Accomplishments/Progress/Results
Characterization of poplar fibers

Poplar fibers <2.36 mm screen

Composition

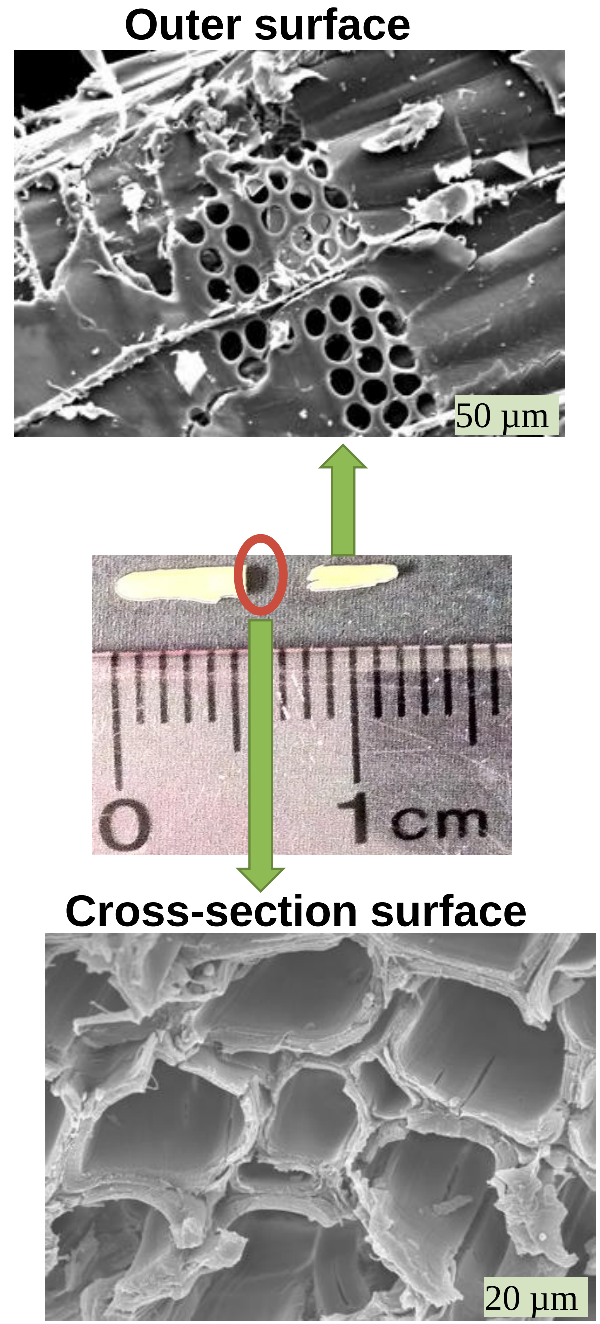
Cellulose = 39 – 48%
Lignin = 27 – 29%
Hemicellulose = 13 – 16%

Aspect ratio:

1.8 – 3.3

Bulk density:

