Hairy Cellulose Nanocrystals: Fundamentals and Emerging Applications

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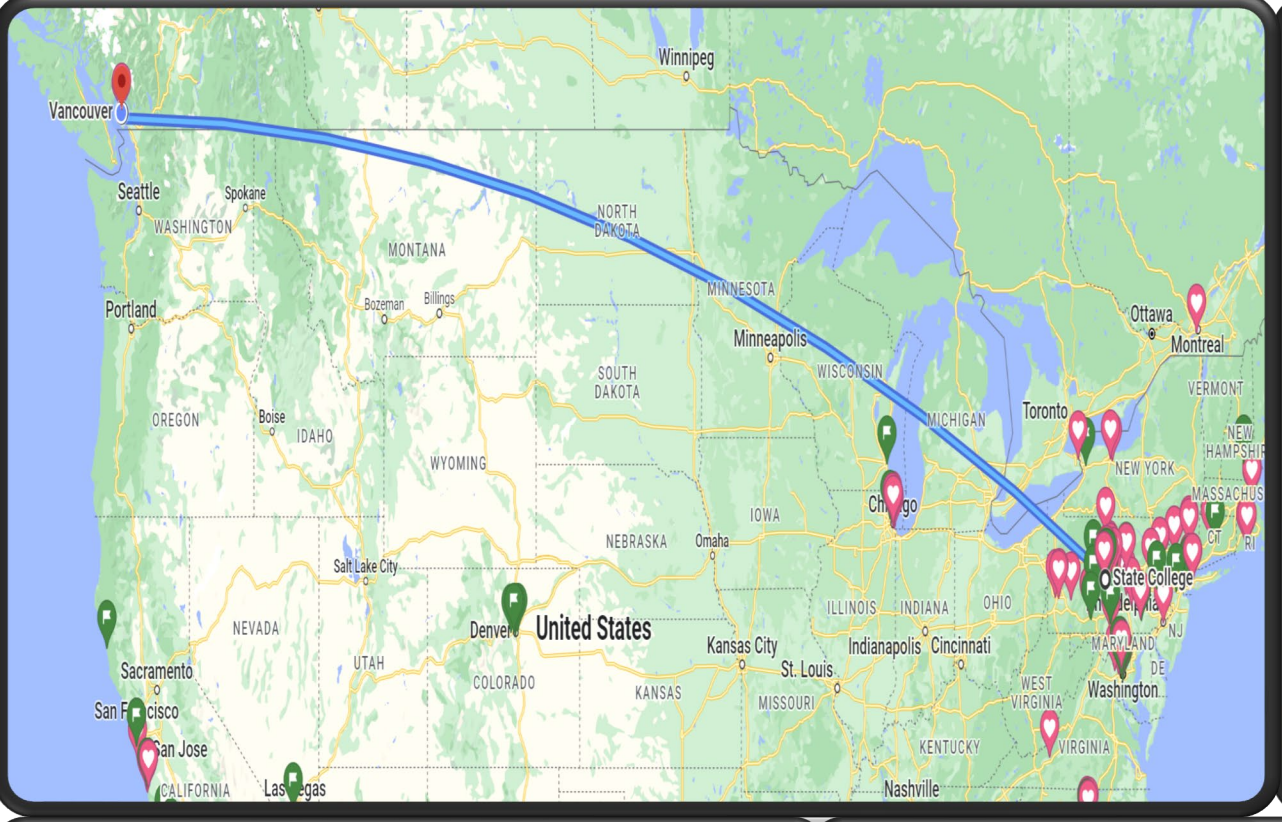
PennState
Chemical Engineering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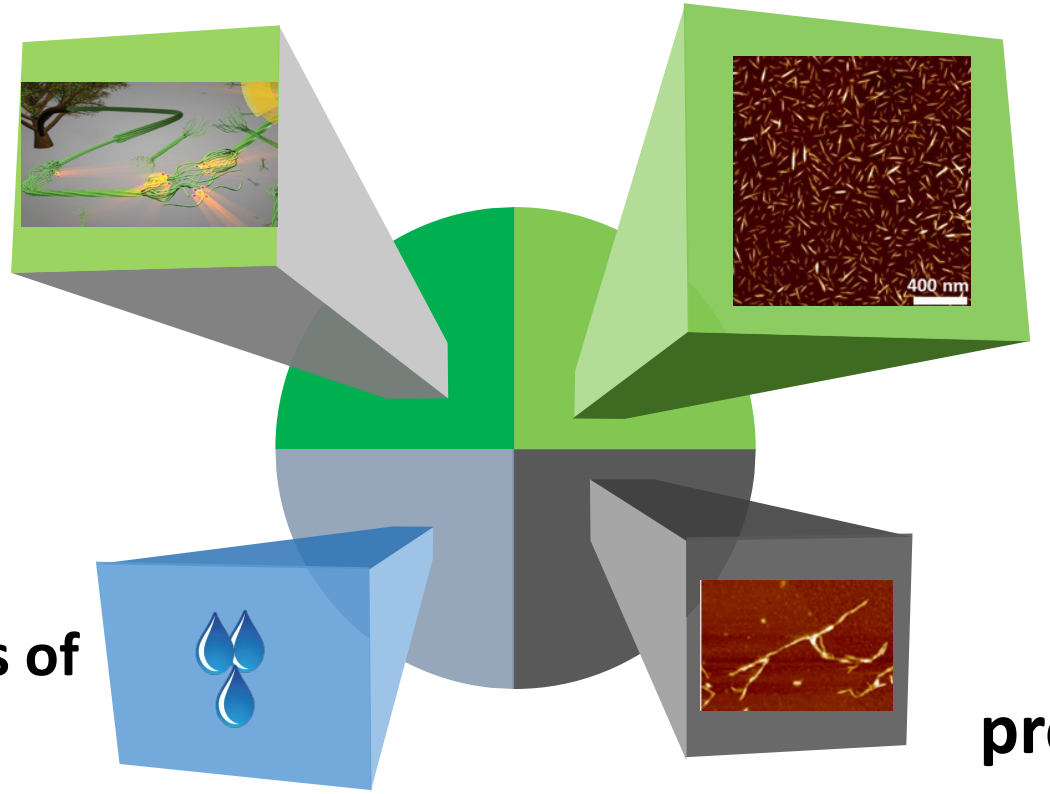
Outline

Part I:
Hairy cellulose nanocrystals (HCNC) synthesis



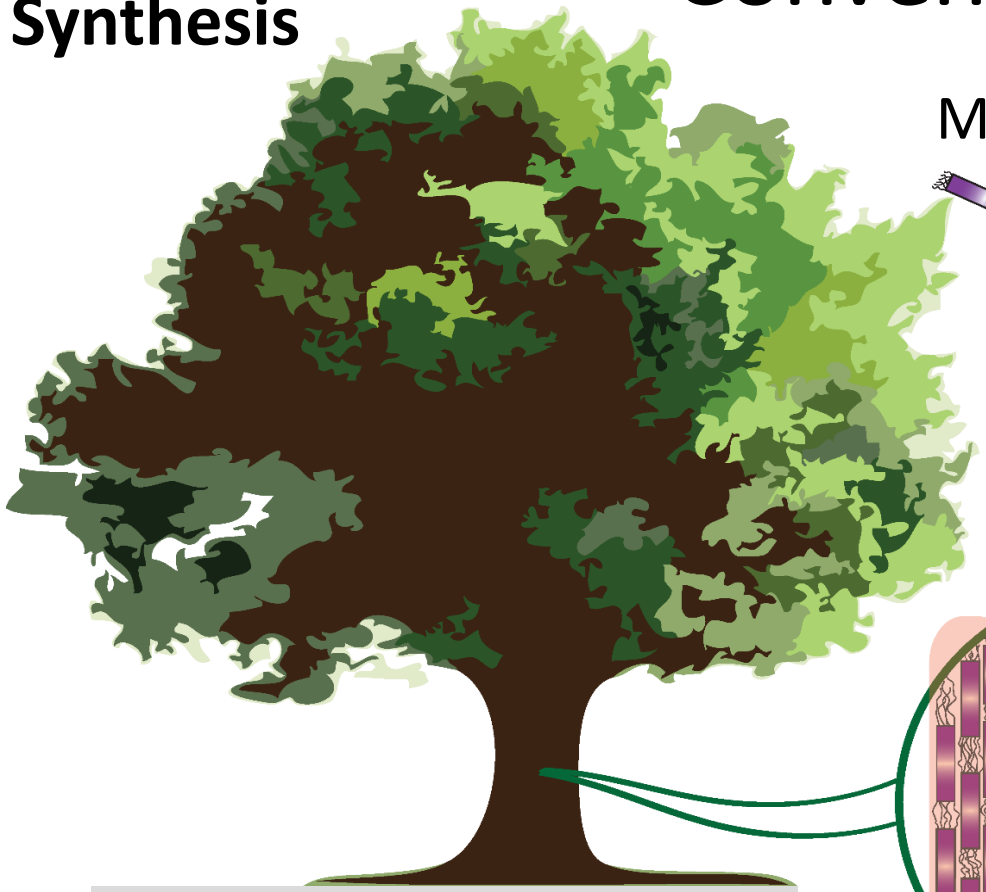
Part II: HCNC properties

Part III: Evidence of protruding chains

Part IV: Unique applications of HCNCs

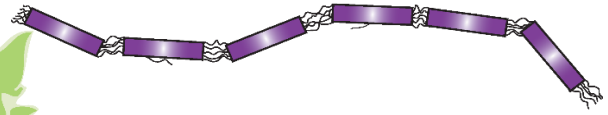
Part I: Synthesis

Conventional nanocelluloses

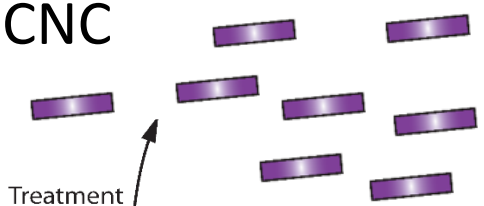


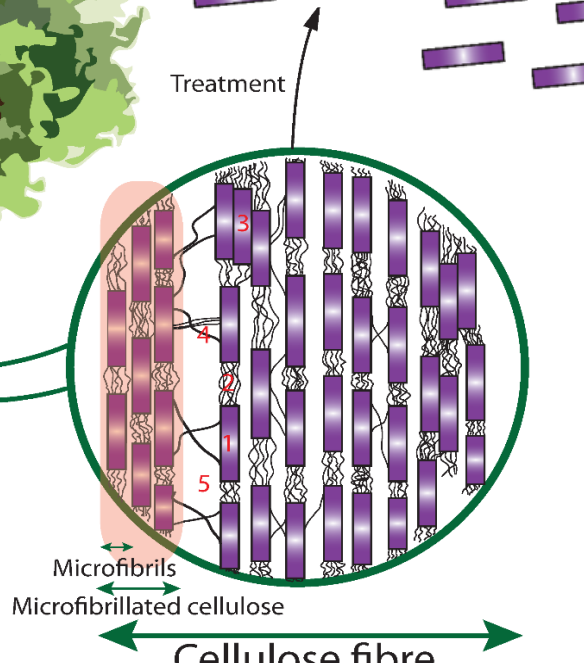
- ✓ Biorenewable
- ✓ Biodegradable
- ✓ Cost effective
- ✓ Environmentally friendly
- ✓ Large surface area (>100 m^2/g)

MFC/NFC

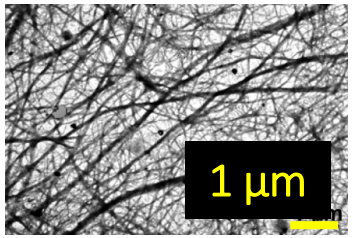


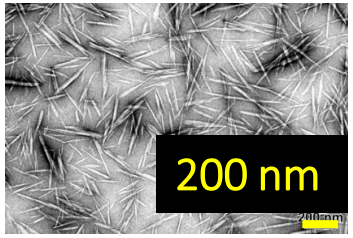
CNC

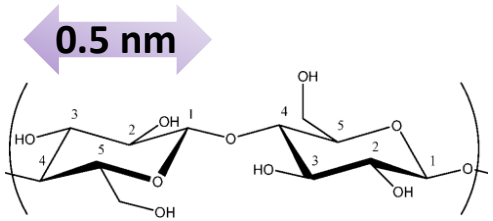




(1) Crystallites, (2) Amorphous region, (3) Cluster, (4) Inter-fibrilar molecular tie, (5) Void



