Mechanochemistry and aging-based methods as novel tools to transform biopolymers into high value materials

Hybrid Workshop: Next generation advanced fossil-free materials

December 10 2025

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McGill UNIVERSITY

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Mooresresearch.org
LinkedIn:
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McGill University
Montreal

McGill University is on land which has long served as a site of meeting and exchange amongst Indigenous peoples, including the Haudenosaunee and Anishinabeg nations.







https://native-land.ca/

200-300 years



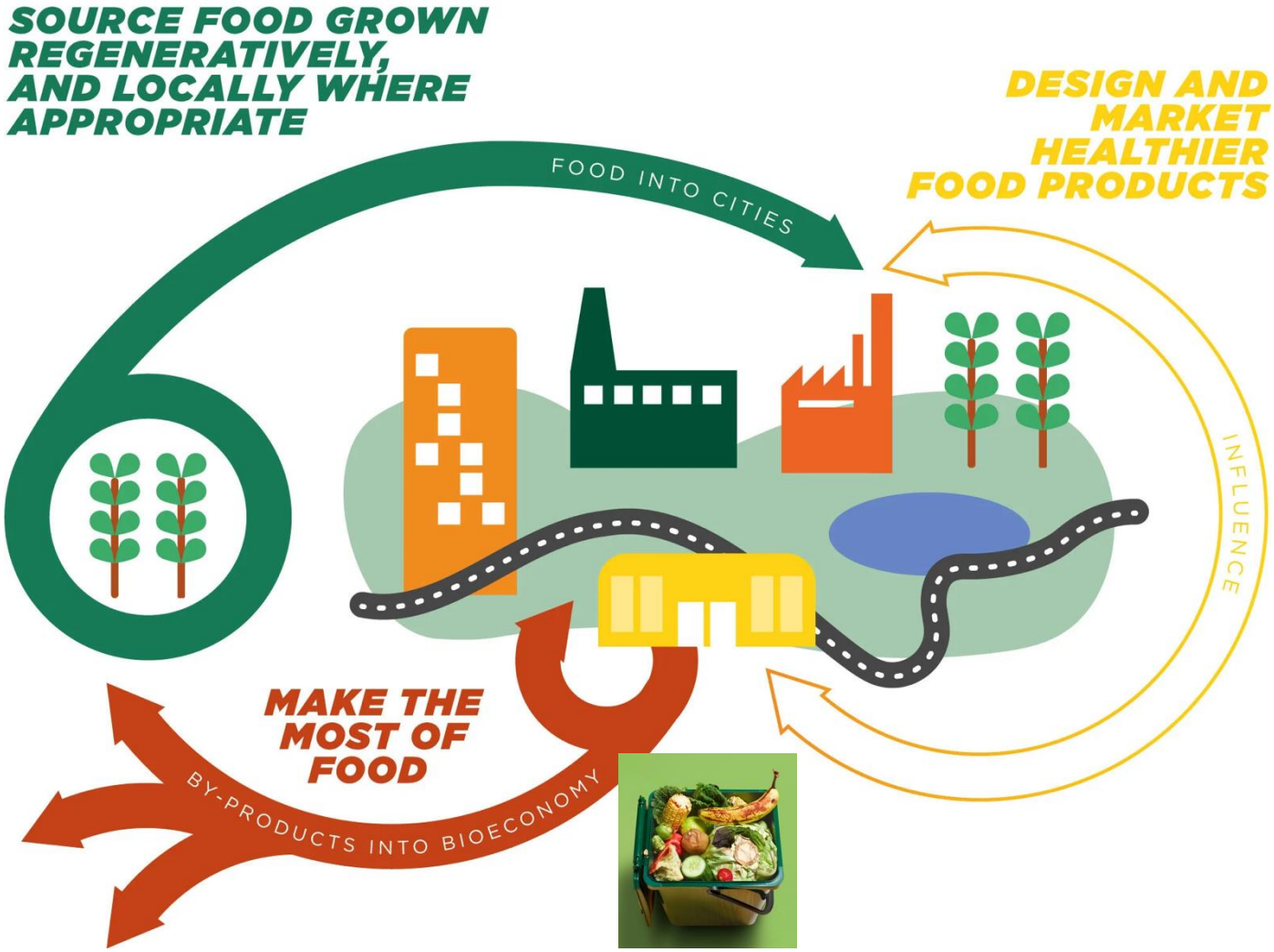
A few minutes to 1 hour

Photo credit: Ingrid Birker, from: Trees of McGill, Black Walnut *Juglans nigra*

What would be a good source of biomass?

1/3 of the annual 1.3 Bt of food produced globally is wasted

- great source of biomass
- circularity
- Avoiding emissions



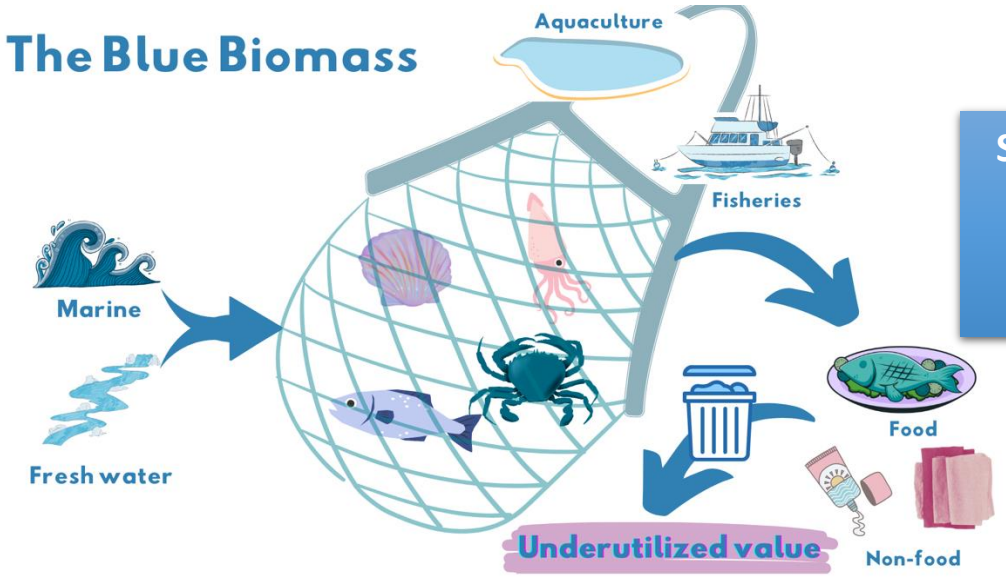
ELLEN MACARTHUR FOUNDATION

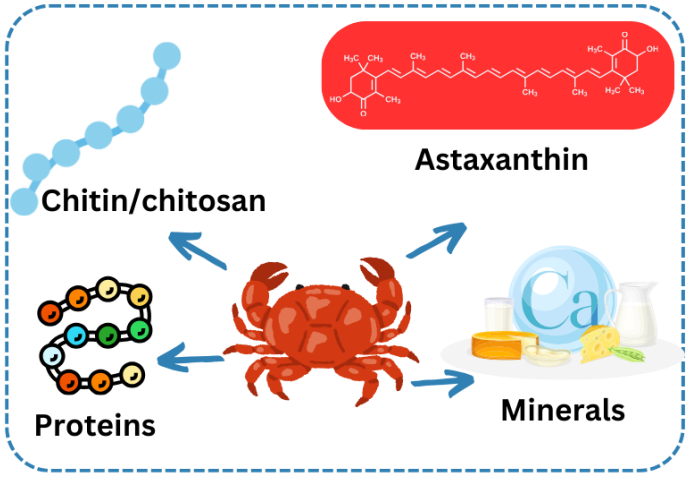
The circular economy is based on three principles, driven by design:

- Eliminate waste and pollution
- Circulate products and materials (at their highest value)
- Regenerate nature

The Food and Agriculture Organisation of the United Nations, 2011 - https://www.ellenmacarthurfoundation.org/food-and-the-circular-economy-deep-dive

Side streams







Some 6 million to 8 million tonnes of waste crab, shrimp and lobster shells produced /yr

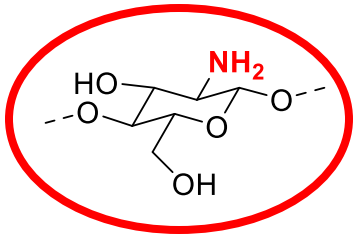


In Quebec alone, 40,000 tonnes of waste crab, shrimp and lobster waste produced /yr

Nutraceutics



Chitosan



Water treatment



Biomedical



Fertilizer



Fibers



G. Yang, I. Kaur, J. Sauvé-St-Pierre, H. Gaminian, A. Moores, Encyclopedia of Green Chemistry, vol.4 p.184-208. Pub. Elsevier

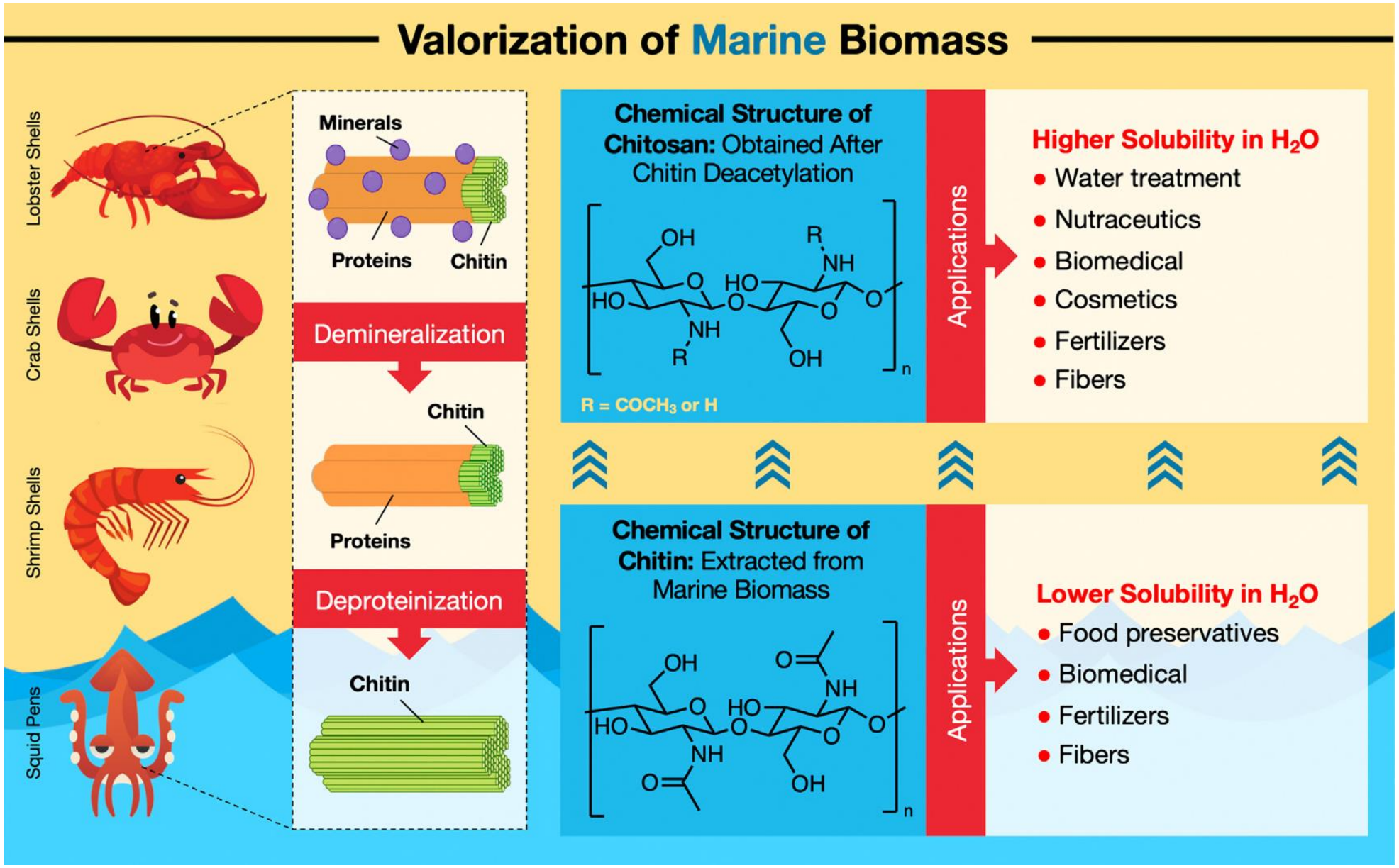
McGill UNIVERSITY

"Blue is the New Green"



Juliana Vidal

Valorization of Marine Biomass



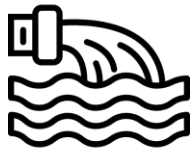




Corrosive and viscous liquid (NaOH)



140°C



Difficult to handle aqueous effluents

J. L. Vidal, **T. Jin**, E. Lam, F. Kerton, A. Moores,, *Curr. Res. Green Sustainable Chem*. **2022**, 100330.

Mechanochemistry addressing problems

IUPAC Gold Book

Mechano-chemical reaction

Online use...

https://doi.org/10.1351/goldbook.MT07141 Copy

Chemical reaction that is induced by the direct absorption of mechanical energy.

Note: Shearing, stretching, and grinding are typical methods for the mechano-chemical generation of reactive sites, usually macroradicals, in polymer chains that undergo mechano-chemical reactions.

Source:

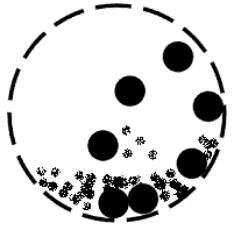
PAC, 2004, *76*, 889. (*Definitions of terms relating to reactions of polymers and to functional polymeric materials (IUPAC Recommendations 2003)*) on page 893 [Terms] [Paper]

Citation: 'Mechano-chemical reaction' in *IUPAC Compendium of Chemical Terminology*, 5th ed. International Union of Pure and Applied Chemistry; 2025. Online version 5.0.0, 2025. https://doi.org/10.1351/goldbook.MT07141 RIS BibTex EndNote

Div. IV PDF Text XML JSON



Mortar pestle



Planetary mill



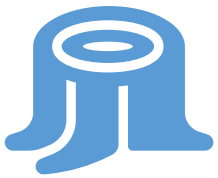
Vibrational mill



Aging

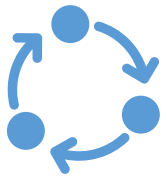


Working with recalcitrant substrates



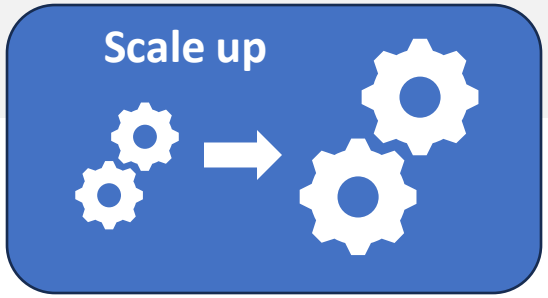


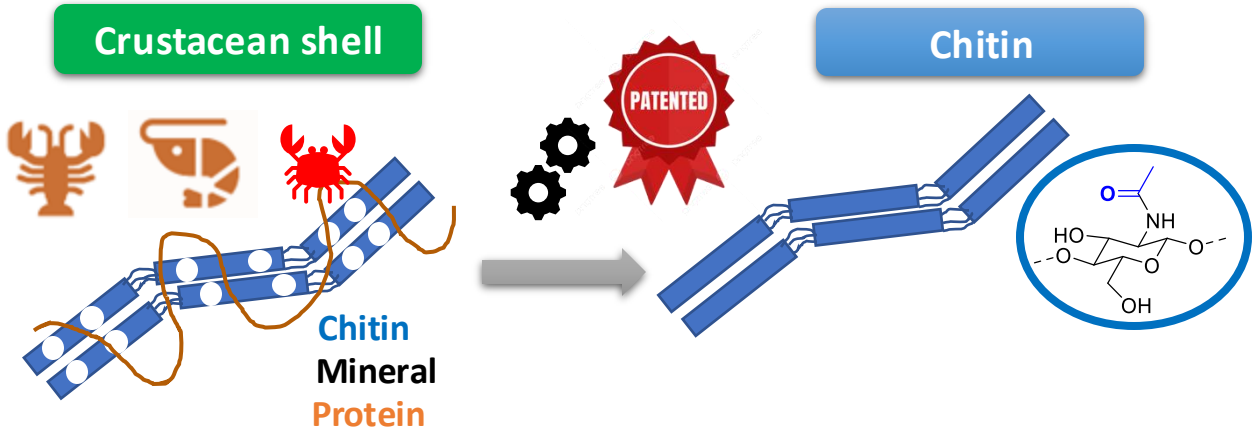
Reducing solvent use

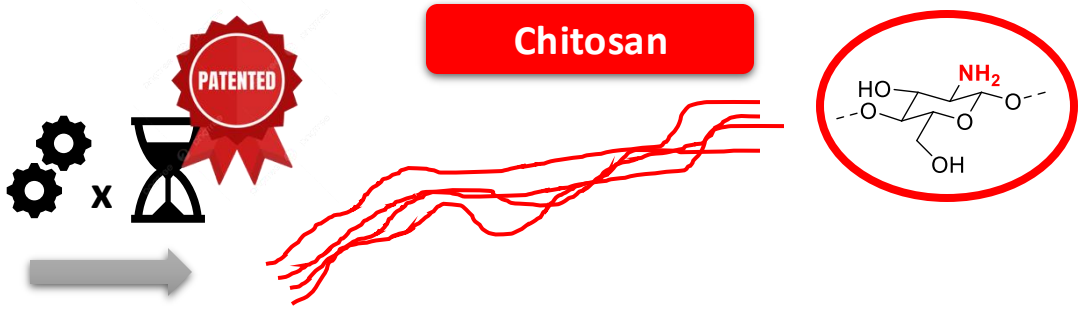


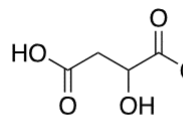
Taking advantage better conditions for the chemistry

Chitin and Chitosan



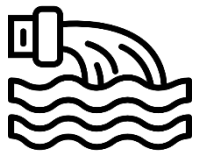




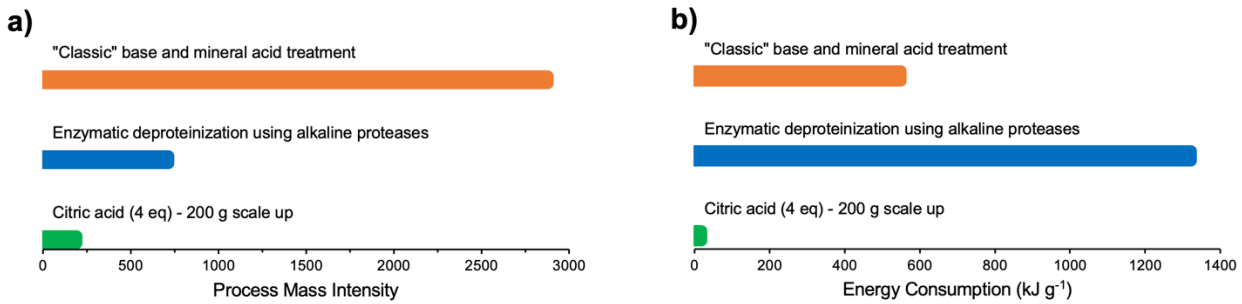


L-malic acid

16% mass efficiency
1.6% ash



NaOH



Quantity of water
> 8 times less

Quantity of chemicals
> 8 times less



Energy use
> 7 times less



Operator safety
No use of viscous hot toxic liquid

T. Di Nardo, C. Hadad, A. Nguyen Van Nhien, A. Moores, *Green Chem.* **2019**, *21*, 3276-3285
Hajiali, F.; Vidal, J.L, Jin, T.; Carlos de la Garza, L.; Yang, G.; Santos, M.; Moores, A. *ACS Sustainable Chem. Eng.* **2022**, 10, 34, 11348–11357

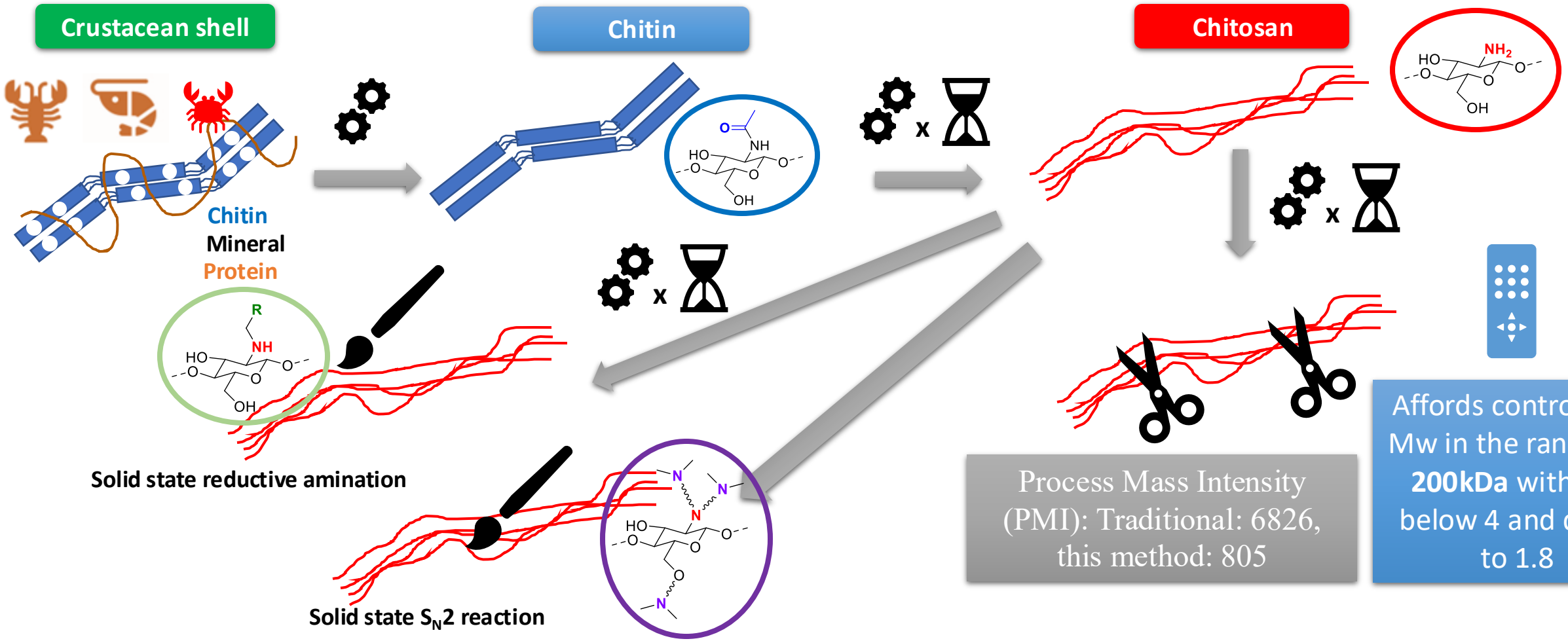
Galen Yang





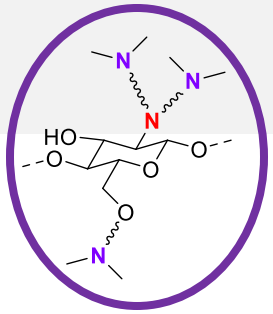
Edmond Lam (NRC)

Chitin and Chitosan



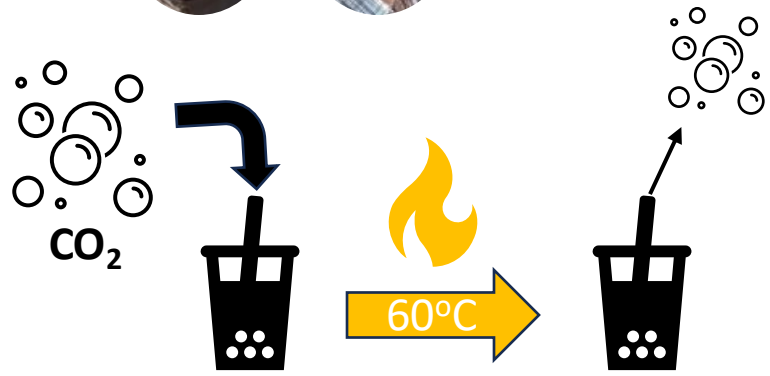
G. Yang, S. Regnier, N. Huin,T. Liu, E. Lam, A. Moores, *Green Chem.*, **2024,** *26*, 5386
G. Yang, R.S. Korchinsky, J. Sauvé-St-Pierre, P.G. Jessop, E. Lam, A. Moores *ChemSusChem.* **2025,** *18 (19)*, e202501187
G. Yang, Lam, E.; Moores, A. *ACS Sustainable Chem. Eng.* **2023**, *11*(20), 7765

