U.S. DEPARTMENT OF
ENERGY
Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Lightweight and Thermally Insulating Nanowood

Performing Organization(s): InventWood, LLC. Maryland, USA
PI Name and Title: Amy S. Gong, Chief Scientific Officer
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Project Summary

Timeline

Start date: July 1st, 2018

Planned end date: June 30th, 2019

Key Partners

Prof. Bao Yang, UMD

Dr. Amy S. Gong, InventWood

Key Milestones

1. Fabricate 10 delignified white wood samples 4in by 4in;
2. Achieve mechanical target of 300-400 MPa and thermal conductivity ~0.02 W/mK;
3. Achieve mechanical target of 500 Mpa and thermal conductivity ~0.01 W/mK;
4. Finish cost analysis and identify the cost-limiting steps;
5. Demonstrate delignified wood with a size of 1m by 1m, thermal conductivity of ~0.1 W/mK and strength of 500MPa;
6. Complete customer evaluations and identify 2-3 potential buyers for the technology.

Budget

Total Project $ to Date:

- DOE: $72,491.76
- Cost Share: $0

Total Project $:

- DOE: $150,000.00
- Cost Share: $0

Project Outcome

1. Demonstrate processes for fabrication and structural characterization of 1m by 1m thermal insulating nanowood;
2. Achieve mechanical (tensile strength of 400-500MPa) and thermal (0.012 W/mK) performances for the thermal insulating nanowood;
3. Design and evaluate operation procedure for rapid manufacturing (5 minutes per wood panel on average) and carry out cost analysis;
4. Evaluate the commercialization of the thermal insulating nanowood through close collaborations with industry undernon disclosure agreement (NDA) and materials transfer agreement (MTA).

Team

InventWood Team

Dr. Amy S. Gong (CSO)

-Track Record

More than 10 years of research experience in chemical and materials engineering. Research findings on wood-cellulose materials were published on leading scientific journals.

-Contributions

- Scale up manufacturing process design and optimization;
- Building integration modeling and evaluation;
- Surface/bulk hydrophobic treatment;

Josh Cable (CEO), Jeff Li (CFO)

-Track Record

Over 10 years of corporate experience in both the U.S and Asia (Josh). Over 10 years of experience in the finance industry and research experience in material technologies (Jeff)

-Contributions

- Cost analysis
- Commercialization and market analysis

UMD Team

Prof. Bao Yang (Co-PI)

-Track Record

Tenured professor holding dual-Ph.D. degrees in Mechanical Engineering and Physics. Over 16 years of research experience in micro/nanoscale thermal transport and energy conversion. Outstanding scientist with over 50 publications on leading refereed journals.

-Contributions

- Process-structure-property relationship
- Energy consumption analysis
- Life cycle analysis

Li-qi Zhu (Technician)

-Track Record

Experienced researcher on processing cellulose materials.

-Contributions

- Materials characterizations (thermal, mechanical, stability, and morphology)

Collaborations

Dr. Junyong Zhu (USDA)

-Track Record

Over 26 years of research experience in production, characterization and utilization of cellulose nanomaterials. Fellow of International Academy of Wood Science and American Chemical Society (ACS). Research findings published on leading scientific journals.