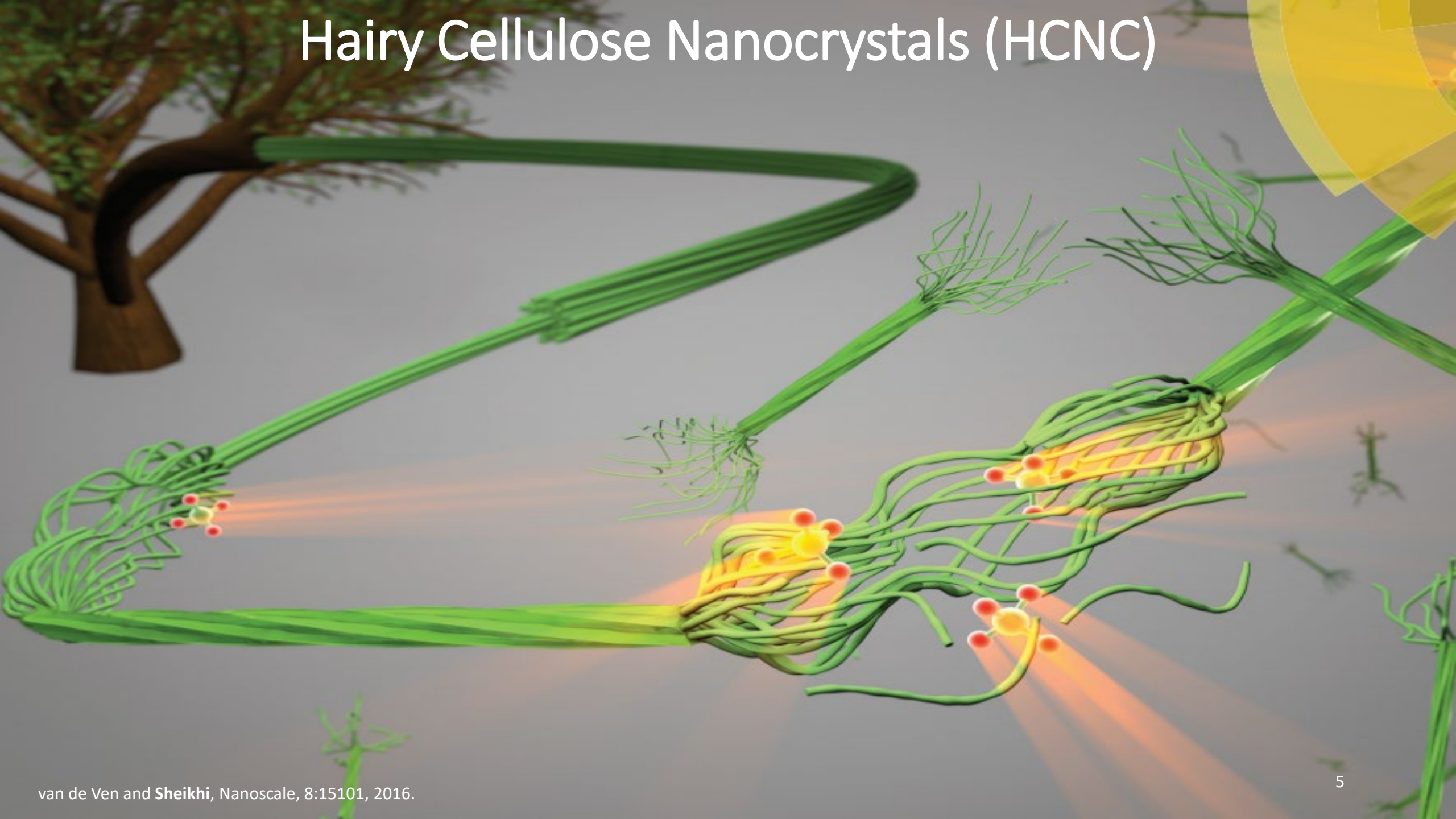




Maximum theoretical charge content ~ 1.4 mmol/g.

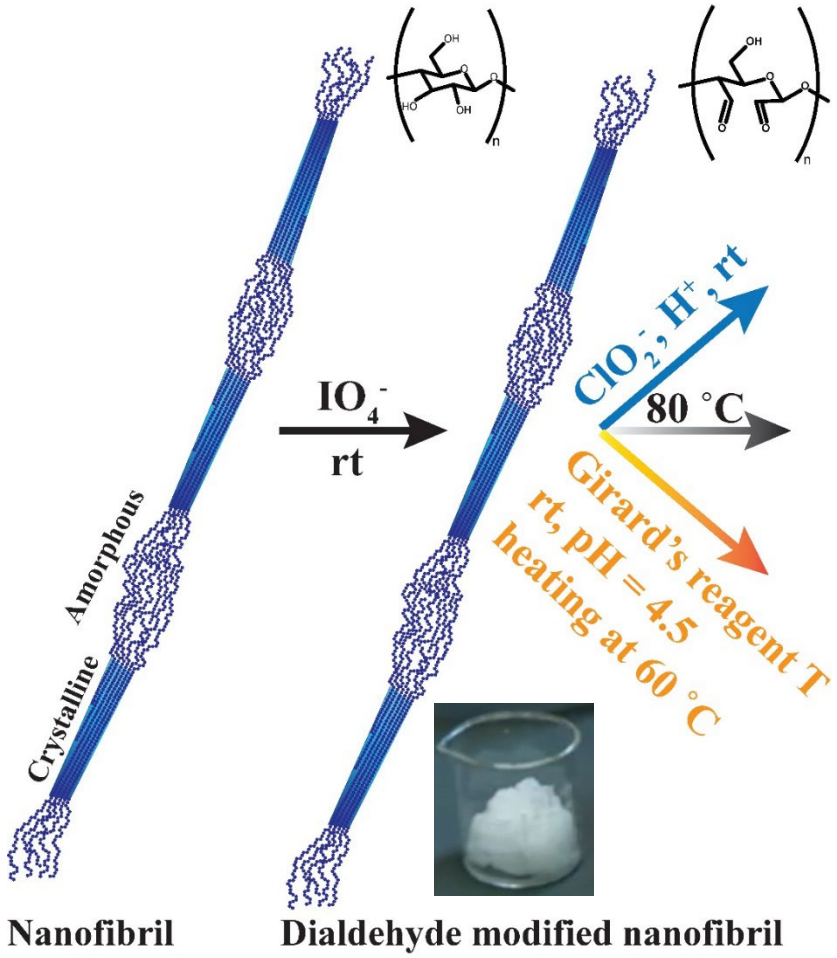
Kontturi et al., Advanced Materials, 30:1703779, 2018.
Dufresene, Materials Today, 16:220, 2017.
Habibi et al., Journal of Materials Chemistry, 18:5002, 2008.
Malainine et al., Carbohydrate Polymers, 51:77, 2003.
Yang et al., Cellulose, 20:1865, 2013.

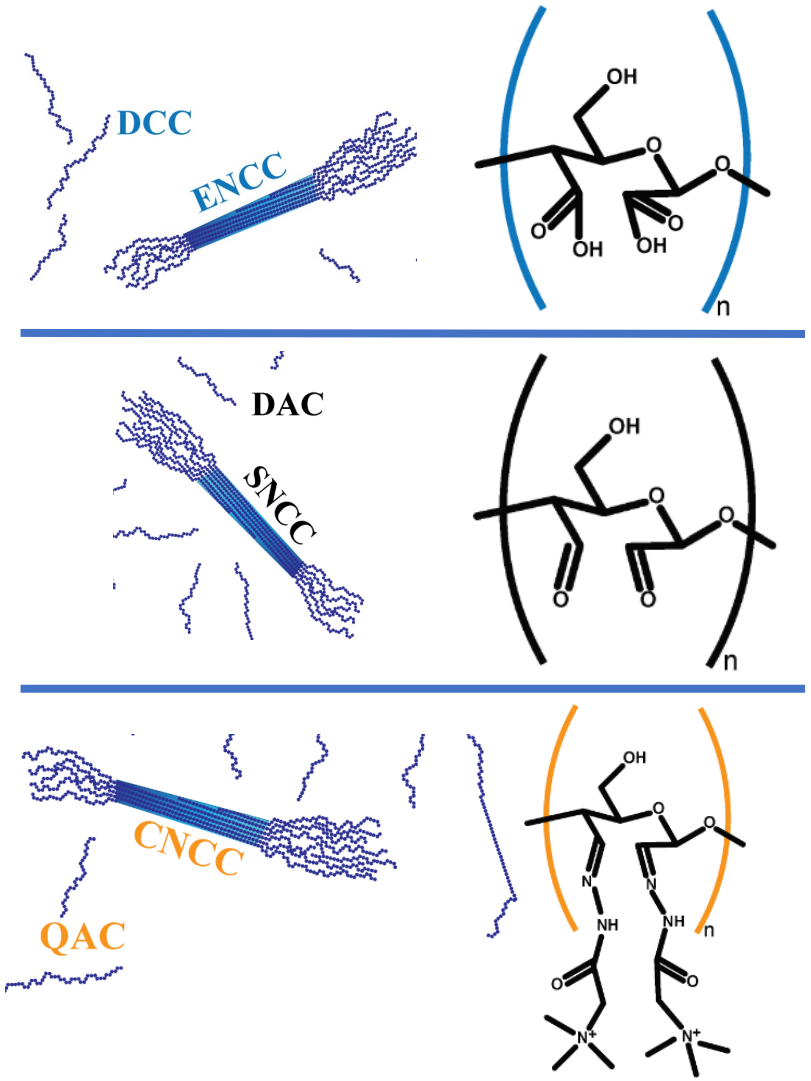
Hairy Cellulose Nanocrystals (HCNC)

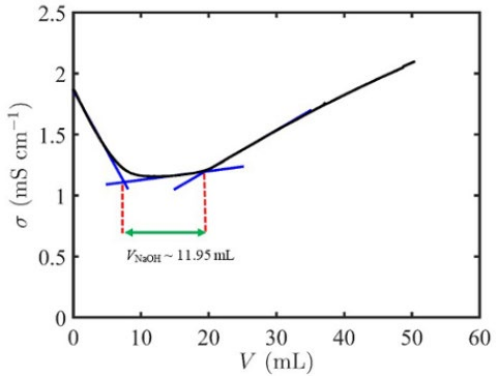


van de Ven and **Sheikhi**, Nanoscale, 8:15101, 2016.

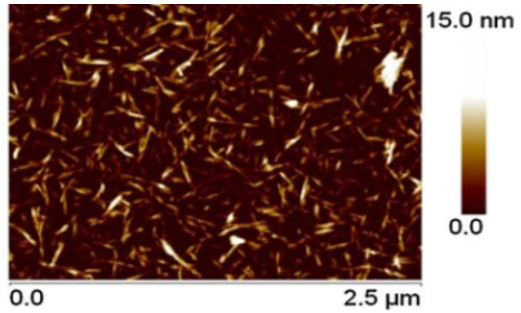
HCNC synthesis







COOH concentration = 0.01195 (V_{NaOH}) × 10 mM (NaOH concentration) / 0.02 g (initial ENCC) ~ 5.98 mmol/g

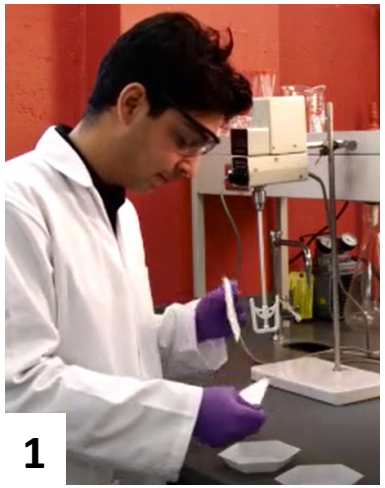


Yang et al., Langmuir, 28:7834, 2012.

Sheikhi and van de Ven, Current Opinion in Colloid & Interface Science, 29:21, 2017.
Sheikhi et al., Journal of Visualized Experiments: JoVE, 113 e54133, 2016.