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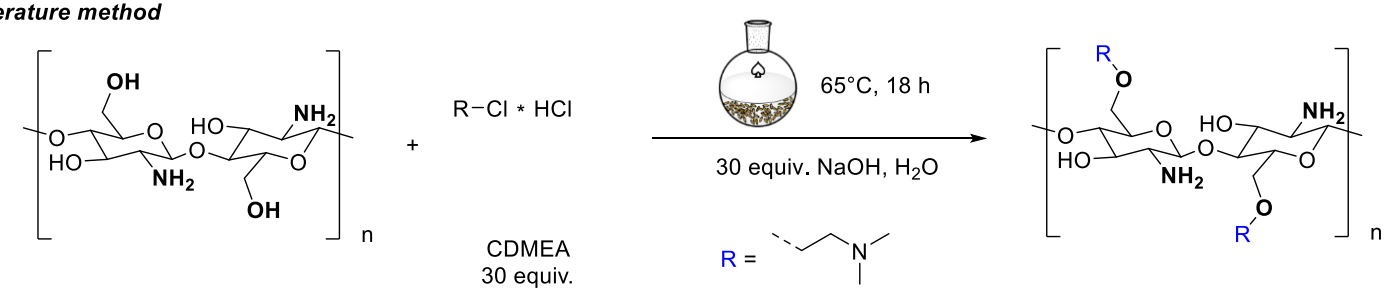


Galen Yang   Phil Jessop

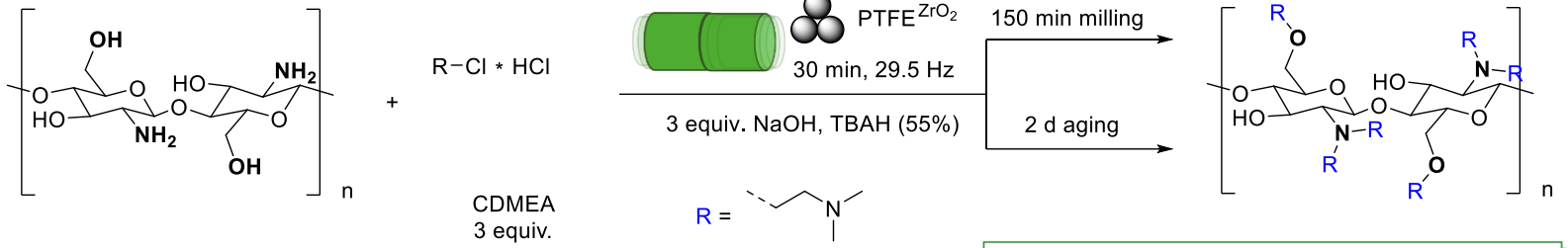
Mechanochemical S_N2



(a) literature method

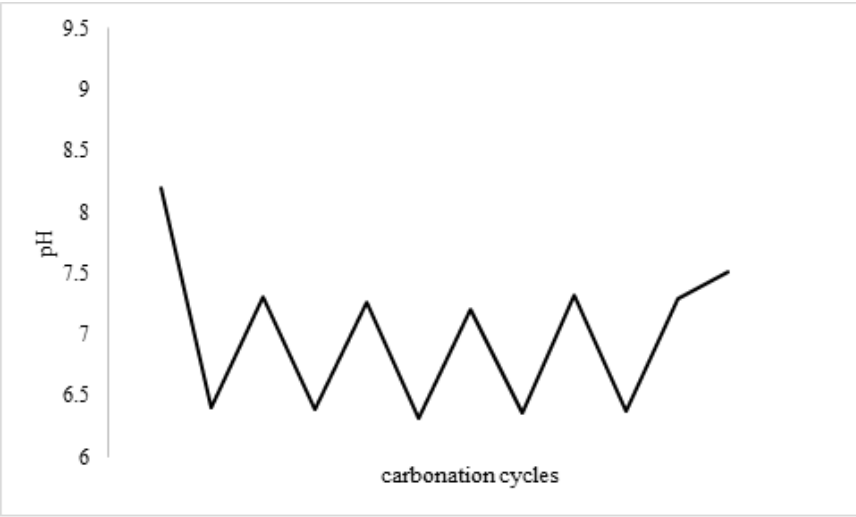


(b) this work

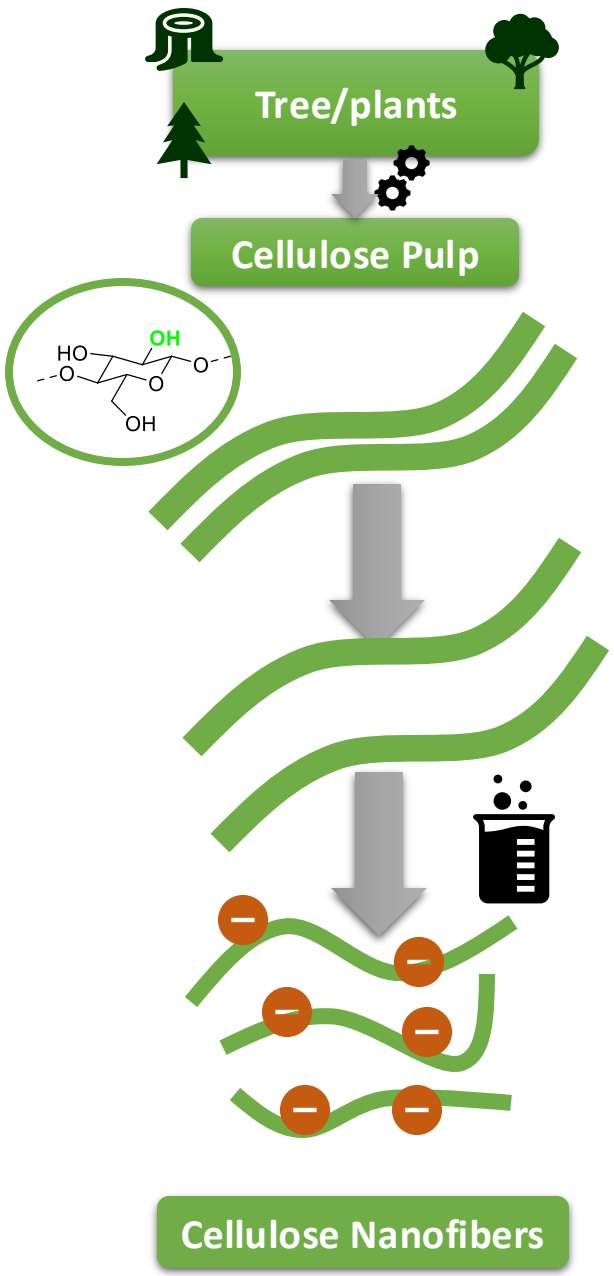


Ten-fold reduction in chemical use
High DS
First example of both amine and alochol functionalization
Low solvent use

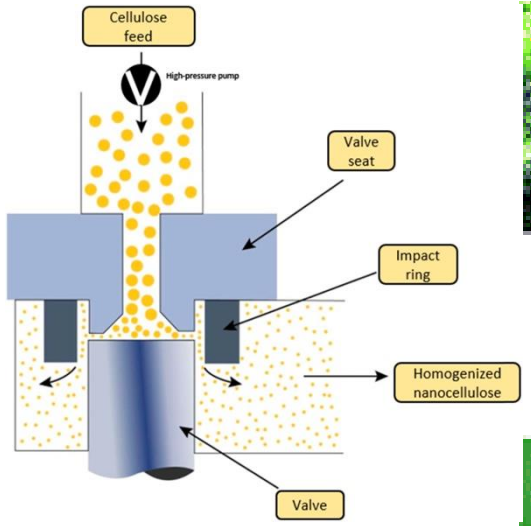
Max DS: 1.67

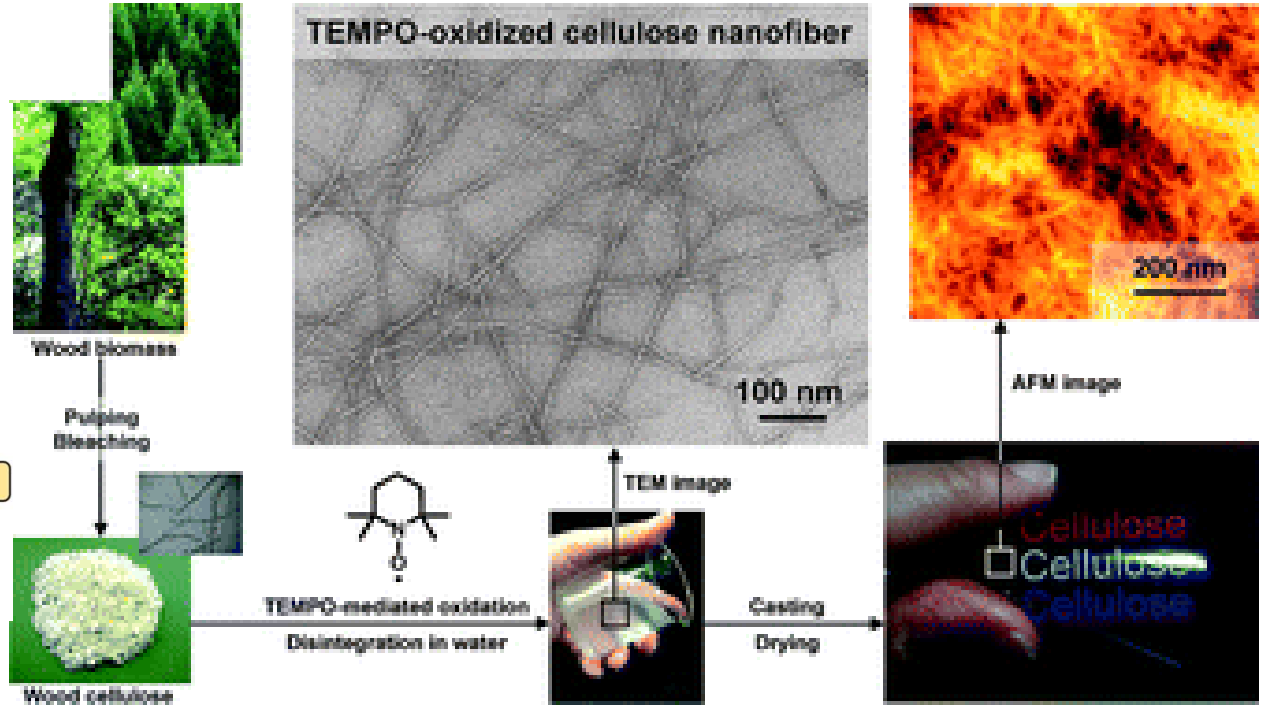


G. Yang, R.S. Korchinsky, J. Sauvé-St-Pierre, P.G. Jessop, E. Lam, A. Moores *ChemSusChem.* **2025,** *18 (19)*, e202501187



High energy defibrillation 1000 bar of pressure





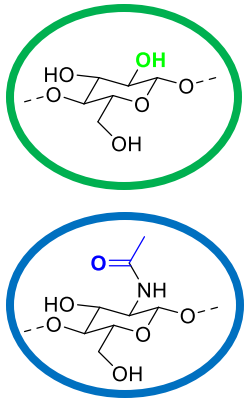


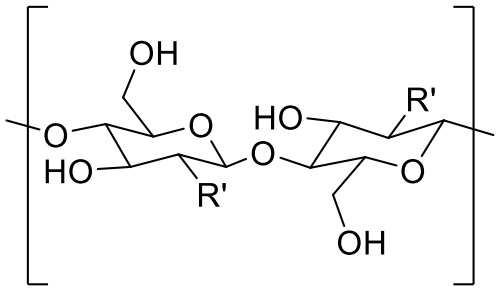
A. Isogai, T. Saito, H. Fukuzumia, *Nanoscale,* **2011**,*3,* 71-85
James A, Rahman MR, Mohamad Said KA, et al *J. Thermoplastic Comp. Mater.*. **2023**;37(6):2149-2199.

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Galen Yang   Tsuguyuki Saito

Mechanochemical S_N2





R' = OH
or $NHCOCH_3$

n

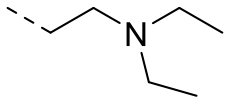
\+ R−Cl * HCl

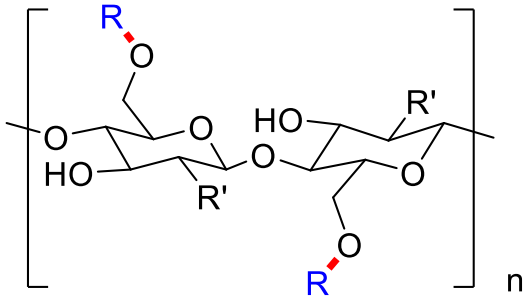
CDEEA
1.0 equiv.

1.  PTFE ZrO_2
10 min, 29.5 Hz

2. 
3 h

1.0 equiv. NaOH
100 µL TBAH (55 wt%, 0.16 equiv)

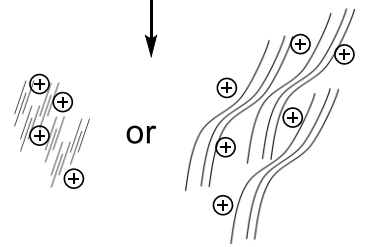
R = 



n

DEEA-polysaccharides

ultrasonication
5 min



or

DEEA-polysaccharides^{UT}



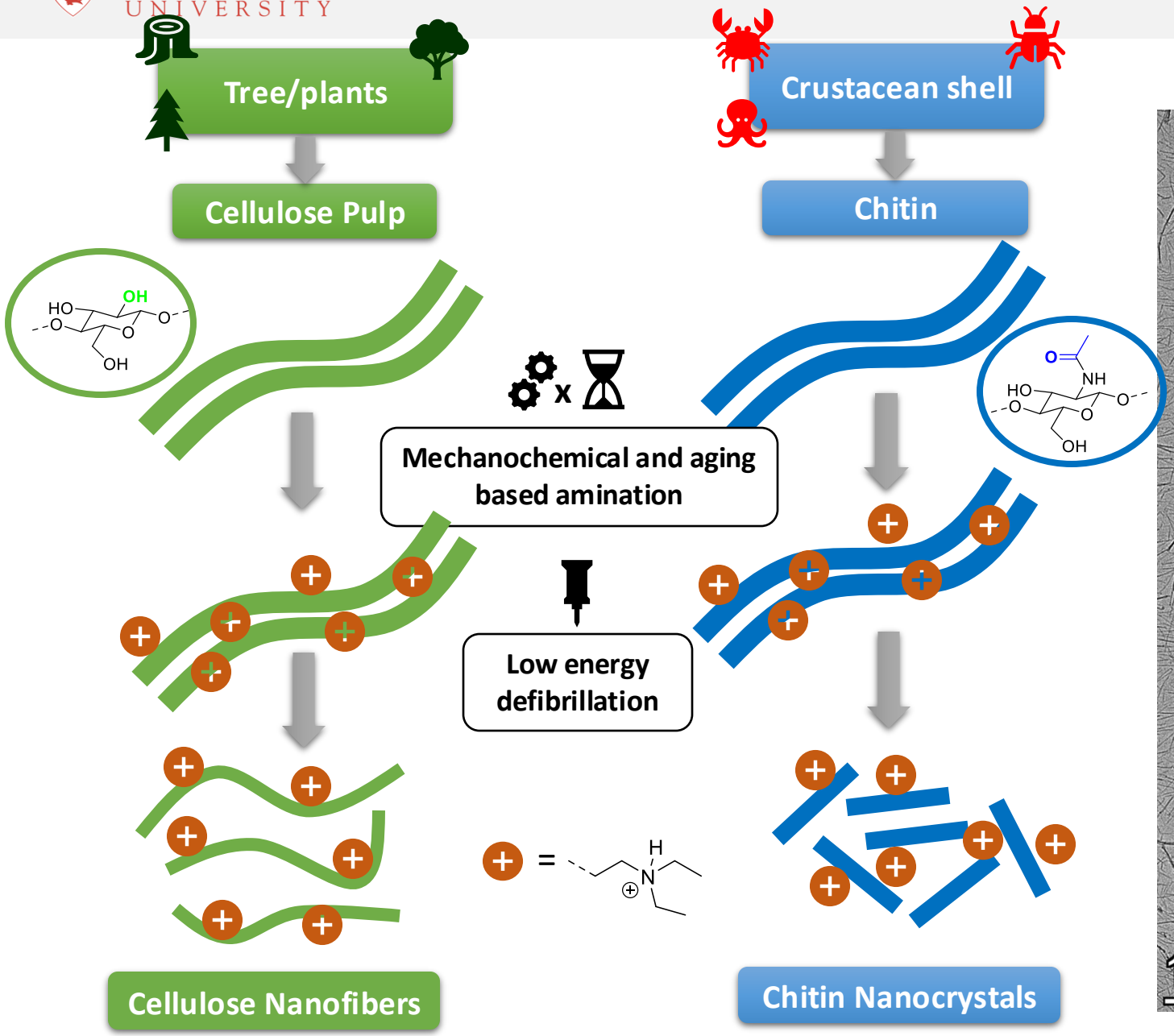
Wood pulp

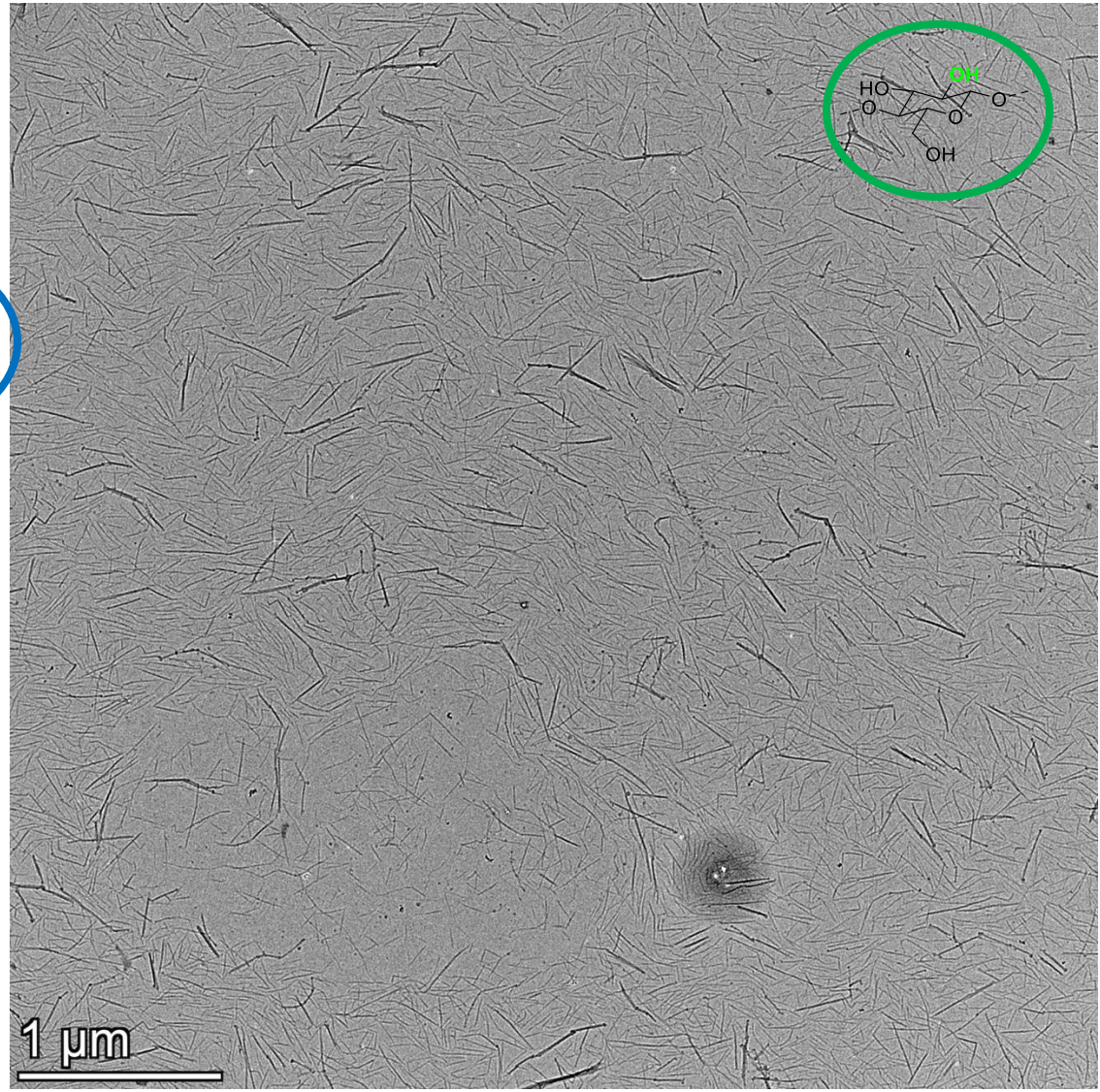


G. Yang, Y. Tomita, A. Richard, S. Fujisawa, E. Lam, T. Saito, A. Moores *Nanoscale Horizon* **2025** 10.1039/D5NH00597C

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G. Yang, Y. Tomita, A. Richard, S. Fujisawa, E. Lam, T. Saito, A. Moores *Nanoscale Horizon* **2025** 10.1039/D5NH00597C

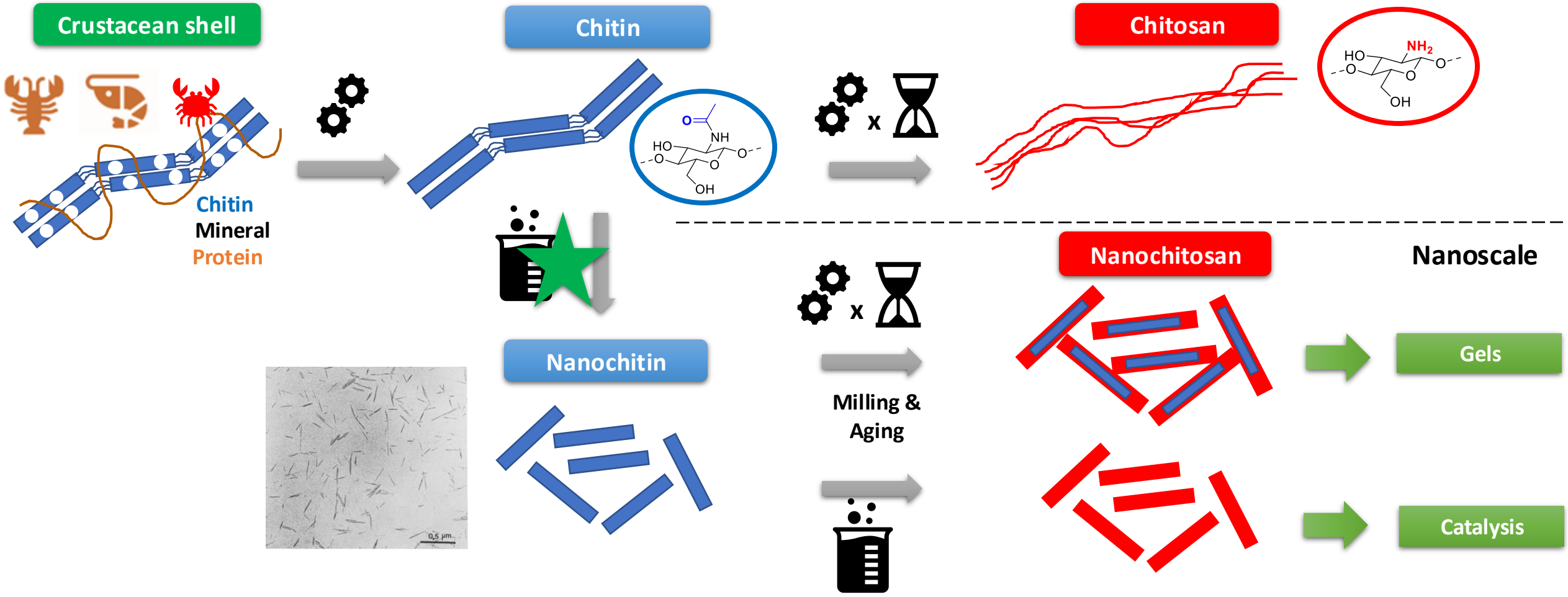
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Tony Jin

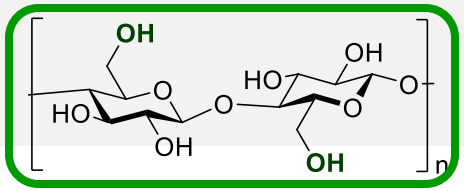


Edmond Lam (NRC)