-Contributions

- Characterizations of wood and nano-cellulose;
- Delignification of wood

Industrial Partners

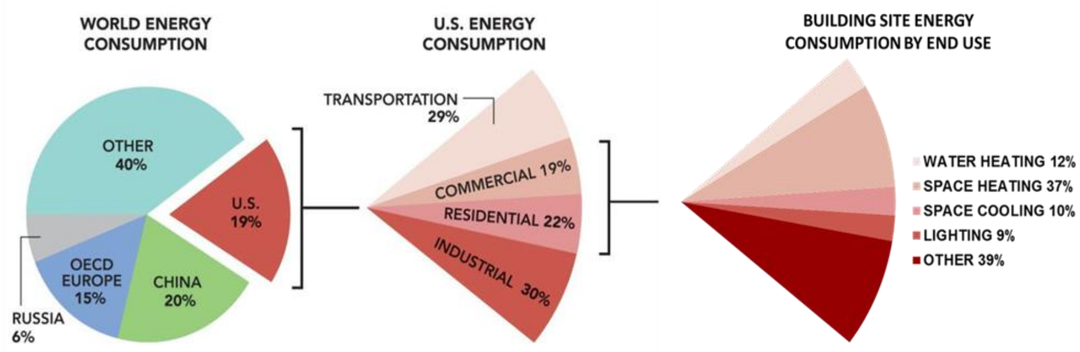
-Contributions

- Commercialization evaluations

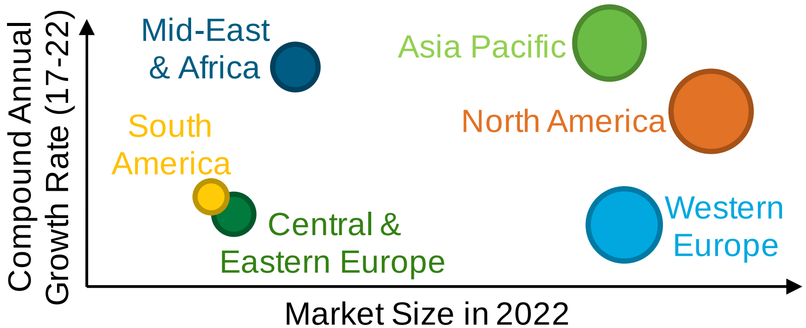
Challenge

Challenge: *Low Energy Efficiency of Thermal Insulating Materials in Current Buildings*

Annually, building consumes about 40% of total energy in the United States, greater than industrial and transportation. The development of high performance building insulation panels is critical in achieving the energy conservation goal mandated by the U.S. Department of Energy's Building Technologies Office (BTO).



Src: DOE, 2011 Buildings Energy Data Book



Opportunity: *Retrofit of Existing Buildings Represent Great Opportunity to Upgrade the Energy Performance*

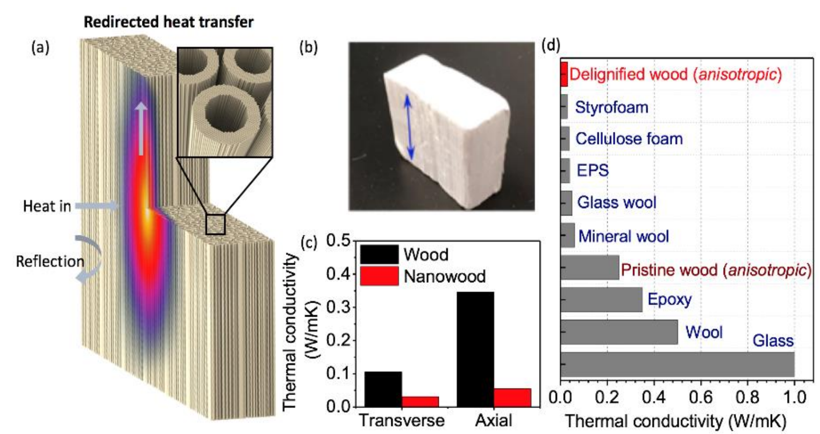
Renovation, retrofit and refurbishment of existing buildings have been adopted as an opportunity to upgrade the energy performance of commercial building assets for their ongoing life. Energy efficiency retrofits can gain a market edge by reducing the operational costs, particularly in older buildings, as well as helping to attract tenants.

Src: Markets and Markets, 2022 Global Forecast

Our Solution ---- Nanowood

Stronger, Better Thermal Insulation

- Outstanding low thermal conductivity of nanowood will greatly **improve the energy efficiency** of buildings when used as a thermal insulating material;
- Low-cost, environmental-friendly nanowood **reduces carbon footprint and operational costs** of buildings, making nanowood a favorable material for energy performance upgrade.



Approach

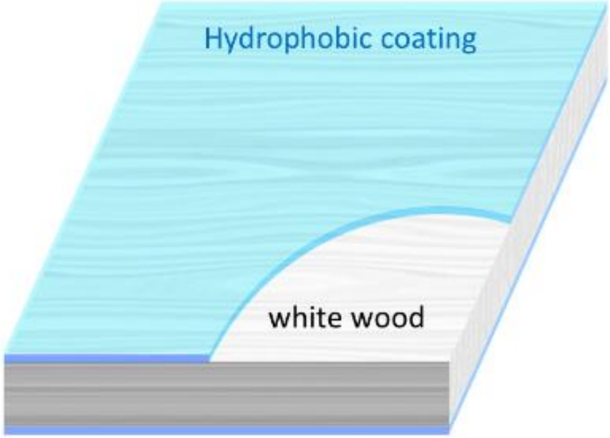
Work Plans

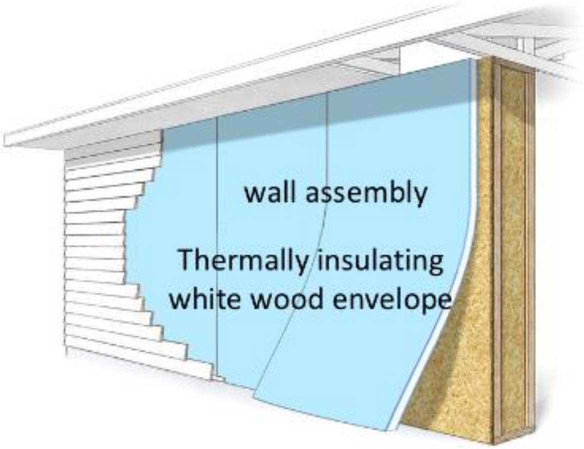
Task 1. Investigate process-structure relationship of nanowood
- Develop/optimize delignification process with basswood;
- Extend chemical treatments to hardwoods/softwoods;
- 3D morphology examinations;
- hydrophobic treatments.