HCNC synthesis

Preparing partially oxidized fibers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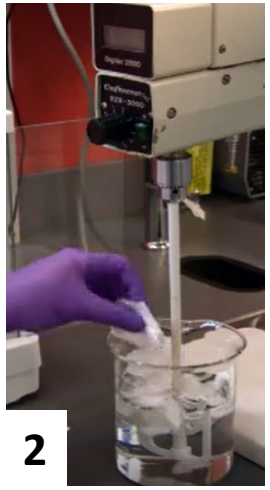
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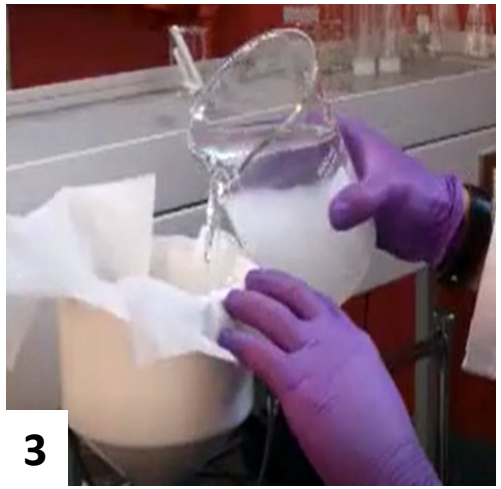
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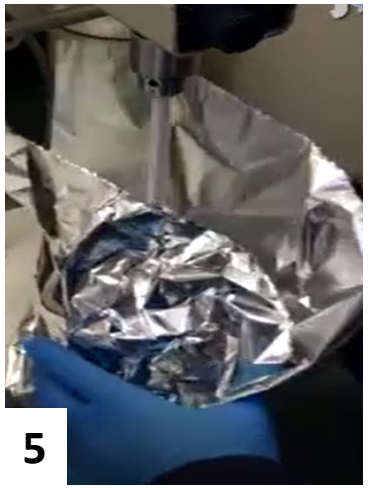
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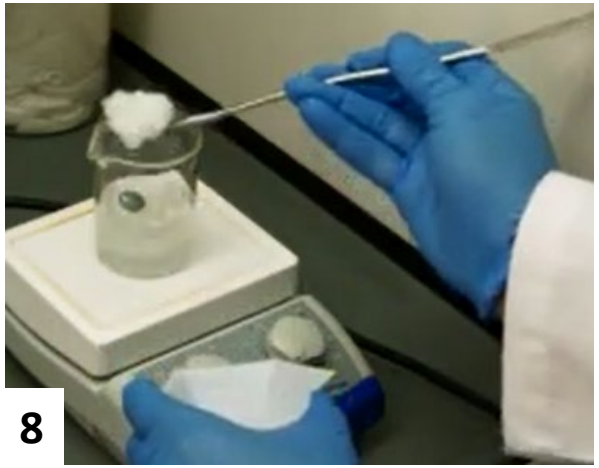
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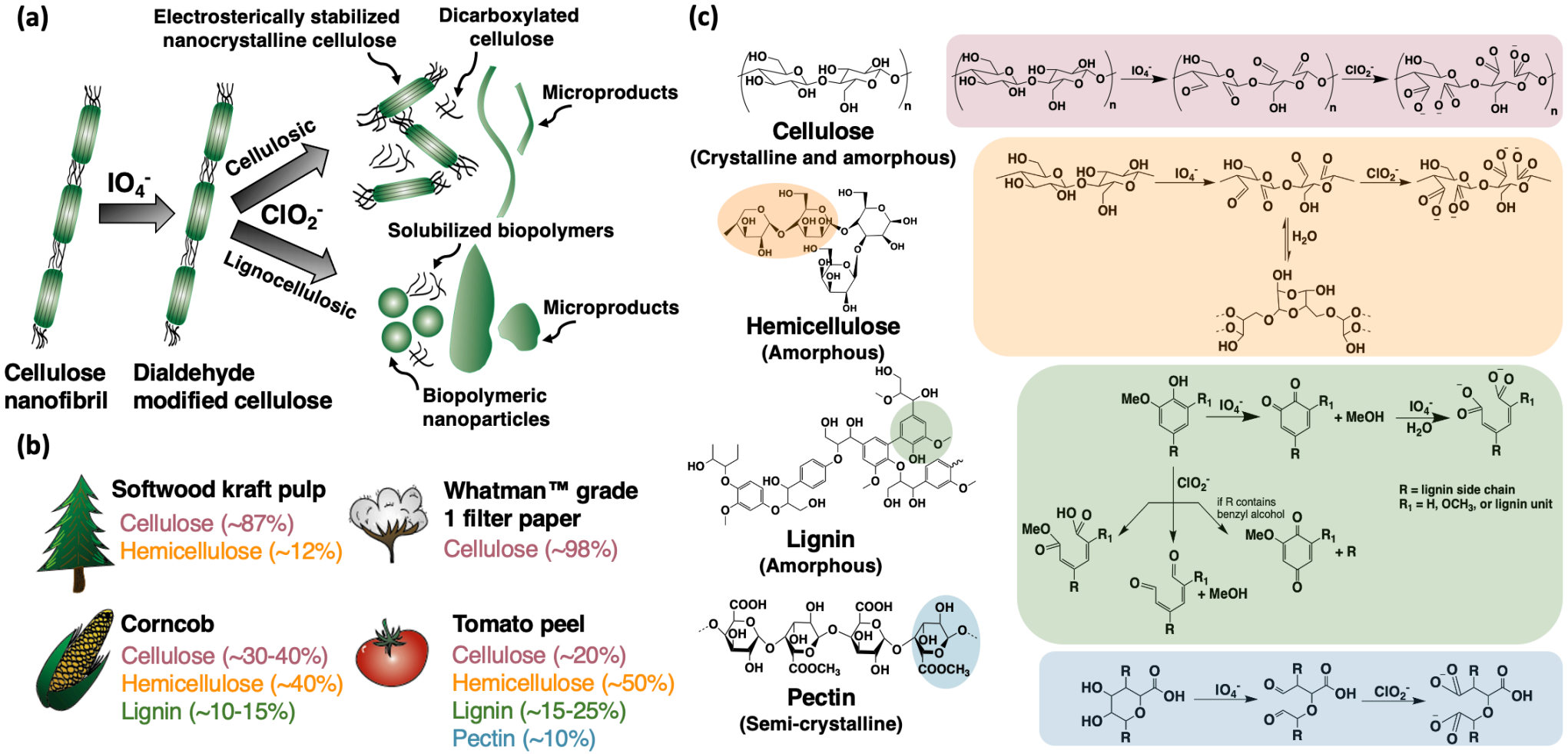
11

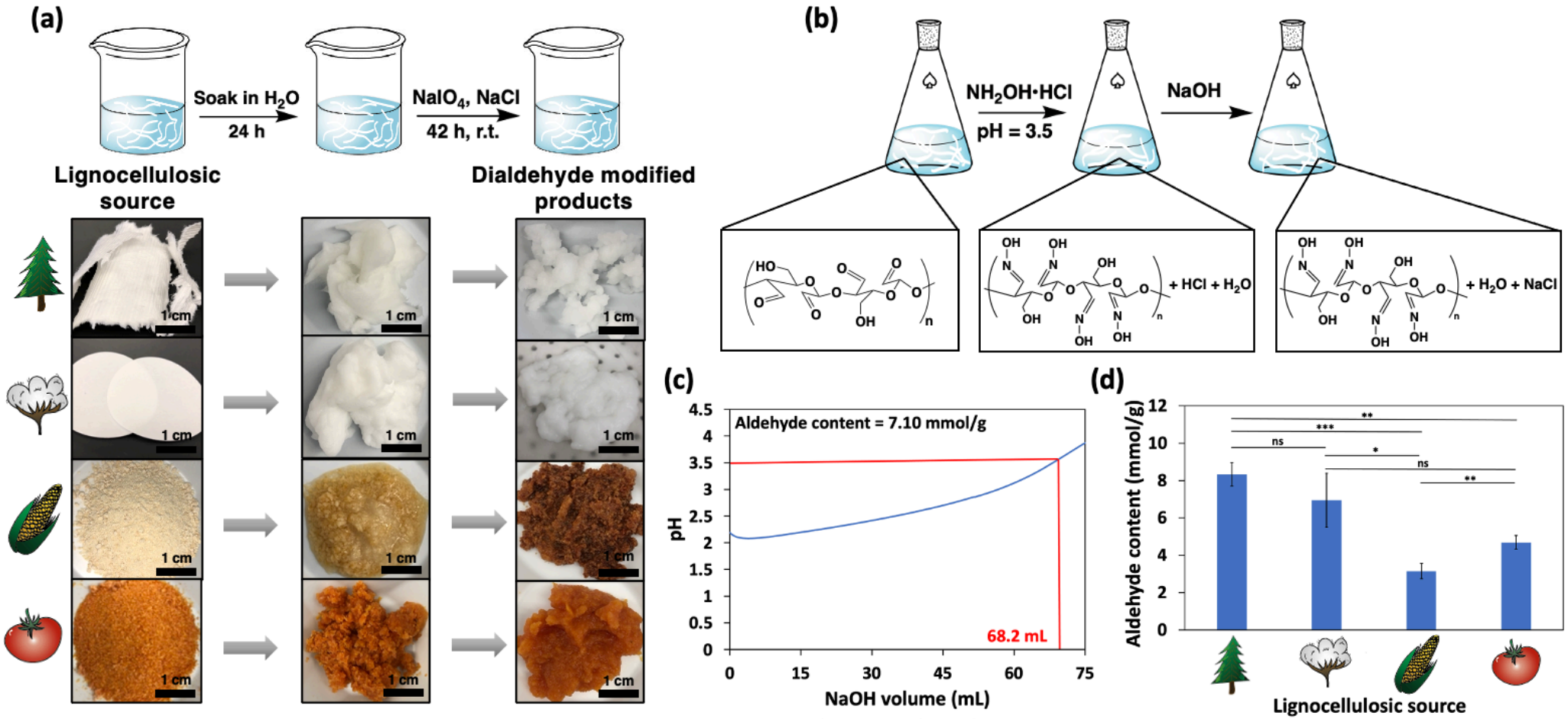
Preparing electrosterically stabilized nanocrystalline celluloses (ENCC)

Universality of HCNC synthesis



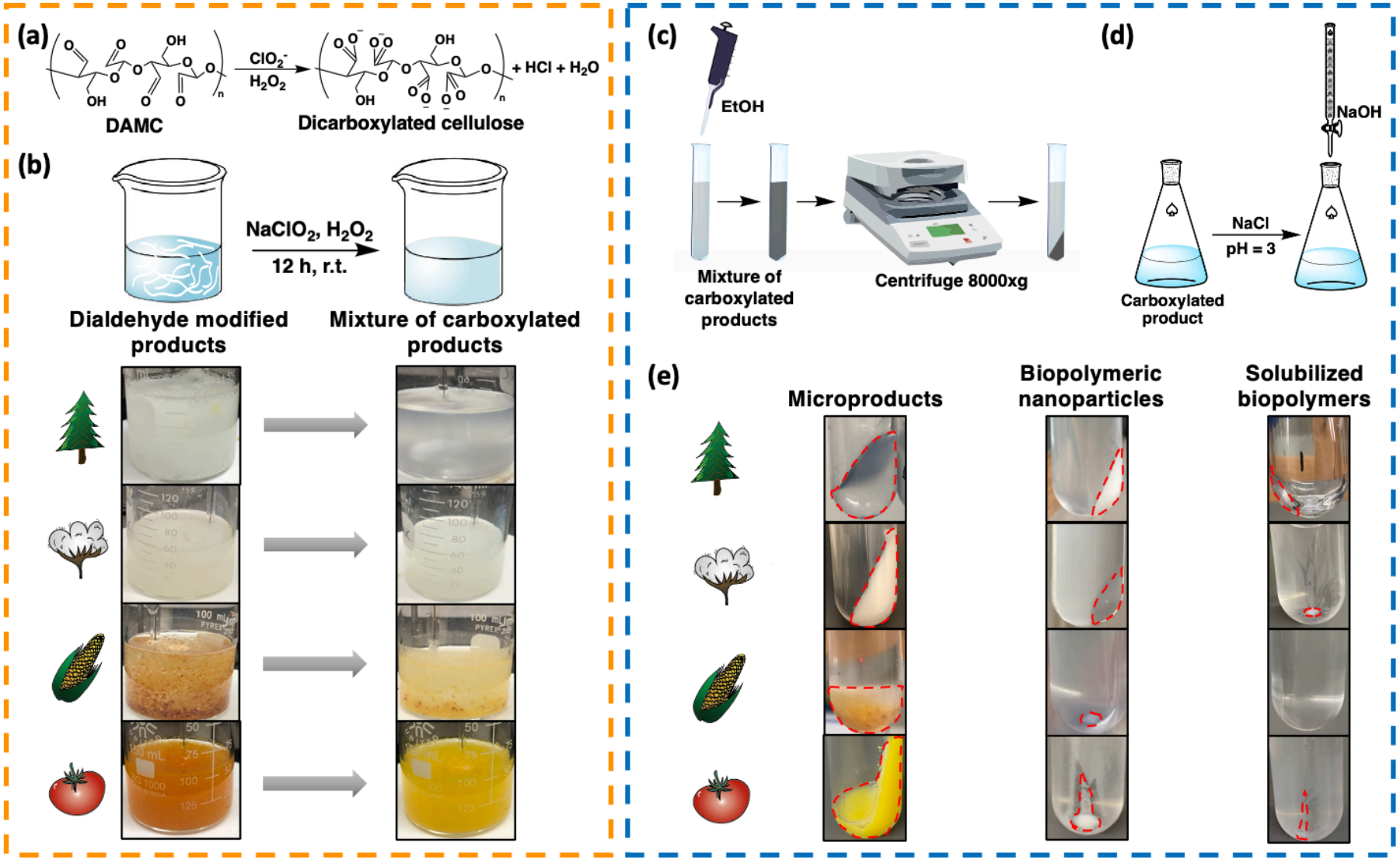
Pitcher and **Sheikhi** et al., Chemical Engineering Journal, 447:137418**,** 2022.
Provisional Patent Application filed.