Chitin and Chitosan in the Nanoscale



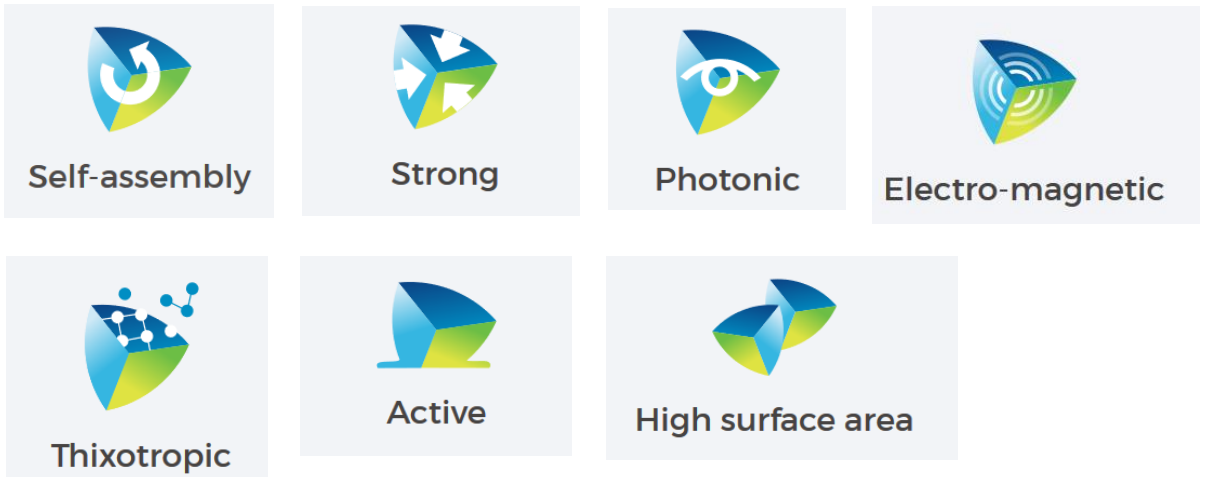
Jin, T.; Liu, T.; Lam, E.; Moores, A. *Nanoscale Horiz.* **2021**, *6,* 505 - 542

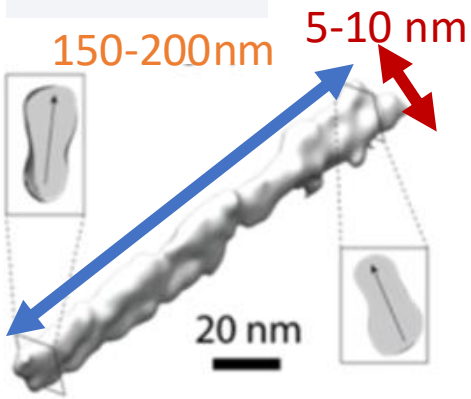


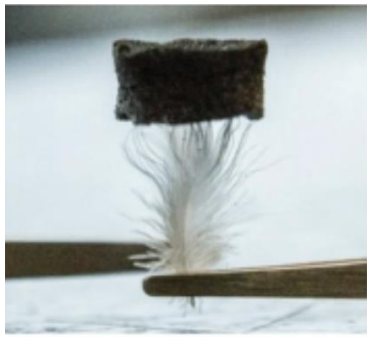
cellulose

Cellulose nanocrystallites

- Renewable, biodegradable and non-toxic

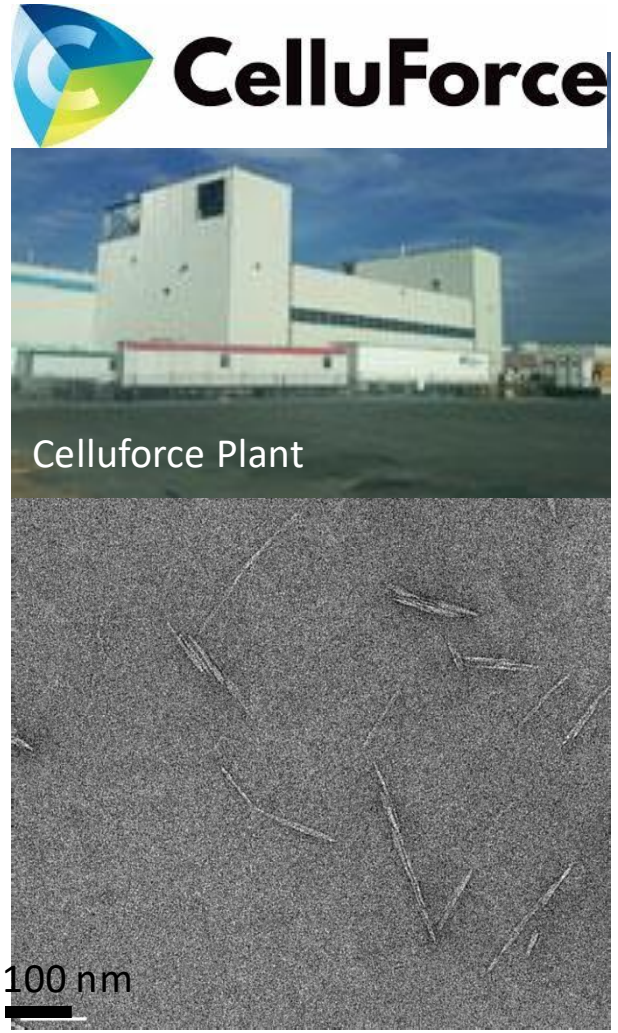




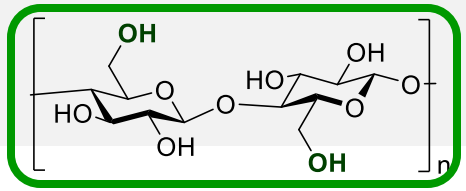


Cranston, *Adv. Mater.* 2015, *27*

Klemm *et. al.*, *Angew. Chem. Int. Ed.*, 2011, *50*, 5438
Ikkala and coll., *J. Am. Chem. Soc.*, 2014, *136*, 866

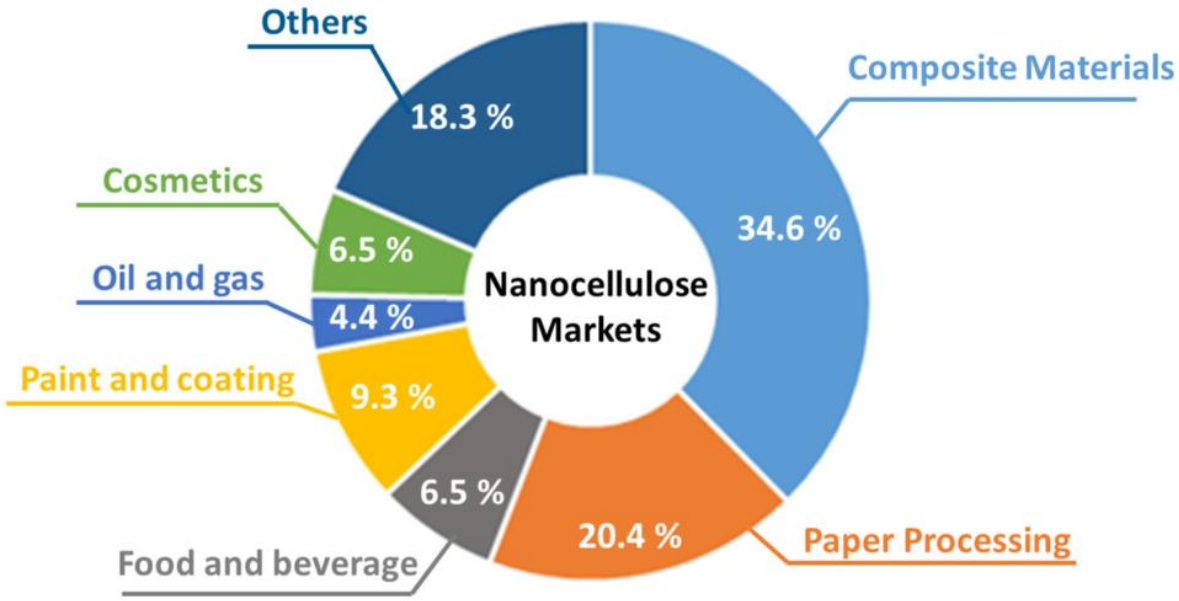


Cellulose Nanocrystals

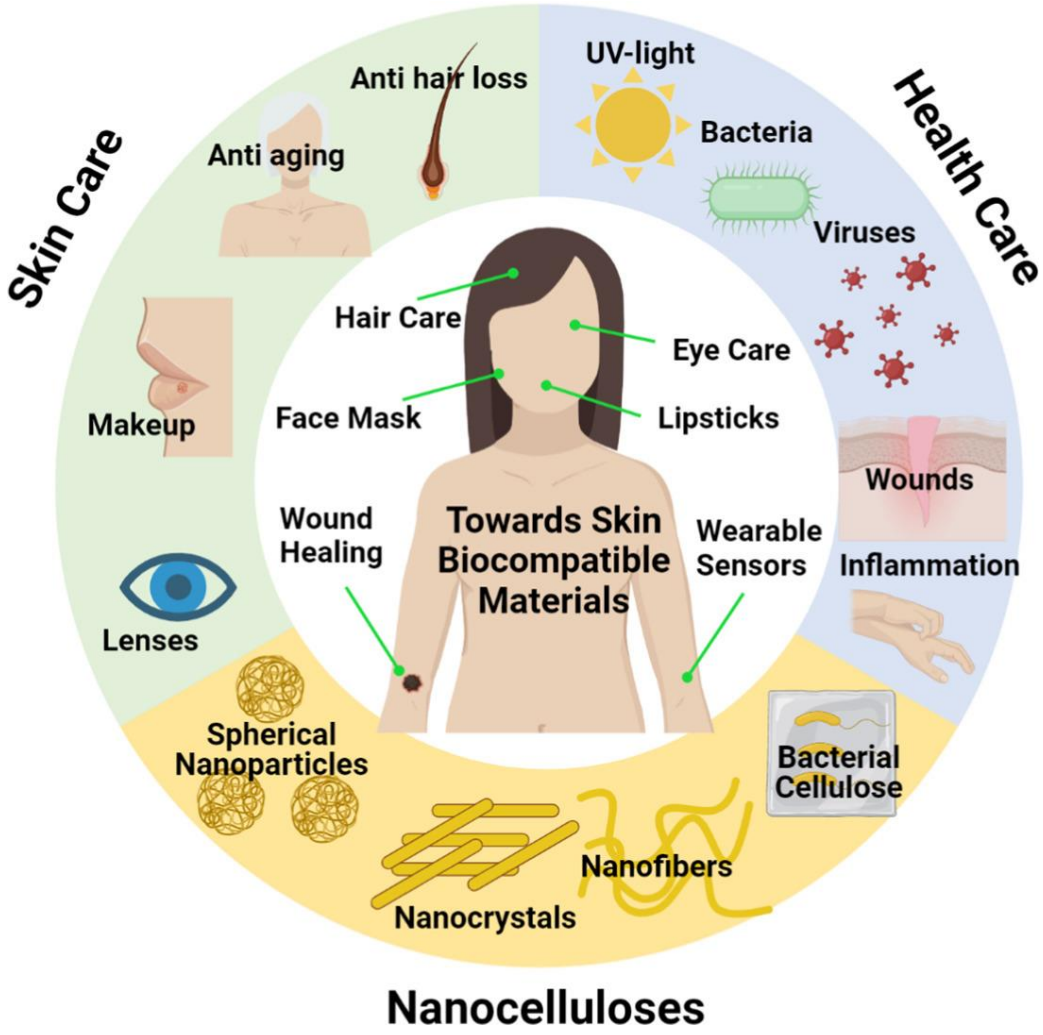


cellulose

An important component for skin care



Market share of the nanocellulose industry



Meftahi, A., Samyn, P., Geravand, S. A., Khajavi, R., Alibkhshi, S., Bechelany, M., Barhoum, A. (2022). *Carbohydrate Polym.*, *278*.

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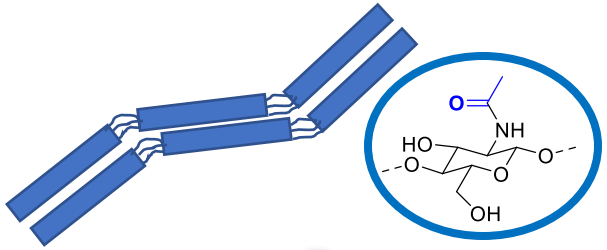
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Chitin and Chitosan in the Nanoscale

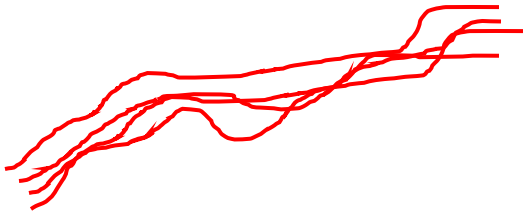
Crustacean shell

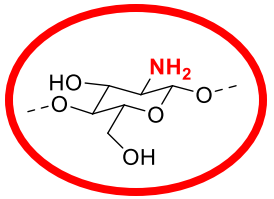


Chitin



Chitosan



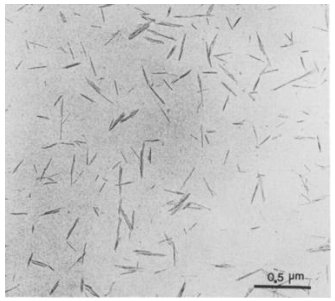


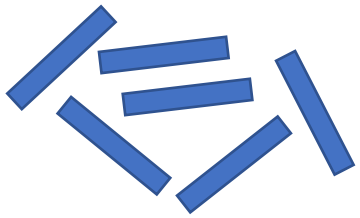
x

Shaker Aging

x

Nanochitin



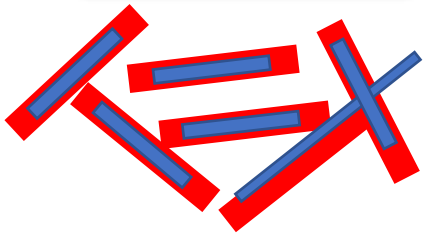


x

Milling & Aging

Nanochitosan

Nanoscale



Gels

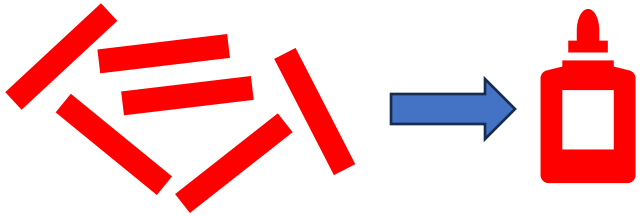


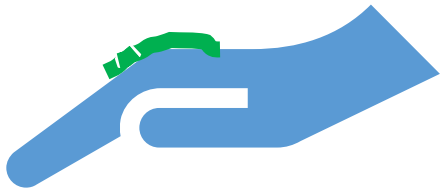
Wound healing

McGill UNIVERSITY

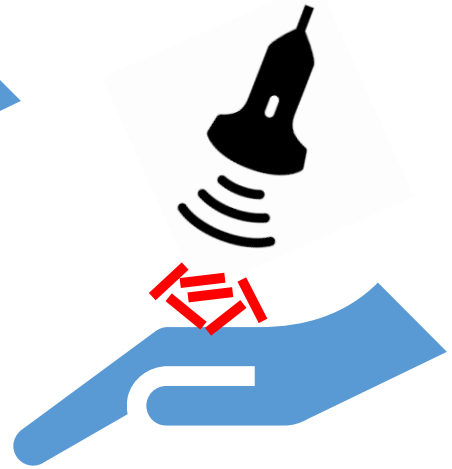
Tony Jin   Shuaibing Jiang

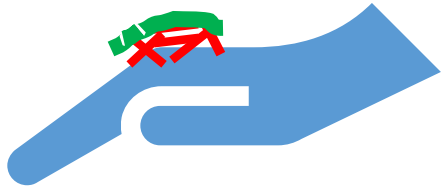
Chitosan nanowhiskers breaking records in nanoadhesion

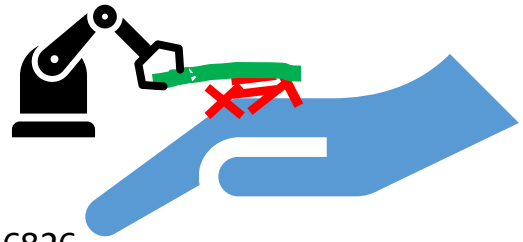


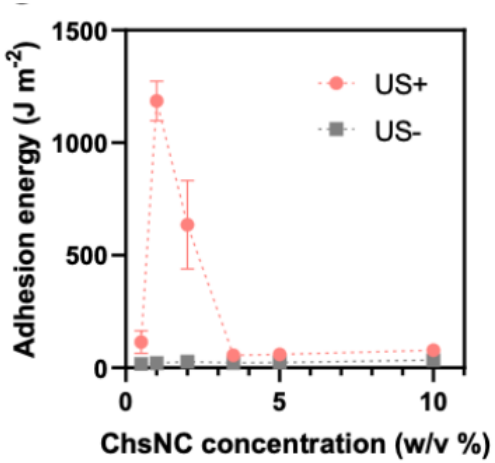


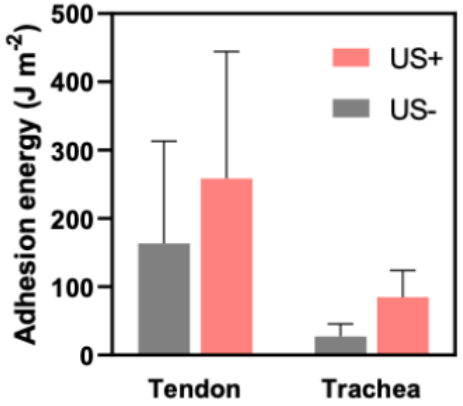












S. Jiang, T. Jin, Z. Ma, R. Huo, Z. Yang, Y. Cheng, T. Ning, G. Bao, D. Kurdyla, E. Lam, A. Moores , J. Li, *Nature Comm.* **2025**, *16*, 6826

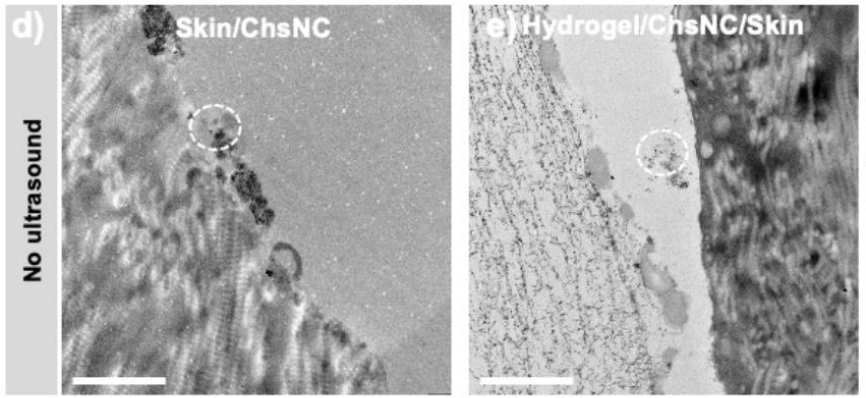
McGill UNIVERSITY

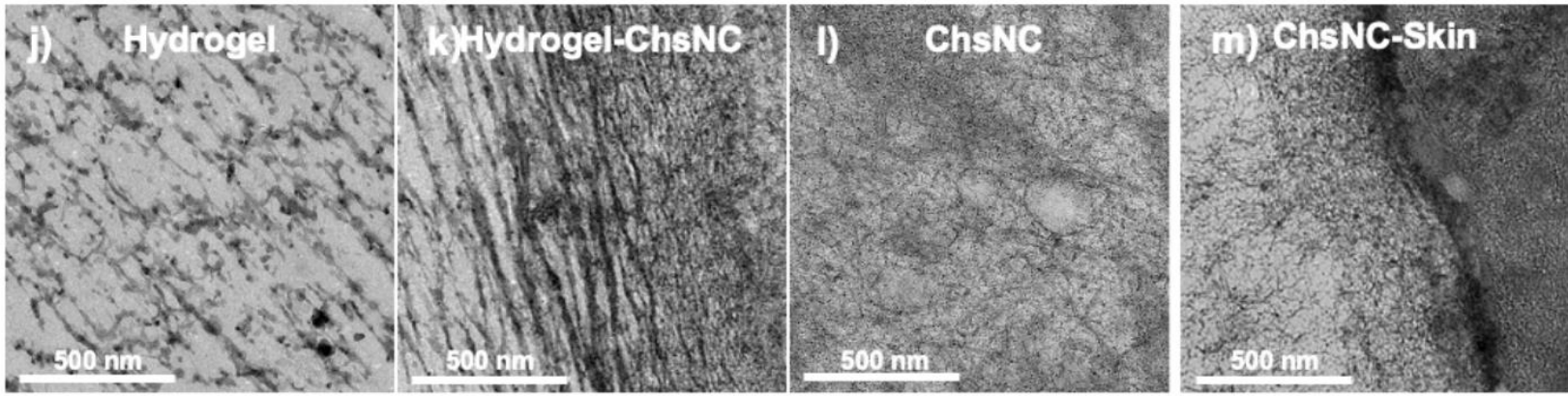
Tony Jin



Shuaibing Jiang

Chitosan nanowhiskers breaking records in nanoadhesion







S. Jiang, T. Jin, Z. Ma, R. Huo, Z. Yang, Y. Cheng, T. Ning, G. Bao, D. Kurdyla, E. Lam, A. Moores , J. Li, *Nature Comm.* **2025**, *16*, 6826

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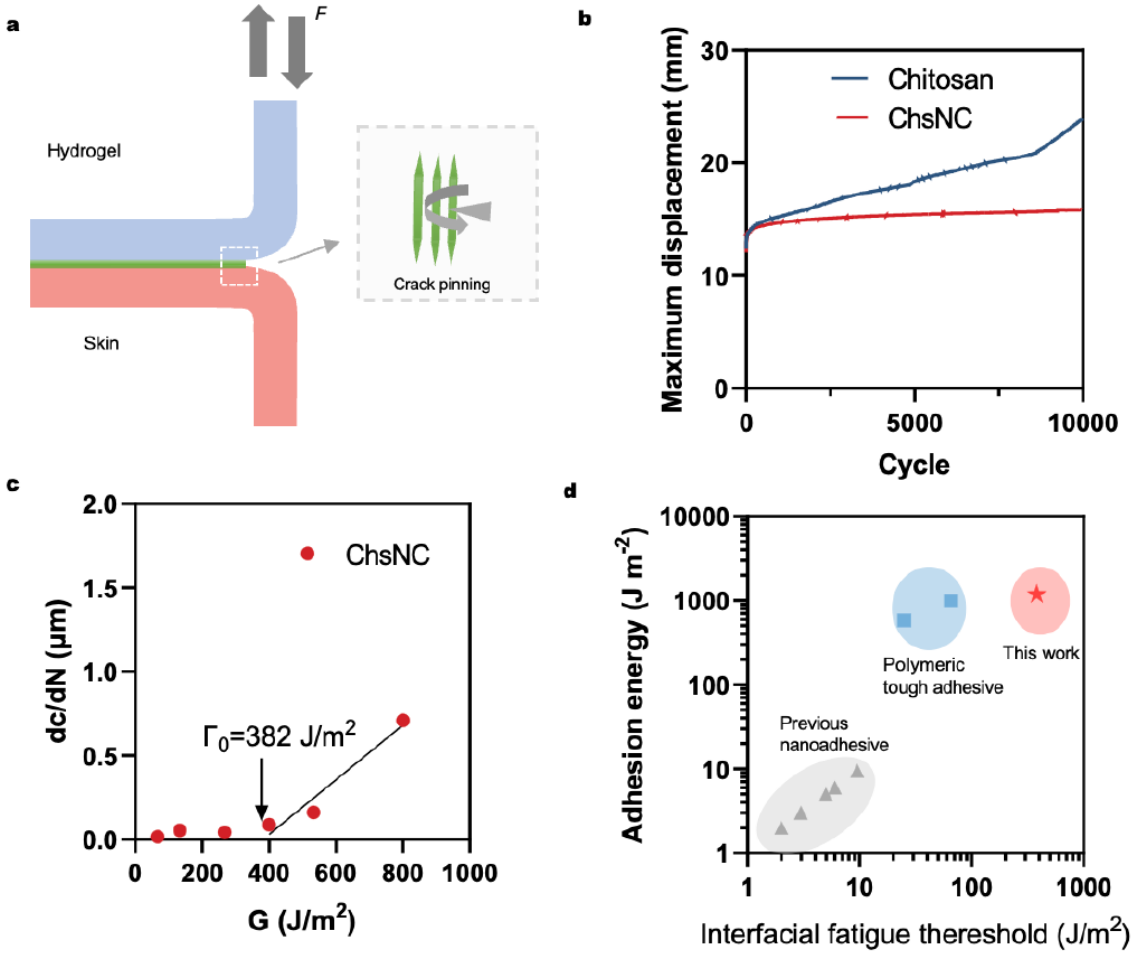
Tony Jin