Task 2. Investigate structure-property relationship of nanowood
- Mechanical strength and toughness;
- Thermal conductivity (resistance);
- UV stability;
- Wall assembly for studying air and moisture infiltration;
- Energy saving modeling.

Task 3. Analysis on cost and scalability and benchmark against commercial products
- Cost analysis and scale-up production

Task 4. Commercialization evaluation
- Evaluations with industry partners for potential integrations/commercialization.

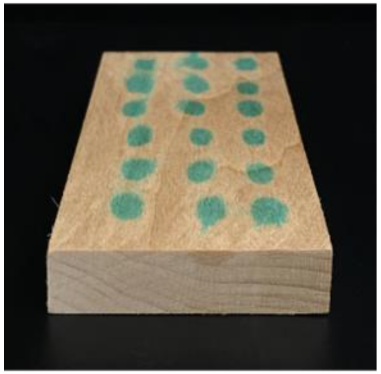




Approach

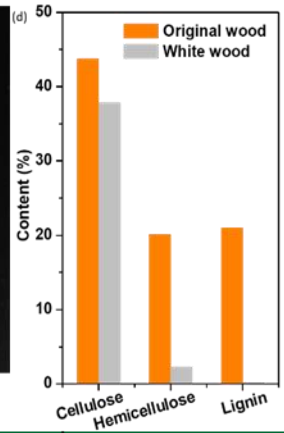
Risk and Mitigation Plans

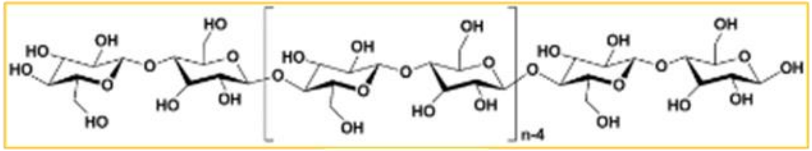
1. Wood break during delignification, especially with low-density wood as the starting materials.
    - *Mitigation: Tailor the delignification process for different kinds of wood by fine-tune chemical concentration, composition, and processing rate;*
2. Delignification time for thick wood might be impractically long, especially for high-density woods.
    - *Mitigation: Study processing-time's dependence on thickness, chemicals, and temperature; Alternatively, use thinner wood to start, then stack after delignification;*
3. Nanowood is hydrophilic and not stable against humidity or water for building applications.
    - *Mitigation: Develop surface treatment method to protect nanowood or use paint or cover materials;*
4. Nanowood is not stable against UV exposure.
    - *Mitigation: Develop surface coating or cover materials to protect nanowood from UV;*