Universality of HCNC synthesis: Periodate reaction



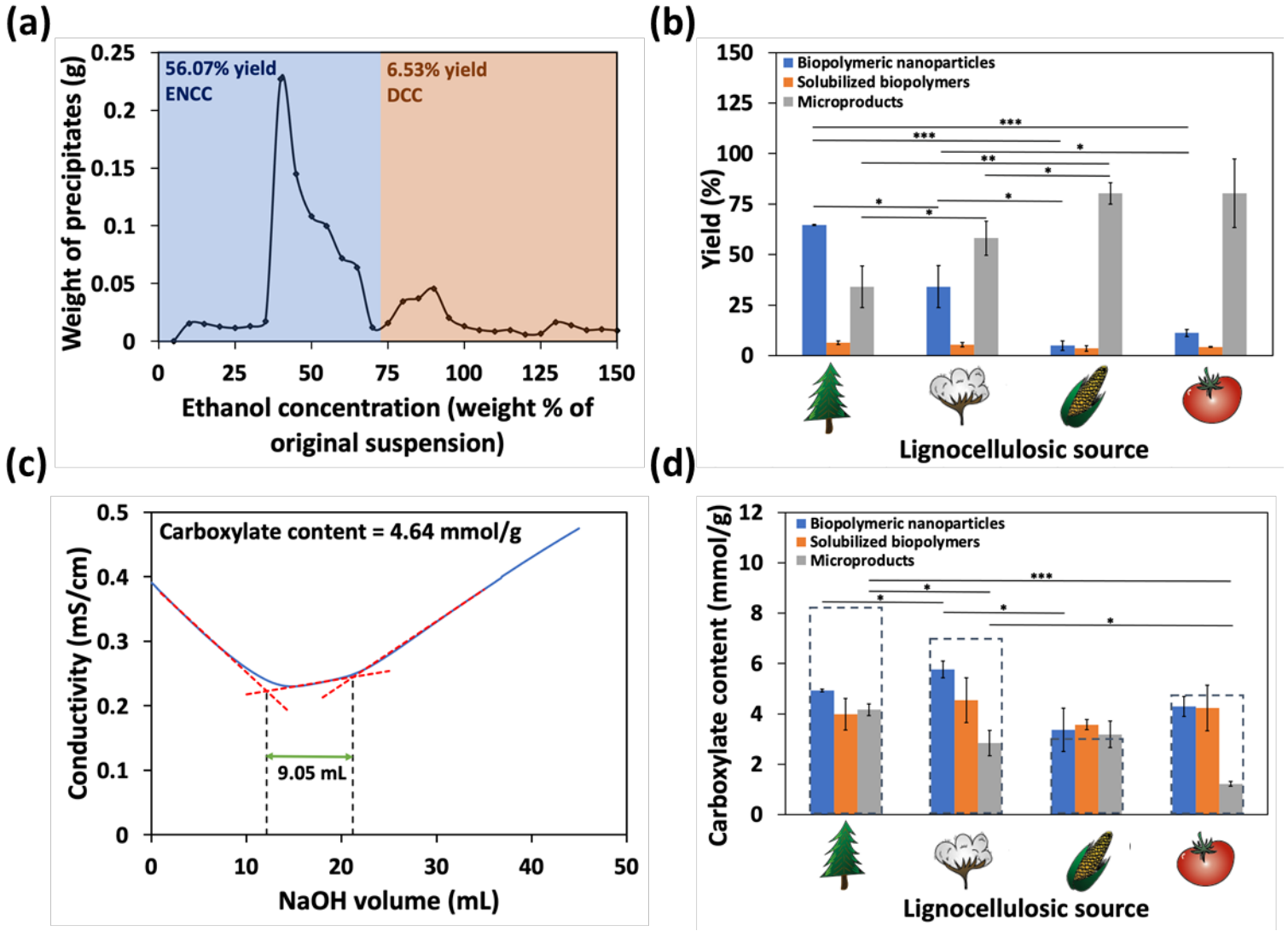
Pitcher and **Sheikhi** et al., Chemical Engineering Journal, 447:137418 (2022).
Provisional Patent Application filed.

Universality of HCNC synthesis: Chlorite reaction



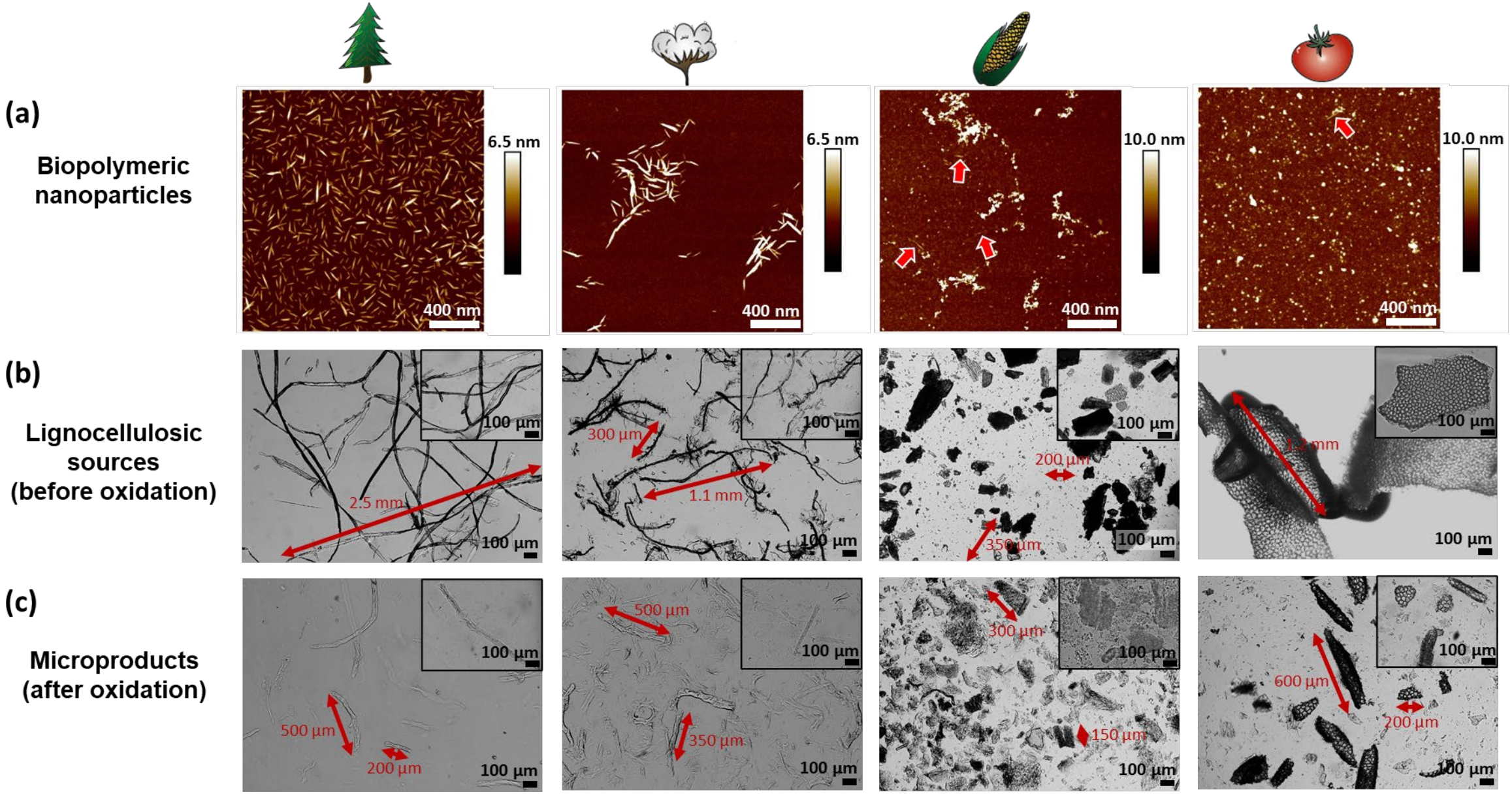
Pitcher and **Sheikhi** et al., Chemical Engineering Journal, 447:137418**,** 2022.
Provisional Patent Application filed.

Universality of HCNC synthesis: Characterization



Pitcher and **Sheikhi** et al., Chemical Engineering Journal, 447:137418**,** 2022.
Provisional Patent Application filed.

Universality of HCNC synthesis: Characterization

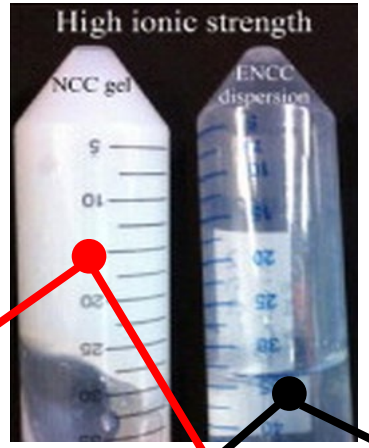


Pitcher and **Sheikhi** et al., Chemical Engineering Journal, 447:137418, 2022. Provisional Patent Application filed.

