Innovative High-Feed Rate Additive Manufacturing Using Sustainable Nano- Micro- Cellulose-Reinforced Thermoplastic Composites

June 2019-Sept 2022

Oak Ridge National Lab & University of Maine

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
11 June 2019

Overview

Project Title: Innovative High-Feed Rate Additive Manufacturing Using Sustainable Nano- Micro- Cellulose-Reinforced Thermoplastic Composites

Timeline:

Project Start Date: 06/01/2019

Budget Period End Date: 09/30/2022

Project End Date: 09/30/2022

Barriers and Challenges:

- Depleting petroleum sources and increasing cost concerns will require alternative resources. To replace the petroleum industry, an industrial ecosystem involving highly competitive processes for conversion of renewable biomass to cellulose fibrils, fuels and chemicals has to be established .
- Creating high value bioproducts from biomass is essential for the realization of this establishment.
- Use of cellulose fibrils in composite applications have the potential to create this high value stream from biomass; however, there are many challenges for creating the ecosystem.
- Cellulose fibrillation and drying are highly energy intensive processes.
- Drying nano- and micro-cellulose leads to significant, irreversible agglomeration of fibrils.
- Dispersion of dried cellulose fibrils in polymer matrix and achieving the fibril-matrix interaction/adhesion is a big challenge.
- The feedstock should not only have good mechanical properties, but also have the right rheology and processability for compatibility to Additive Manufacturing

AMO MYPP Connection:

- 3.1.6 Additive Manufacturing
- 3.1.7 Composite Materials
- 3.1.14 Sustainable Manufacturing

Planned Project Budget and Costs:

Budget	DOE Share	Cost Share	Total	Cost Share %
Planned Overall Budget	$20,000,000	$7,500,000	$27,500,000	27%

Project Team and Roles:

Soydan Ozcan – Project Lead

Bill Peter – Business Contact
Halil Tekinalp – R&D Scientist
Vlastimil Kunc – R&D Scientist

Academic Partners
Habib Dagher – U-Maine lead -Contact
James Anderson – U-Maine R&D Engineer
Doug Gardner – U-Maine R&D Scientist – Professor

Project will also include
Industrial partners, academics (students, interns, postdocs, and faculty), and national lab scientists.

Project Objective(s)

Objective

- To advance nanocellulose and other forest products composite technology, to reduce time from laboratory discovery to market impact, and facilitate the transition of bio-based Additive Manufacturing (AM) technologies to industry.
- To solve the associated challenges of nano- and micro-cellulose reinforced polymer composite production to produce a new quality feedstock for AM with large potential for a wide impact on the greater composites market.
- To demonstrate developed material systems/composites in use phase at different applications, from structural to lightweighting applications, from stay in place molding to tooling applications.
- To establish sustainable manufacturing practice of use of cellulose-based composites from recycling to biodegradation.
- Utilization of nano- and micro- cellulose fibrils to develop fully sustainable low cost feedstock will not only boost AM technology and its adoption by broader industry, but it will also help pulp and paper industry improving competitiveness.

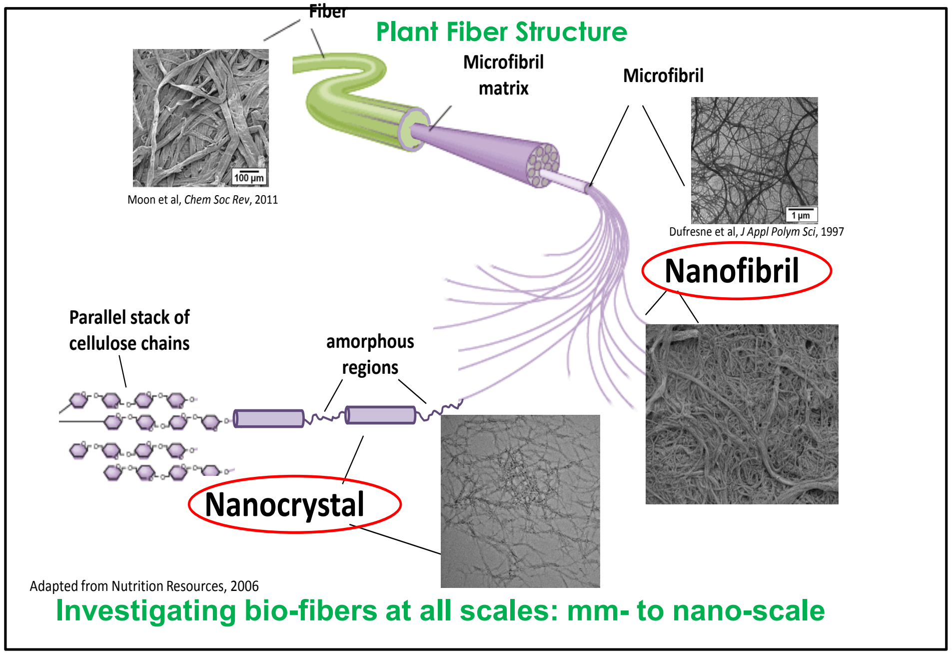
Problem:

- Current technology to fibrillate biomaterials/pulp into cellulose fibrils and to dry are energy intensive processes. They also cause agglomeration of fibrils which leads to inefficient dispersion into polymer resins and inferior composite properties.

Technical Innovation

- Modern additive manufacturing relies on energy intensive, petroleum-based materials such as carbon fiber reinforced ABS thermoplastics with a high cost of ~$6/lb. To date no domestically sourceable, low embodied energy, composite resins are available for additive manufacturing. Nanocellulose fibers, capable of reinforcing 3D printing resins, are abundant in nature.

- ***Approach:*** Utilization of nano- and micro-cellulose fibrils to produce fully sustainable, low energy, low cost AM feedstock with improved mechanical performance and processability.
  - Preliminary results show that nanocellulose fibrils can significantly improve mechanical properties of biopolymers, such as PLA, provided that the right morphology, dispersion and surface interaction with polymer is achieved.
  - The new feedstock is projected to meet the properties of current state of the art feedstock, CF-ABS at half of the cost (~$3/lb) using sustainable, bio-based options.



- ***Takeaway:*** A bio-based renewable alternative—a nanocellulose/polymer formulation for AM—has approximately **1/3 as much embodied energy** as petroleum based current state of art materials and offers the potential for raw material **cost savings of near 50%.** Other benefits include up to **90% reduction in carbon footprint and improved biodegradability and sustainability.**

Technical Approach

The proposed research efforts will be centered around 3 main thrusts:

Fiber Production

1.1 Fibrillation

1.2 Surface Treatment

1.3 Dewatering and Drying
- Simulation of energy requirement

Composite Innovation

2.1 Composite technology
- Utilizing currently available cellulose fibers

2.2 Innovative Composites
- Impact of fibrillation
- Impact of surface treatment
- Impact of drying

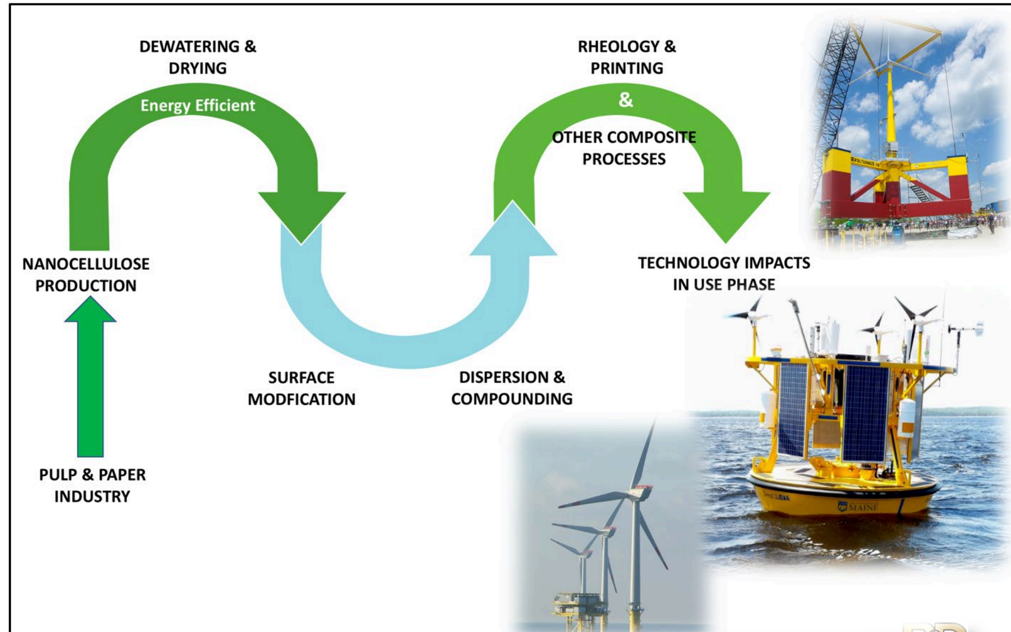
2.3 Process Integration - Additive Manufacturing
- Foams
- Thermoset composites
- Thermoplastic composites

