Sustainable, High-Performance, Cellulose-Based Thermal Insulation

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Cellulose Nanomaterials Researchers Forum
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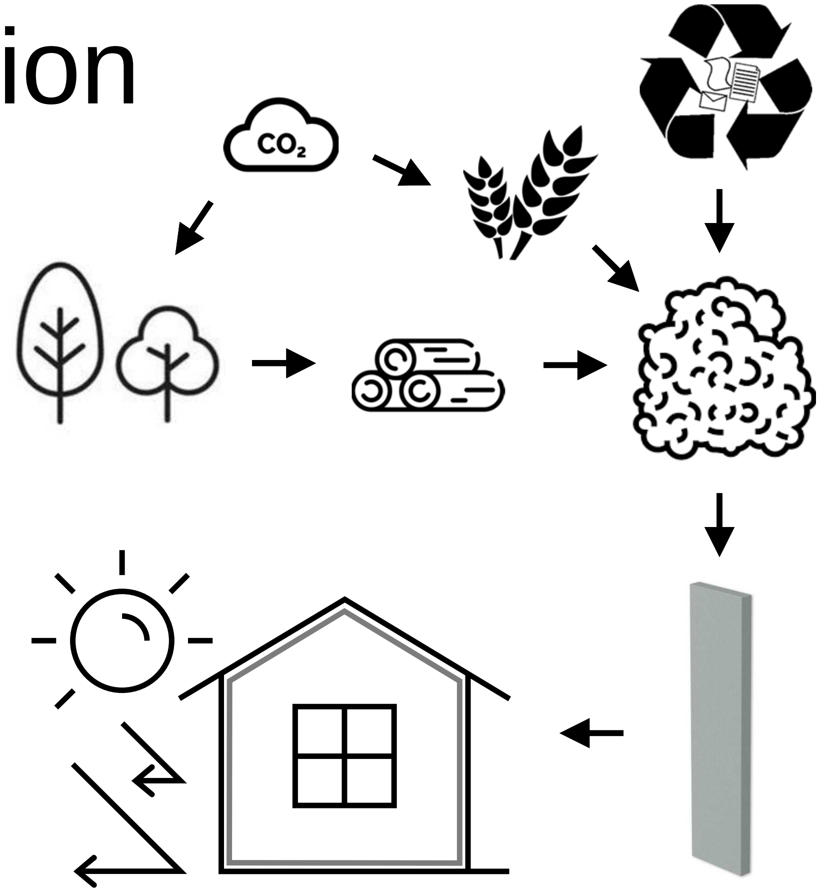

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Residential Building Insulation Requirements

- 22% of US energy consumption is associated with residential buildings (20 quads)
- Heat/cooling/ventilation (43%), appliances (16%), water (13%), lighting (3%)
- Heat transfer through building envelope is the primary driver of HVAC load
- Insulation requirements for new US homes are becoming more stringent
- Maine (Climate Zone 6A)

International Energy Conservation Code	Wall R-Value	Ceiling R-Value
2006	19 or 13+5ci	49
2009	20 or 13+5ci	49
2012, 2015, 2018	20+5ci or 13+10ci	49
2021	30 or 20+5ci or 13+10ci or 0+20ci	60

~8” of fiberglass! ~4” of external foam board! ~18” of loose-fill!