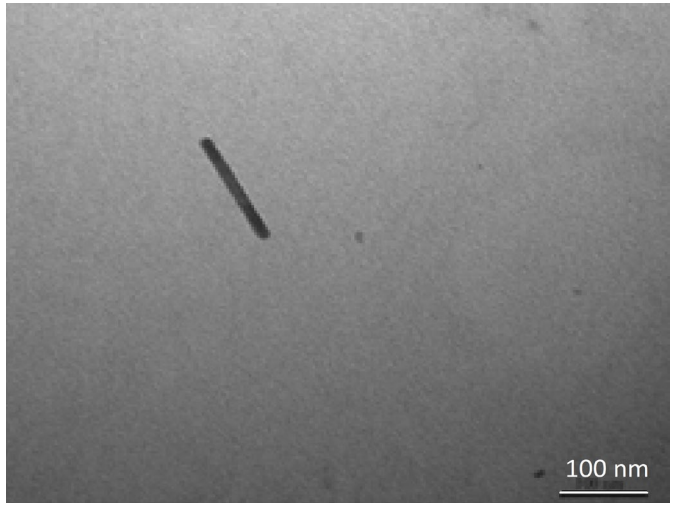
Part II: Properties

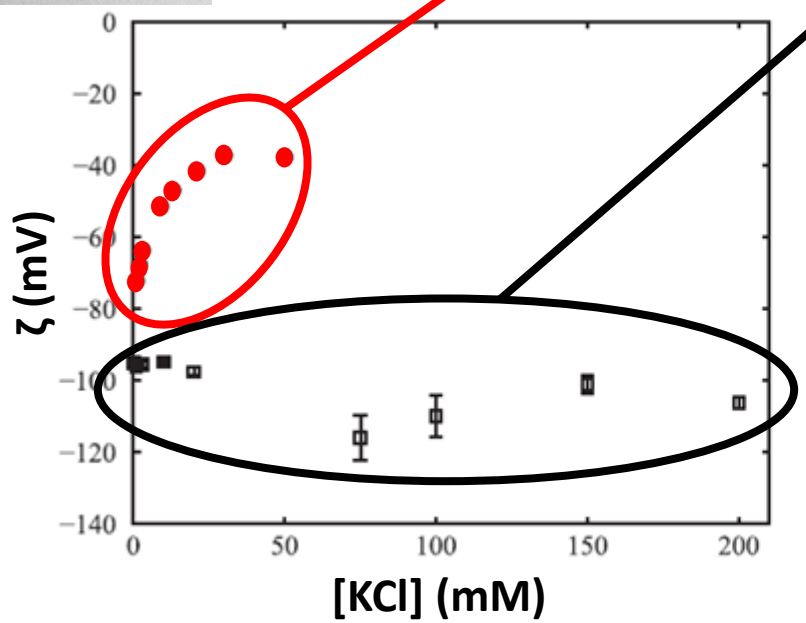
CNC versus HCNC

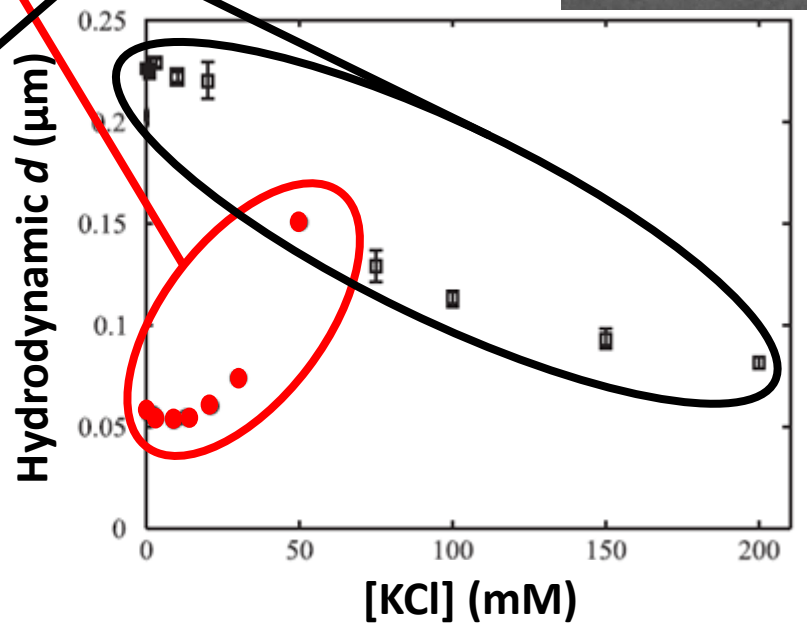
Anionic CNC



Anionic HCNC

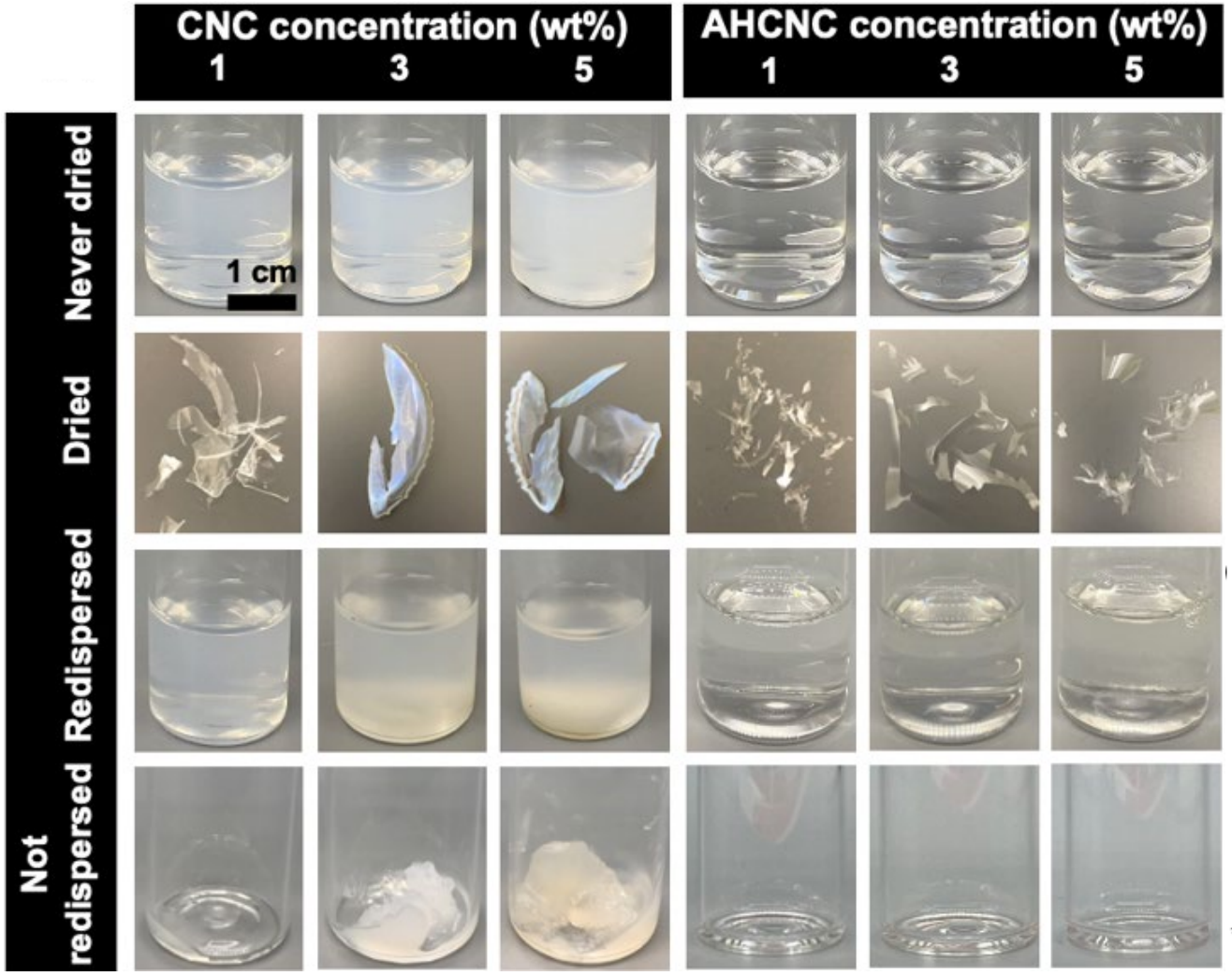


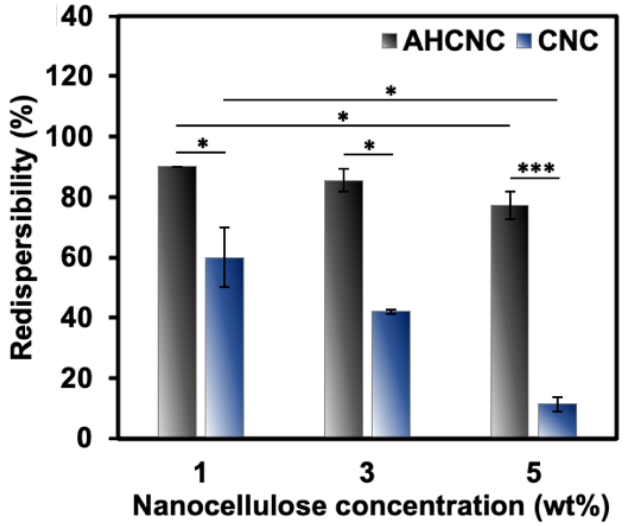


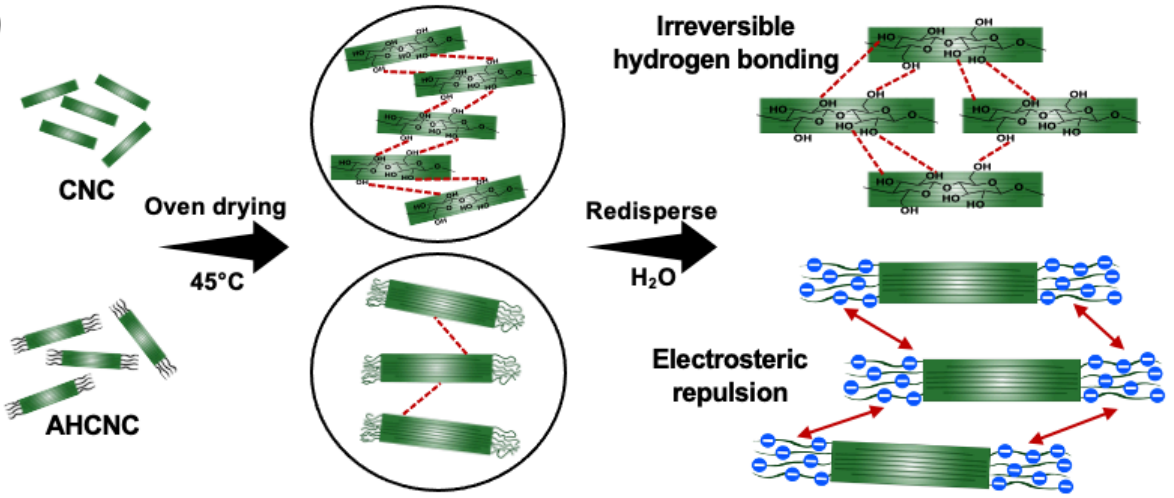


Sheikhi et al., Journal of Colloid and Interface Science, 432:151, 2014.

Part II: Properties
Redispersibility

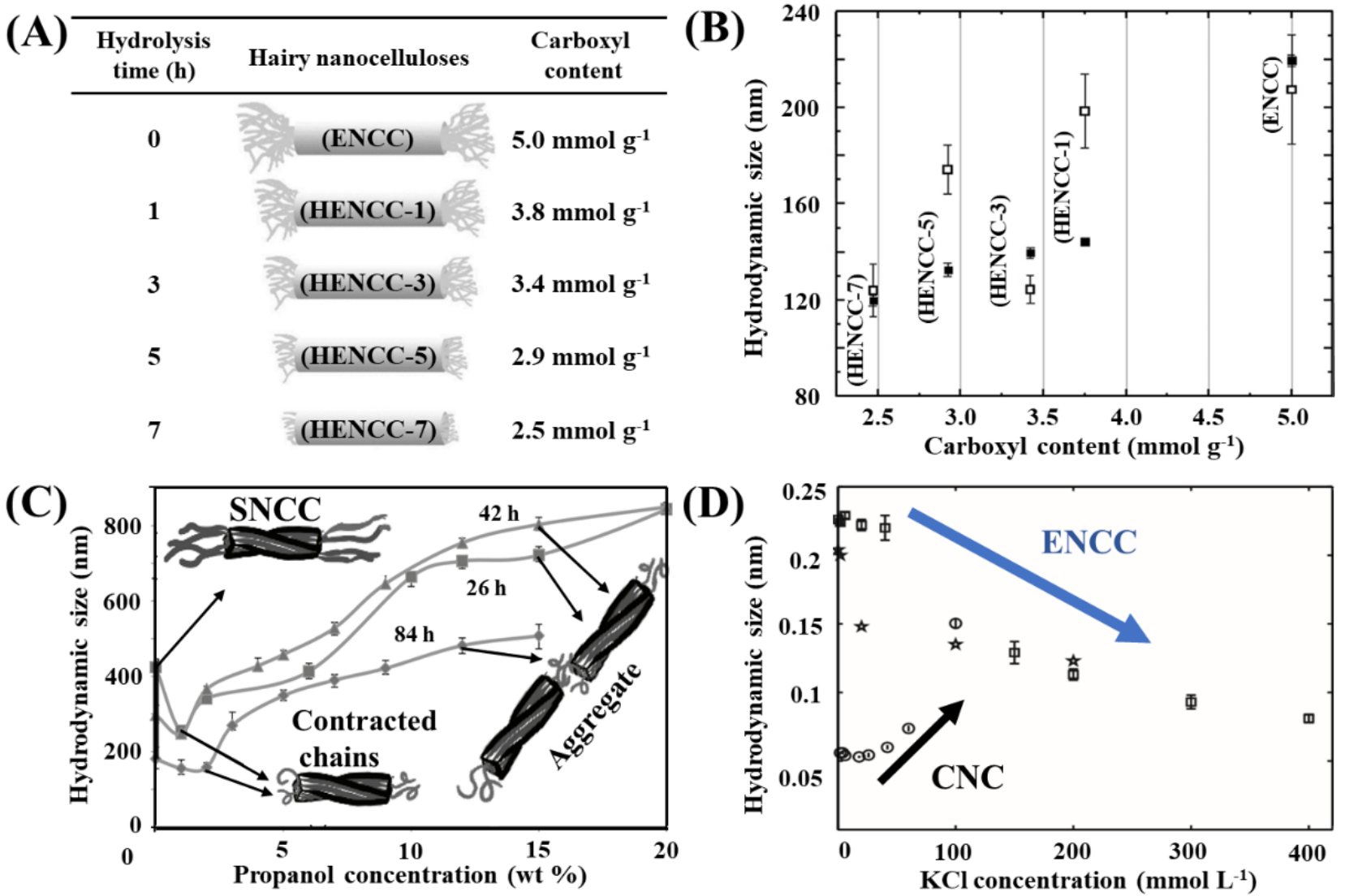






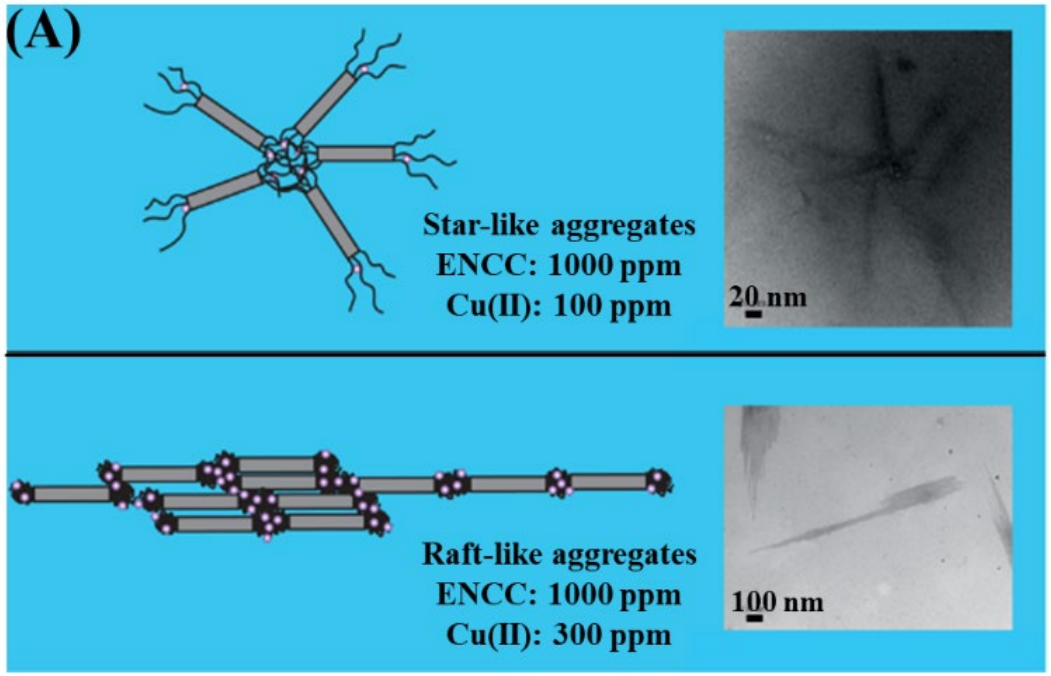
Pitcher and **Sheikhi** et al., Biomacromolecules, **Accepted** (2023).

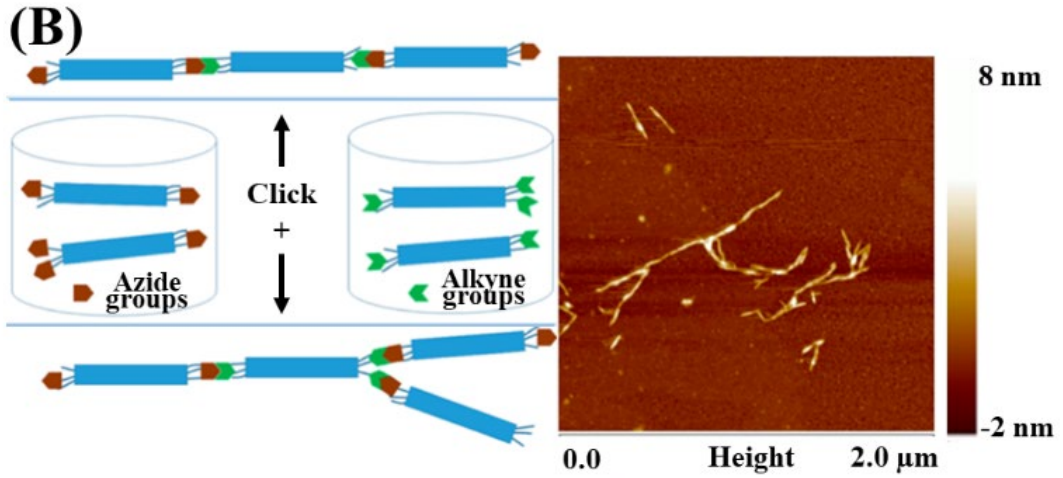
Part III: Evidence of protruding chains

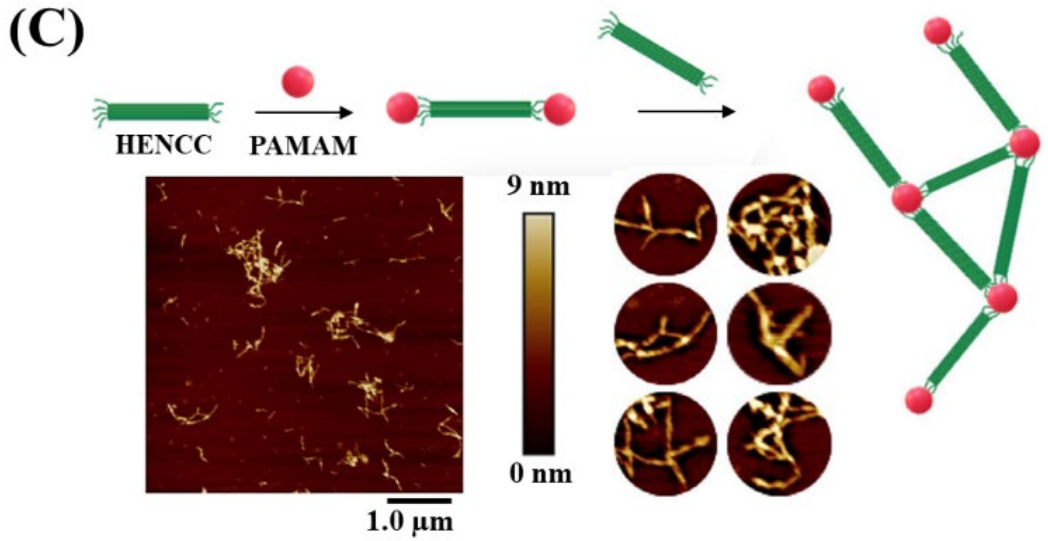


Koshani and van de Ven, Journal of Colloid and Interface Science, 563:252, 2020.
Chen and van de Ven, Cellulose, 23:1051, 2016.
Sheikhi et al., Journal of Colloid and Interface Science, 432:151, 2014.