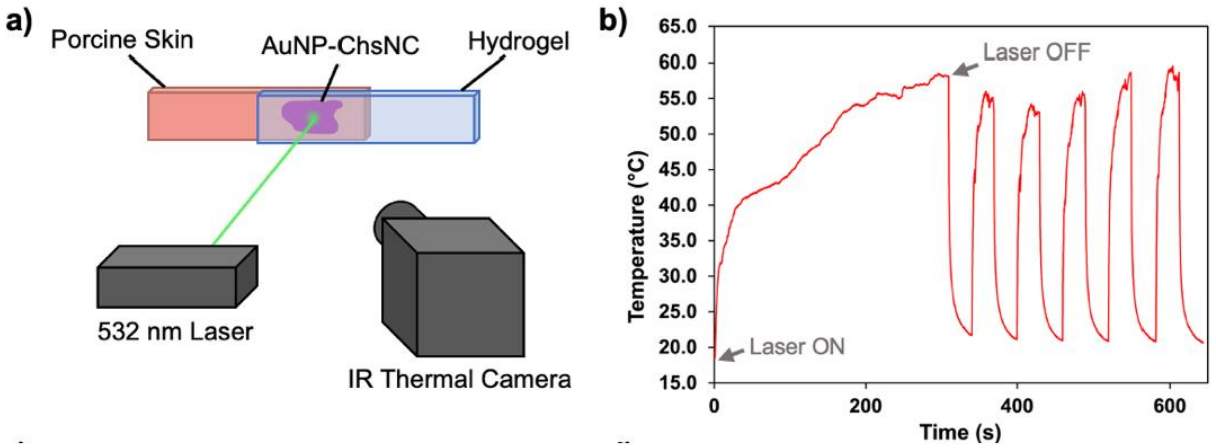
Shuaibing Jiang

Chitosan nanowhiskers breaking records in nanoadhesion

Fatigue resistance



Photothermal therapy



S. Jiang, T. Jin, Z. Ma, R. Huo, Z. Yang, Y. Cheng, T. Ning, G. Bao, D. Kurdyla, E. Lam, A. Moores , J. Li, *Nature Comm.* **2025**, *16*, 6826

Completing the chitin/osan mechano-map

Crustacean shell

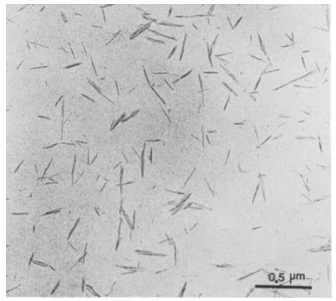
Chitin
Mineral
Protein

Chitin

Chitosan

Shaker
Aging

Nanochitin

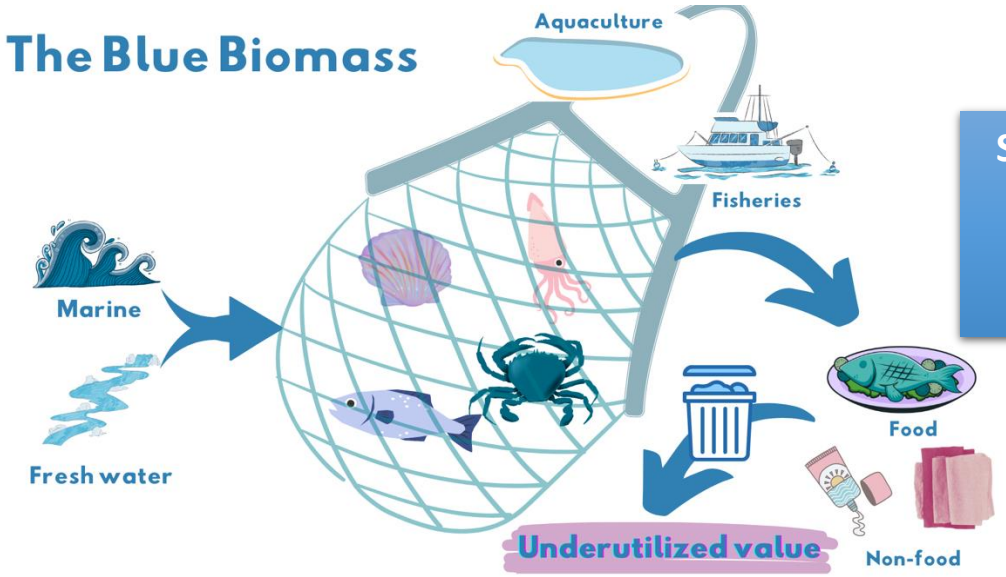


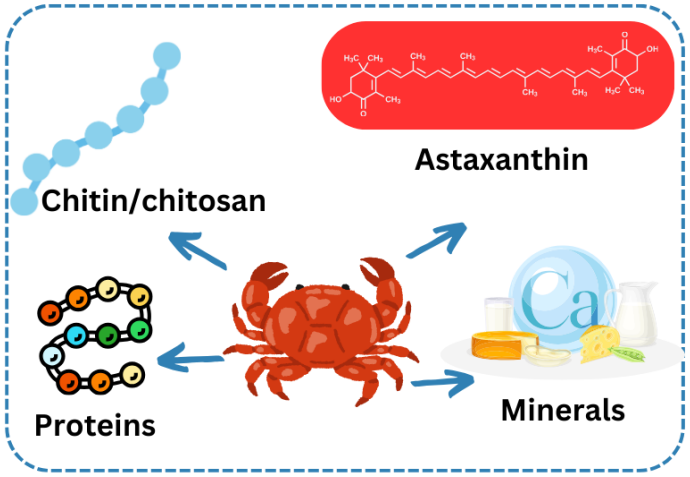
Milling &
Aging

Nanochitosan

Advantages:
- High yields
- Lower the chemical input
- Lower waste and effluents
- High quality materials
- Working on scale up

Side streams







Some 6 million to 8 million tonnes of waste crab, shrimp and lobster shells produced /yr

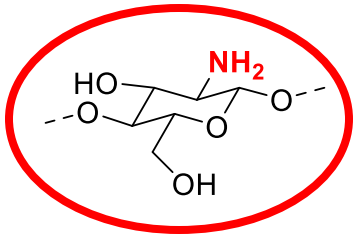


In Quebec alone, 40,000 tonnes of waste crab, shrimp and lobster waste produced /yr

Nutraceutics



Chitosan



Water treatment



Biomedical



Fertilizer



Fibers



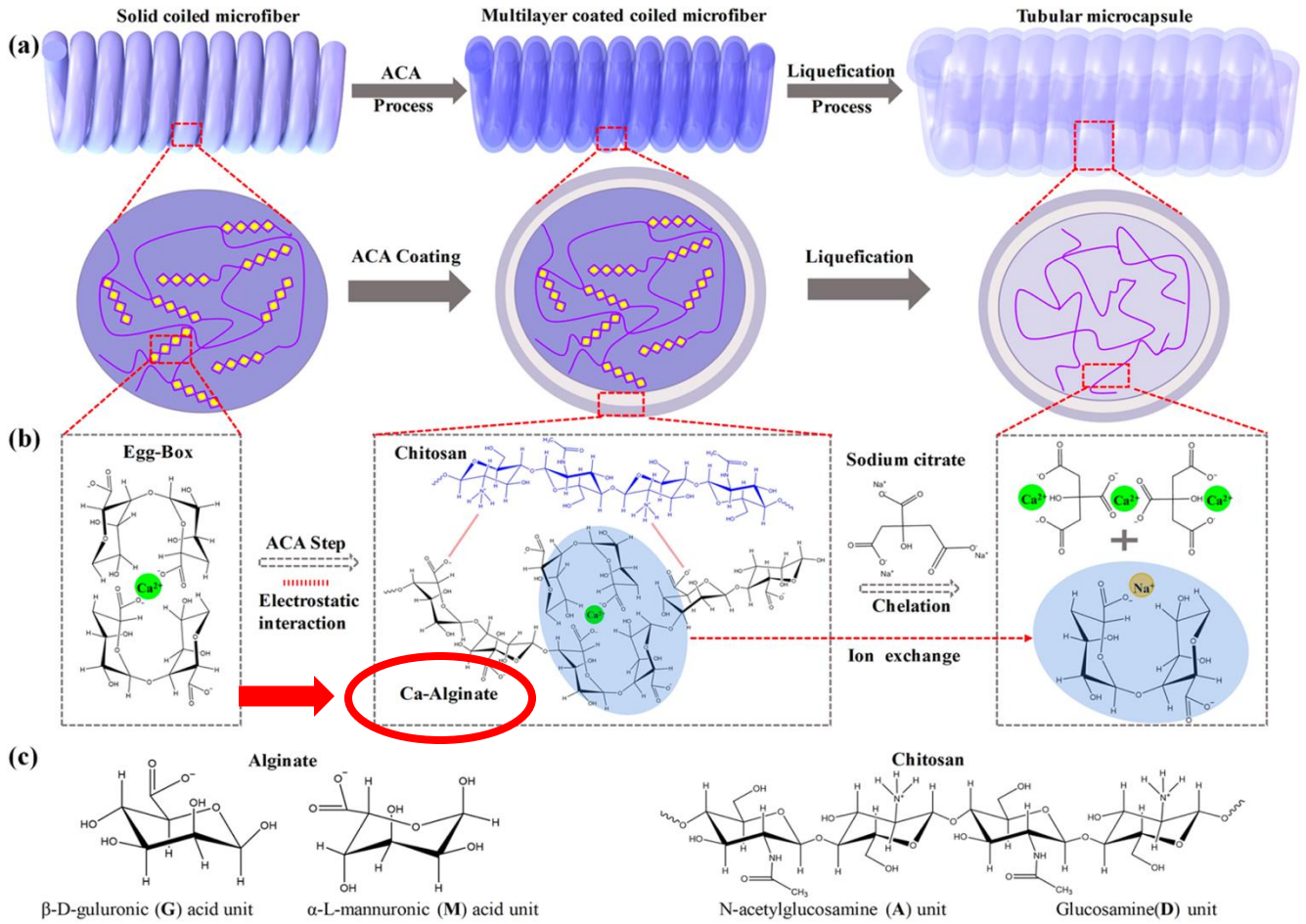
G. Yang, I. Kaur, J. Sauvé-St-Pierre, H. Gaminian, A. Moores, Encyclopedia of Green Chemistry, vol.4 p.184-208. Pub. Elsevier

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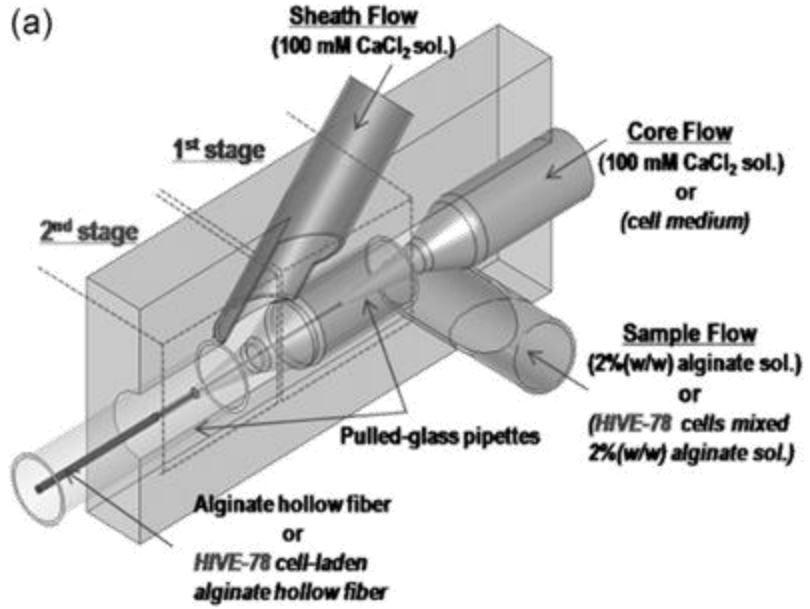
Ishneet Kaur

From nanocrystals to microfibers



Microfibers are essential for biotechnology
But they rely on alginate:
➔ Limited biocompatibility
➔ Contain cross linking agents (Ca^{2+})

Microfluidic spinning



ACS Biomaterials Science and Engineering 5, 2019, 6281−6289
Journal of Biomedical Materials Research Part B: Applied Biomaterials 107(8), 2019, 2451-2683

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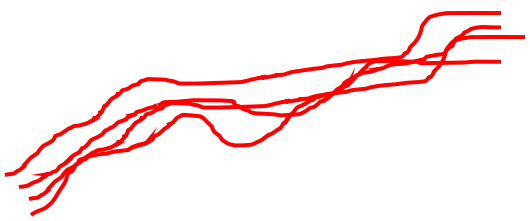


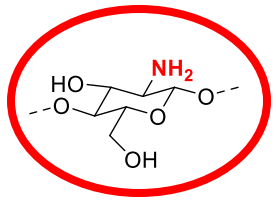
Ishneet Kaur

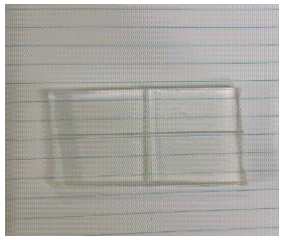
From nanocrystals to microfibers

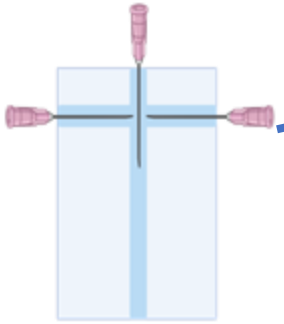
Can we spin pure chitosan with MFS?

Chitosan





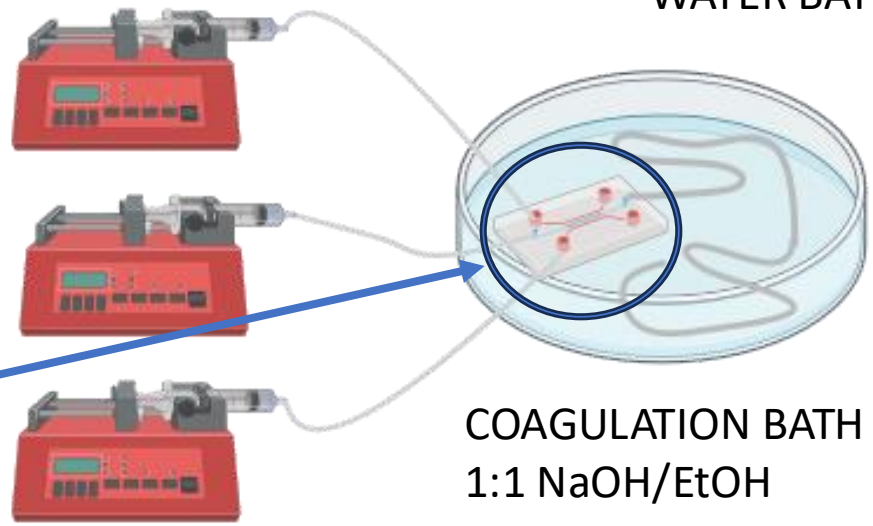




SHEATH

CORE

SHEATH



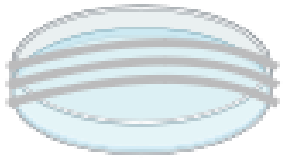
MICROFLUIDIC CHIP

COAGULATION BATH
1:1 NaOH/EtOH

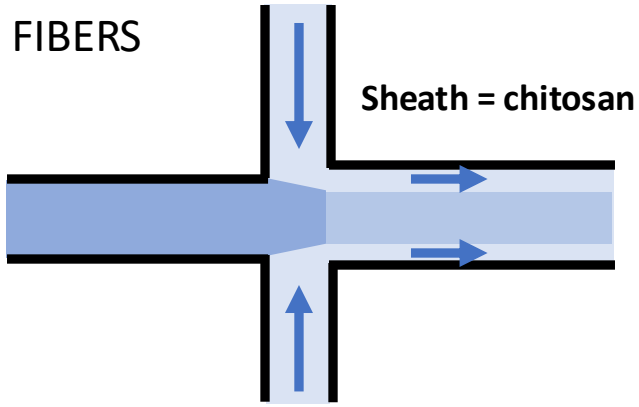


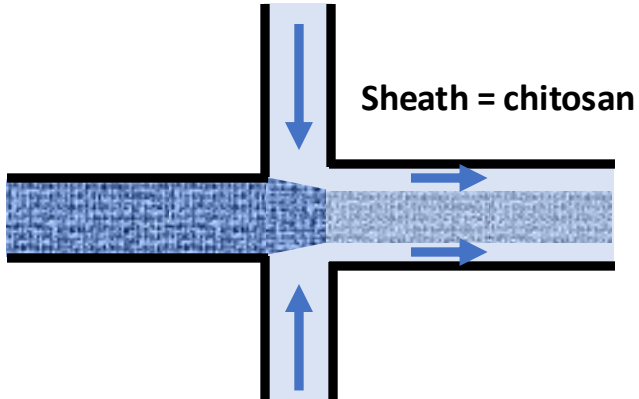
WATER BATH





DRIED FIBERS





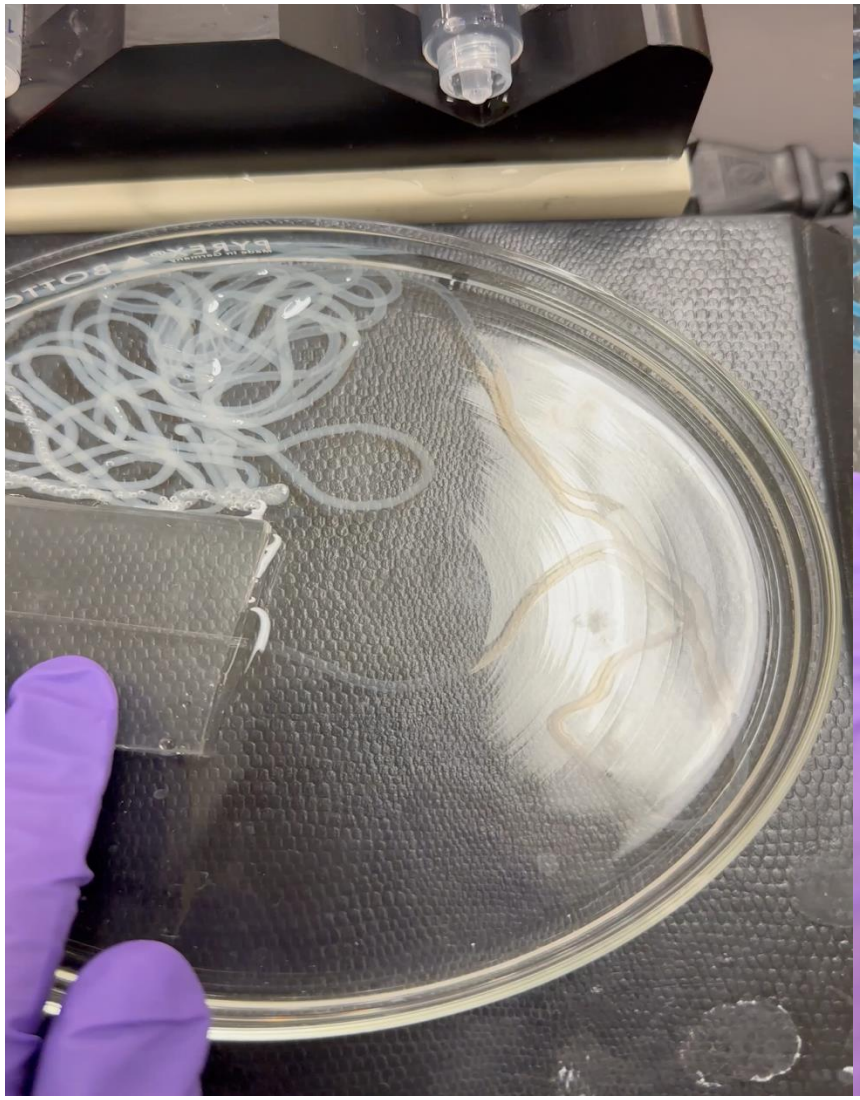
I. Kaur, A. Forigua, H. Titi, C. Moraes, A. Moores, *ChemRxiv.* 2025 10.26434/chemrxiv-2025-578z7-v2