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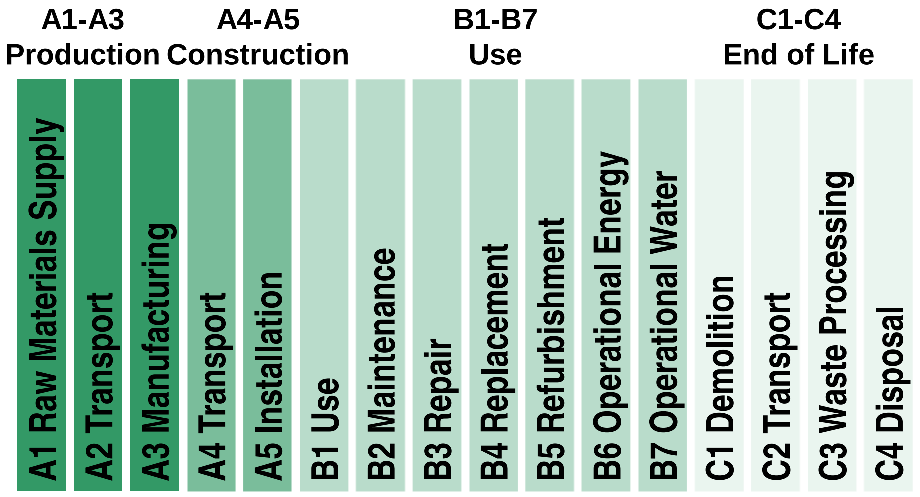
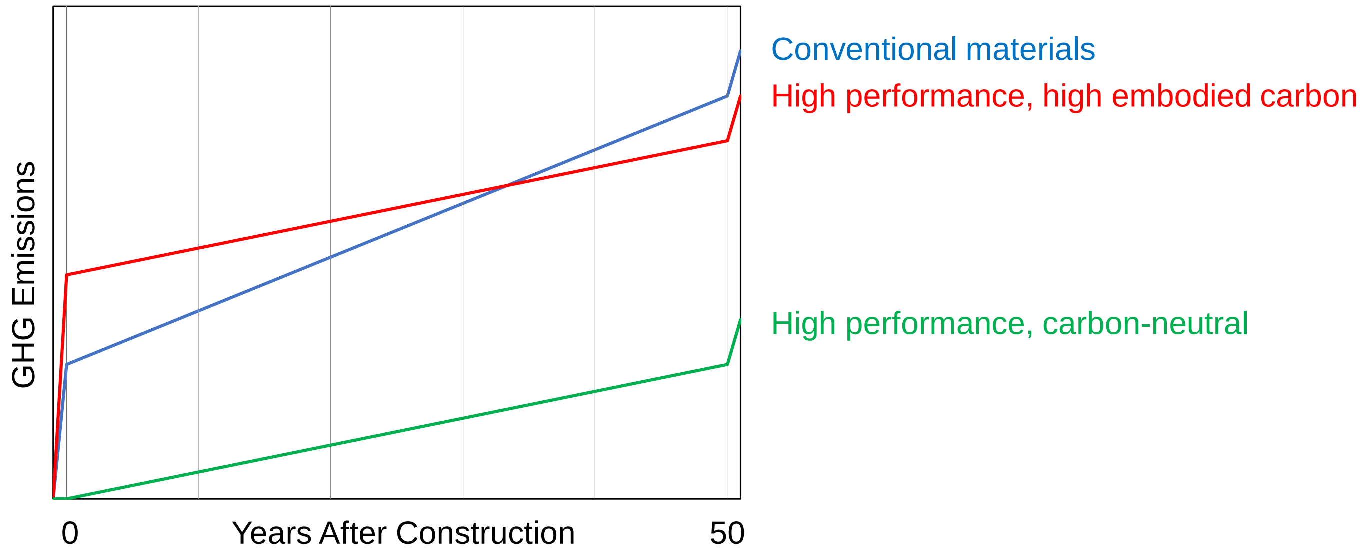
Life-Cycle Energy Footprint of Buildings

- Improved insulation reduces operational GHG emissions
- Operational emissions are only a small part of building life-cycle emissions





Embodied emissions become an important consideration as operational emissions are reduced

