Electrochemical Dewatering of Cellulosic Nanomaterials

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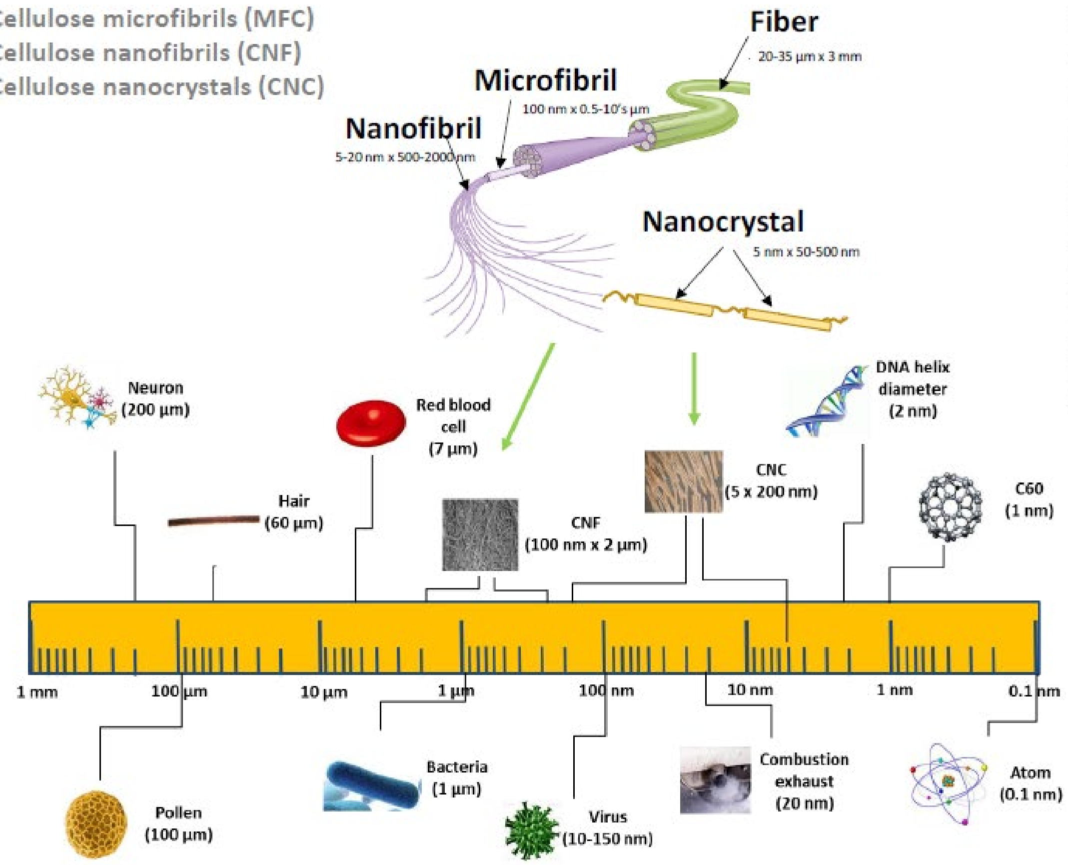
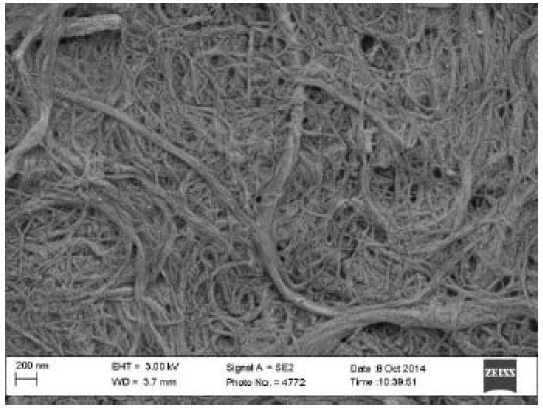
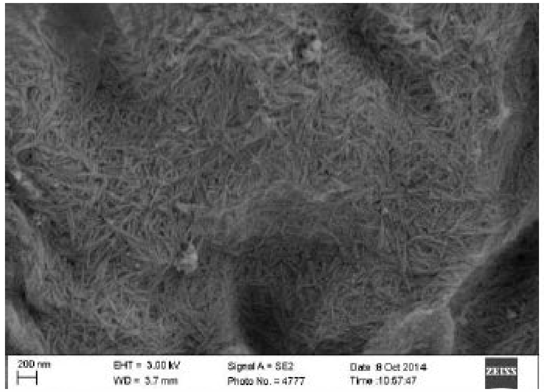
Nanocellulose

Cellulose microfibrils (MFC)
Cellulose nanofibrils (CNF)
Cellulose nanocrystals (CNC)