Part III: Evidence of protruding chains



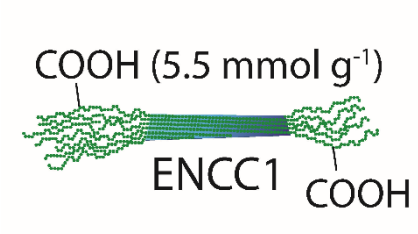


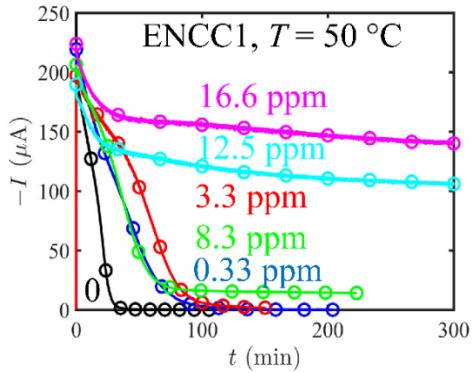


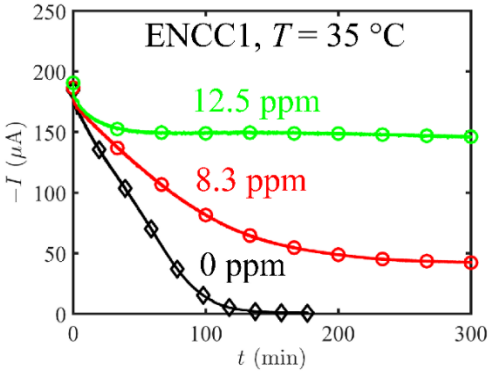
Sheikhi et al., ACS Applied Materials & Interfaces, 7:11301, 2015.
Yang et al., Biomacromolecules, 17:2240, 2016.
Tavakolian et al., Journal of Colloid and Interface Science, 541:444, 2019.

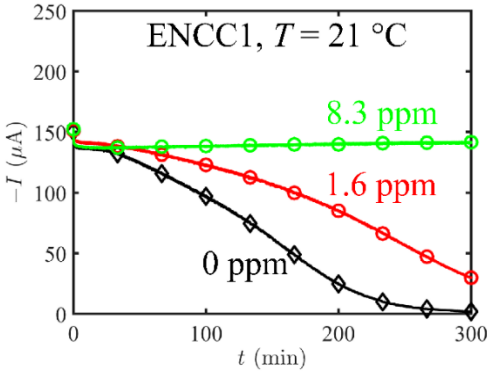
Part V: Unique applications

- **Scale inhibition**



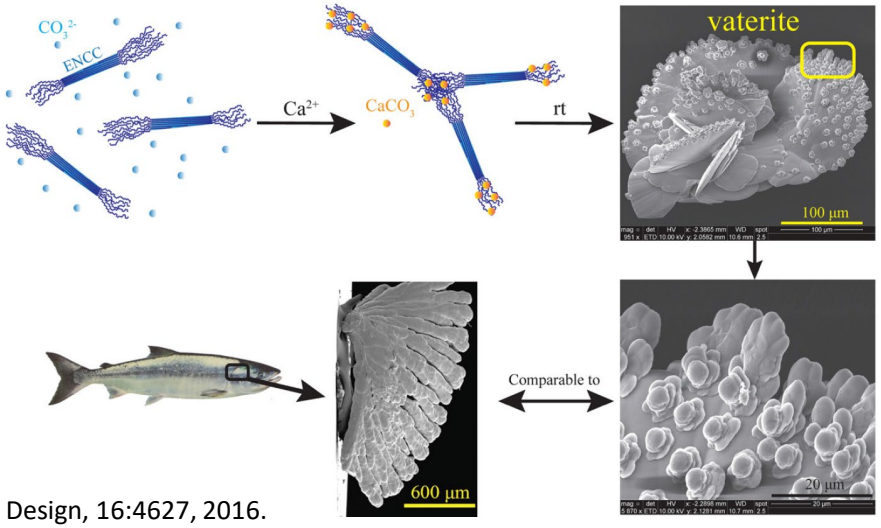






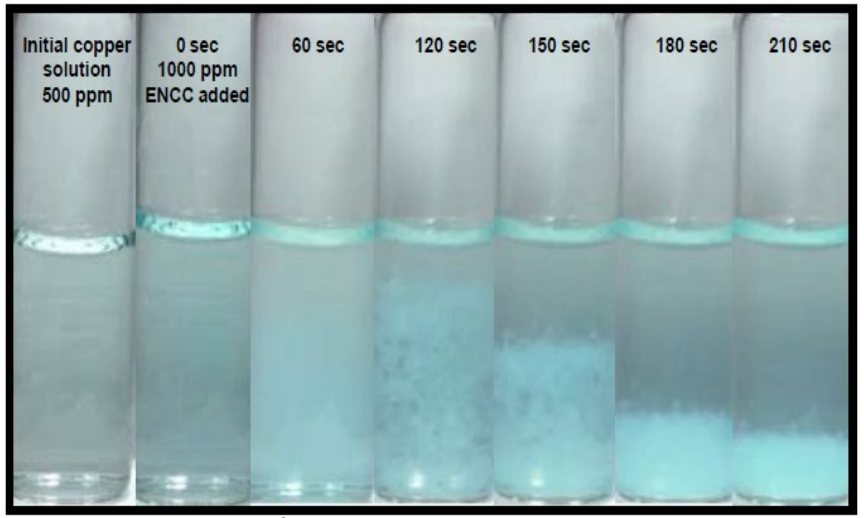
Sheikhi et al., Materials Horizons, 5:248, 2018.

- **Biomimetic mineralization**



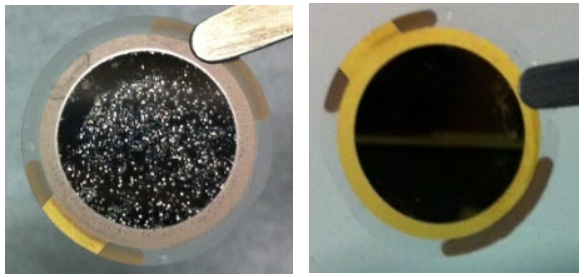
Sheikhi et al., Crystal Growth & Design, 16:4627, 2016.

- **Water treatment**



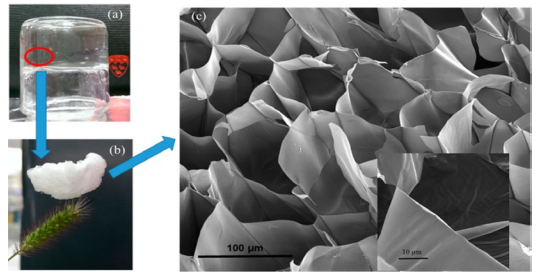
Sheikhi et al., ACS Applied Materials & Interfaces, 7:11301, 2015.

- **Anti-scaling surfaces**

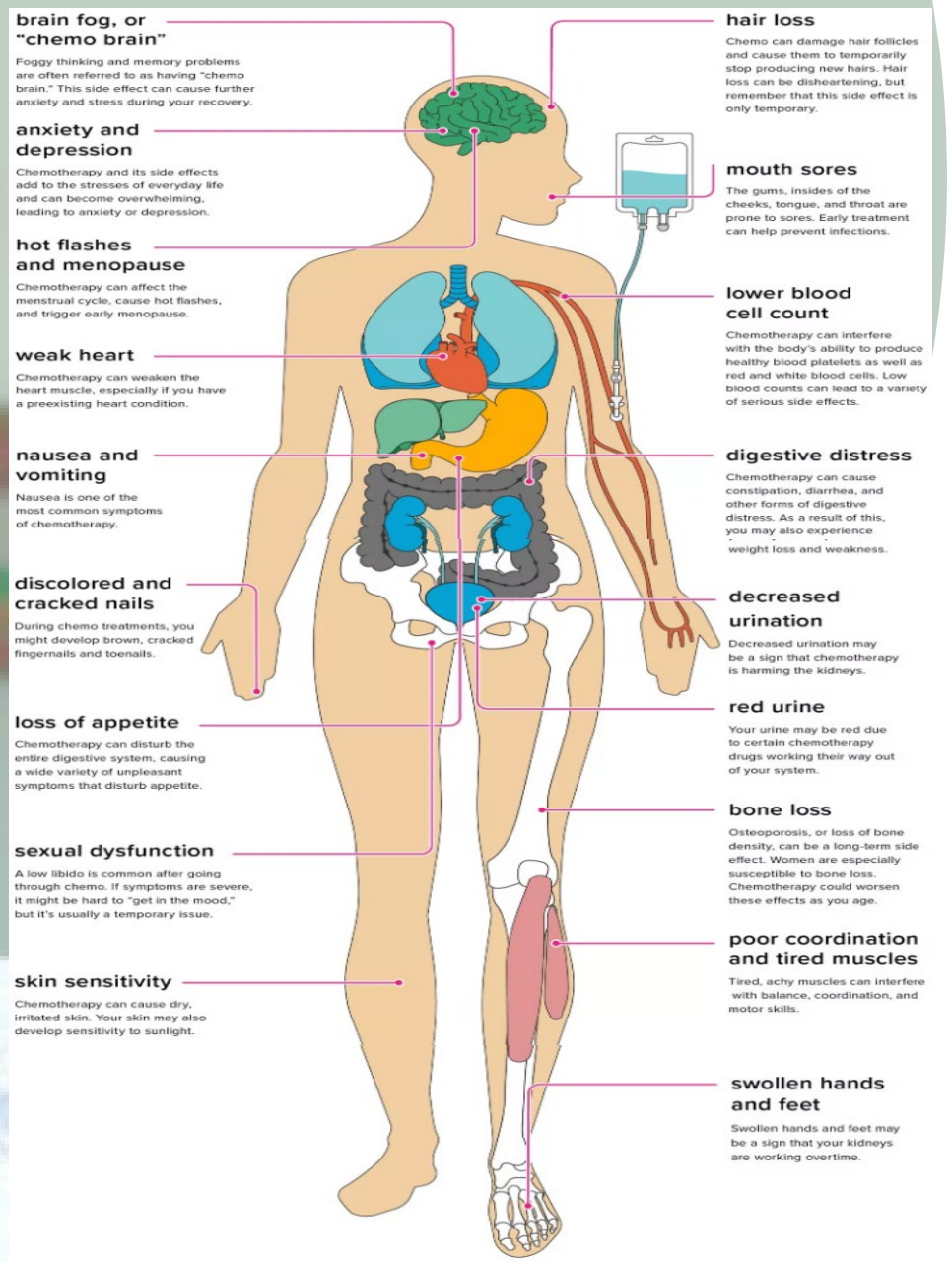


Sheikhi et al., ACS Applied Materials & Interfaces, 10:34553, 2018.

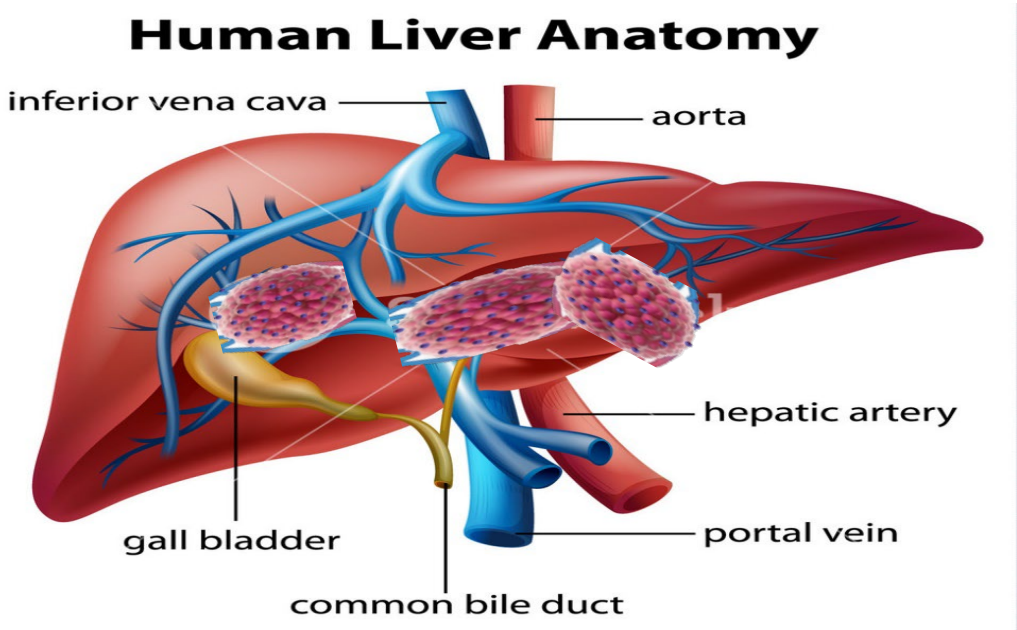
- **Lightweight materials**



Yang and **Sheikhi** et al., Langmuir, 32:11771, 2016.