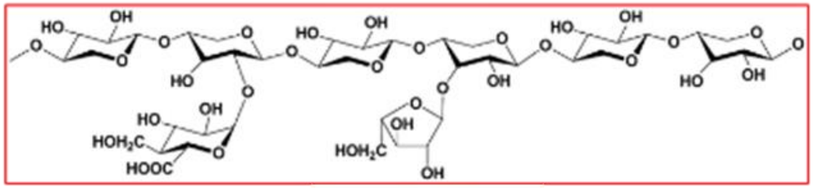
Hydrophilic un-treated natural wood

Hydrophobic nanoparticle coated densified wood

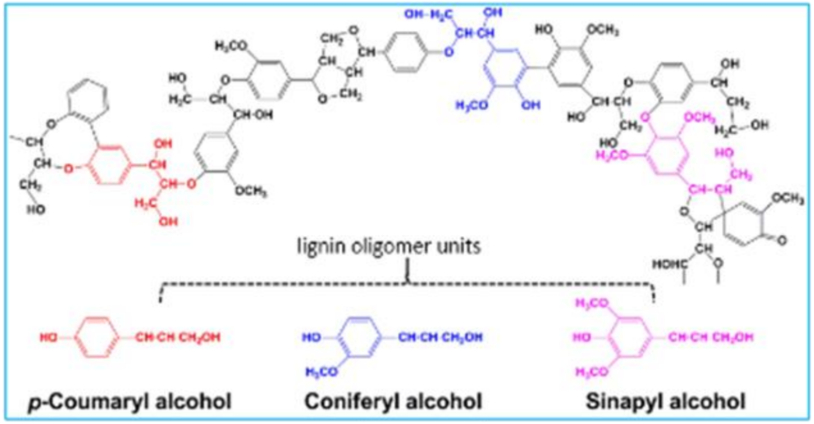




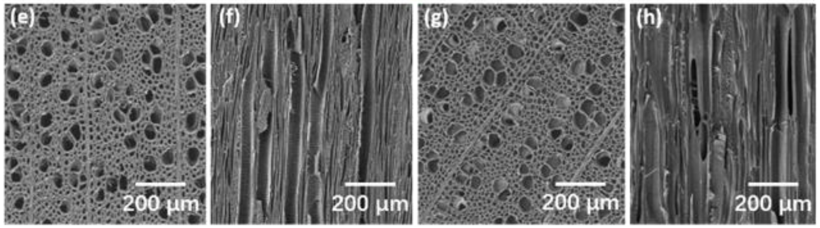
cellulose



hemicellulose



Lignin



Original Wood Nanowood

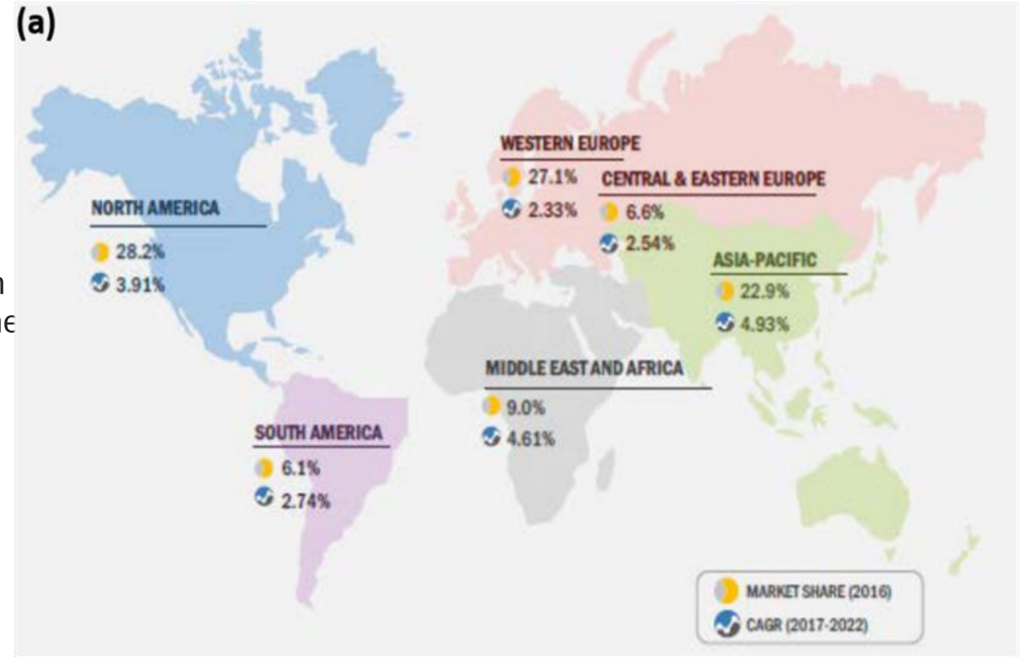
Impact

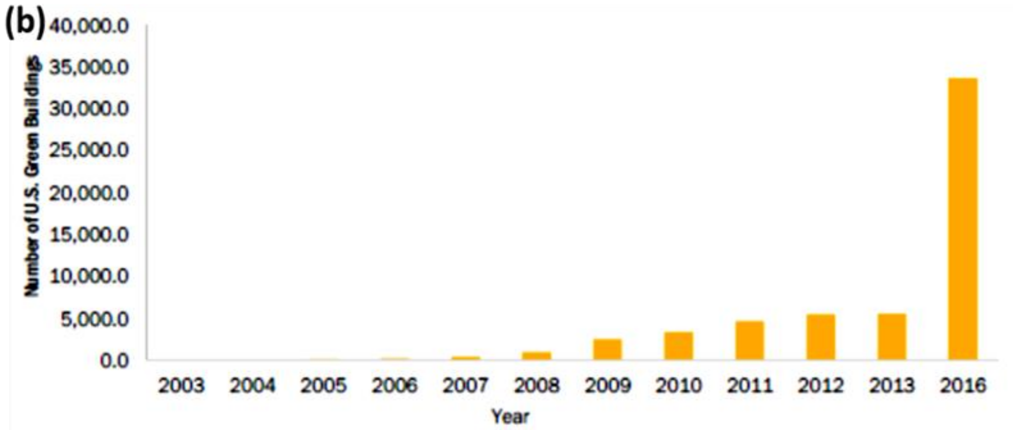
The lack of green insulation material is the restraining factor for the growth of the building thermal insulation market.