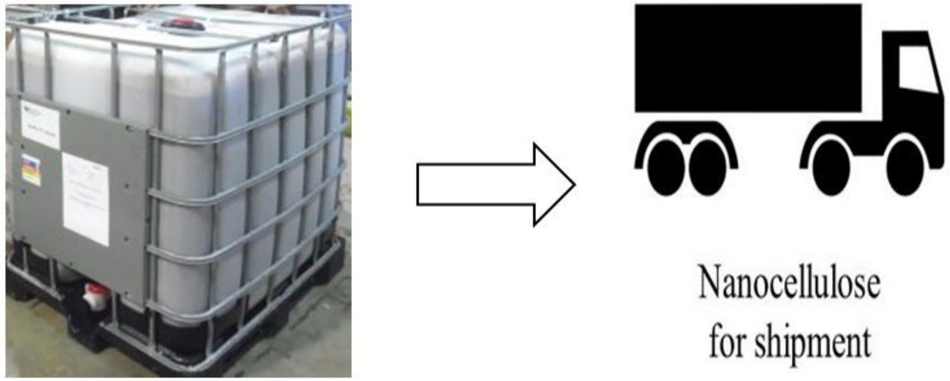


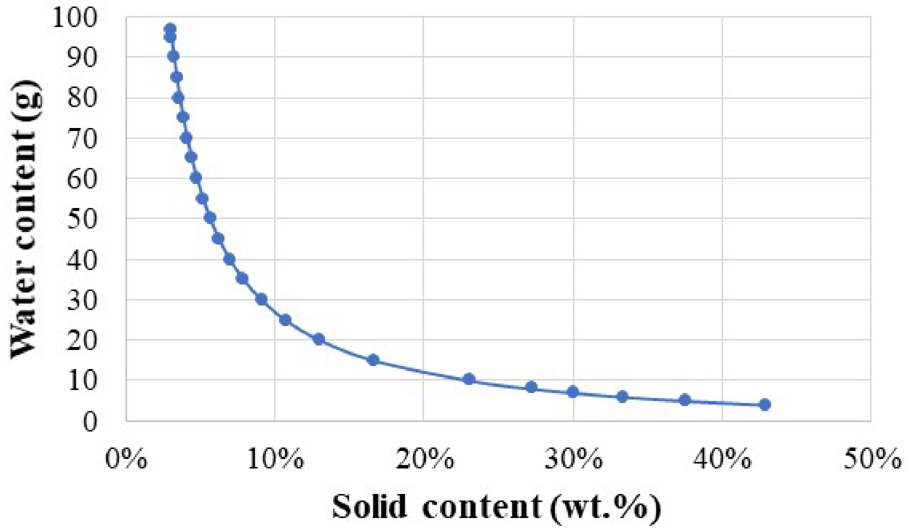




Problem/Opportunity

Challenges:
- Cellulosic materials contain significant water content
- Not economical to ship long distances





Opportunity:
- Development of novel electrochemical technology to dewater cellulosic materials
  - o Maintain the material properties when dried and re-dispersed
  - o Economical, scalable, and energy efficient

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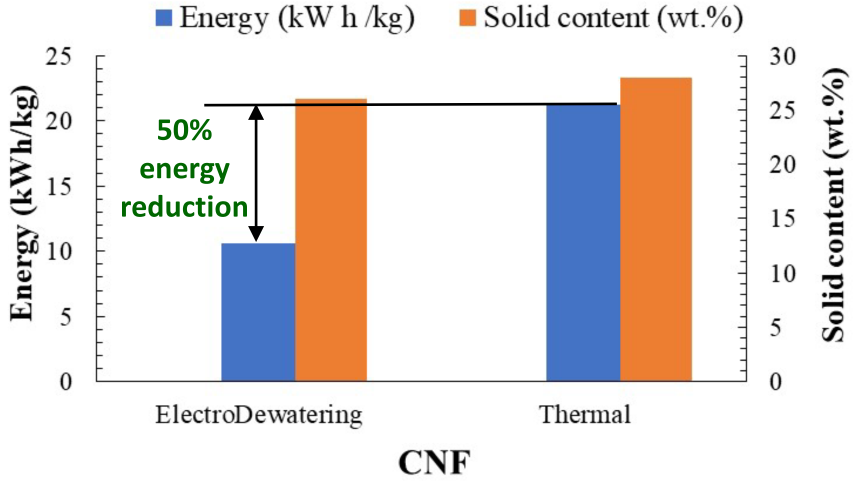
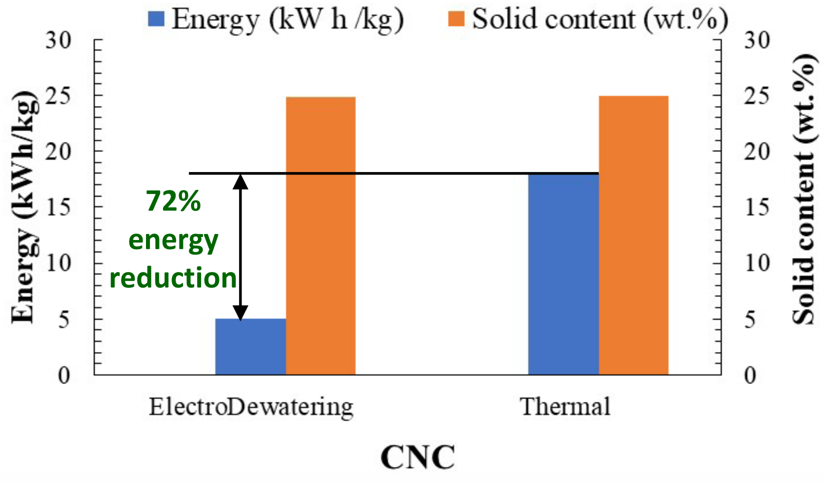
Key Results To Date

1. ElectroDewatering uses electro-osmotic, electrophoresis, and viscosity moderated process.
2. Achieves high solid content
   a) Up to 70 wt.% solid content
   b) ~25 wt.% solid content without hornification (batch)
   c) ~17 wt.% solid content without hornification (alpha-scale continuous)
3. Highly efficient
   a) 50% and 72% reduced energy requirements for CNF and CNC
   b) 31% reduction in cost per ton for processing CNC
   c) 51% reduction of emissions for processing CNC
4. Can be batch or continuous process