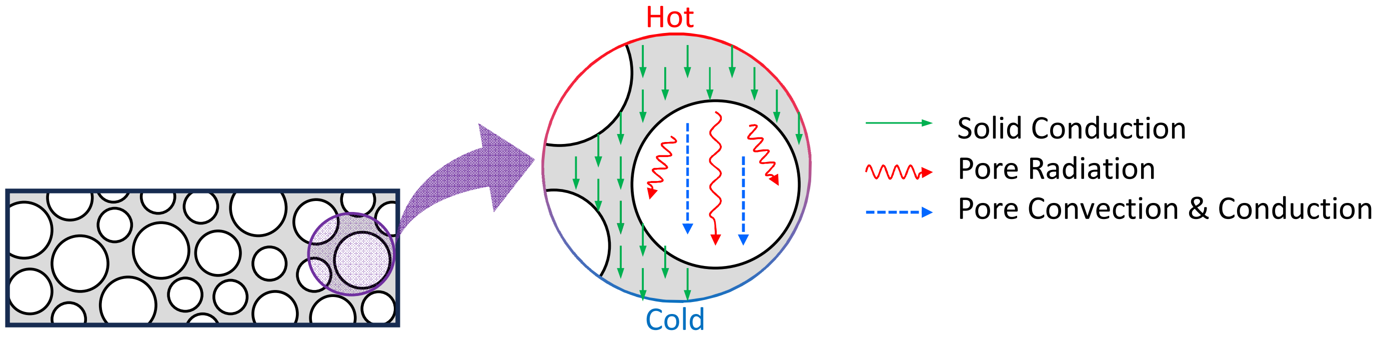
Current Insulation Products

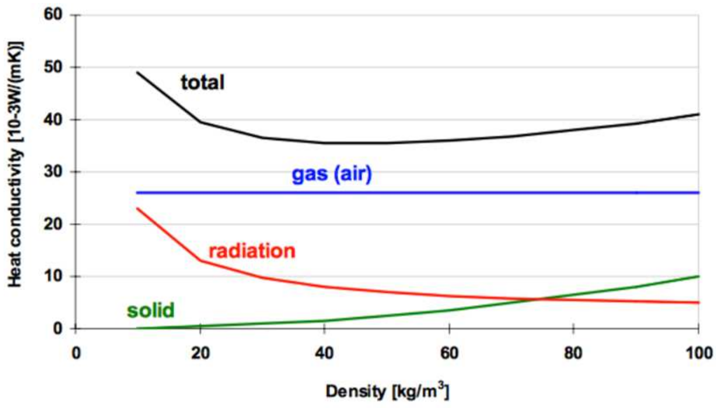
Material	R-value per inch	Cost ($/FU)	Embodied GHG (kg CO_2eq/FU)
Cellulose	3-4	1-2	-2.0
Fiberglass/Mineral Wool	3-4	1-2	0.2-0.5
Polymer Foam	4-7	5-10	2.5-4.0
Silica Aerogel	6-10	>100	>15
Vacuum Panel	13-48	>20	>15

- Low embodied carbon → Low insulating performance
- High insulating performance → High embodied carbon

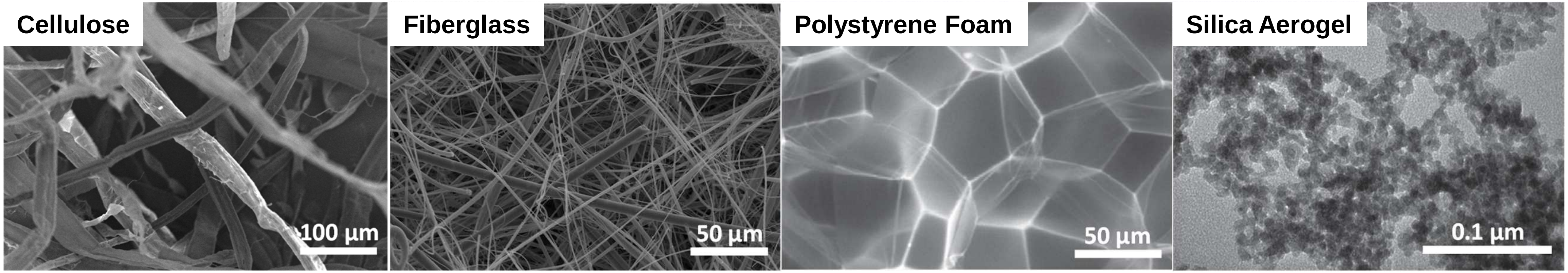
What makes foams and aerogels better insulators than cellulose and fiberglass?