The adoption of our thermal insulation wood as a green building thermal insulation material can help address the great need for better building envelop. Note that more than 70% of electricity was used in buildings (both residential and commercial), ~ 35% of which can be attributed to losses through the building envelope (via heat transfer and air infiltration) *according to the FOA*.

Nanowood is better because of its high mechanical strength, high thermal insulation properties, and easy scaling up

By using natural wood as the starting material, this technology will be a green, cost-effective, and scalable way to insulate. The developed material will be high-performing yet mechanically strong, as to be used as a load bearing material, and will be suitable for energy efficiency building retrofit applications.





Src: Markets and Markets, August 2017 report.

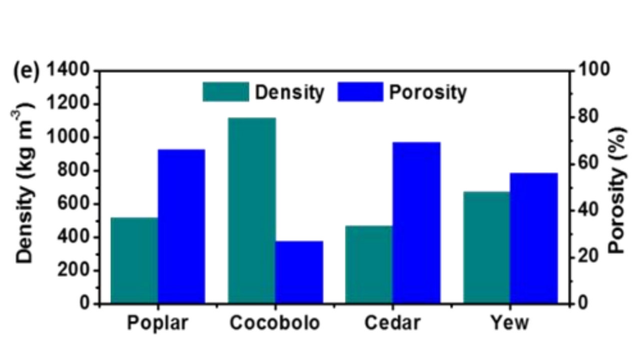
Progress

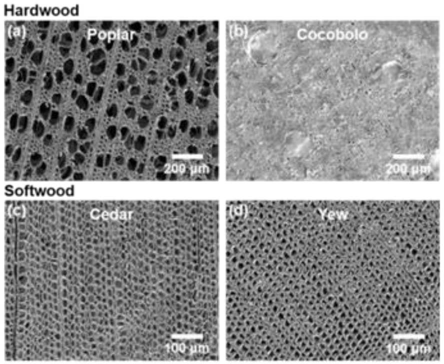
Project Stage: Mid-Project

Optimized Delignification Process for Basswood and Beyond (Task 1)

Delignification process was optimized for the following wood types;

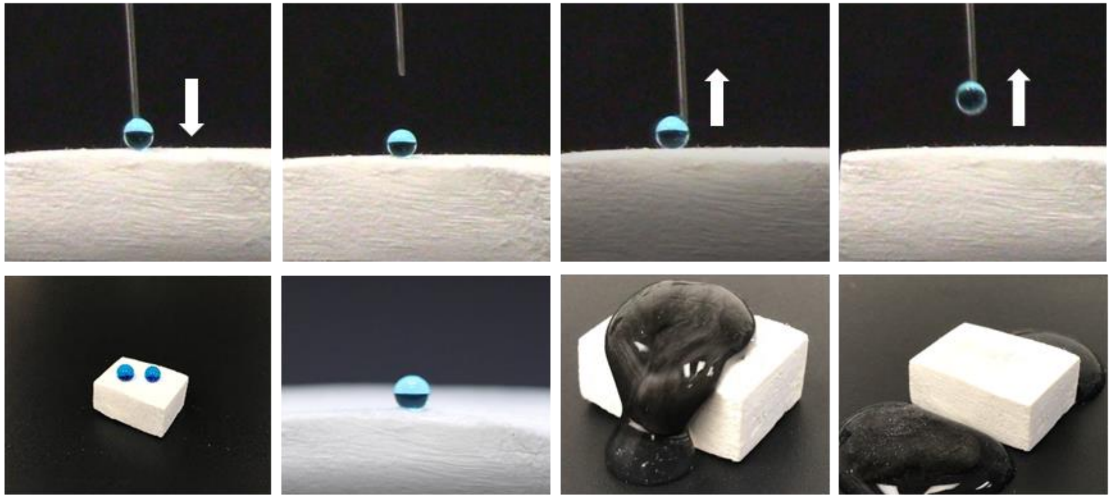
- Hardwood: *poplar, cocobolo*
- Softwood: *Cedar, yew*





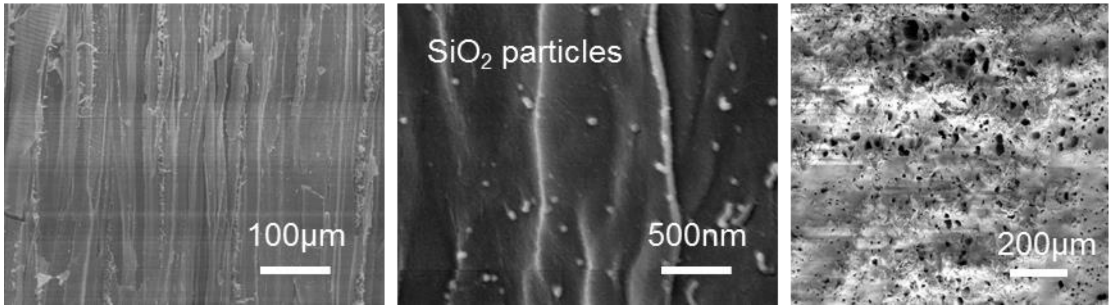
Developed Hydrophobic Surface Treatments (Task 1)