Drug capture



HCNC for capturing off-target drugs

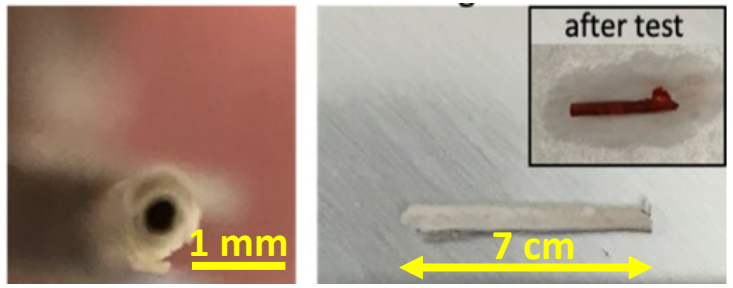
Magnetic device

25 µg mL^{-1} → 5 µg mL^{-1}

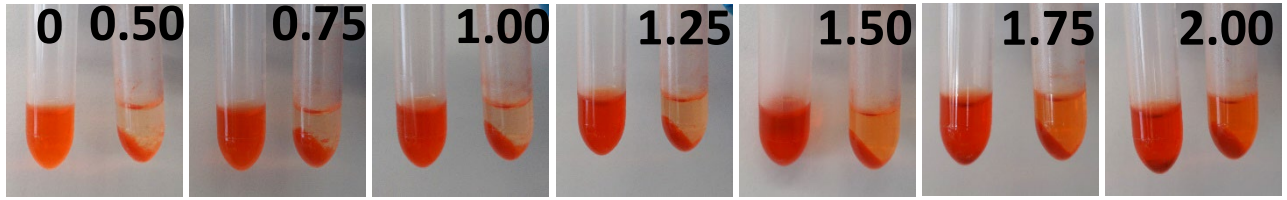
Blumenfeld et al., Nature Communication (2018) (Grubbs @ Caltech)

ENCC device

100 µg mL^{-1} → 10 µg mL^{-1}

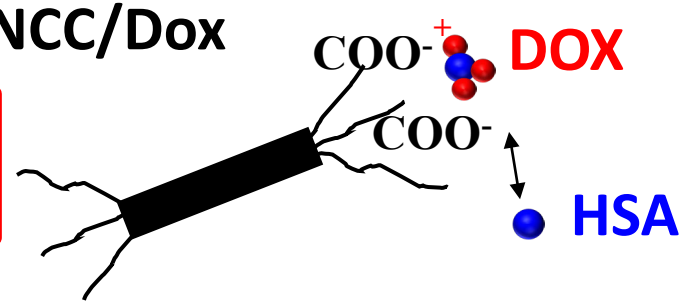


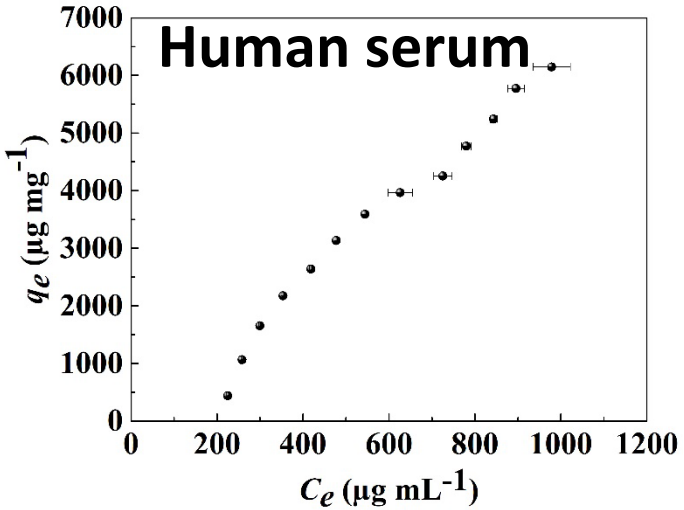
***V* = 100×5 ~ 500 time smaller**

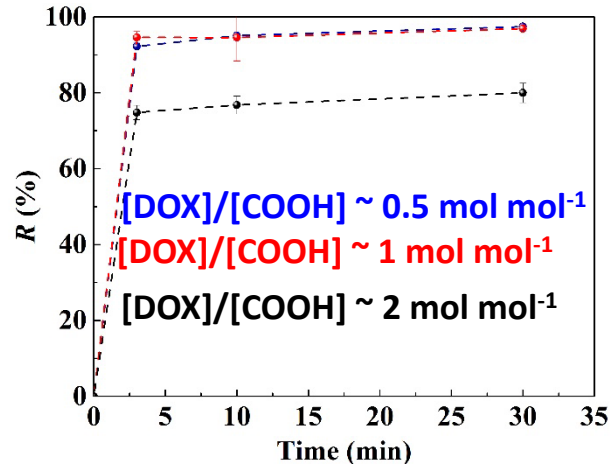


ENCC/Dox

6000 µg mg^{-1}

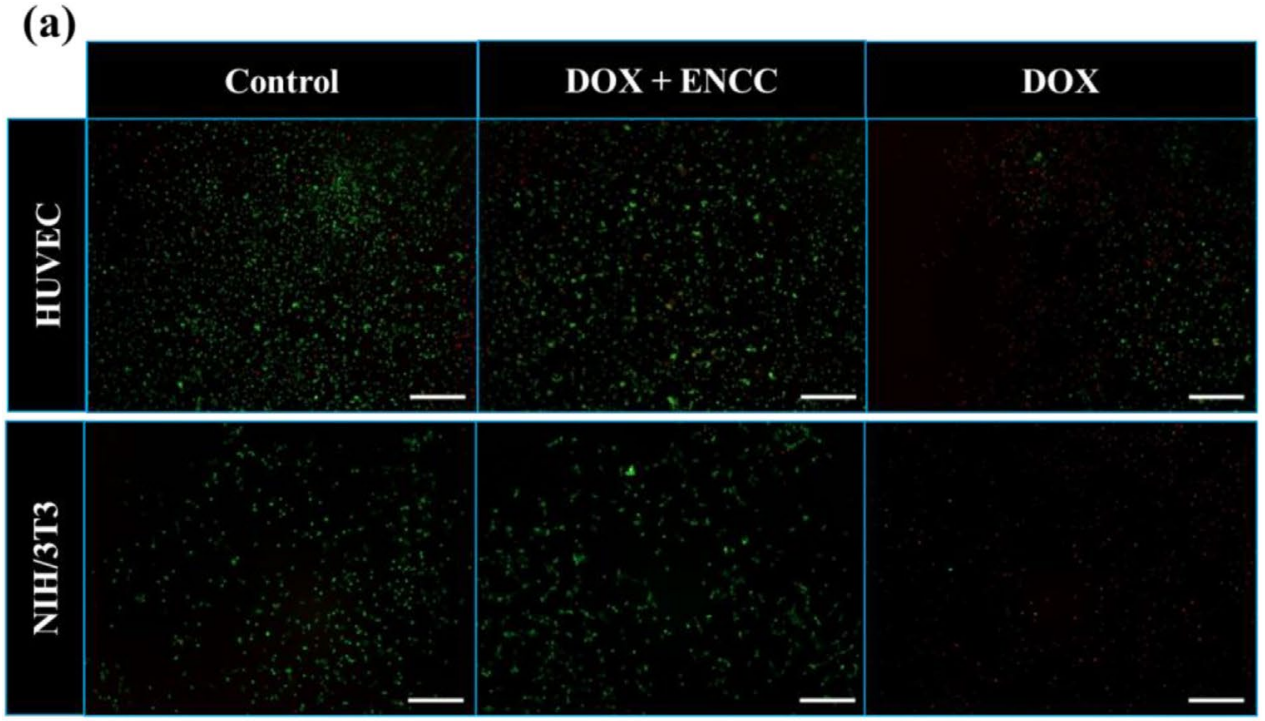


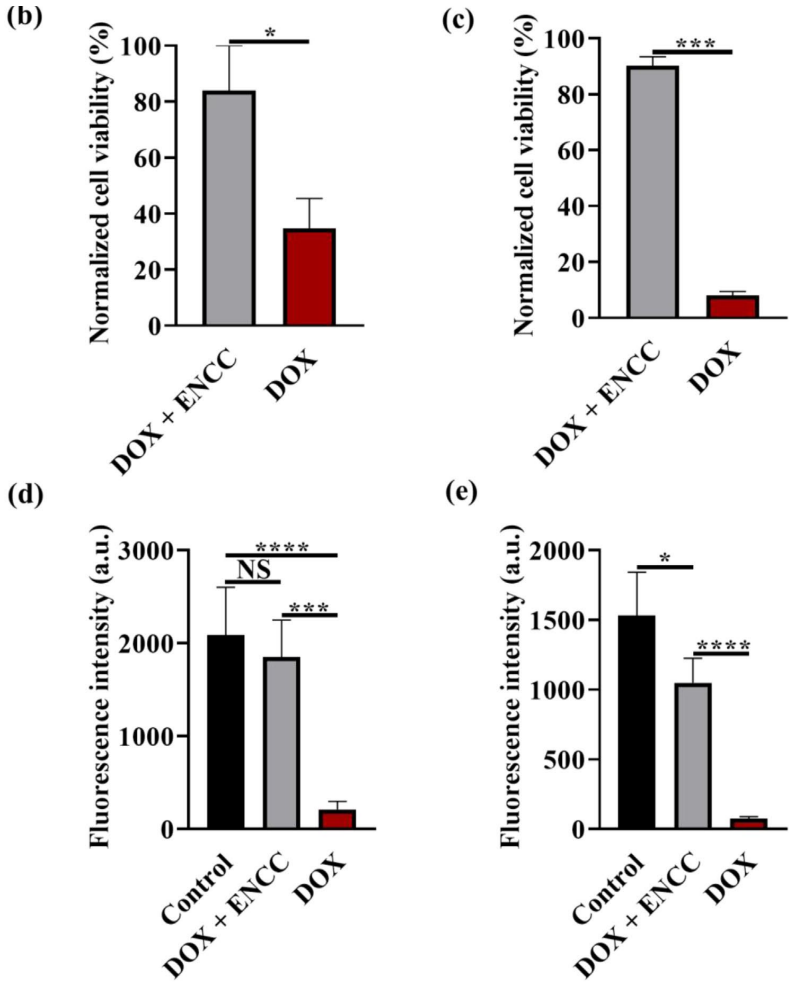




Young and **Sheikhi** et al., Materials Today Chemistry, 23:100711, 2022.
Provisional Pending Application filed.