Application

3.1 Direct use
- Structural
- Lightweight

3.2 Indirect use
- Mold for marine industry and concrete precast
- Off-Shore energy applications

3.3 After end of use: Recycling and biodegradability



UMaine has the only US pilot plant for the production of cellulose nano-fibrils (CNFs) at 1 ton/day and patented technology for the spray drying of CNFs with ongoing research to scale this technology for mass production.

MDF is an ORNL user facility focusing on cost-shared early-stage applied R&D and a leader in the areas of additive manufacturing. It has 35 systems and $12M of industry-provided equipment.

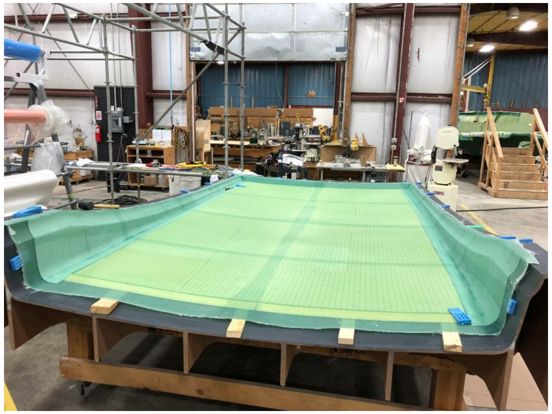
Results and Accomplishments

Bio-Manufacturing and Materials Vision

A competitive America utilizing sustainable forest products in additive and composite processes in mainstream manufacturing industries to achieve carbon neutrality and energy independence.

Accomplishment:

A pilot platform between U-Maine and ORNL has been successfully built. Three partners from Maine marine industry has already been involved in additively manufacturing of a marine mold that was used to produce a roof of an actual yacht.



End of Project Goal (2022)
By September 2022, Develop high performance/cost materials from forest products for composites and Additive Manufacturing processes with attributes:

- As strong as the current state of the art carbon fiber (CF) – thermoplastic ABS (70MPa),
- The throughput of 100lb/hr or faster,
- 30% or more saving on the cost of a product (CF-ABS as basis)
- 30% saving in embodied energy (CF-ABS as basis)

Transition

- *Technology readiness (TR) level of 6 anticipated by project end.*

- *Intellectual property or recruitment of further development funding beyond 09/2022.*

- *20+ Industrial partners will be involved in the course of the project utilizing Tech-Collaboration mechanism of MDF*

- *A new hub-and-spoke partnership will accelerate the advancement of nanocellulose and other forest products composite technology, reduce time from laboratory discovery to market impact, and facilitate the transition of bio-based Additive Manufacturing (AM) technologies to industry. Solving the associated challenges of nanocellulose reinforced polymer composite production will yield a new quality feedstock for AM with large potential for a wide impact on the greater composites market.*

- *Hub-and-Spoke engagement model will be built upon the successfully established pilot platform between U-Maine and ORNL to strengthen regional manufacturing ecosystems by connecting university–industry clusters with Department of Energy (DOE) laboratories and the Manufacturing Demonstration Facility (MDF) at Oak Ridge National Laboratory (ORNL). This approach will transplant the successful laboratory-industry-university collaborative manufacturing model of ORNL's MDF to regional manufacturing ecosystems and leads to a national impact.*