Heat Transfer In Porous Thermal Insulation





Convective/conductive transport within pores is main difference between conventional insulations



Can the pore size of cellulose insulation be reduced to improve its insulation properties?

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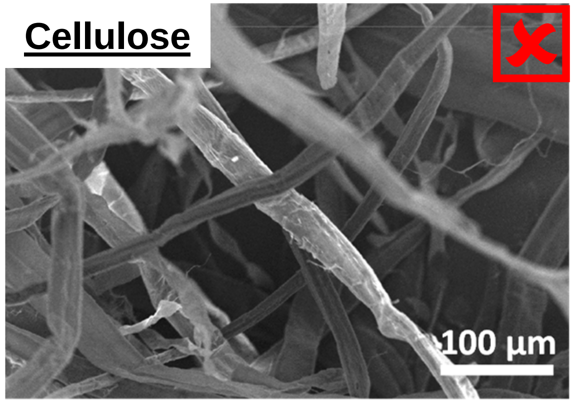
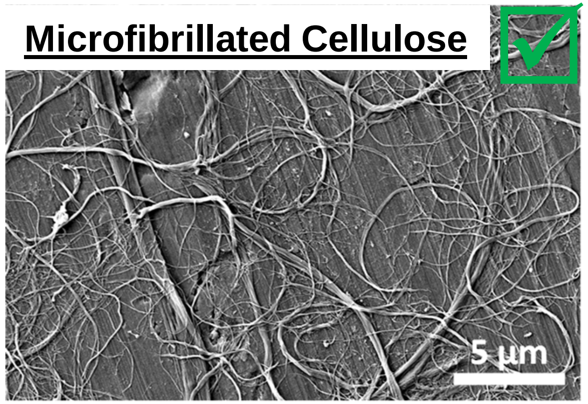
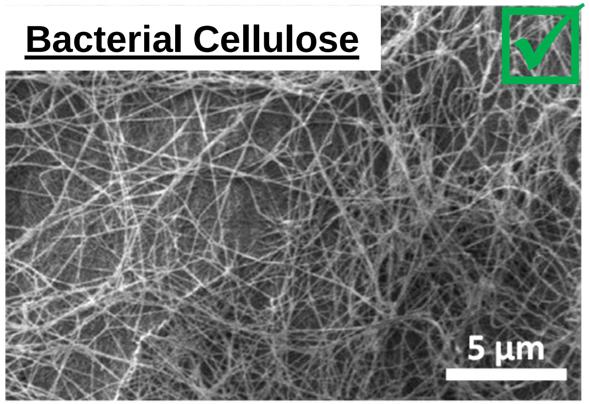
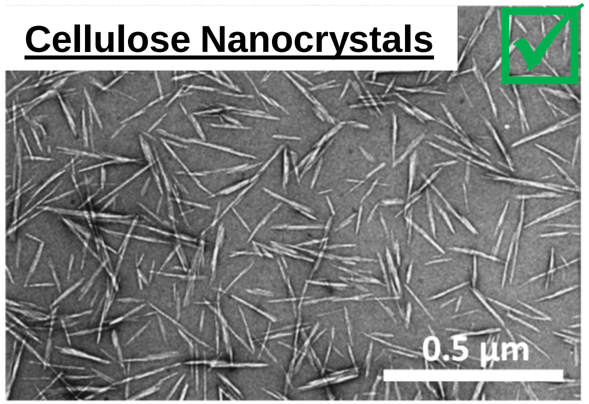
Nanocellulose-Based High Performance Insulation