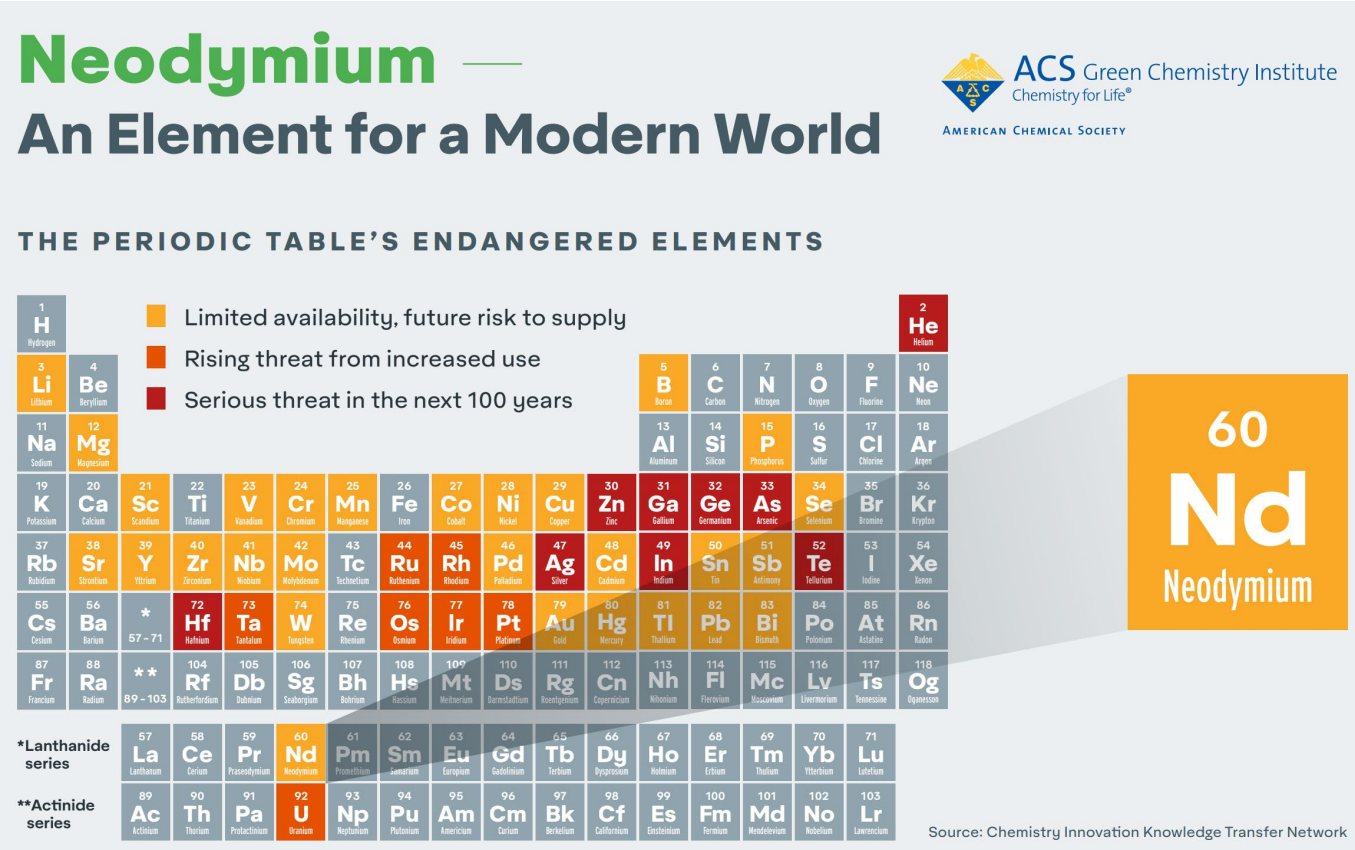
HCNC for capturing off-target drugs





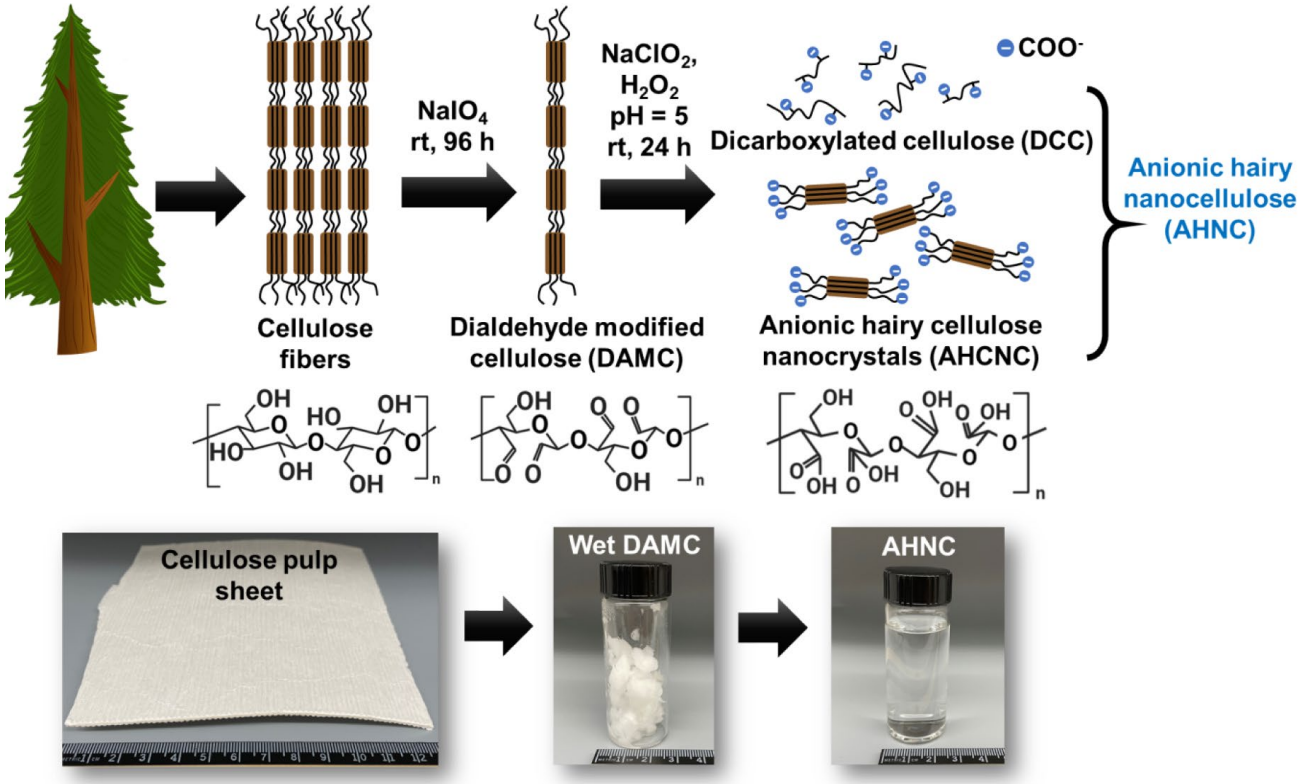
Young and **Sheikhi** et al., Materials Today Chemistry, 23:100711, 2022.
Provisional Pending Application filed.

HCNC for the selective removal of rare earth elements (REEs)

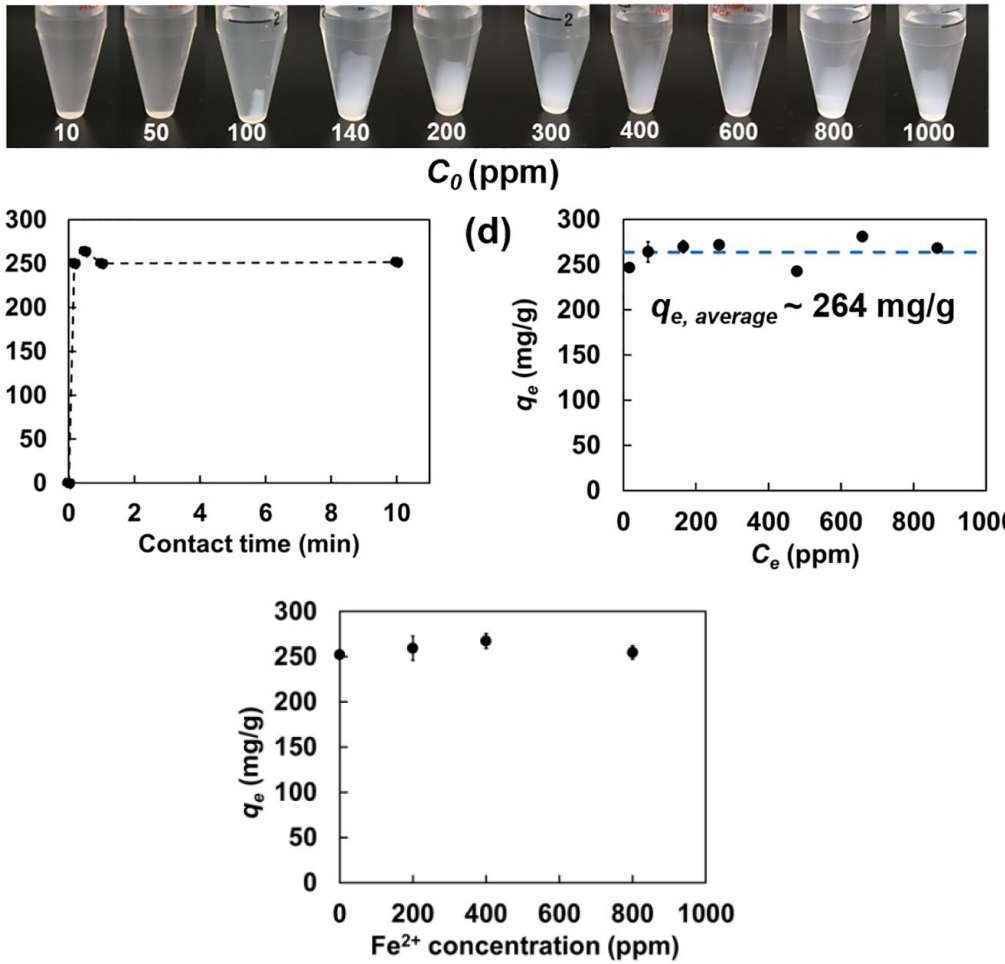


Creating a sustainable, circular economy for neodymium will empower us to meet U.N. Sustainable Development Goal #11: Sustainable Cities and Communities.

HCNC for the selective removal of rare earth elements (REEs)



Wamea and **Sheikhi** et al., Chemical Engineering Journal, 428:131086, 2022.
Provisional Patent Application filed (2022).

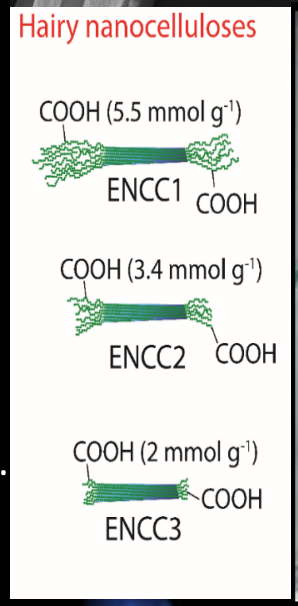


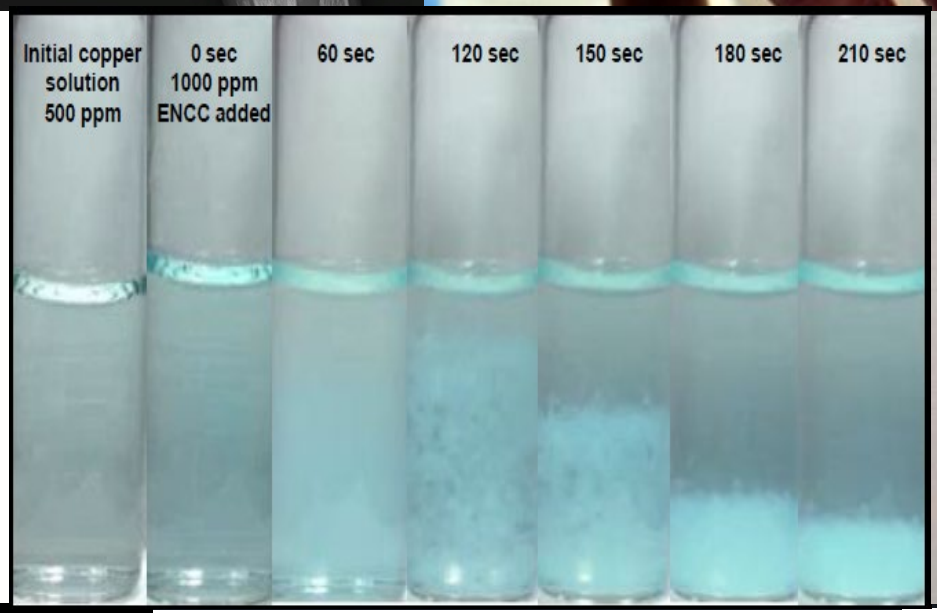
Future directions

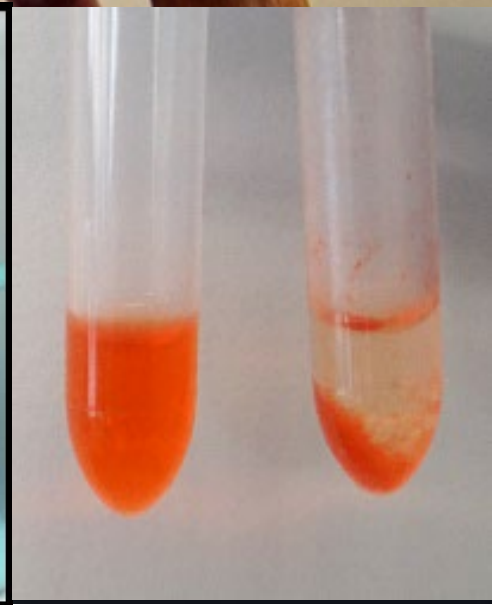
1) Pathological crystal inhibitors
2) Pickering emulsions
3) Food additives
4) Water treatment
5) Blood purification
6) Bioadsorption
7) Sensors
8) Additive manufacturing
9) Inorganic nanoparticle synthesis
10) Antifouling coatings

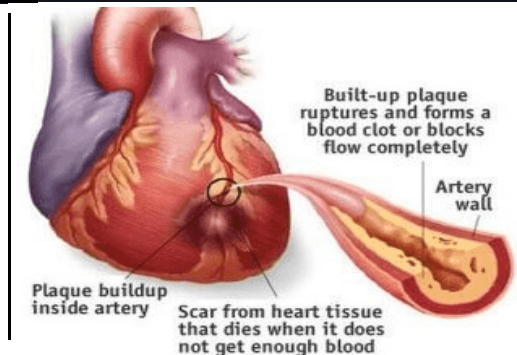
Conclusions

1) HCNC has unique colloidal properties.
2) HCNC is an emerging sustainable nanomaterial for environmental and healthcare applications.
3) Scale up of HCNC could be the next step in democratizing its use.









Acknowledgments

Sheikhi lab members:

From Left to Right: Jules, Rhea, Kyler, Mica, Aneesh, Shambhavi, Sam, Nawaf, Sean, Arian, Carter, Amir, Zeming, William, Shang-Lin, Colin, Gerald, Luke, Naveen, Daksh, Christian, Alex, Jenna, Zaman
From Top to Bottom: Roya, Hai, Angelo, Marisa, Shufang, Catherine, Caitlyn, Mitchel, Sina

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