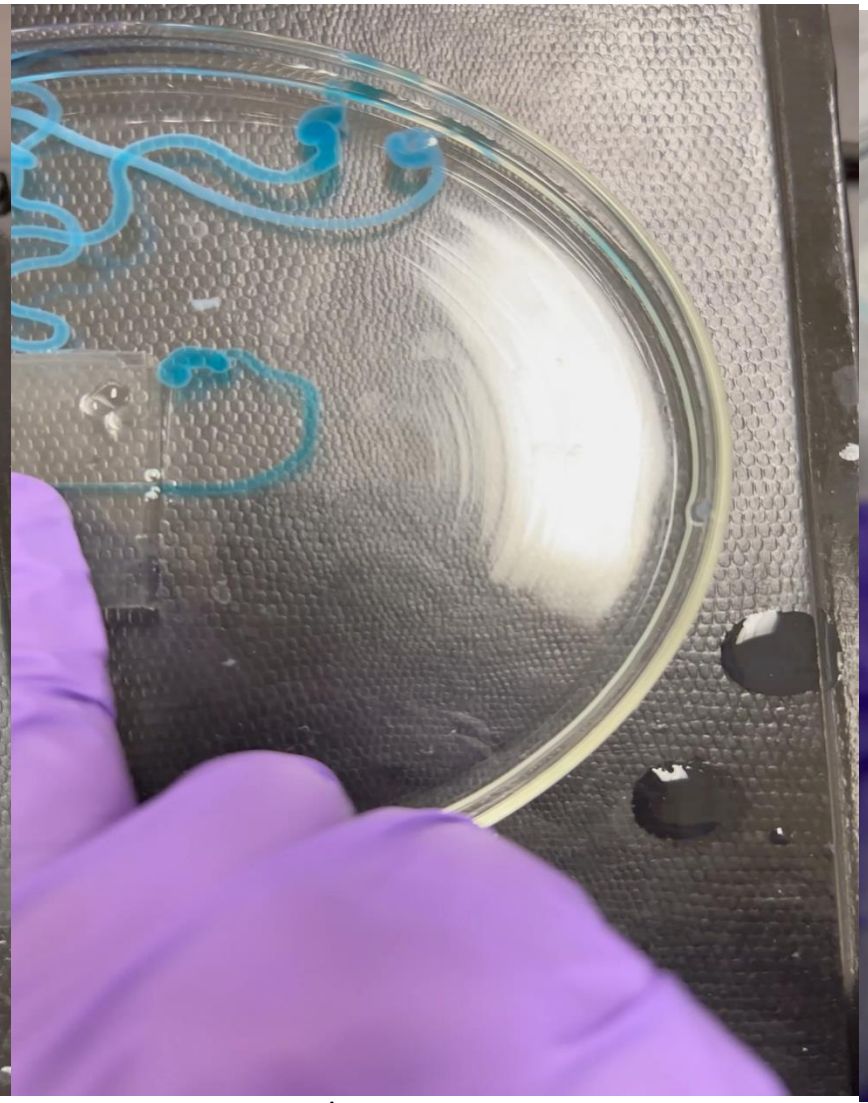
McGill UNIVERSITY

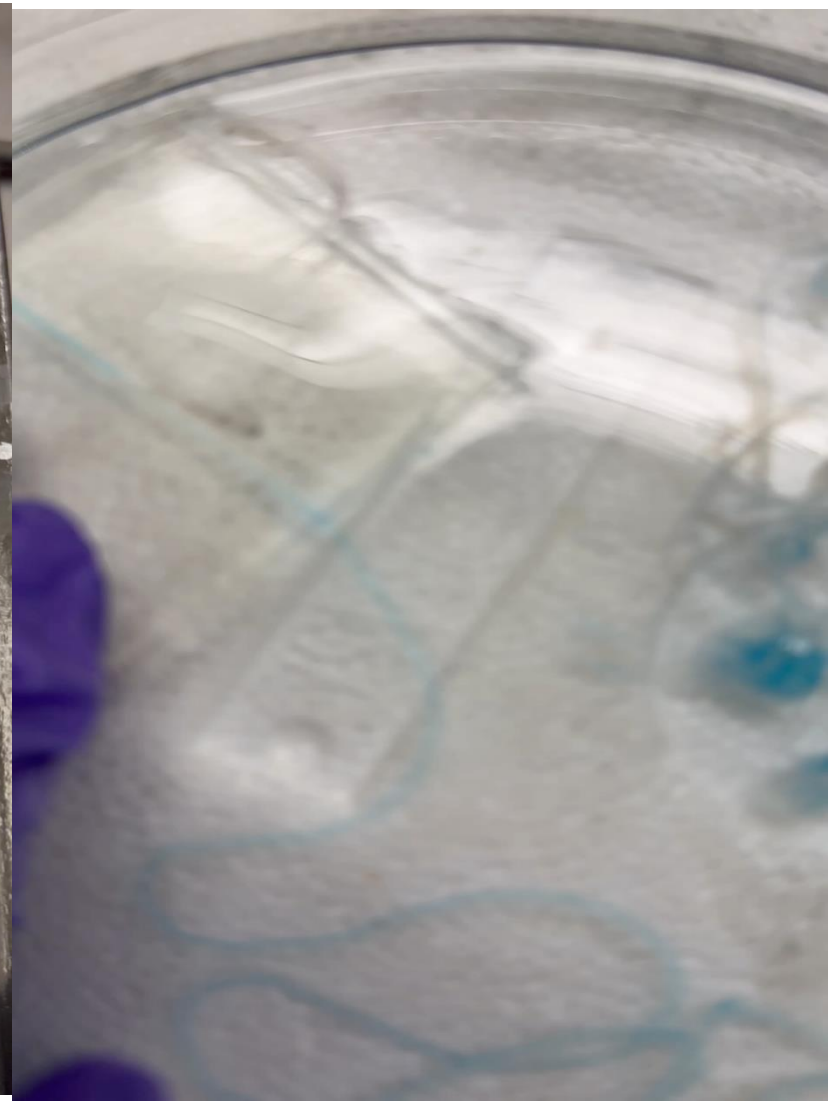


Ishneet Kaur

From nanocrystals to microfibers





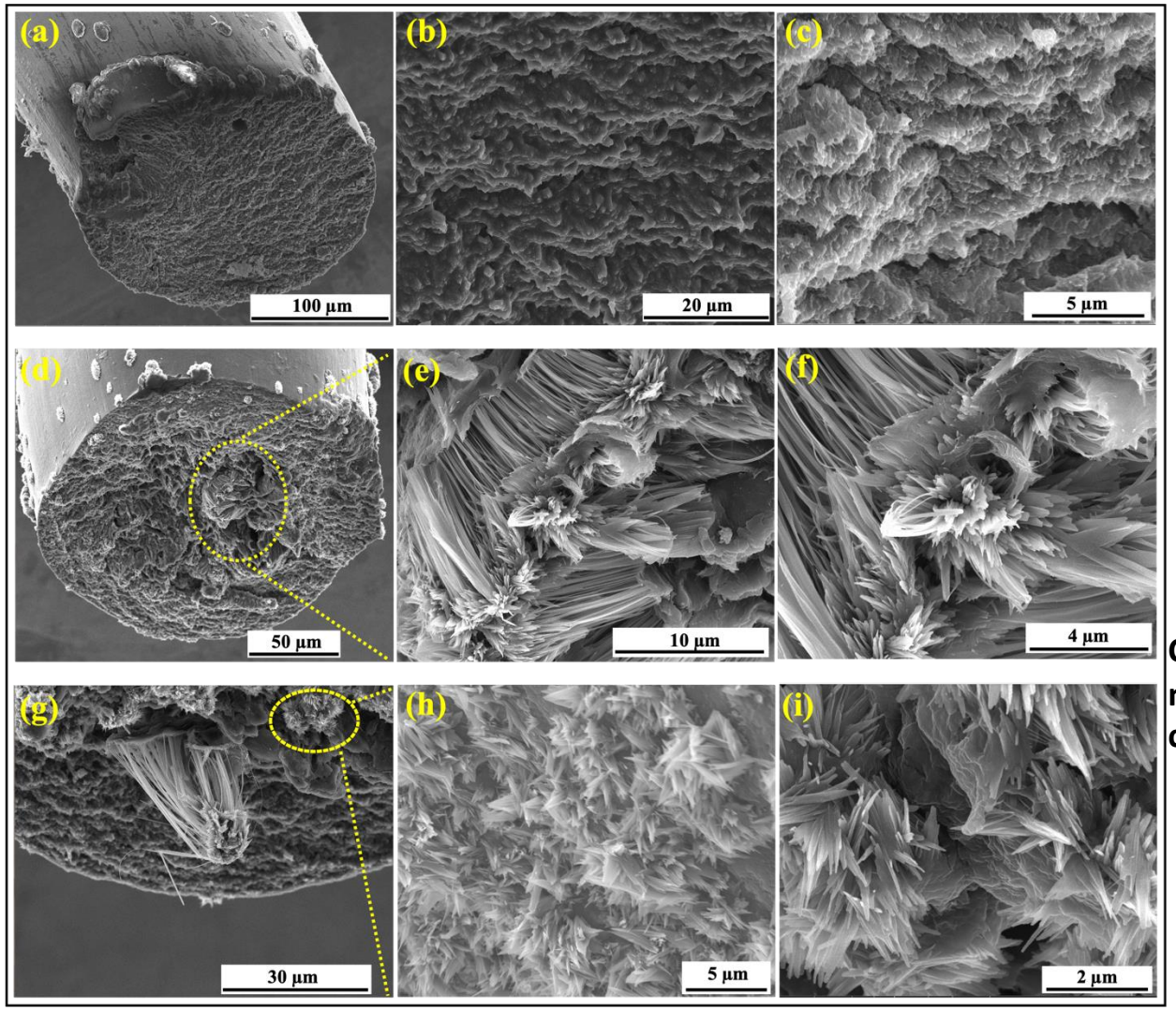


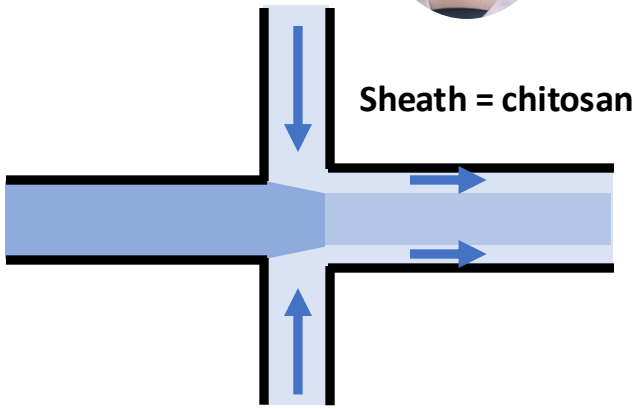
I. Kaur, A. Forigua, H. Titi, C. Moraes, A. Moores, *ChemRxiv.* 2025 10.26434/chemrxiv-2025-578z7-v2

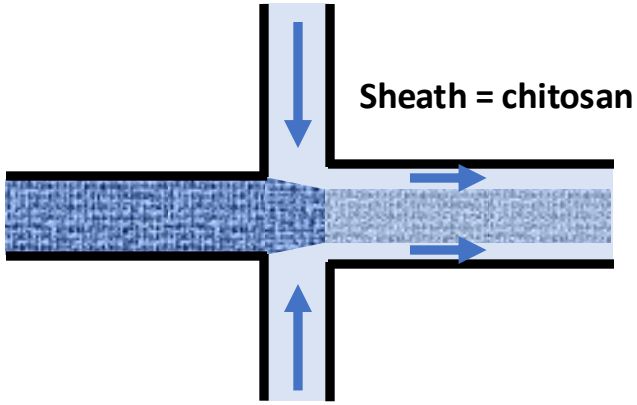


Ishneet Kaur

From nanocrystals to microfibers







I. Kaur, A. Forigua, H. Titi, C. Moraes, A. Moores, *ChemRxiv.* 2025 10.26434/chemrxiv-2025-578z7-v2

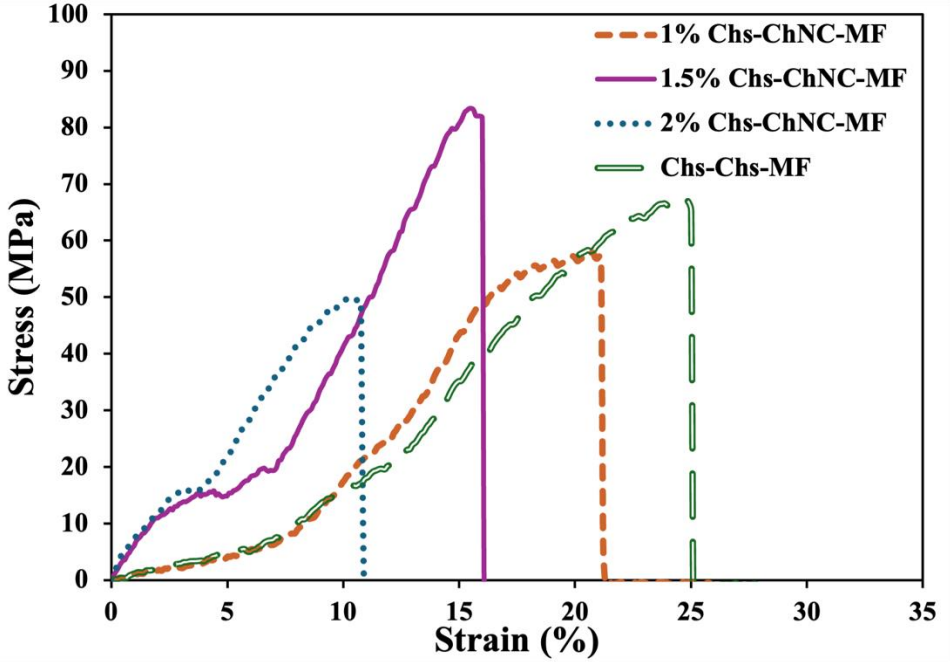
McGill UNIVERSITY



Ishneet Kaur

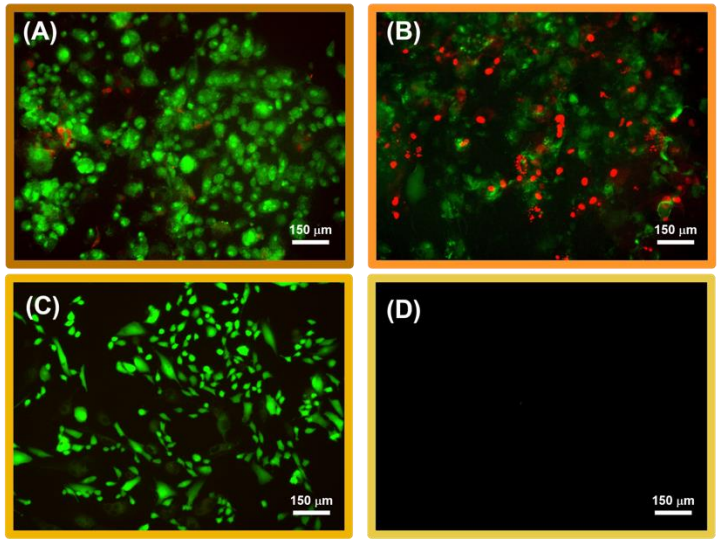
From nanocrystals to microfibers

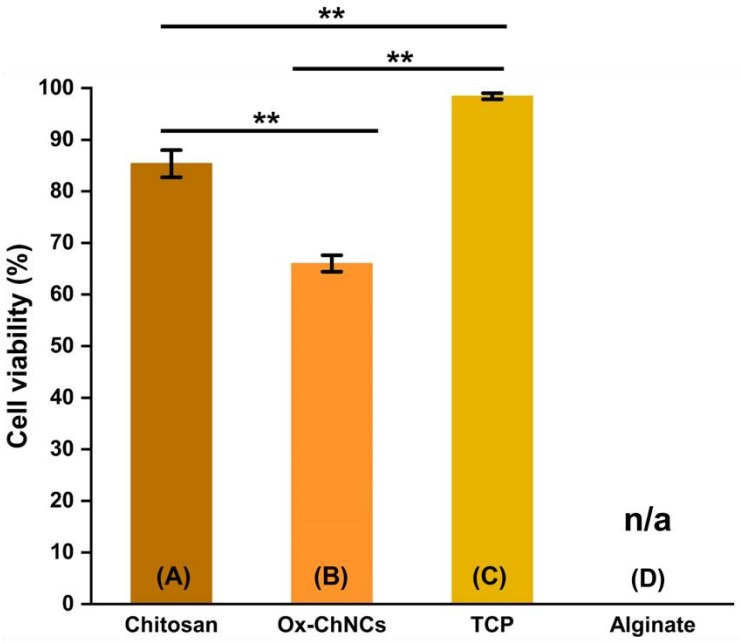
Mechanical properties



Alginates: 200-400 Kpa
Gel MA: 2-4 MPa
PCL: 2-4 MPa

Cell viability

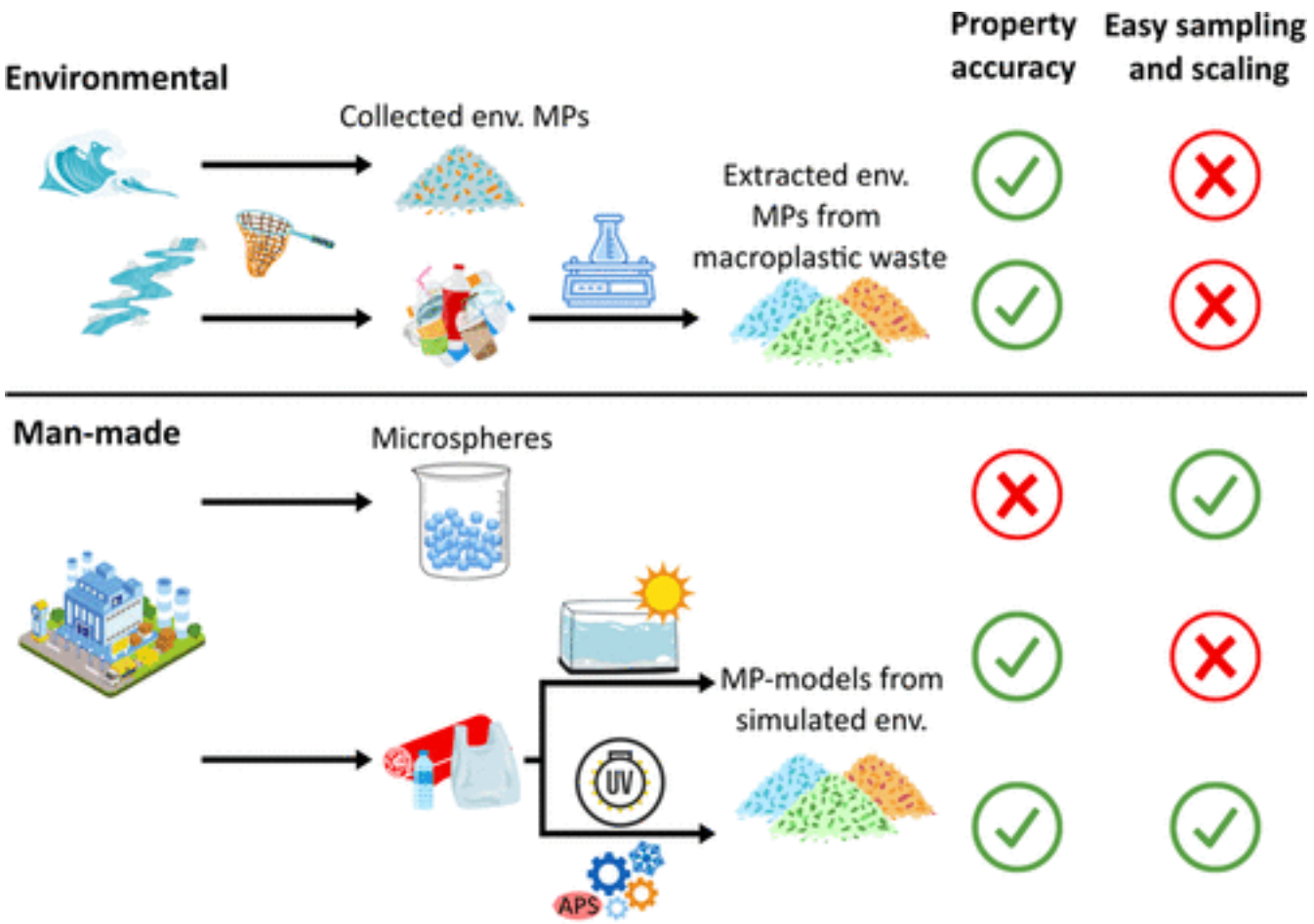


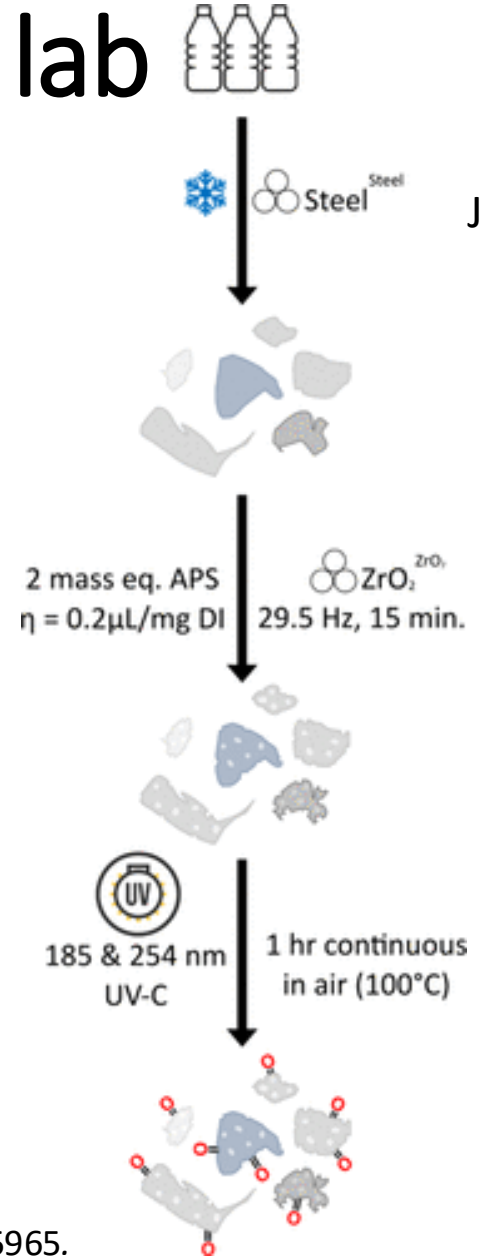


Live/dead (green/red) viability analysis. (A) Chitosan, **(B)** Chitosan Oxide Nanocrystals (Ox-ChNCs), **(C)** Tissue Culture Plastic (TCP), and **(D)** Alginate. Data presented as mean ± standard deviation. Statistical analysis was performed using one-way ANOVA with Tukey's post hoc test (n = 3; ** $p < 0.01$).

I. Kaur, A. Forigua, H. Titi, C. Moraes, A. Moores, *ChemRxiv.* 2025 10.26434/chemrxiv-2025-578z7-v2

Making microplastics in the lab

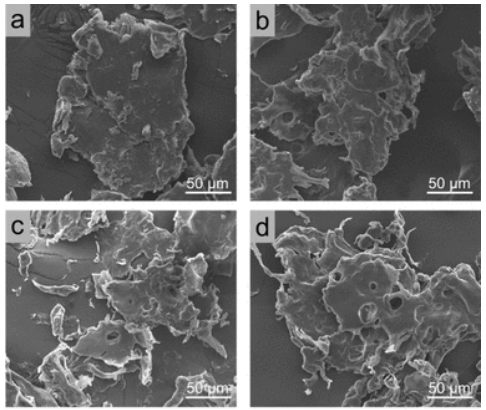








Jasmine Hong Subhasis Ghoshal



Sample	SSA (m^2/g)	BET Mass (g)
PP (6-125)	8.392	0.119
PP 2eq 0.2 DI	17.071	0.0988
PP 4eq 0.2 DI	23.199	0.0854
PP 10 eq 0.2 DI	53.859	0.048

J. Hong, O. Hengelbrok, J. Gigault, S. Ghoshal, A. Moores *Env. Sci. Tech.* **2025** *59 (30)*, 15956–15965.

Acknowledgments



Tony Jin (PhD)



Faezeh Hajiali (PDF)



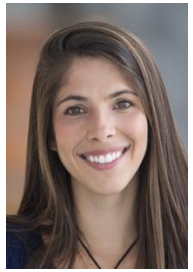
Galen Yang PhD



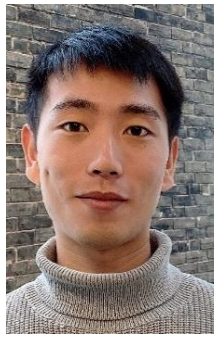
Vincent Banville



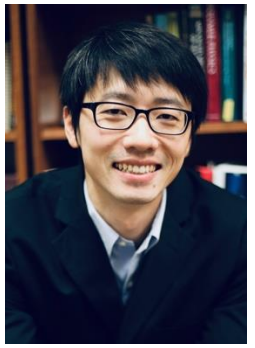
Justine Sauvé St Pierre (PhD)



Juliana Vidal (PDF)



Shuaibing Jiang (PhD)



Jianyu Li



Ishneet Kaur (PhD)



Madison Santos (UG)





Edmond Lam

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- Sara Catingan
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- Rebecca Yan
- Yasmeen Jaberi
- Daniela Olivan-Ponce

RA/PDFs

- Dr. Angel Valdez
- Dr. Wanting He
- Dr. Ruby Liu

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- Makenna Depage
- Natalie Chang

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- Bérénice Baltzinger
- Renzo Favaro
- Maeve Holm
- Dr. Galen Yang
- Francisco Gàmez
- Anaïs Hamelin
- Dr. Hamdam Gaminiam
- Noah Huin
- Madison Santos
- Kiran Hidayat
- Dr. Pravin Vejan
- Dr. Tony Jin
- Dr. Julio Cesar Terra
- Dr. Michael Ferguson
- Dr. Juliana Vidal
- Georgia Douglas
- Austin Richard
- Dr. Blaine Fiss
- Tracy Liu
- Dr. Aude Bechu
- Dr. Faezeh Hajiali
- Dr. Alexandra Gellé
- Dr. Luis de la Garza
- Dr. Yanyan Zhang
- Dr. Lin Yang
- Dr. Alain Li

L'Or Rouge de la Côte Nord



Acknowledgments











It’s important to use metrics for mechanochemistry



Mechanochemistry is in a Green Chemistry toolbox

Mechanochemists must demonstrate their method is better in the context of their work



Metrics



Weigh the importance of improvement

McGill UNIVERSITY

Tony Jin



Edmond Lam (NRC)

Building a new family of nanomaterials

BioMACROMOLECULES

pubs.acs.org/Biomac Article

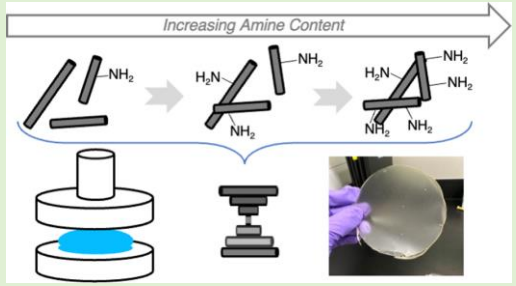
Effect of Surface Functionality on the Rheological and Self-Assembly Properties of Chitin and Chitosan Nanocrystals and Use in Biopolymer Films

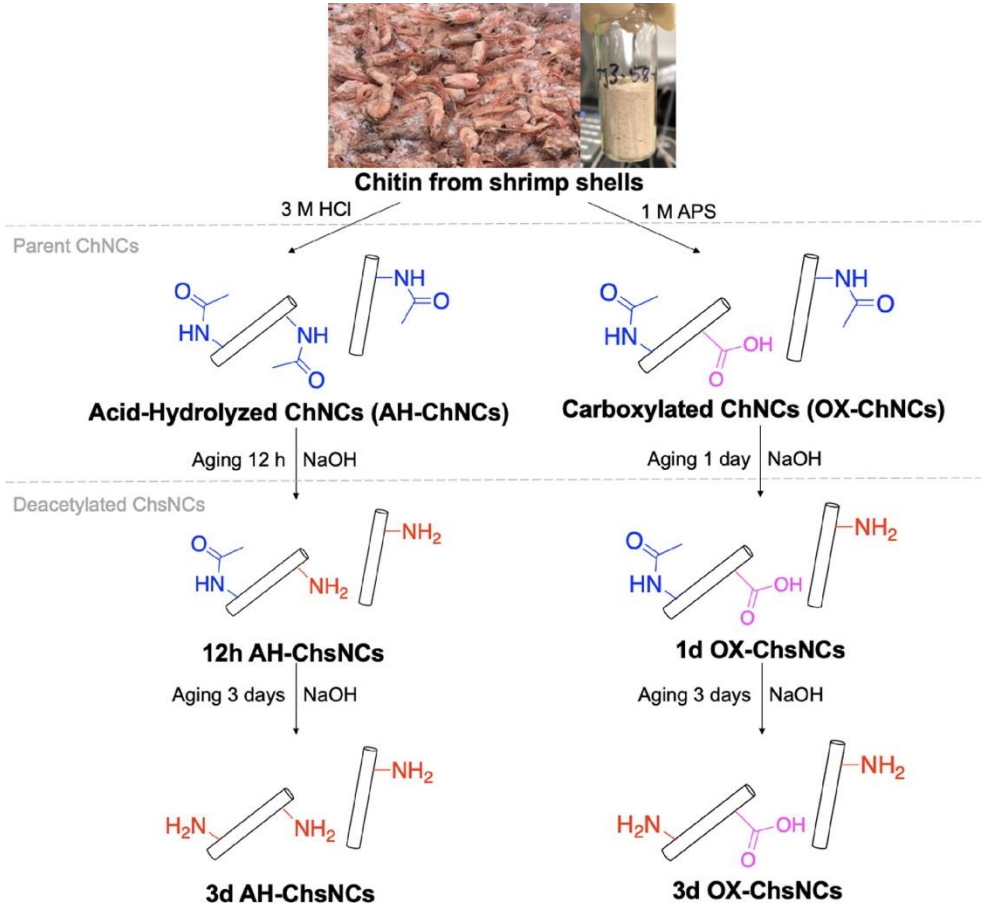
Madison Santos, Olivia Del Carlo, Jasmine Hong, Ziruo Liu, Shuaibing Jiang, Sabahudin Hrapovic, Edmond Lam, Tony Jin,* and Audrey Moores*

Cite This: *Biomacromolecules* 2023, 24, 4180−4189 Read Online

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ABSTRACT: Chitin nanocrystals (ChNCs) are unique to all other bio-derived nanomaterials in one aspect: the inherent presence of a nitrogen moiety. By tuning the chemical functionality of this nanomaterial, and thus its charge and hydrogen bonding capacity, one can heavily impact its macroscopic properties such as its rheological and self-assembly characteristics. In this study, two types of ChNCs are made using acid hydrolysis (AH-ChNCs) and oxidative (OX-ChNCs) pathways, unto which deacetylation using a solvent-free procedure is utilized to create chitosan nanocrystals (ChsNCs) of varying degree of deacetylation (DDA). These nanocrystals were then studied for their rheological behavior and liquid crystalline ordering. It was found that with both deacetylation and carboxylation of ChNCs, viscosity continually increased with increasing concentrations from 2 to 8 wt %, contrary to AH-ChNC dispersions in the same range. Interestingly, increasing the amine content of ChNCs was not proportional to the storage modulus, where a peak saturation of amines provided the most stiffness. Conversely, while the introduction of carboxylation increased the elastic modulus of OX-ChNCs by an order of magnitude from that of AH-ChNCs, it was decreased by increasing DDA. Deacetylation and carboxylation both inhibited the formation of a chiral nematic phase. Finally, these series of nanocrystals were incorporated into biodegradable pectin−alginate films as a physical reinforcement, which showed increased tensile strength and Young's modulus values for the films incorporated with ChsNCs. Overall, this study is the first to investigate how surface functionalization of chitin-derived nanocrystals can affect their rheological and liquid crystalline properties and how it augments pectin/alginate films as a physical reinforcement nanofiller.