- Outstanding hydrophobic property with a contact angle of 151º;
- Fully prevent water/moisture adsorption;
- Improved moisture stability of nanowood



Developed Impregnation Treatments (Task 1)

- Developed impregnation method for SiO_2/nanowood
- Reveals potential of impregnating flame-retardant into nanowood



Progress

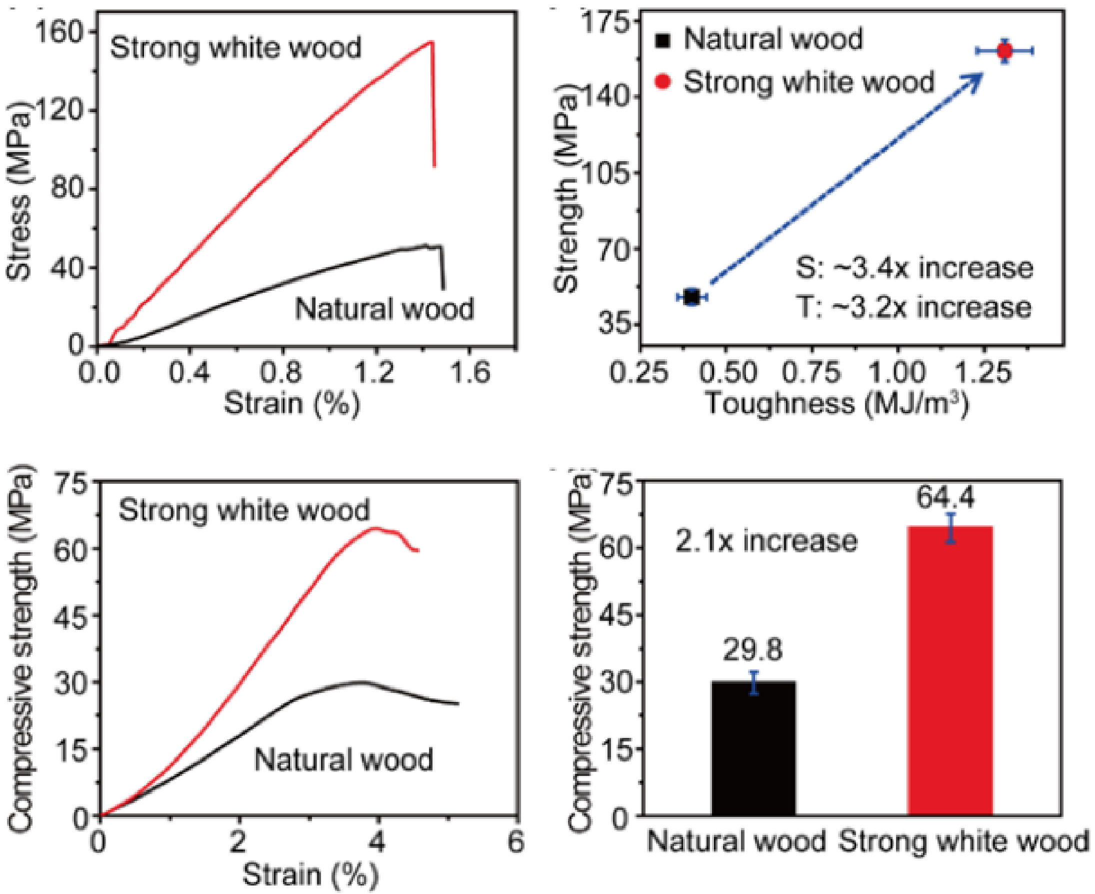
Project Stage: Mid-Project

Improvement of Mechanical Strength (Task 2)

- **3.4X** higher tensile strength;
- **3.2X** higher toughness;
- No sacrificing thermal insulation performance;
- Achieved outstanding specific young's modules of **3.01 GPa·cm^3·g^{-1}**, much higher than natural wood.

Further Reduction of Thermal Conductivity (Task 2)

- Achieved anisotropic thermal conductivity of 0.21 W/mK (along grain), and **0.06W/mK** (cross grain);
- *Latest thermal conductivity achieved is **0.03W/mK (R= 0.33 m^{2}K/W)**(non-pressed);
- Achieve high anisotropic factor of 3.4, which indicates high efficiency in heat re-direction.