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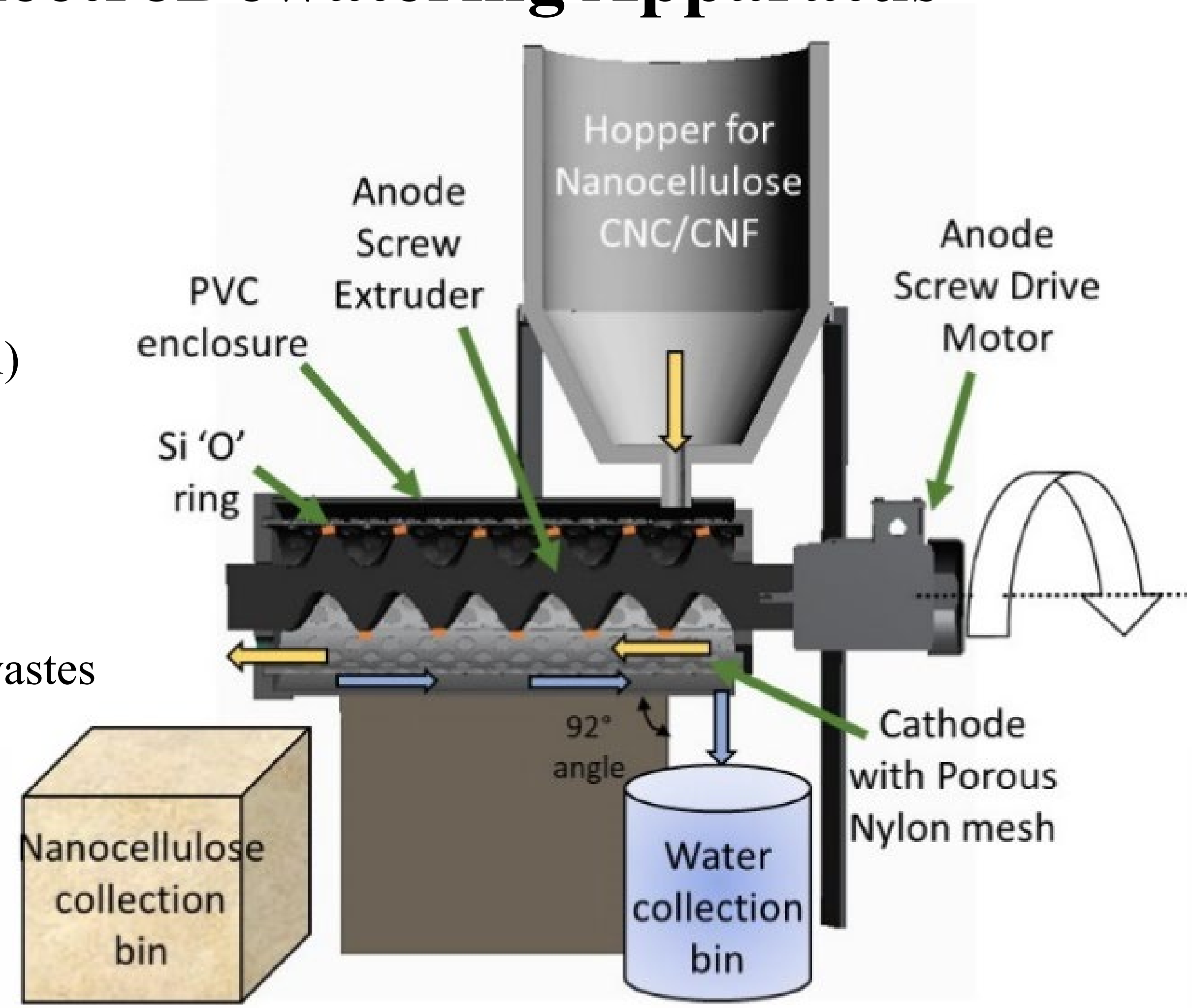
ElectroDewatering Apparatus

- Continuous processing
- Demonstrated at 0.6 to 2 tpy
- Scalable to
  - 20 tpy (**Current Goal**)
  - 200 tpy (Pilot scale)
  - 2000 tpy (Full scale commercial)
- Other potential applications
  - Municipal Wastewater
  - Black liquor
  - Algae
  - Food processing products and wastes
  - Coal fines
  - Refuse slurries
  - Sewage sludge



"Method and Apparatus for Electrochemical Dewatering of Suspensions of Cellulosic Nanomaterials"
US Pat. Appl. No. 62/842,037, filed U.S. utility on March 10, 2020;
PCT Patent Application No. PCT/US20/30232, filed April 28, 2020

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Technical Approach

DeWatering Mechanism	Function	Energy Requirement
Water Consumption:		
Joule Heating	Water vaporization	HIGH
Electrolysis	Water electrolysis	HIGH
Separation/Transport:		
Electroosmotic	Water transport to cathode	LOW
Electrophoretic	CNC-CNF transport to anode	LOW
Viscosity	Rotation rate effects: wall slip, shear banding	LOW

- Utilizes a combination of electrochemically driven H_2O consumption and/or CNF-CNC/H_2O separation mechanisms
- Minimize structural damage of the nanocellulose
- Low-energy process by emphasizing low-energy separation mechanisms

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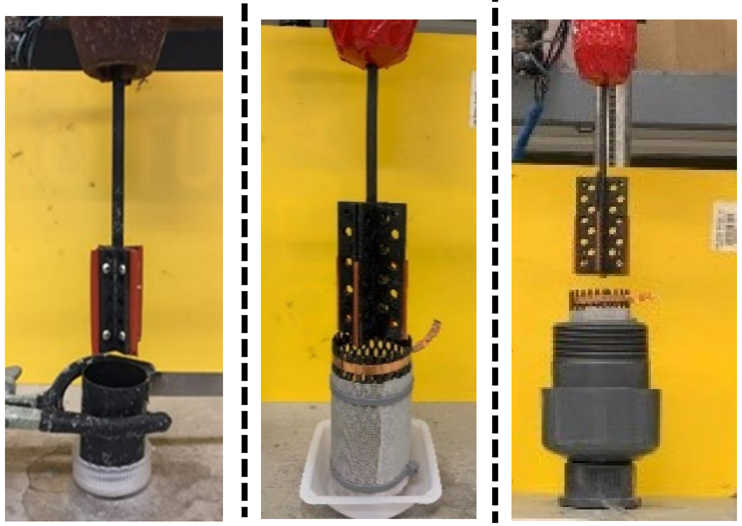
Preliminary Batch-Scale



Sub-scale batch reactor

Sub-alpha scale batch reactor

- 25 mL beaker with paddle wheel (sub-scale batch reactor)
- 50 mL beaker with paddle wheel (sub-scale batch reactor)
- 100 mL screw extruder based batch (sub-alpha scale batch reactor)