What is chemistry?



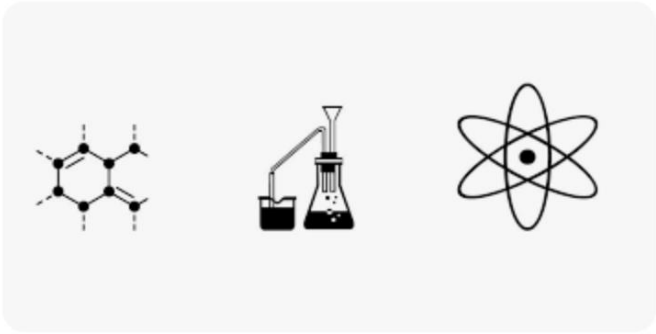
The Conversation

The philosophy of chemist...



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OnePointe Solutions

The 5 Main Types of Chemistry ...



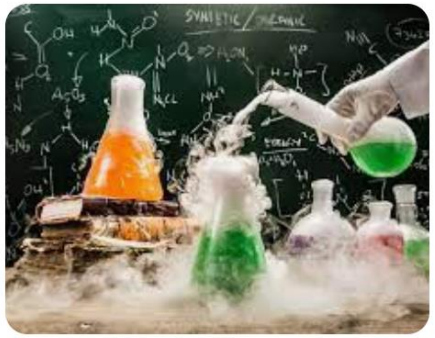
Research Method

What is Chemistry - Definition, Types ...



New Scientist Jobs

What Does a Chemist Do? | Ne...



ThoughtCo

What Chemistry Is and What Che...



Freepik

Chemistry Images - Free...



Reference - YourDictionary

Common Chemistry Terms for Students t...

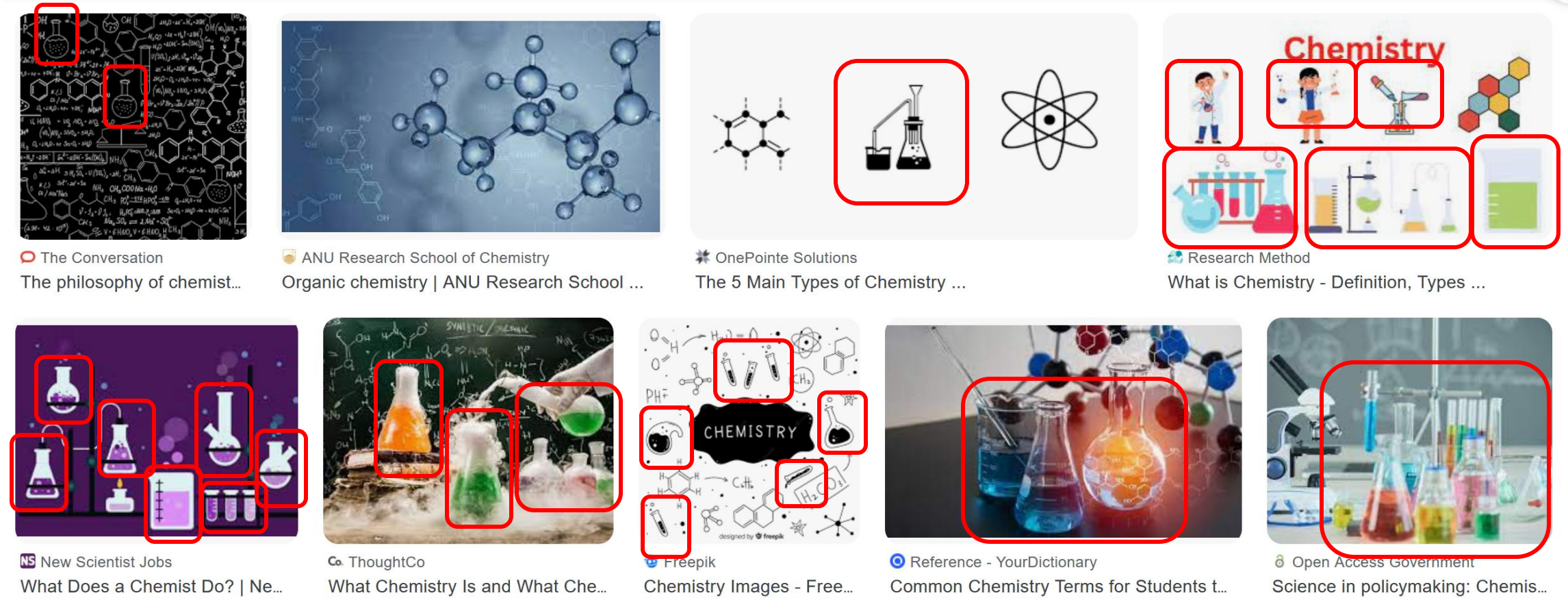


Open Access Government

Science in policymaking: Chemis...

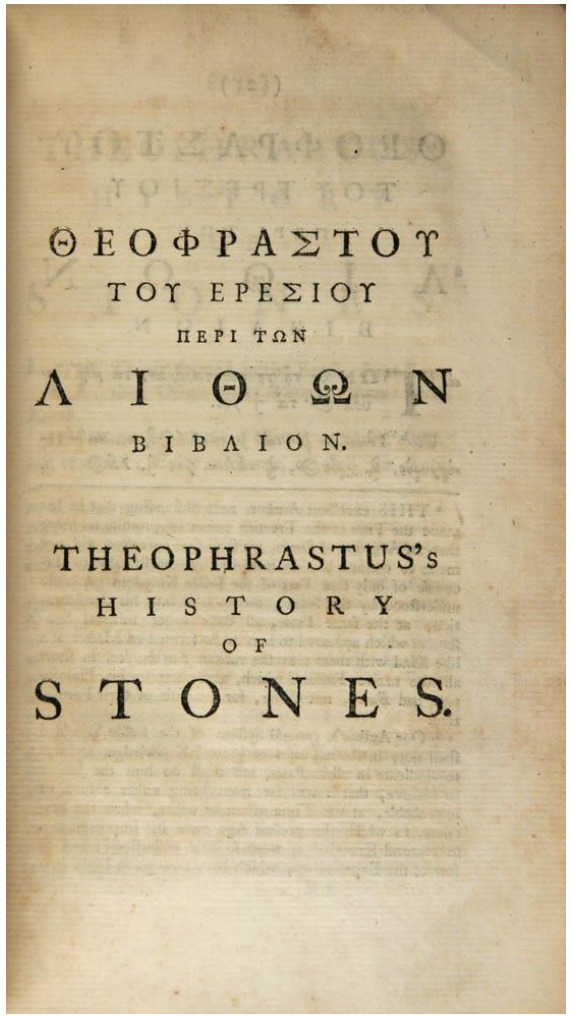
Google Search: Chemistry, June 12 2023

What is chemistry?

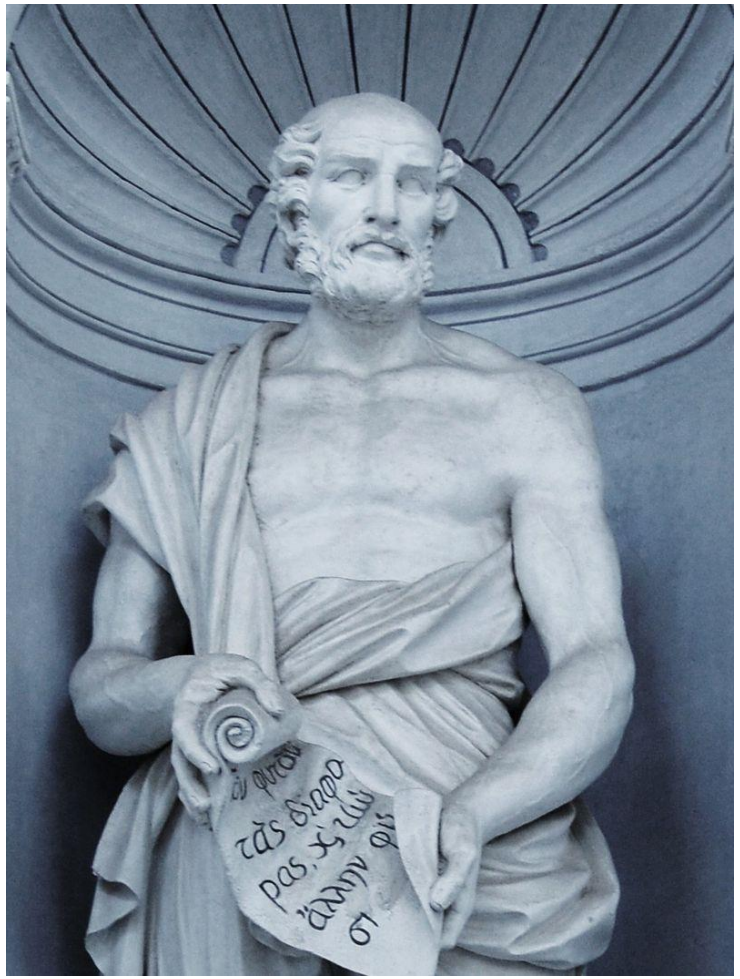


Google Search: Chemistry, June 12 2023

Short history of mechanochemistry


ΘΕΟΦΡΑΣΤΟΥ
ΤΟΥ ΕΡΕΣΙΟΥ
ΠΕΡΙ ΤΩΝ
ΛΙΘΩΝ
ΒΙΒΛΙΟΝ.

THEOPHRASTUS's
HISTORY
OF
STONES.



Theophrastus of Eresus

Theophrastus of Eresus, Aristotle's student and successor at the helm of the Lyceum, wrote a short booklet titled “On Stones” in about 315 B.C. that is the earliest surviving document related to chemistry

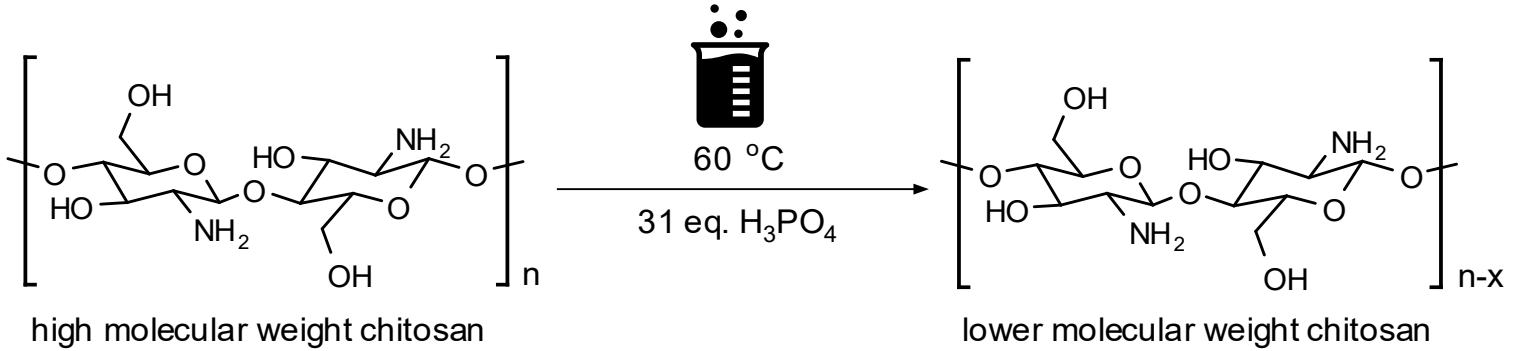
Takacs, L. (2013). The historical development of mechanochemistry. *Chemical Society Reviews*, *42*(18), 7649–7659.

McGill UNIVERSITY

Galen Yang   Edmond Lam (NRC)

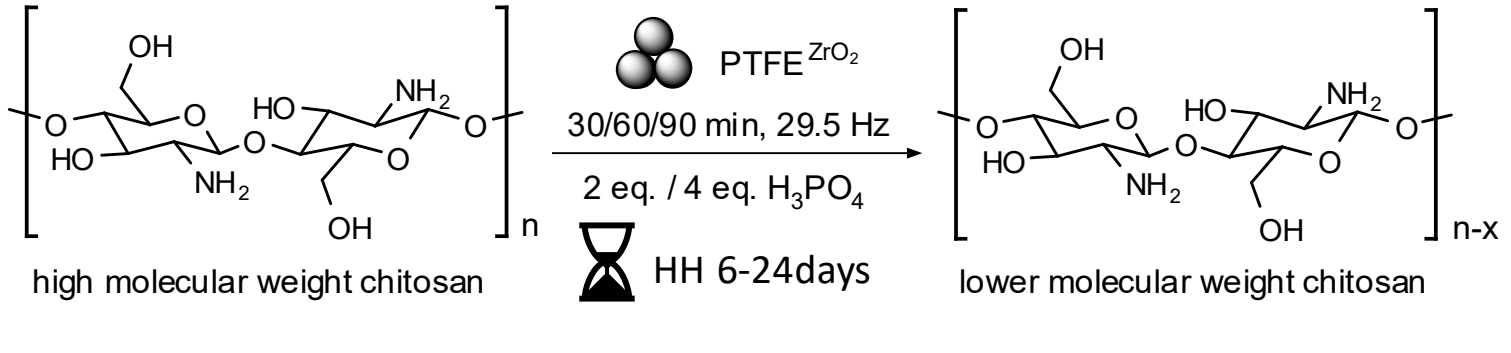
Turning sea biomass waste into materials

Traditional



high molecular weight chitosan — lower molecular weight chitosan

This method



high molecular weight chitosan — lower molecular weight chitosan

Affords controllably Mw in the range **20-200kDa** with DPI below 4 and down to 1.8

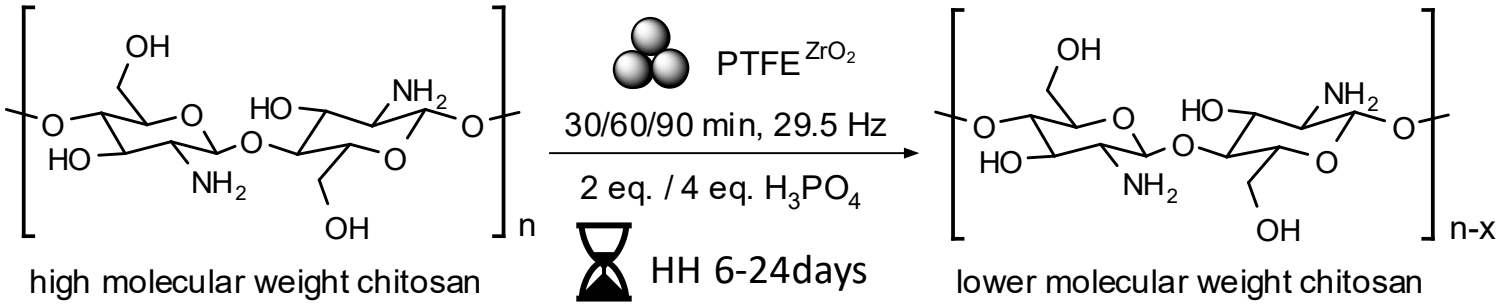
Process Mass Intensity (PMI): Traditional: 6826, this method: 805

G. Yang, Lam, E.; Moores, A. *Unpublished*

McGill UNIVERSITY

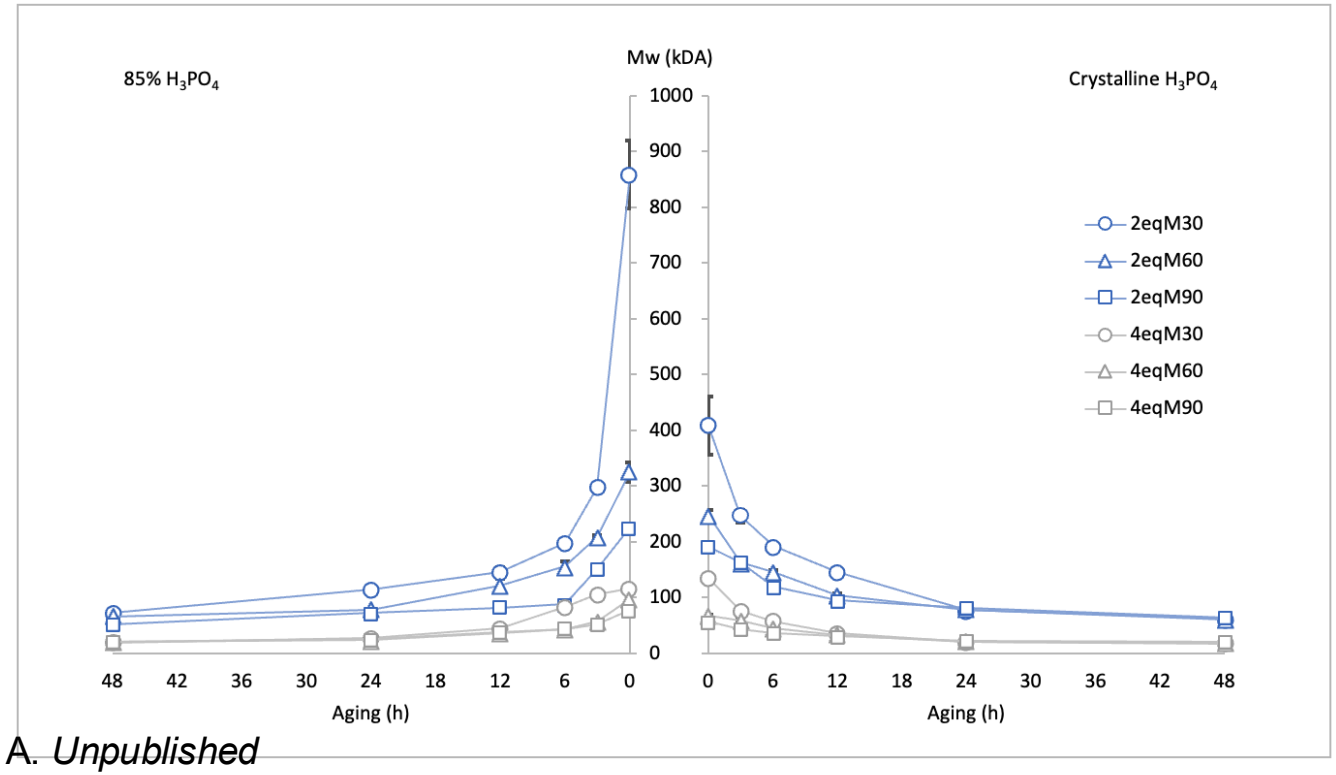
Galen Yang   Edmond Lam (NRC)

Turning sea biomass waste into materials



high molecular weight chitosan

lower molecular weight chitosan



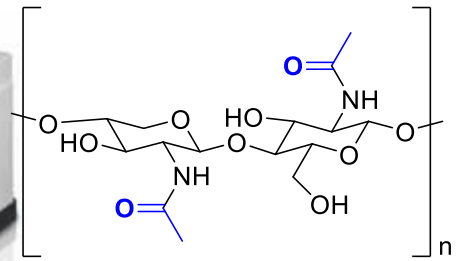
G. Yang, Lam, E.; Moores, A. *Unpublished*

Thomas Di Nardo



From chitin to chitosan

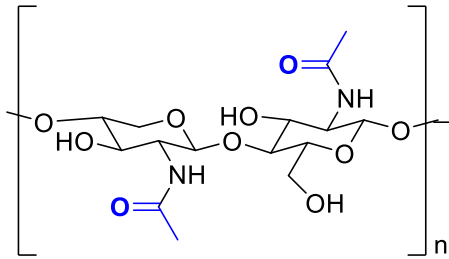




Crystalline

Chitin

1. ZrO_2^{ZrO2}
30 min, 29.5 Hz

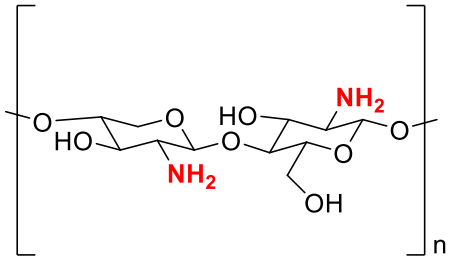


Amorphous

Chitin

2. $PTFE^{ZrO2}$
5 min, 29.5 Hz
5 eq. NaOH

3.
3-6 days, RH = 98%
Temp = RT-50°C

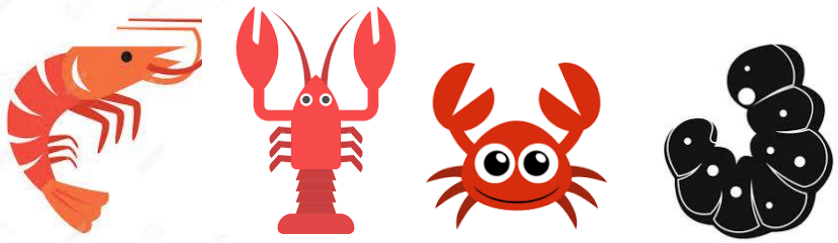


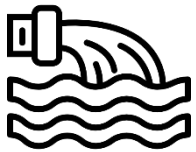
DDA = 73 to 95%

Chitosan

Chitin source	% DDA	Intrinsic viscosity [η]
Shrimp	95	1.61
Lobster	96	2.58
Crab	98	3.40
fly larva	90	4.33
Beetle	74	2.84







NaOH

Quantity of water
> 8 times less

Quantity of chemicals
> 8 times less



Energy use
> 7 times less



Operator safety
No use of viscous hot toxic liquid

T. Di Nardo, C. Hadad, A. Nguyen Van Nhien, A. Moores, *Green Chem.* **2019**, *21*, 3276-3285

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"Blue is the New Green"



Juliana Vidal

Valorization of Marine Biomass

Lobster Shells

Crab Shells

Shrimp Shells

Squid Pens

Minerals

Proteins

Chitin

Demineralization

Chitin

Proteins

Deproteinization

Chitin

Chemical Structure of Chitosan: Obtained After Chitin Deacetylation

$R = COCH_3$ or H

Applications

Higher Solubility in H_2O

- Water treatment
- Nutraceutics
- Biomedical
- Cosmetics
- Fertilizers
- Fibers

Chemical Structure of Chitin: Extracted from Marine Biomass

Applications

Lower Solubility in H_2O

- Food preservatives
- Biomedical
- Fertilizers
- Fibers

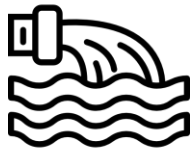




Corrosive and viscous liquid (NaOH)