Progress

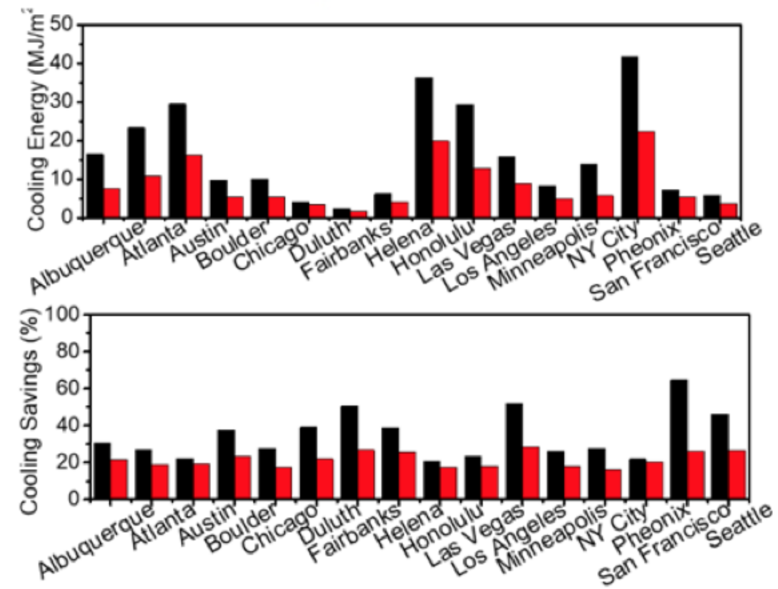
Project Stage: Mid-Project

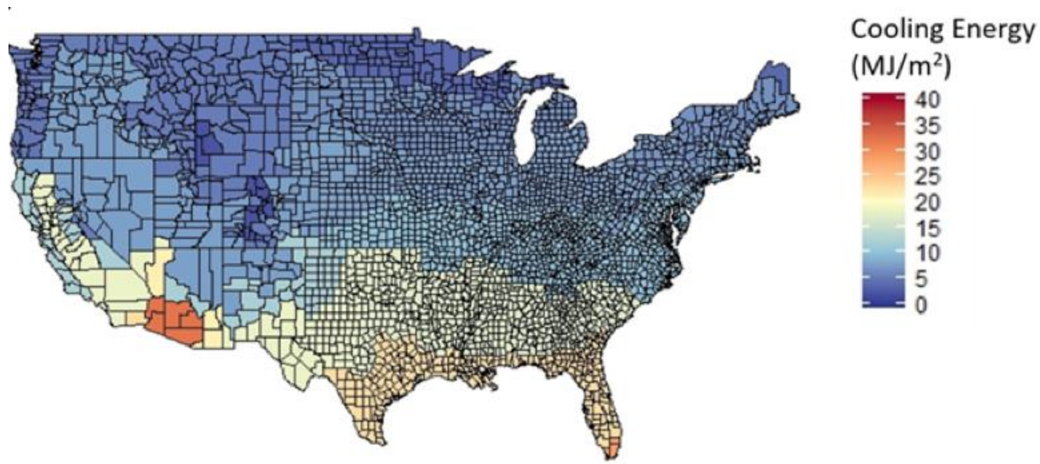
Heat Balance and Energy Saving (Task 2)

- **96%** backscatter solar radiation;
- Achieved high cooling power of **63 W/m^2** (night) and **16 W/m^2** (daytime), leading to an average below-ambient temperature of **>9 ^{o}C** (night), and **>4 ^{o}C** (mid-day);

- **8.7X** higher mechanical strength;
- **10.1X** enhanced toughness;

- Modeling results predicts**16%** and **18% more energy savings** in old and new buildings by using nanowood;





Progress

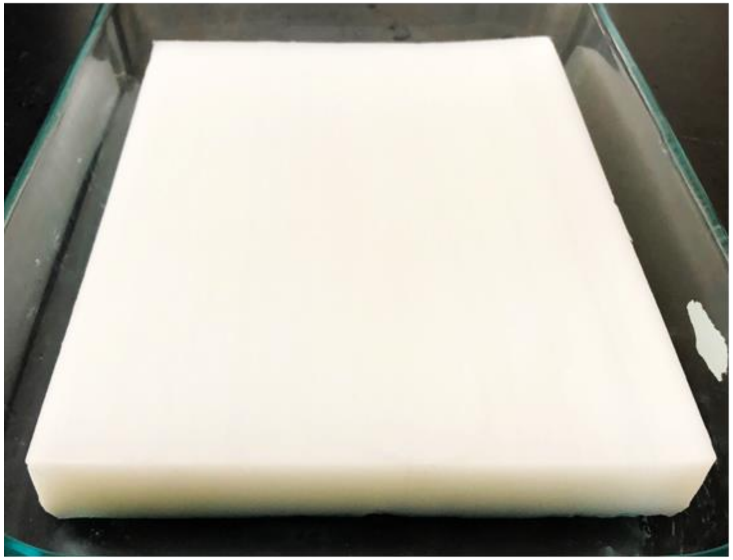
Project Stage: Mid-Project

Initial Cost Analysis (Task 3)

- Performed initial cost analysis* for nanowood based on lab-scale fabrication;
- Demonstrated **11in X 8in X 1in (L x W x T)** large white wood for further cost evaluation.