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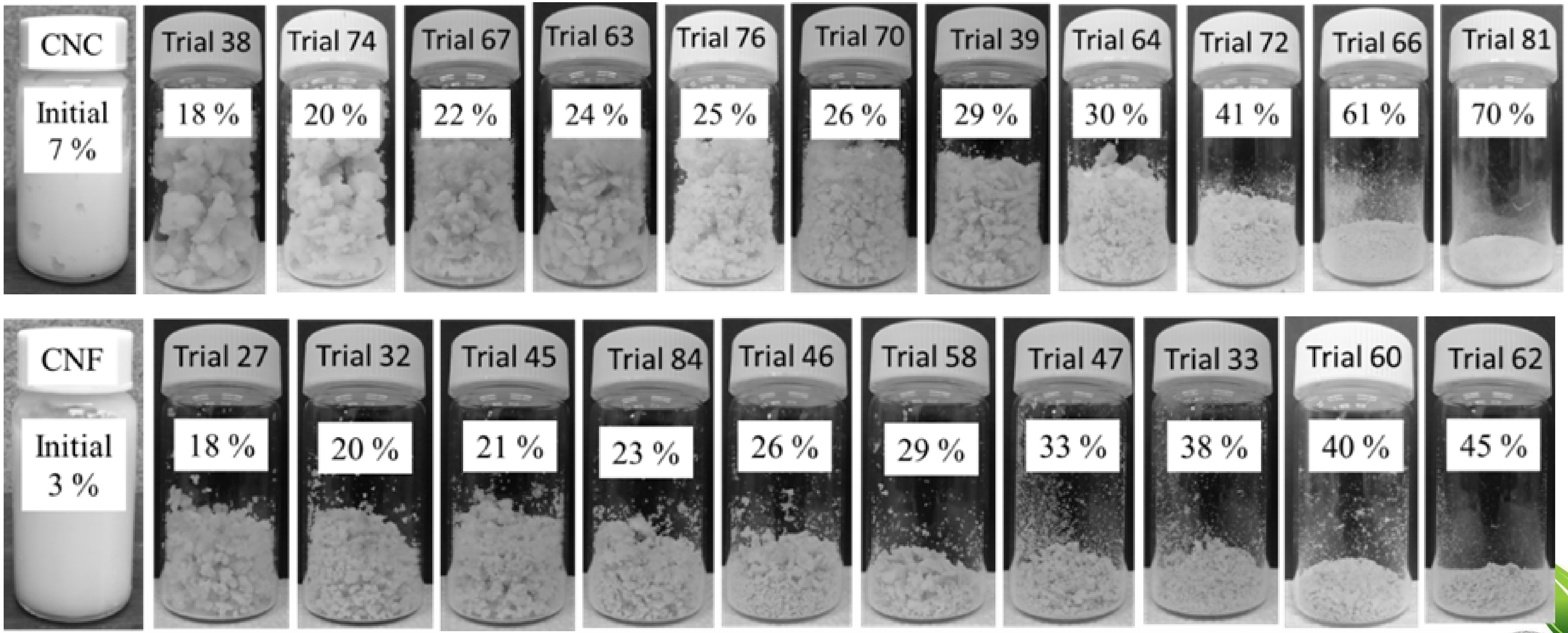
Range of Final Solid Content



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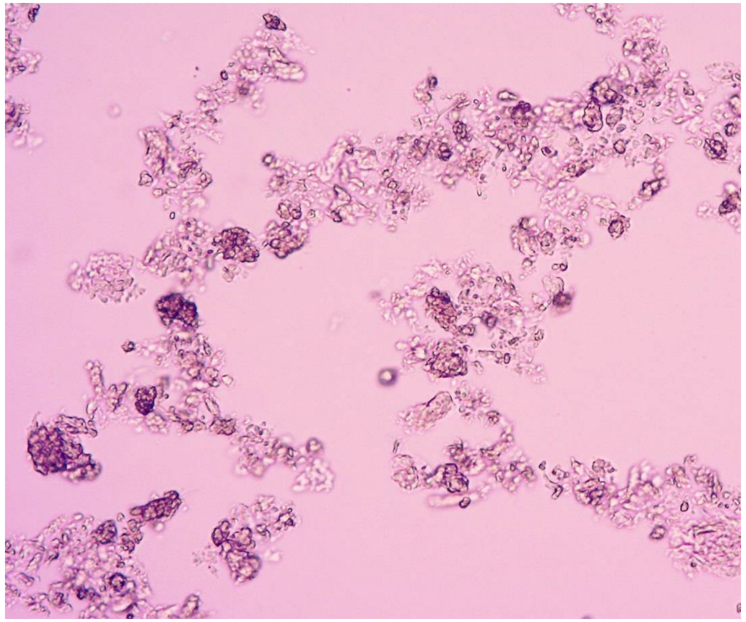
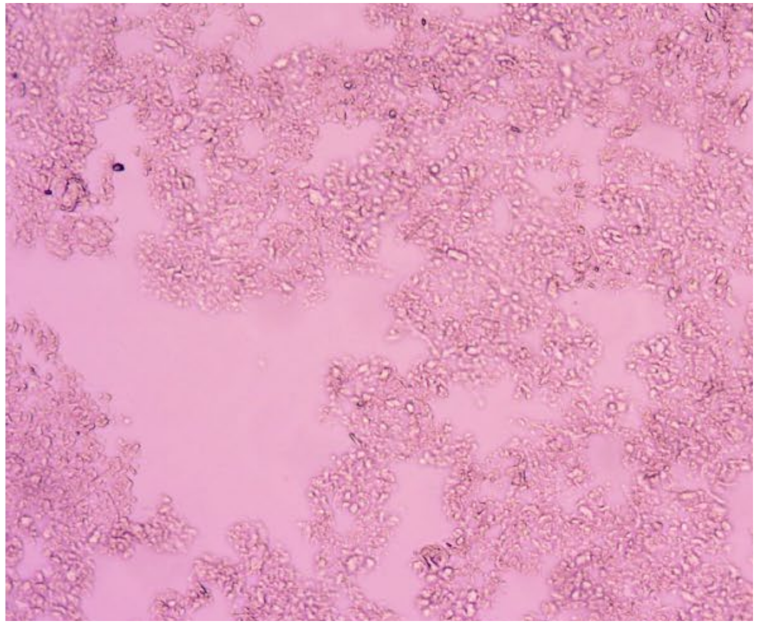
Characterization

- *Dispersion analysis:* Re-dispersion occured at ~ 0.2 wt% in water using a vortex mixer for 2-10 minutes
  - Full redispersion required in 10 minutes
- *Nanocellulose structure/size:* Optical microscopy
  - Hornified/un-redispersed samples were rejected