140°C



Difficult to handle aqueous effluents

J. L. Vidal, **T. Jin**, E. Lam, F. Kerton, A. Moores,, *Curr. Res. Green Sustainable Chem*. **2022**, 100330.

McGill UNIVERSITY

Faezeh Hajiali

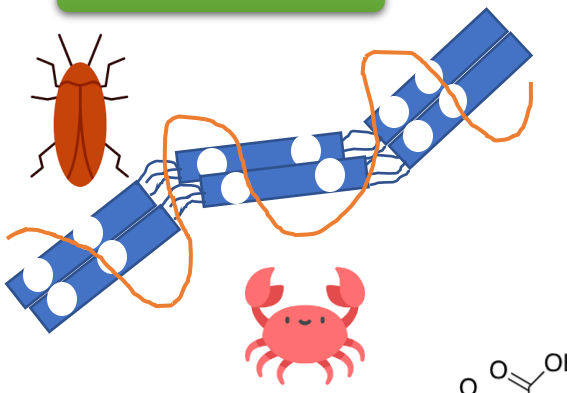


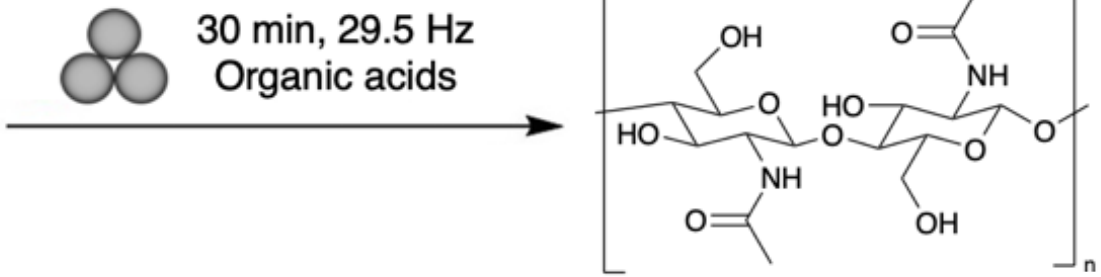


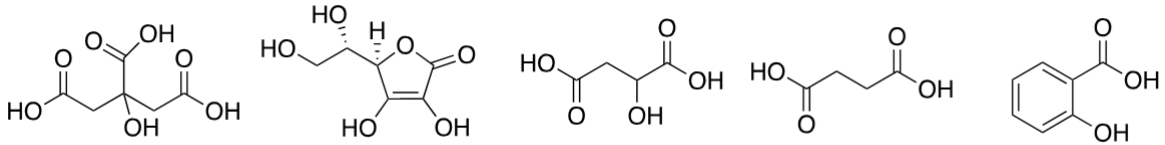
Juliana Vidal

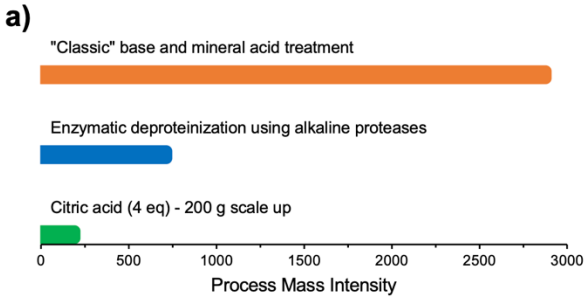
From the crustacean shell to chitin

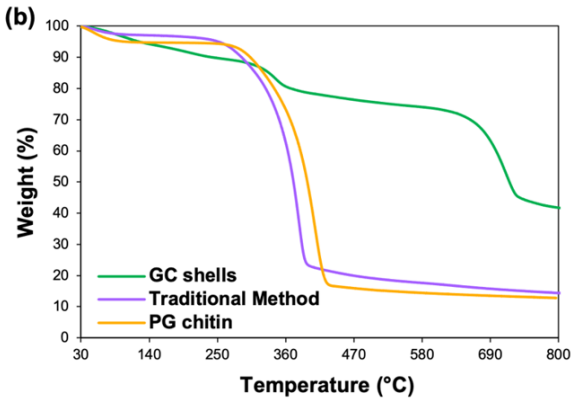
Shell

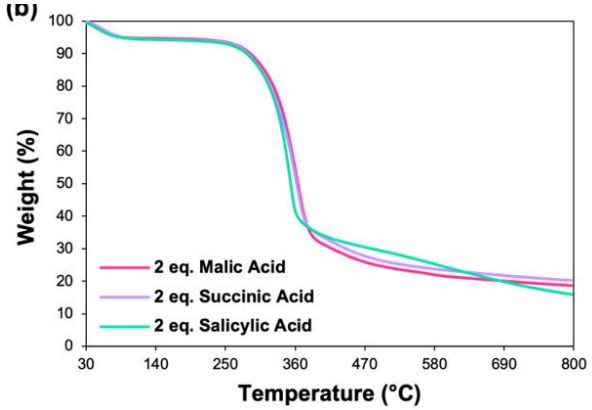


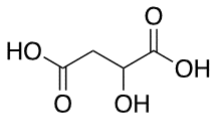




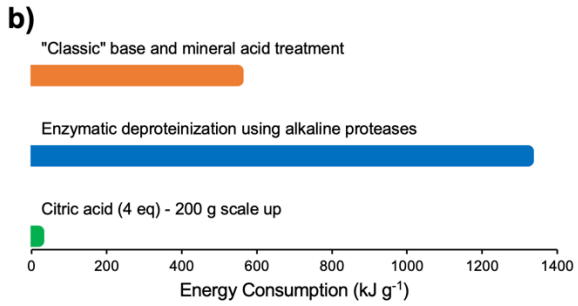








16% mass efficiency
1.6% ash



Hajiali, F.; Vidal, J.L, Jin, T.; Carlos de la Garza, L.; Yang, G.; Santos, M.; Moores, A. *ACS Sustainable Chem. Eng.* **2022**, 10, 34, 11348–11357

Then comes Gabrielle and Chris

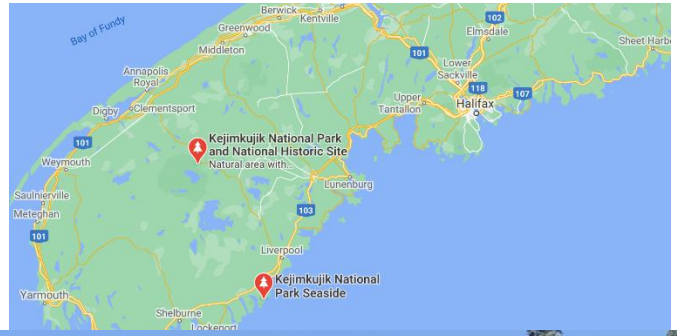
- From Kejimkujik Park Seaside in Nova Scotia

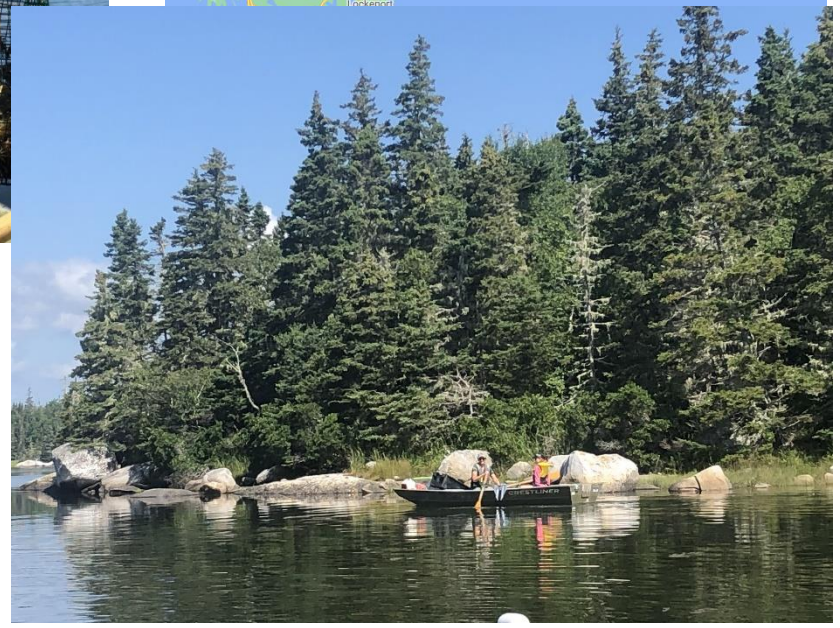


Gabrielle Beaulieu



Chris McCarthy







Towards a scale up

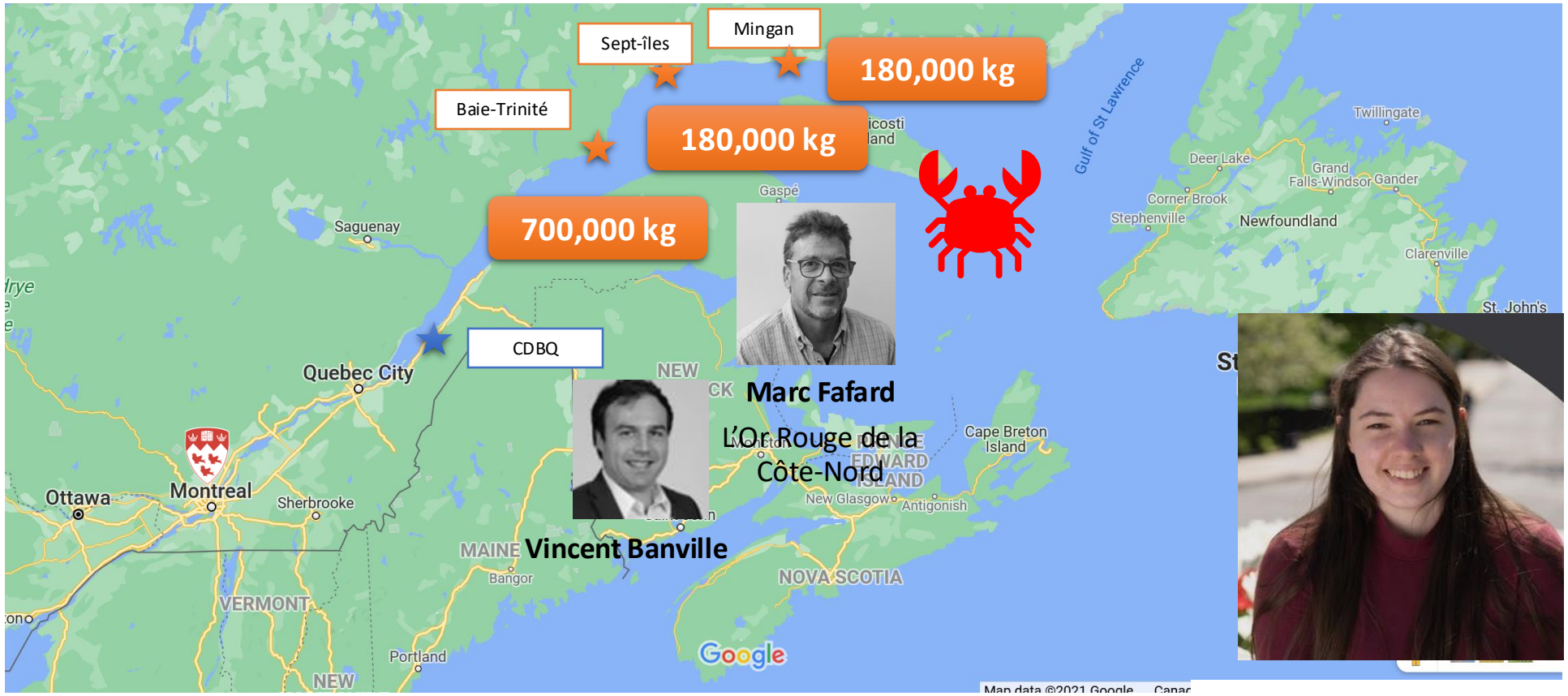
$ CRIBIQ PLAN NORD $

pêcheries shipek'

L'Or Rouge de la Côte Nord

CREVETTES DE SEPT-ÎLES

Waste on the North Coast of Quebec, just for crabs



Marc Fafard

L'Or Rouge de la Côte-Nord

Vincent Banville

LAURÉATS
APPEL À PROJETS
2024
POUR DES INNOVATIONS D'AVENIR
axelys

Justine Sauvé St Pierre



Hamdam Gaminian

Towards a scale up

$ CRIBIQ PLAN NORD $

Pêcheries Shipek'

L'Or Rouge de la Côte Nord

CREVETTES DE SEPT-ÎLES

CDBQ





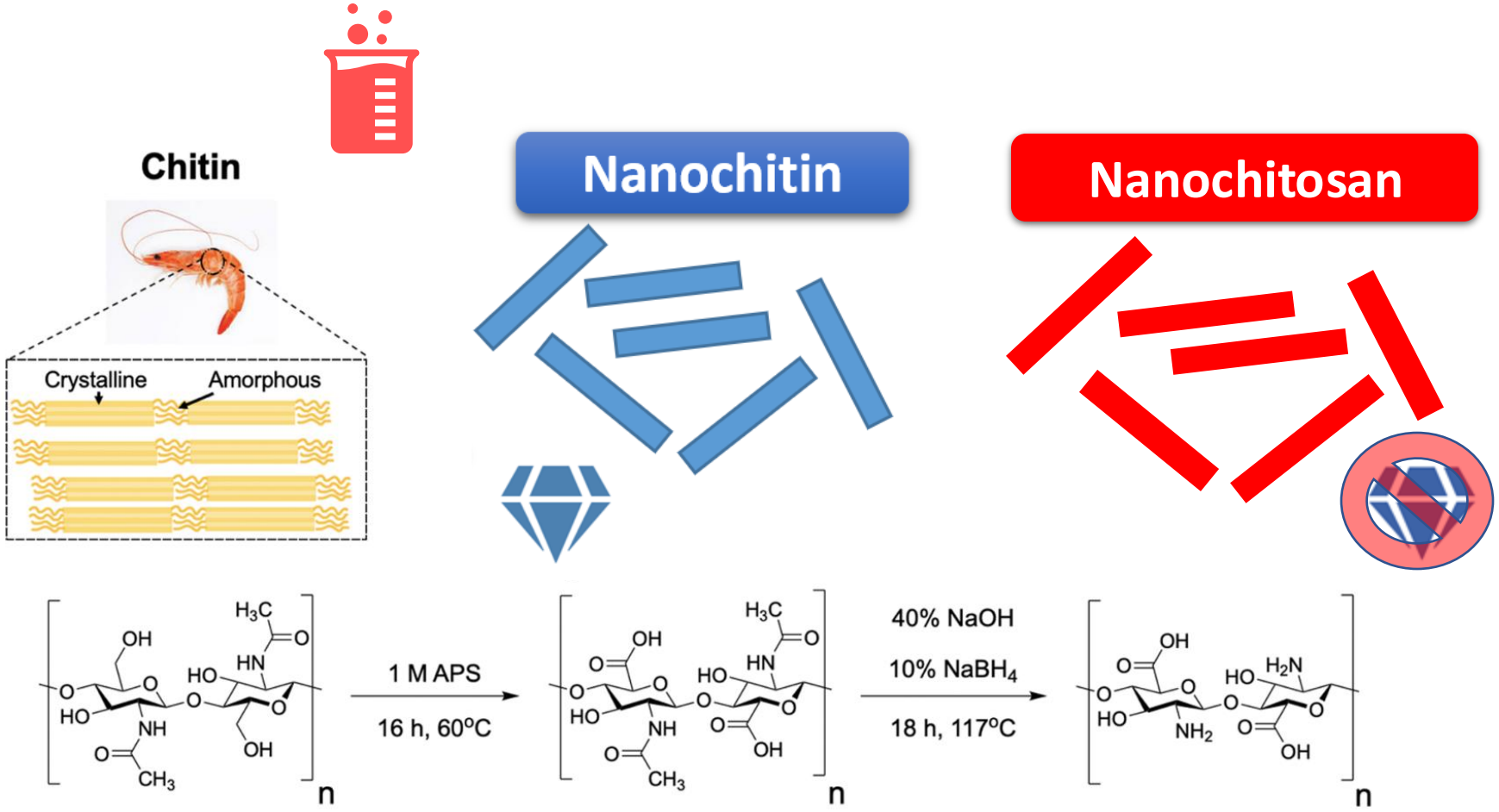
McGill UNIVERSITY

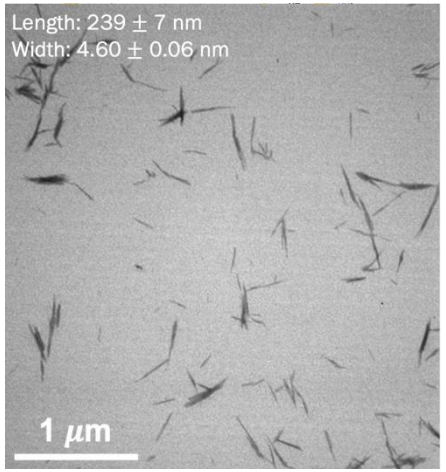
Tony Jin



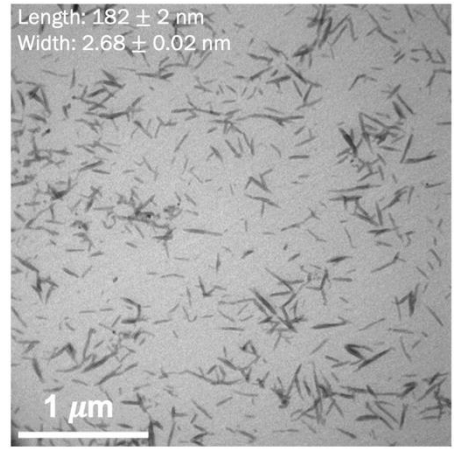
Edmond Lam (NRC)

Sustainable Nanochitin and nanochitosans





TEM of stained Nanochitin



TEM of stained Nanochitosan

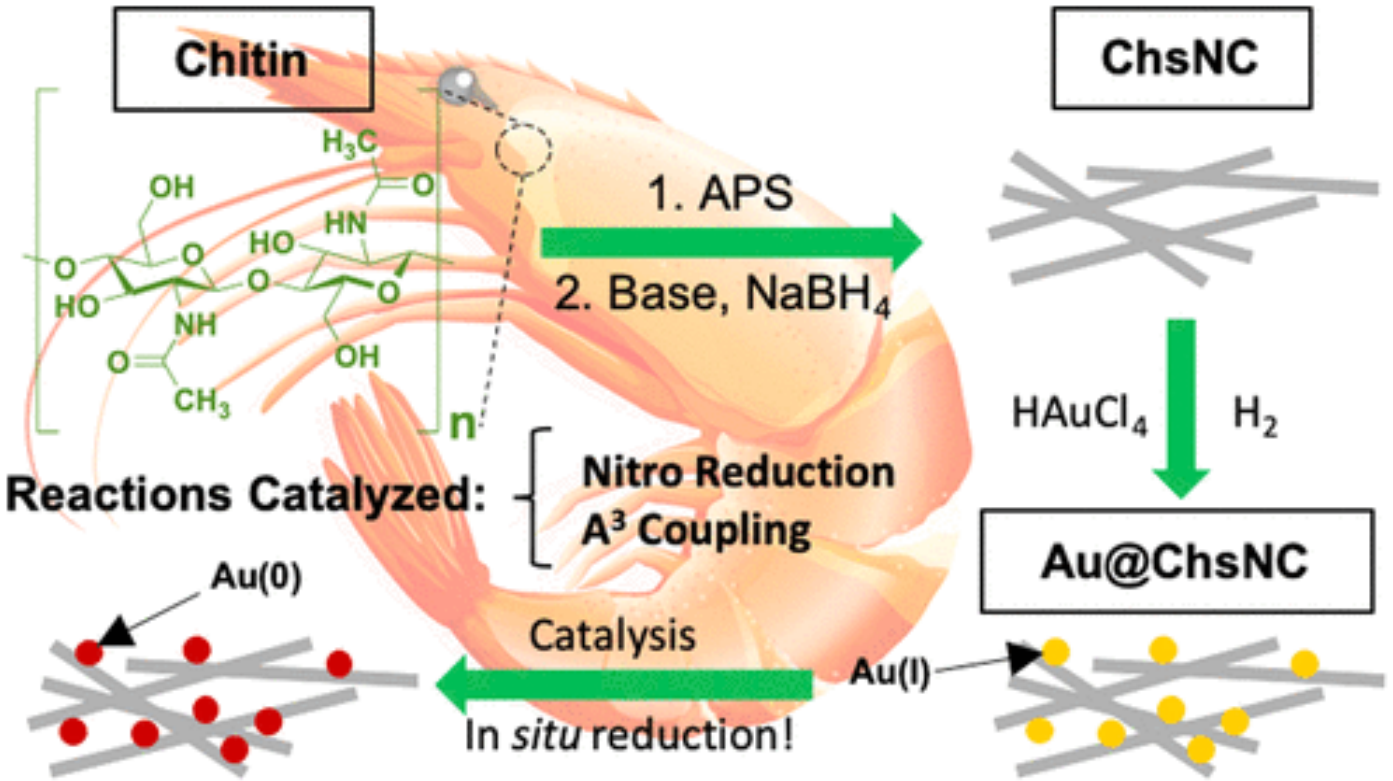
Jin, T.; Kurdyla, D.; Hrapovic, S.; Leung, A.; Régnier, S.; Liu, Y.; Moores, A.; Lam, E. *Biomacromolecules* **2020**, *21* (6), 2236–2245.

Tony Jin



Edmond Lam (NRC)

Applications to catalysis



Jin, T.; Kurdyla, D.; Hrapovic, S.; Leung, A.; Régnier, S.; Liu, Y.; Moores, A.; Lam, E. *Biomacromolecules* 2020, *21* (6), 2236–2245.

7. Use of Renewable Feedstocks



"Biofuels play a particularly important role in decarbonising transport by providing a low-carbon solution for existing technologies, such as light-duty vehicles in the near term and heavy-duty trucks, ships and aircraft with few alternative and cost-effective solutions in the long term." International Eenergy Agency

"When it comes to production, the majority of renewable energy comes from bioenergy, such as biomass (55.7 %), followed by wind (13.6 %), hydro (12.3 %), solar (7.5 %), ambient heat i.e. heat pumps (6.2 %) and geothermal energy (2.8 %). European Commission

Anastas, P. T., & Warner, J. Charles. (1998). Green chemistry : theory and practice. Oxford University Press
https://www.iea.org/energy-system/low-emission-fuels/biofuels

200-300 years

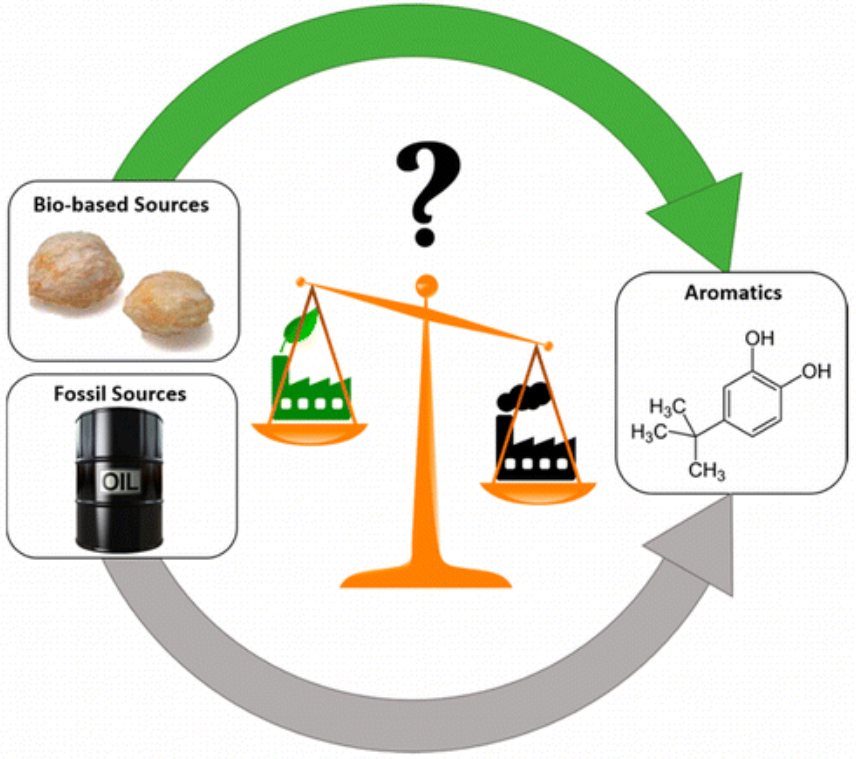


A few minutes to 1 hour

Photo credit: Ingrid Birker, from: Trees of McGill, Black Walnut *Juglans nigra*

LCA and biobased materials

Can we compare the LCA of a material made fr
study of catechols





Montazeri, M.; Eckelman, M. J. *ACS Sustain. Chem. Eng.* **2016**, *4* (3), 708–718.


Tomislav Friscic, McGill

Mechanochemistry and aging



Mortar pestle

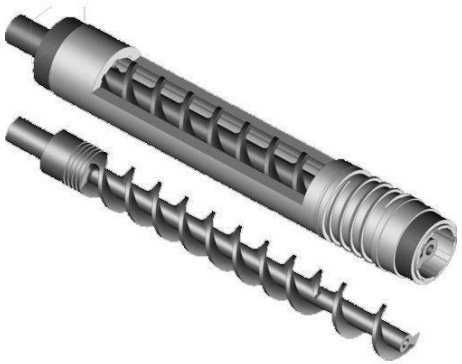




Vibrational mill



Resonant acoustic mixing



Extrusion



Planetary mill



Speed mixing



Aging

McGill UNIVERSITY

Mechanochemistry

5 Mechanochemistry and reactive extrusion

Mechanochemistry – inducing reactions though mechanical forces – sometimes makes processes possible that are hard to do by traditional solution synthesis. But scientists are still struggling to understand how the process works on a molecular scale.

That hasn't kept them from trying to scale up mechanochemical processes. Reactive extrusion is a polymer manufacturing technique combining synthesis and shaping into a single, solvent-free process. It's essentially solid-state flow chemistry and could be a way to scale up mechanochemical syntheses. Chemists have already demonstrated that they can make MOFs by screw extrusion.