0.17 – 0.20 g/mL



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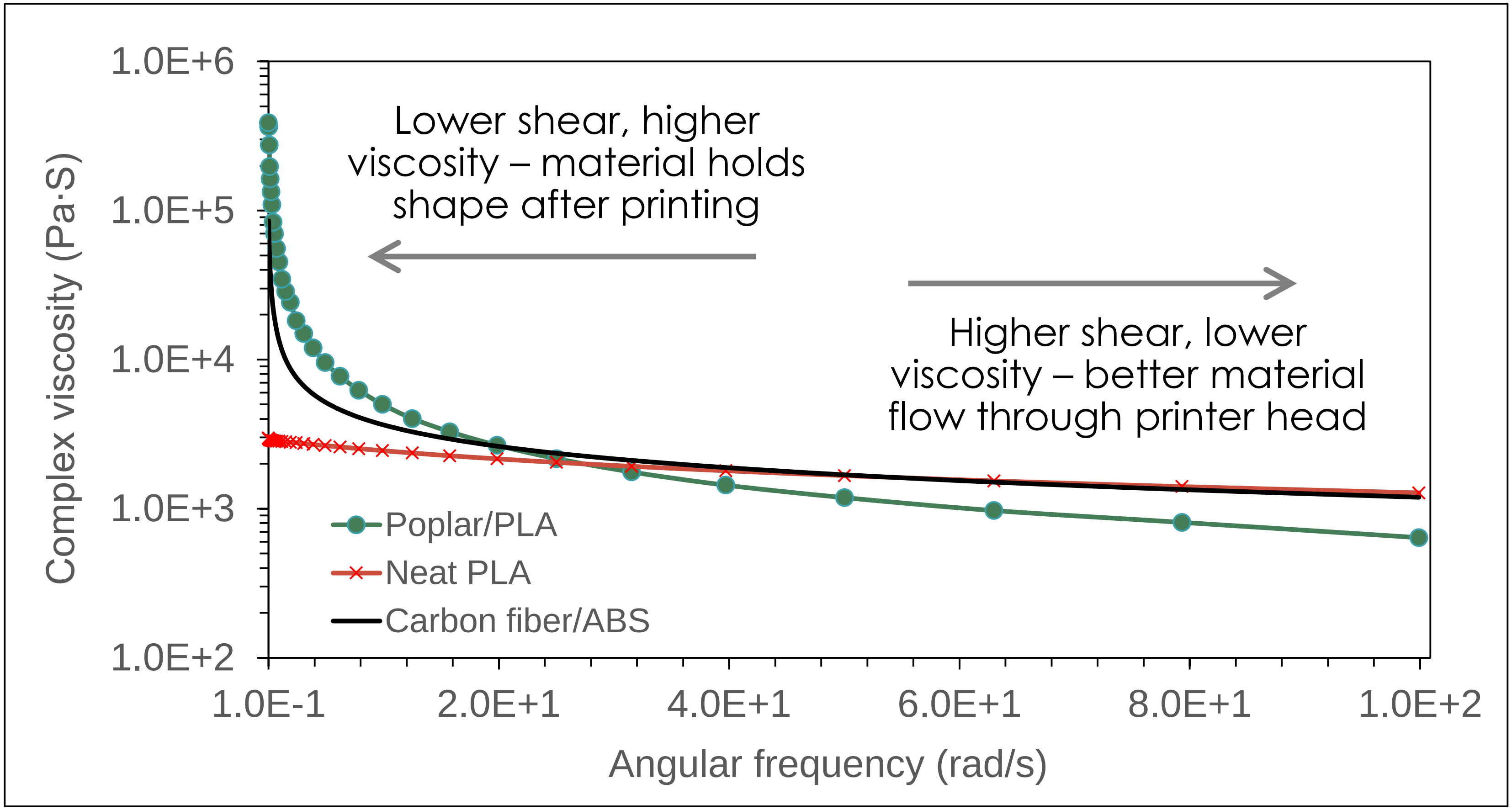
Technical Accomplishments/Progress/Results

Printability of poplar based composites



- All composites here meet the viscous characteristics of 3D printing according to a printability model created by Duty et al.
- PLA/poplar printability outperforms CF/ABS and neat PLA (no fiber reinforcement)

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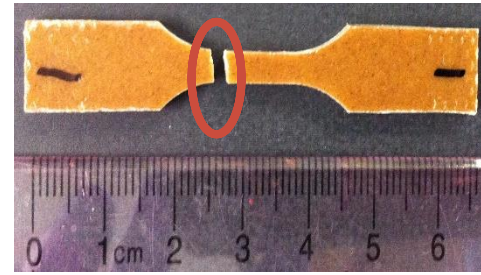
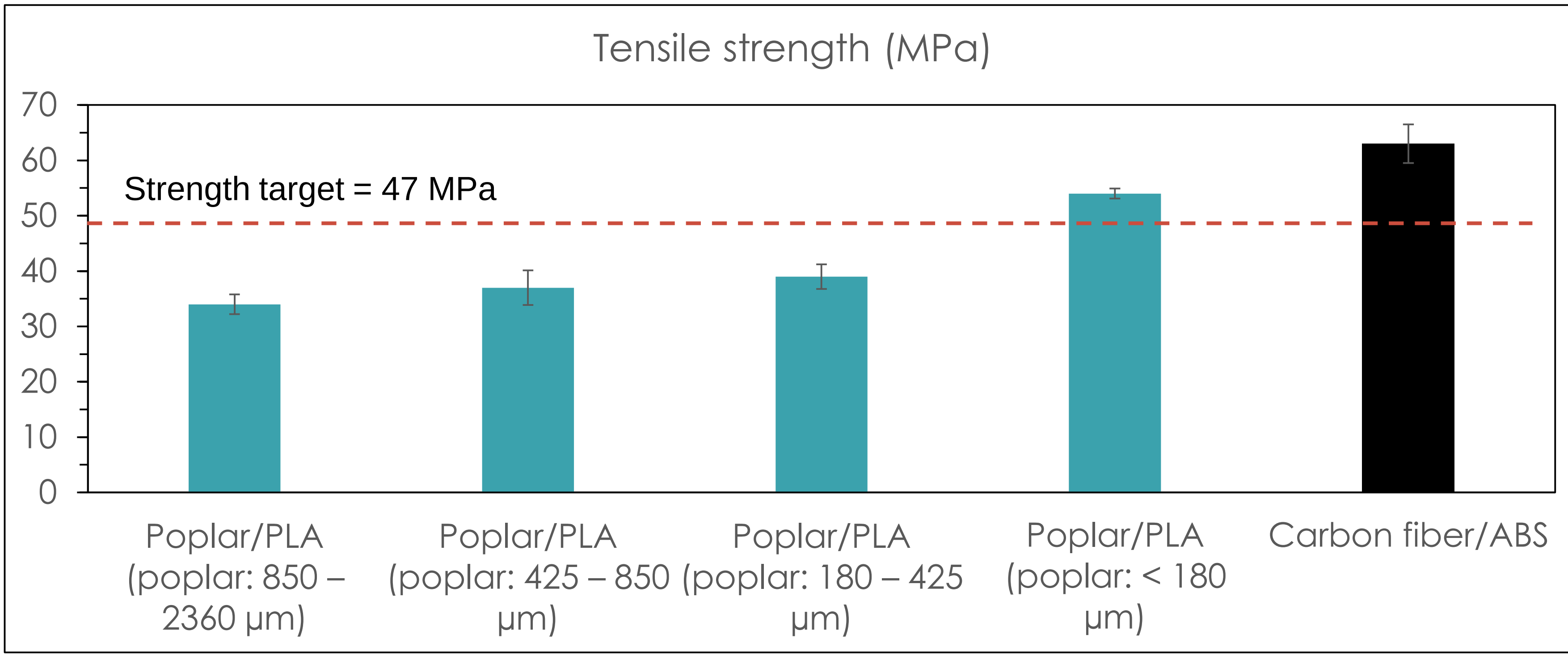
Duty, Chad, et al. "What makes a material printable? A viscoelastic model for extrusion-based 3D printing of polymers." *Journal of Manufacturing Processes* 35 (2018): 526-537.