Un-dispersible CNCs at ~61 wt.% solid content



Re-dispersible CNCs at ~25 wt.% solid content

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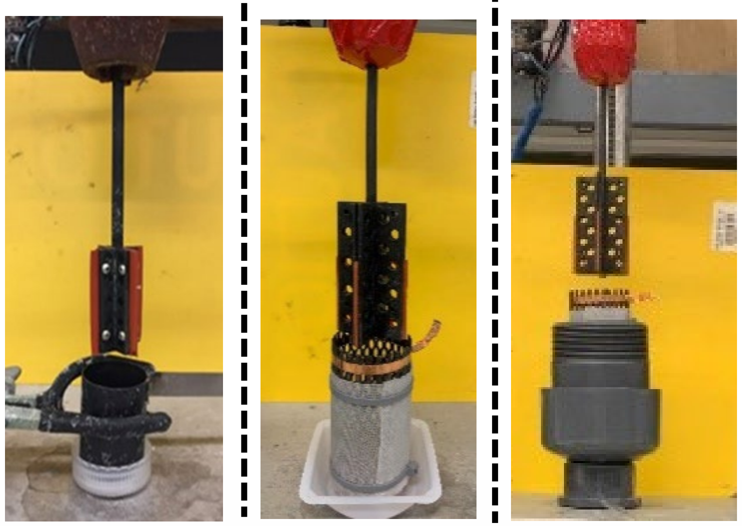
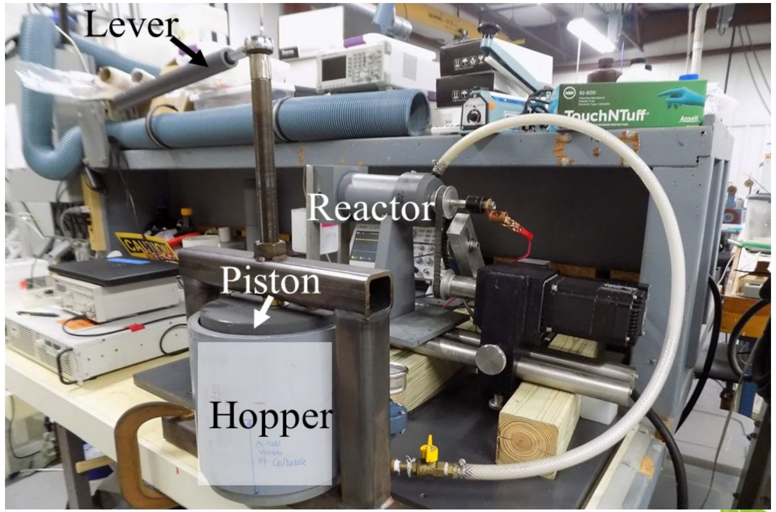
Process Scale-Up

- Batch beaker with paddle wheel
  - Sub-scale reactor
- Screw extruder based batch to continuous system
  - Sub-alpha scale batch
  - Alpha-scale continuous (up to 2 ton/yr)



Sub-scale batch reactor

Sub-alpha scale batch reactor



Alpha scale continuous reactor

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Alpha-scale Apparatus

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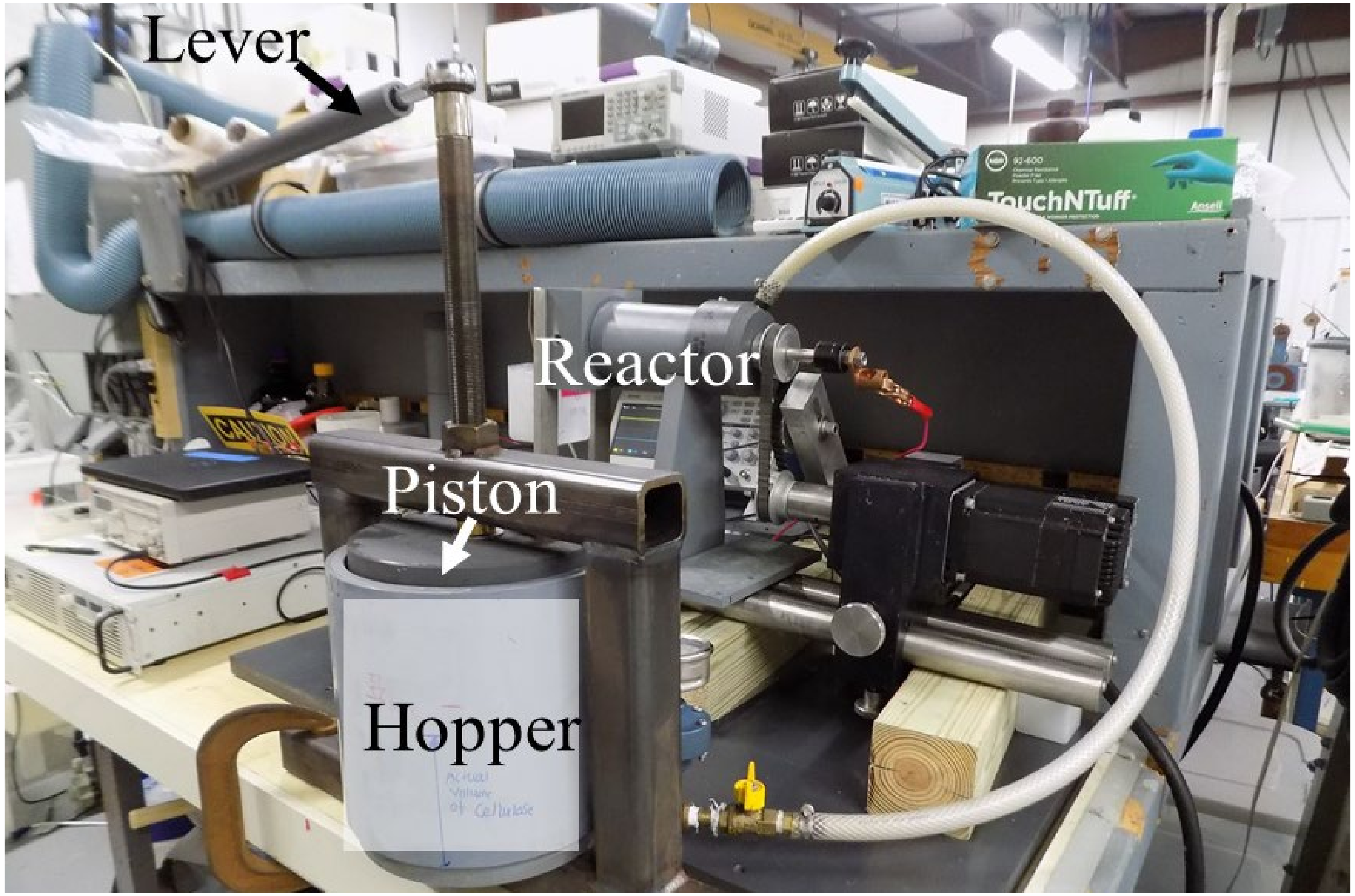

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Mechanical Extrusion Dewatering