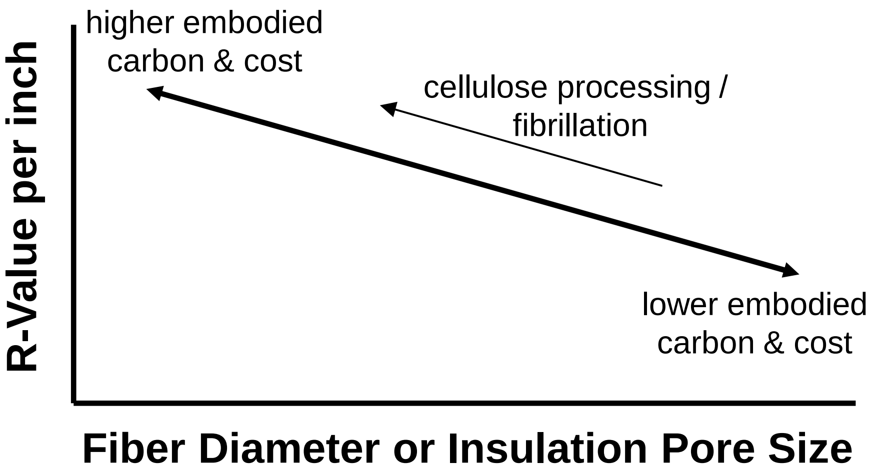
Smaller diameter cellulose fibers = Smaller pore sizes











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Nanocellulose Insulation Synthesis

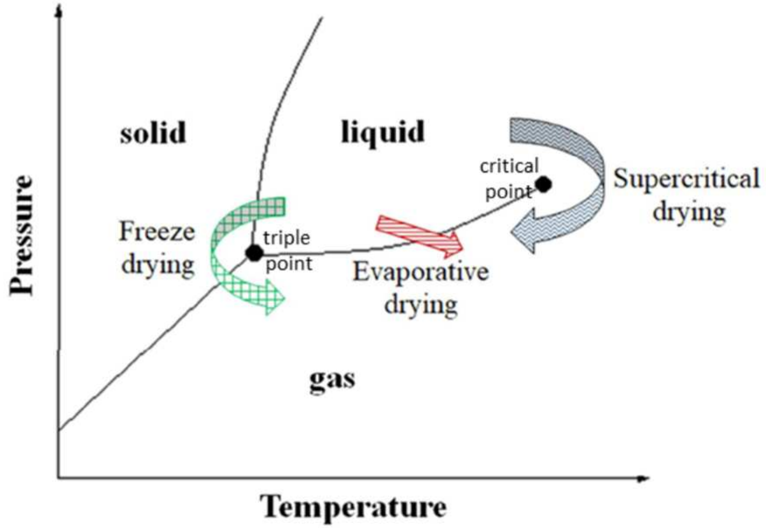
Challenge: Dewatering nanocellulose while preserving microstructure of wet cellulose network

- Capillary forces at water-air interface contribute to collapse of pore structure → membrane/film

$$\text{capillary pressure, } p_c = 2\,\gamma\cos\theta / r_c$$

<u>Common approaches to preserve porosity during drying</u>

- Strengthen wet gel network (crosslinking)
- Reduce surface tension of solvent (mixed solvents, surfactants)
- Alter cellulose-solvent wetting angle (surface modification)
- Remove liquid while avoiding liquid-gas interface
  - Supercritical drying
  - Freeze drying



Nanocellulose Insulation Properties

Microfibrillated cellulose board insulation
- R-value up to R-8 per inch
- Contains over 90% cellulose
- Sustainable/carbon-negative

<u>Other building insulation product considerations</u>

- Hydrophobicity
  - Liquid Water Sorption
  - Water Vapor Sorption
  - Water Vapor Permeance
- Flammability
  - Flame Spread
  - Smoke Development
- Odor Emission
- Corrosiveness
- Fungal Resistance
- Compressive & Tensile Strength

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