Technical Accomplishments/Progress/Results
Composite strength



– Compared composites with 20% by weight fiber reinforcement (poplar/PLA vs carbon fiber/ABS)
– Strength target (FY19 Go/No Go) is 75% of CF/ABS



With particle size <180 μm, composite of 20% poplar and 80% PLA had tensile strength 89% of carbon fiber/ABS

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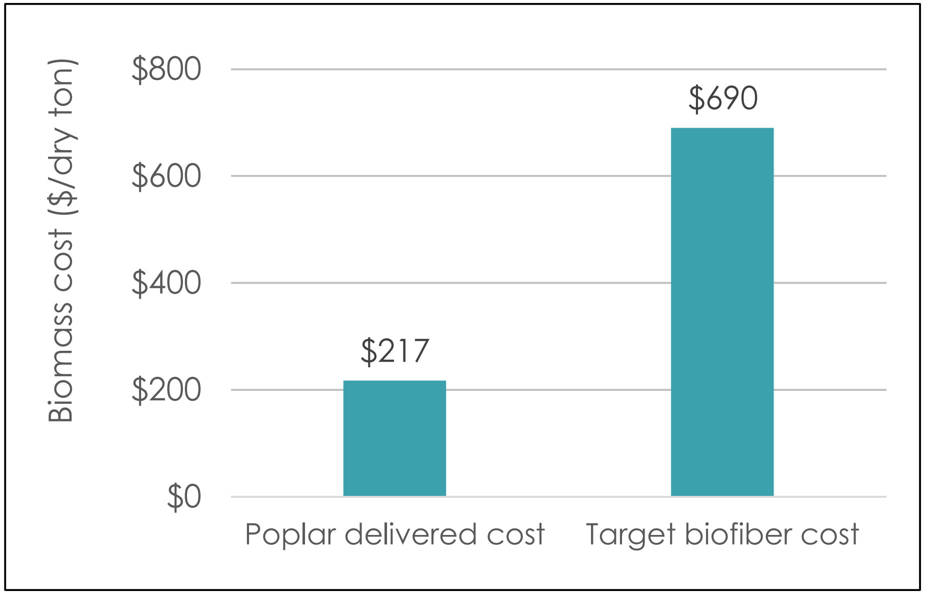
Technical Accomplishments/Progress/Results
Cost Analysis

- Biomass cost to meet biomaterial cost target = $690/dry ton
- Delivered cost of high-quality poplar = $217/dry ton
- Recent market price of pine wood flour ≈ $500/lb



Fraction to biomaterials	Fraction to biofuels	Minimum biomaterial feedstock price if biofuel feedstock is $73/dry ton (BETO cost target)
30%	70%	$552/dry ton
50%	50%	$360/dry ton
70%	30%	$278/dry ton

For example: If we divide biomass 50/50, and the biofuel feedstock is valued at $73/dry ton, fiber for biomaterial should earn at least $360/dry ton.