ElectroDewatering Demonstration

Electro-Dewatering

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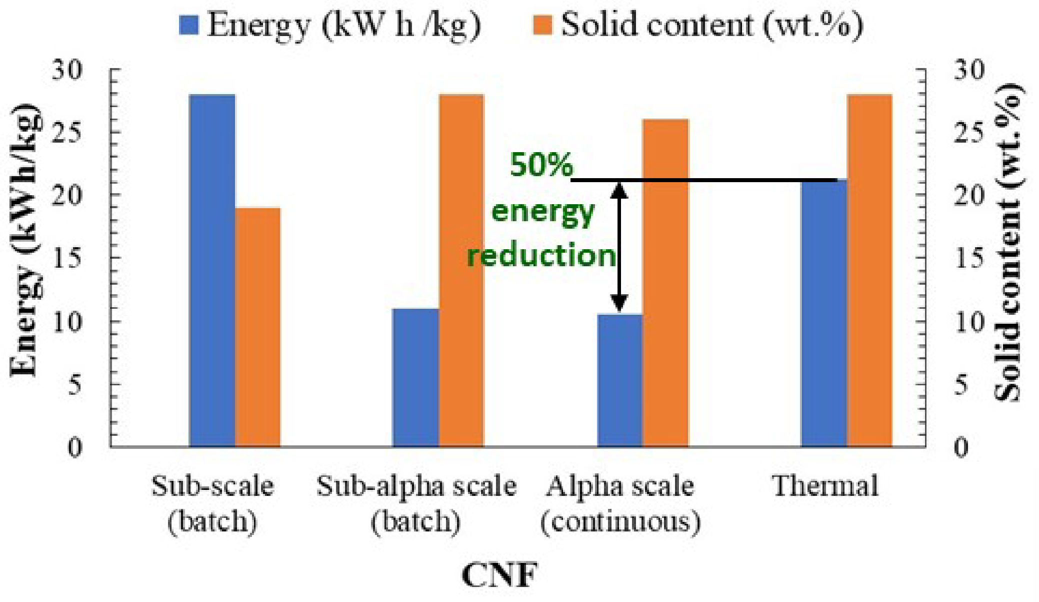
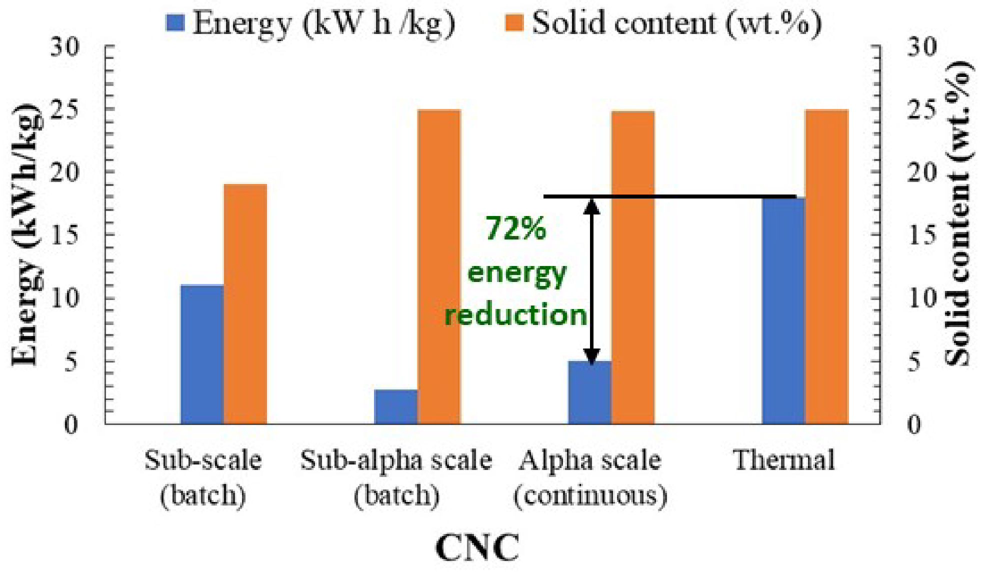
Energy Comparison

- Observed 50% and 72% energy saving compared to the latent heat of vaporization calculation for CNF/CNC
- Alpha-scale system can process:
  - 0.6 tpy dried CNF
  - 1.3 to 2 tpy of dried CNC





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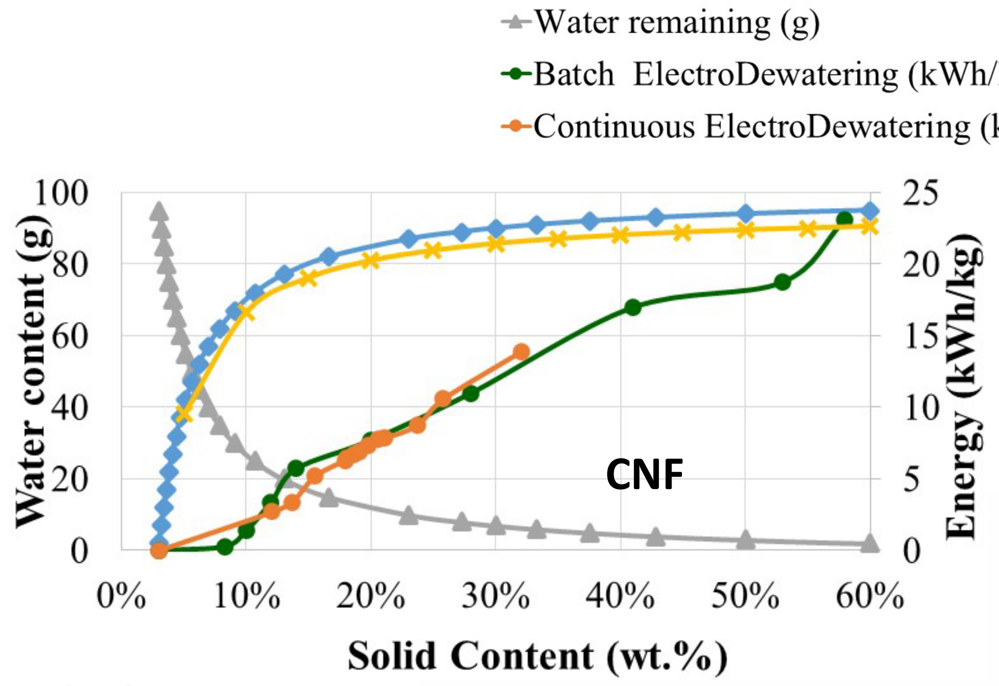
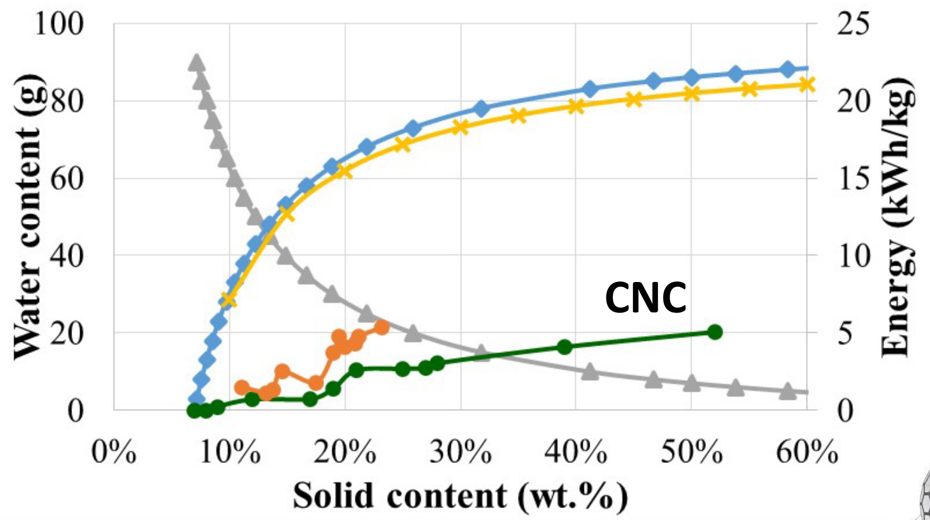
Energy Comparison