Chemicals	Price ($/ton)	Dosage (kg)	Cost ($)
H_2O_2	150	12.5	1.875
Basswood	135 $/m^3$	0.02 m^3	0.675
Total nanowood			2.55 $/m^2$
PUR	/	/	2.63 $/m^2$
PIR	/	/	3.24$/m^2$

*price is based on lab-scale fabrication



Stakeholder Engagement

Project Stage: Mid-Project

Engagement of Partners for Commercialization, Scale-up and R&D Collaborations (Task 4)

- Met with over **15** potential customers with interest in purchasing nanowood;
- Non-disclosure agreements with **2** potential customers for commercializing nanowood.

Targeted Commercial Applications for Nanowood

Sampling of Customer Interactions Regarding Nanowood

Organization	Industry	Summary of discussions
Forterra Building Products Limited	Construction / Building Products	UK-based manufacturer of insulated structural ground floors exploring use of nanowood as substitute for polystyrene due to its superior properties and ecological profile
Jeni's Splendid Ice Creams	Food Service	Major shipper of ice cream (65,000 boxes per year) exploring nanowood as a more environmentally-friendly container material (to replace Styrofoam).
Kawneer (subsidiary of Arconic)	Construction / Building Products	Large producer of commercial facades is interested in nanowood as a substitute for intra-frame window insulation.
[Names withheld due to NDA]	Materials / Chemicals	Two large chemical / materials companies are interested in using nanowood for a variety of purposes.

Project Plan and Schedule

Project Schedule	
Project Start: July 1st, 2018 (Phase I)	Completed Work
Projected End: June 30th, 2019 (Phase I)	Active Task (in progress work)
	Milestone/Deliverable (Originally Planned)
	Milestone/Deliverable (Actual)

	FY 2018	FY2019				FY2020				FY2021		
Task	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)
Past Work												
Q1 Milestone 1: Fabricate 10 delignified nanowood samples 4 in by 4 in												
Q2 Milestone 2: Achieve mechanical target of 300-400 MPa and thermal conductivity ~0.02 W/mK												
Current/Future Work												
Q3 Milestone 3: Achieve mechanical target of 500 Mpa and thermal conductivity ~0.01 W/mK												
Q4 Milestone 4: Finish cost analysis and identify the cost-limiting steps												
Q4 Milestone 5: Demonstrate delignified wood with a size of 1 m by 1m, thermal conductivity of ~0.1 W/mK and strength of 500MPa												
Q4 Milestone 6: Complete customer evaluations and identify 2-3 potential buyers for the technology.												
Phase II: Application in Preparation												

Milestone 1 & 2 accomplished

Milestone 3 in progress: Achieved 404.3 MPa, and 0.026 W/mK to date.

Milestone 4, 5 & 6 on schedule to be finished April, May, & June

Remaining Project Work

Project Stage: Mid-Project

Proposed Milestones

1. Demonstrate processes for fabrication and structural characterization of 1 meter by 1 meter thermal insulating nanowood;
2. Achieve mechanical (tensile strength of 400-500 MPa) and thermal (0.012 W/mK) performances for the thermal insulating nanowood, which has distinct advantages compared to other thermal insulation materials;
3. Design and evaluate operation procedure for rapid manufacturing (5 minutes per wood panel on average) and carry out cost analysis;
4. Evaluate the commercialization of the thermal insulating nanowood through close collaborations with industry under nondisclosure agreement (NDA) and materials transfer agreement (MTA).

Remaining Tasks

Task#	Description	Status	Planned Date
Task1	Achieve 1m by 1m nanowood	On-going	June 30th, 2019
	Achieve thermal conductivity of 0.012 W/mK	On-going	June 30th, 2019
Task2	Life cycle analysis of strong white wood in residential buildings	On-going	April 30th, 2019
	Humidity resistant and UV stability	On-going	April 30th, 2019
Task3	Finalized cost analysis for industry-scale manufacturing	On-going	May 31st, 2019
Task4	Evaluations with industry partners for potential commercialization	On-going	June 30th, 2019

Thank You

Performing Organization(s): InventWood, LLC.
PI Name and Title: Amy S. Gong Chief Scientific Officer
PI Tel and/or Email: 240-478-1671 amygong@inventwood.com

REFERENCE SLIDES