"Biofiber reinforcement is attractive to manufacturing industry because as fiber loading increases, product strength increases and cost decreases"

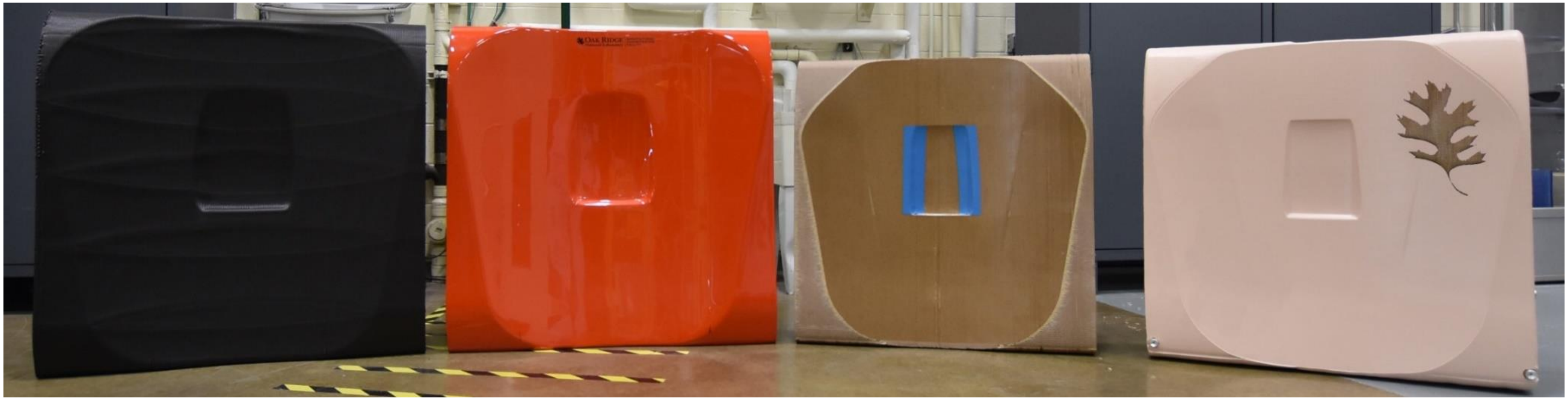
- Lonnie Love, ORNL Corporate Fellow and Manufacturing Systems Group Leader

Relevance

- There are opportunities to develop low-cost, sustainable materials for large-scale 3D printing for applications that do not require the full strength of carbon fiber/ABS
- Successful completion of this project will provide a new, high-value feedstock coproduct stream that reduces biofuel costs by sharing feedstock supply chain resources and costs with biofuel feedstocks
- Biomass for bio-derived materials can either compete with or complement biofuel feedstock supply chains

Future Work

- **Test** other feedstocks (e.g., pine and switchgrass)
- **Compare** performance of biofiber reinforcement with carbon fiber reinforcement in printed products.
- **Optimize and scale up** feedstock size reduction and fractionation operations.
- **Optimize** biocomposite strength with biomass treatments, increased fiber loading, and improved fiber:resin bonding.
- Match biocomposites with **best applications**.



Molds for a car hood printed from CF/ABS and biocomposites. Molds are a target application for large-scale additive manufacturing.

Summary

- **GOAL:** Improve the economic viability of biomass supply chains with integration of materials coproducts
- **SUCCESSFULLY ACHIEVED TECHNICAL TARGETS** to: (1) create biocomposites for large-scale additive manufacturing with 75% of strength at 50% cost of CF/ABS and (2) Reduce biofuel feedstock cost
- **NEXT STEPS**: optimize printed product performance, test other feedstocks, optimize and scale-up biomass preprocessing

Is this material durable?

Miami
December 2018
2 years after installation

Damage sustained during Hurricane Irma in 2017

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Additional Slides

Publications and Presentations

Publications

Kooduvalli, K., B. Sharma, E. Webb, U. Vaidya, and S. Ozcan. 2019. Sustainability Indicators for Biobased Product Manufacturing: A Systematic Review. *Journal of Sustainable Development* (accepted)

Presentations

Xianhui Zhao, Erin Webb, Soydan Ozcan, Halil Tekinalp, Tim Theiss, Darby Ker. *Bioderived Materials for Large-Scale Additive Manufacturing*. ASABE Annual International Meeting, Detroit, MI July 29 – August 1, 2018.