- ElectroDewatering shows similar solid content versus energy regardless of type of operation batch or continuous (2 tpy)
- Dewatering mechanism seems to change with solid content, where
  - Low energy separations (electroosmotic/ electrophoretic) dominates up to 20 wt.% solids
  - Higher energy separations (electrolysis / joule heating) are required for achieving >25 wt.% solids





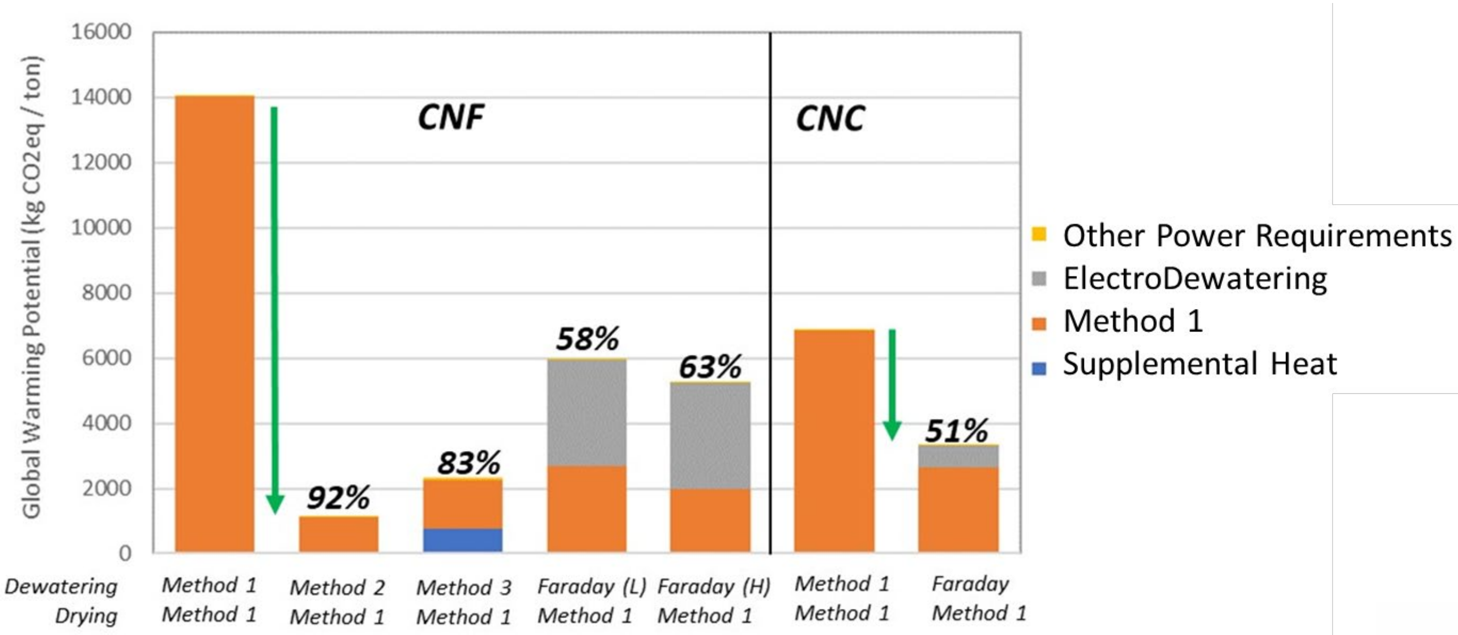
Life Cycle Analysis (LCA)

Life cycle analysis will be utilized to improve ElectroDewatering method and apparatus such that these processing steps can be transitioned to an industrial scale

LCA Scenarios

Initial % solids	Dewatering Step (% output solids)	Drying Step (% output solids)
CNF		
3%	Method 1 (100%)	
3%	Method 2 (30%)	Method 1 (100%)
3%	Method 3 (23%)	Method 1 (100%)
3%	ElectroDewatering (14%)	Method 1 (100%)
3%	ElectroDewatering (18%)	Method 1 (100%)
CNC		
7%	Method 1 (100%)	
7%	ElectroDewatering (14%)	Method 1 (100%)

** Client confidentiality, unable to reveal the Methods*



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- ElectroDewatering provides significantly less global warming potential than dewatering method 1 for CNC
- 51% reduction in GHG emissions

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Techno-Economic Analysis (TEA)

Techno-Economic analysis will be used to improve ElectroDewatering method and apparatus such that these processing steps can be transitioned to an industrial scale

TEA Scenarios

Initial % solids	Dewatering Step (% output solids)	Drying Step (% output solids)
CNF		
3%	Method 1 (100%)	
3%	Method 2 (30%)	Method 1 (100%)
3%	Method 3 (23%)	Method 1 (100%)
3%	ElectroDewatering (14%)	Method 1 (100%)
3%	ElectroDewatering (18%)	Method 1 (100%)
CNC		
7%	Method 1 (100%)	
7%	ElectroDewatering (14%)	Method 1 (100%)

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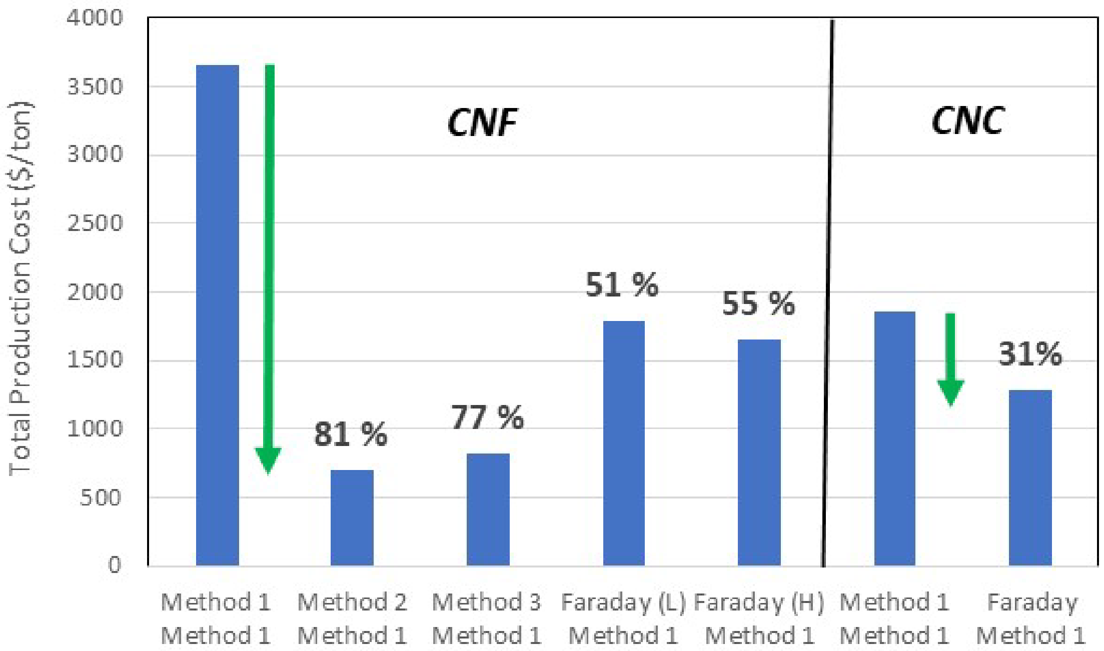

- ElectroDewatering process works best for CNC
- 31% reduction in cost per ton of dried CNC

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Summary

- Demonstrated ElectroDewatering process for dewatering of cellulosic materials

- **Achievements:**
  - Design/build of alpha-scale continuous ElectroDewatering system
    - System throughput of up to 2 tpy of dried cellulosic nanomaterials demonstrated
  - Validated dewatering performance for cellulosic nanofibrils (CNF) and cellulosic nanocrystals (CNC)
    - Up to 70 wt.% solid content
    - ~25 wt.% solid content without hornification in batch operation
    - ~17 wt.% solid content without hornification in alpha-scale continuous operation
    - CNC/CNF maintained structural integrity after re-dispersion
    - 50% and 72% reduced energy requirements for CNF and CNC
    - TEA suggested a 31% reduction in cost per ton for CNC
    - LCA suggested a 51% reduction of emissions for CNC

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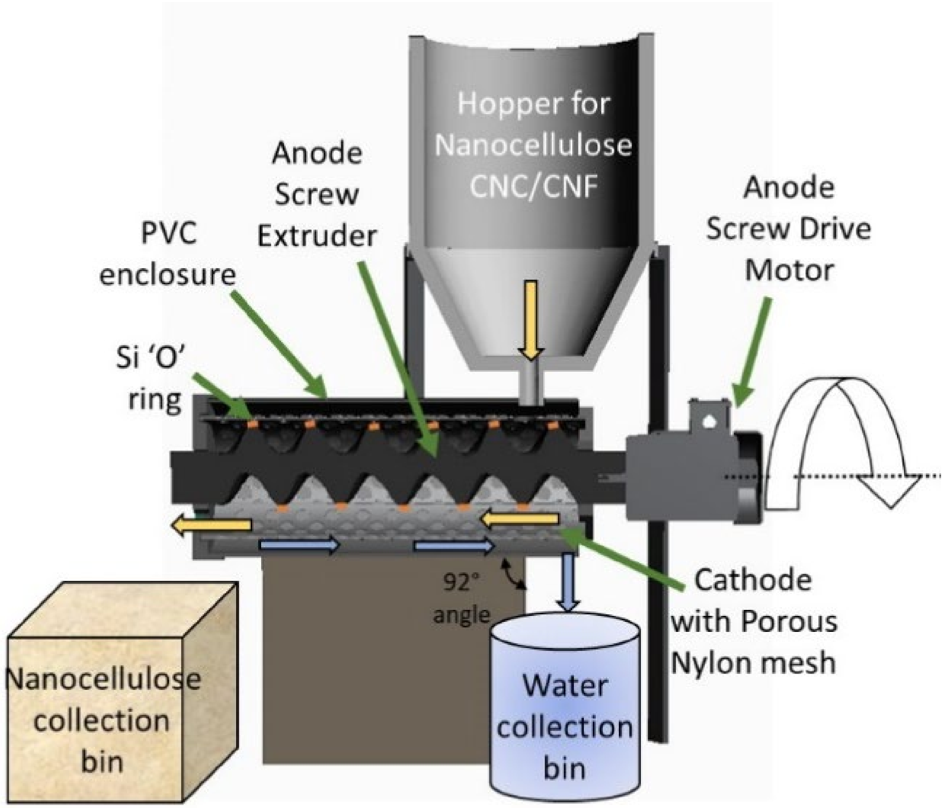
Next Steps

- Investigate ElectroDewatering approach for:
  - Other cellulosic materials
  - Pharmaceuticals
  - Waste treatment, etc.
- Modify ElectroDewatering system design to:
  - Reduce energy consumption
  - Increase solid content without hornification
- Scale process to 20 tpy dry cellulosic materials
  - Target demonstration for CNC is FY24



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THANK YOU FOR YOUR ATTENTION!
QUESTIONS?

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