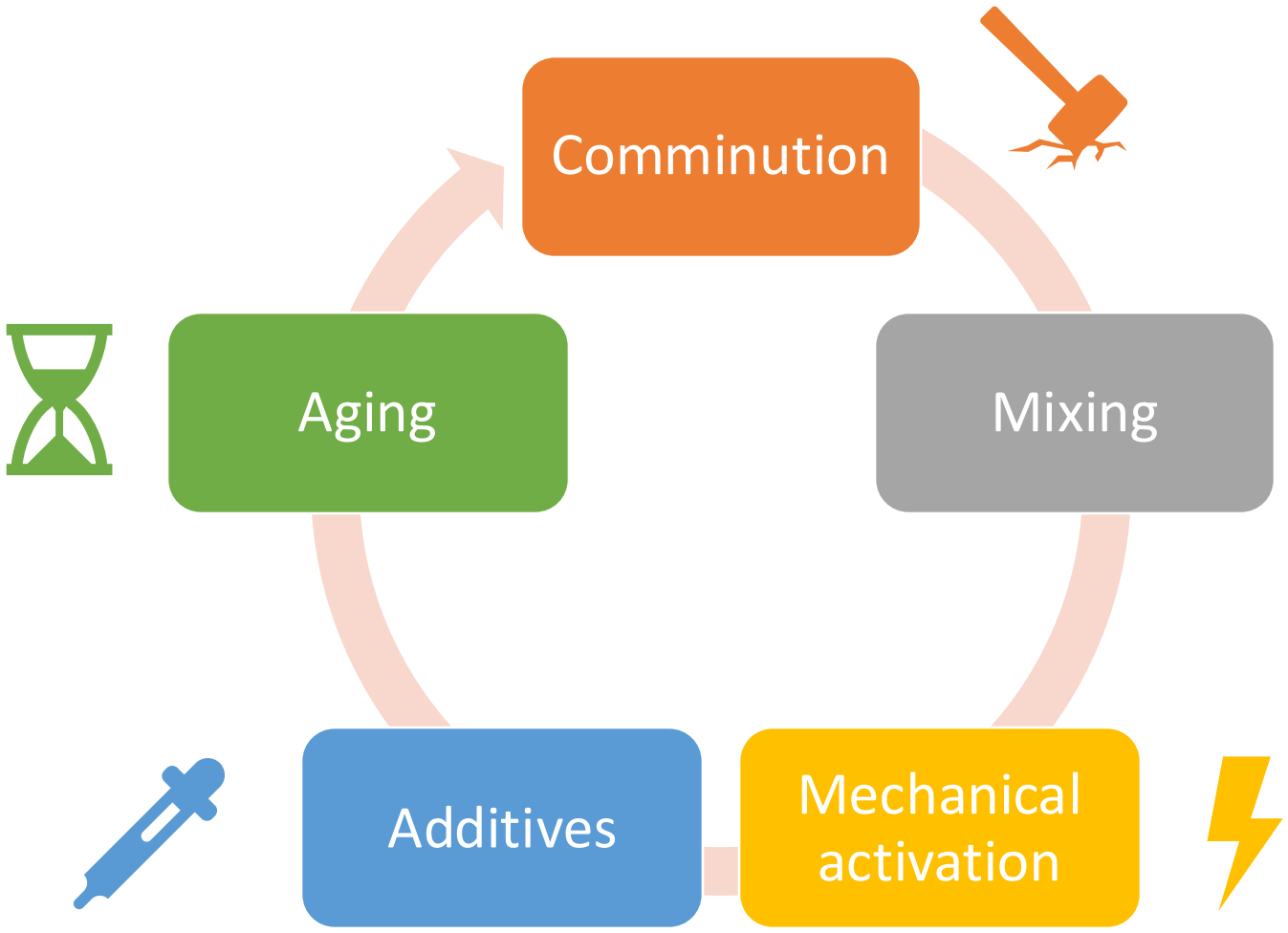
IUPAC

Mechanochemistry named one of the ten innovations that will change the world

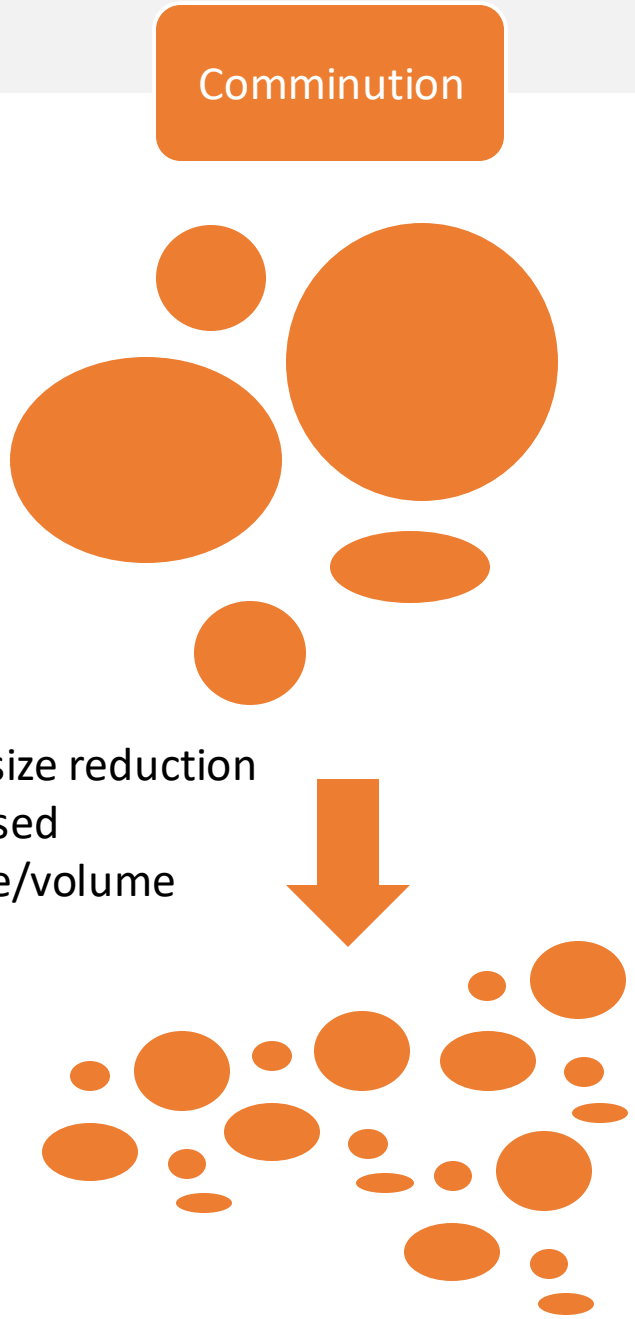
Mechanochemistry can reduce in input in chemicals and energy, and reduce waste

K. Krämer, *Chemistry World.*, **2019**, *April 3*.

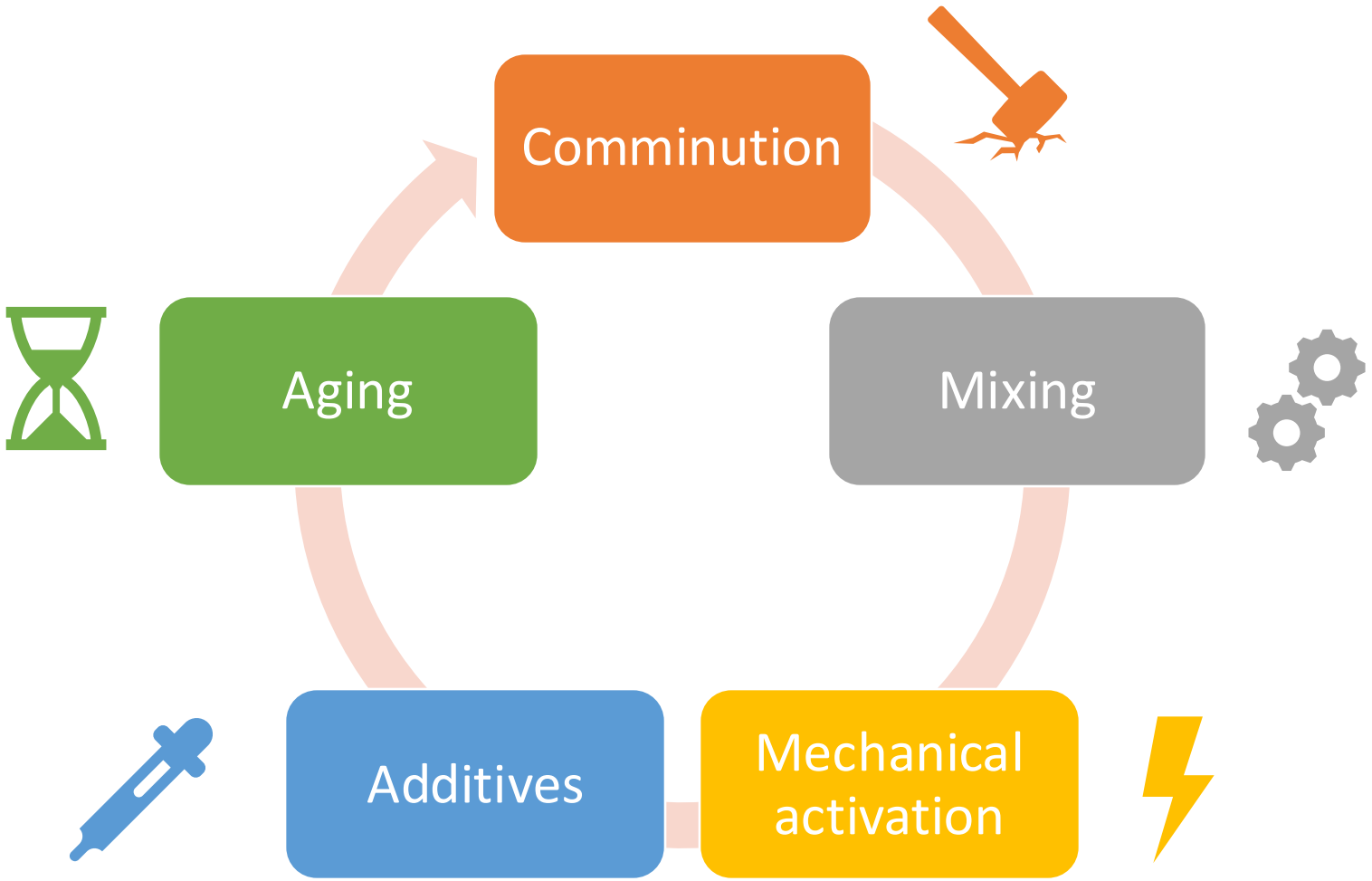
Mechanochemistry



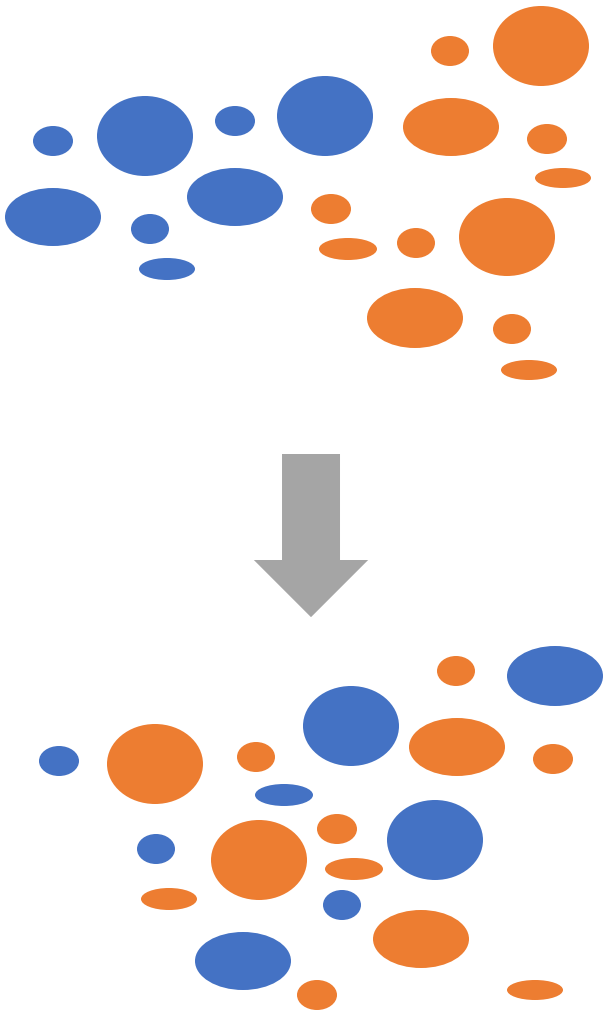
- Grain size reduction
- Increased surface/volume ratio



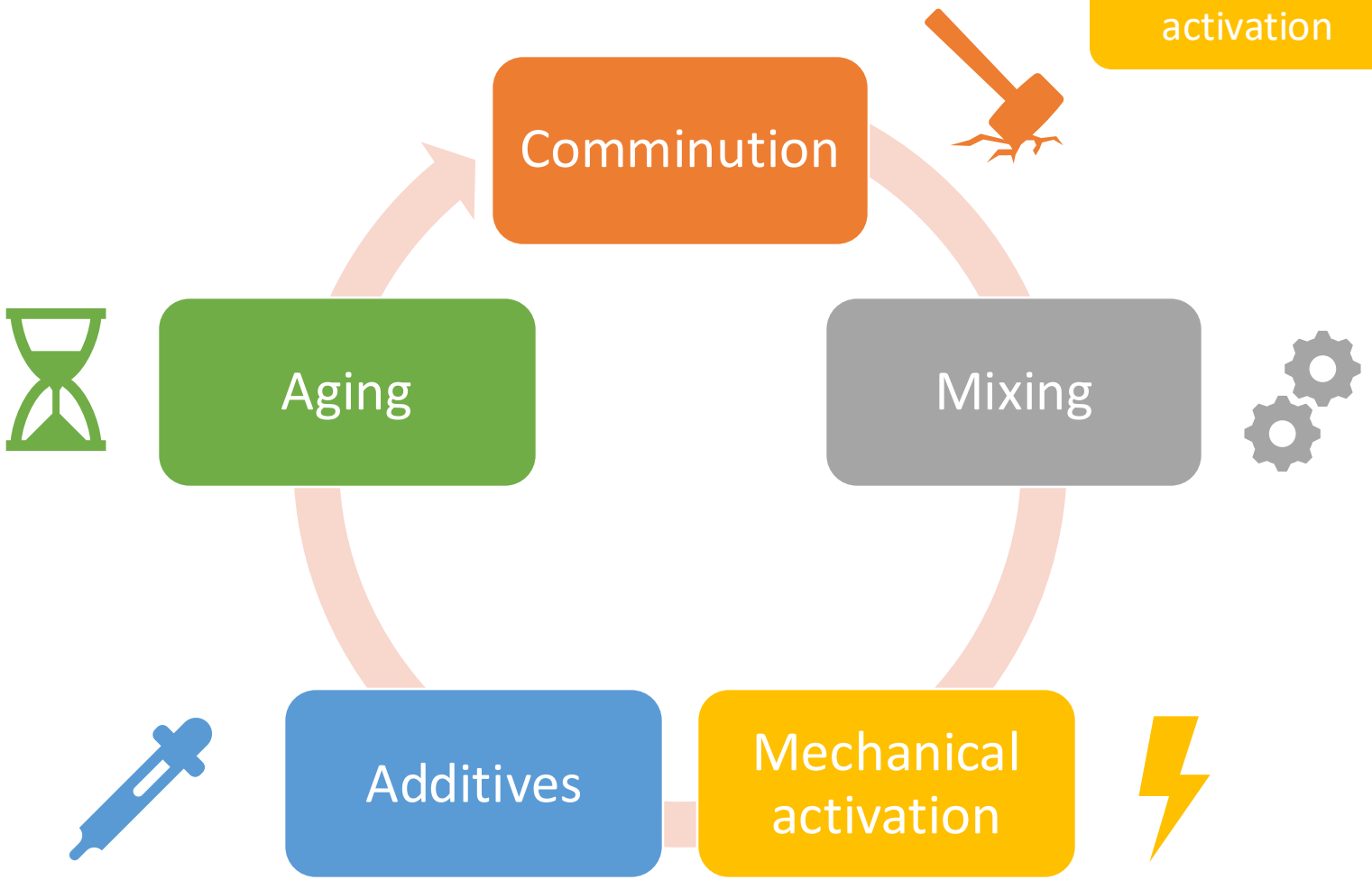
Mechanochemistry

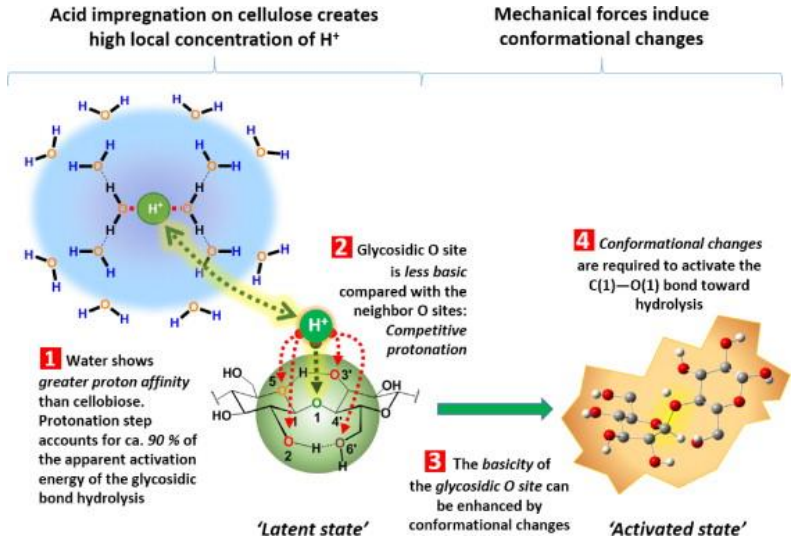


Mixing (solid state)

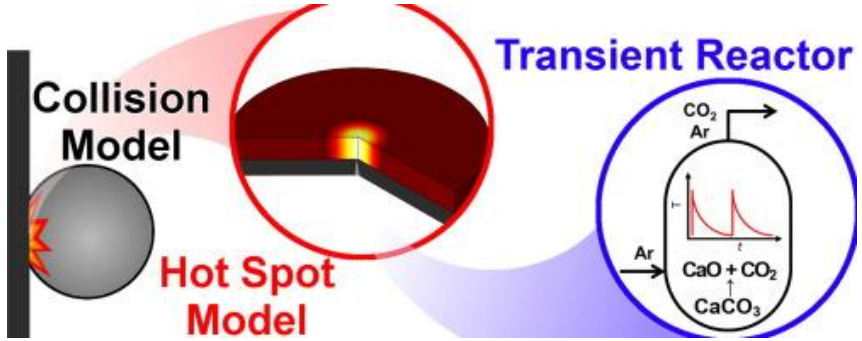


Mechanochemistry





Deformation -> activation



Hot spot formation (harsh)

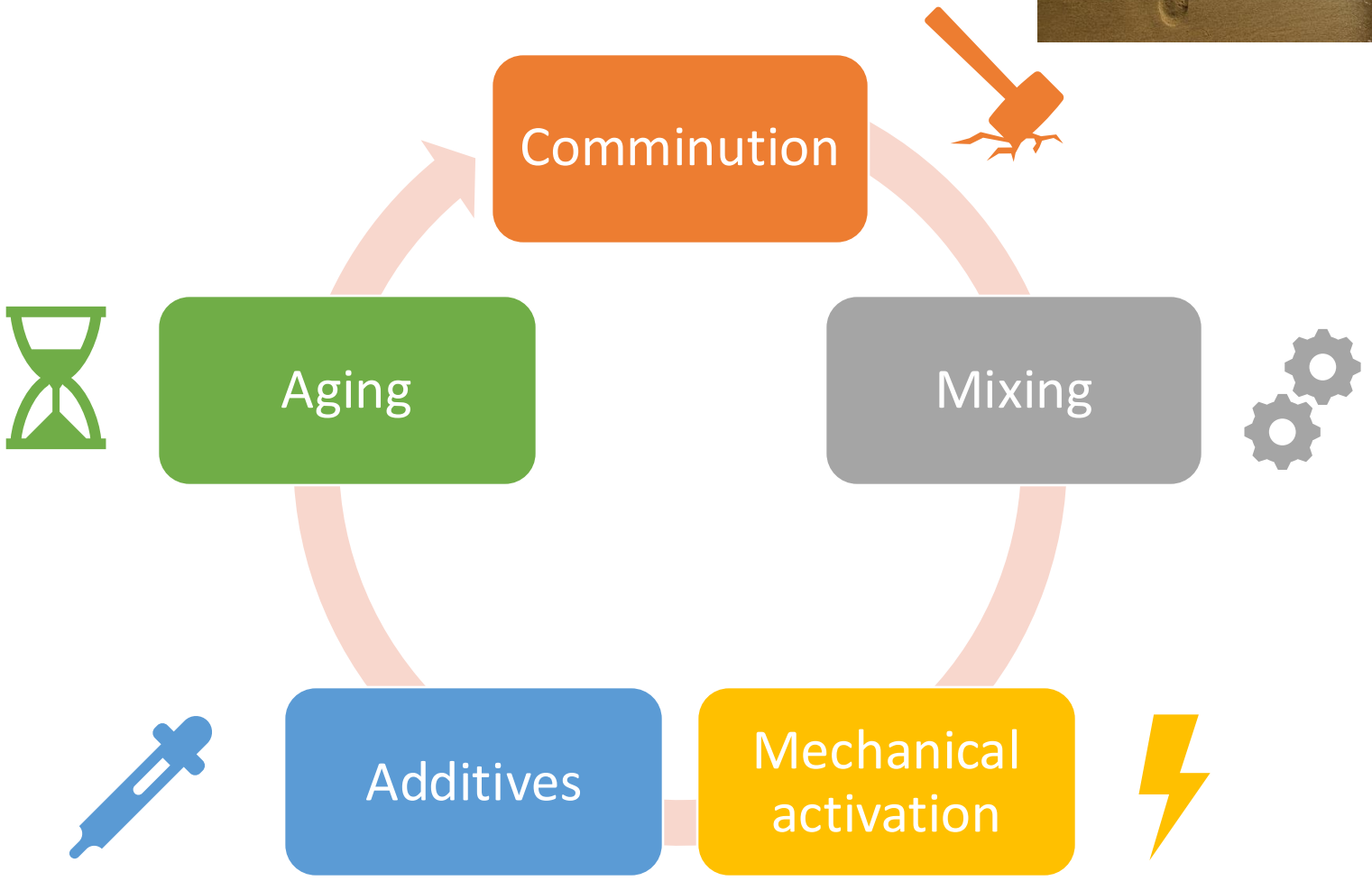
Schüth, F., Rinaldi, R., Meine, N., Käldström, M., Hilgert, J., & Rechulski, M. K. (2014) *Catalysis Today*, *234*, 24-30.
Tricker, A. W., Samaras, G., Hebisch, K. L., Realff, M. J., & Sievers, C. (2020) *Chem. Eng. J.*, *382*, 122954.

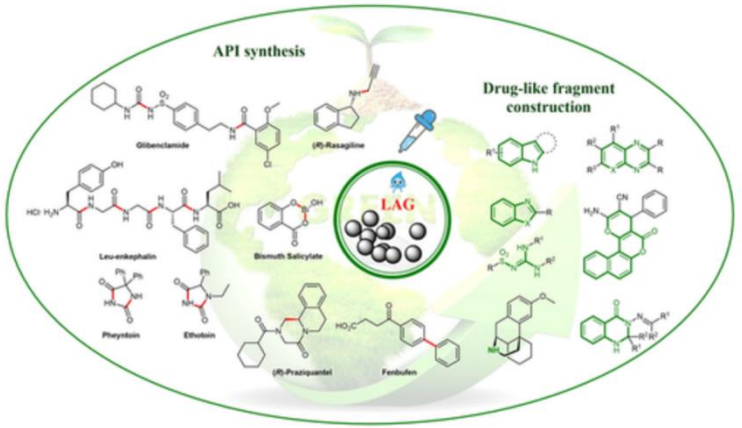
Mechanochemistry

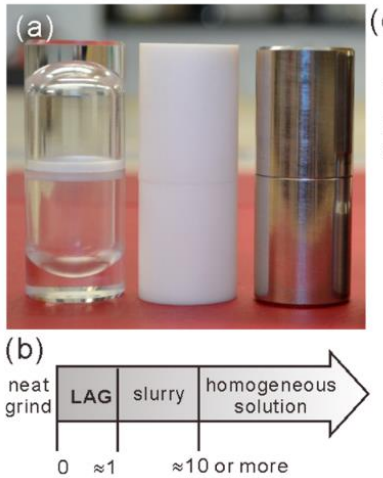


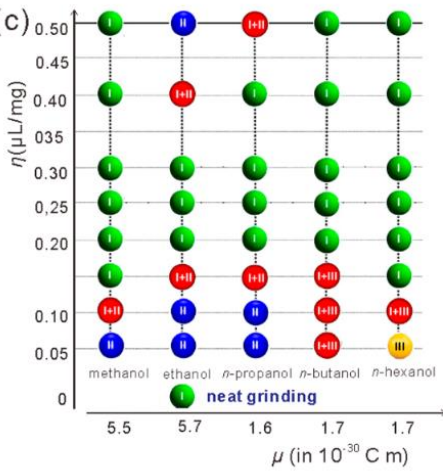
Additives

- Liquid assisted grinding (LAG)
- Ion assisted grinding (ILAG)



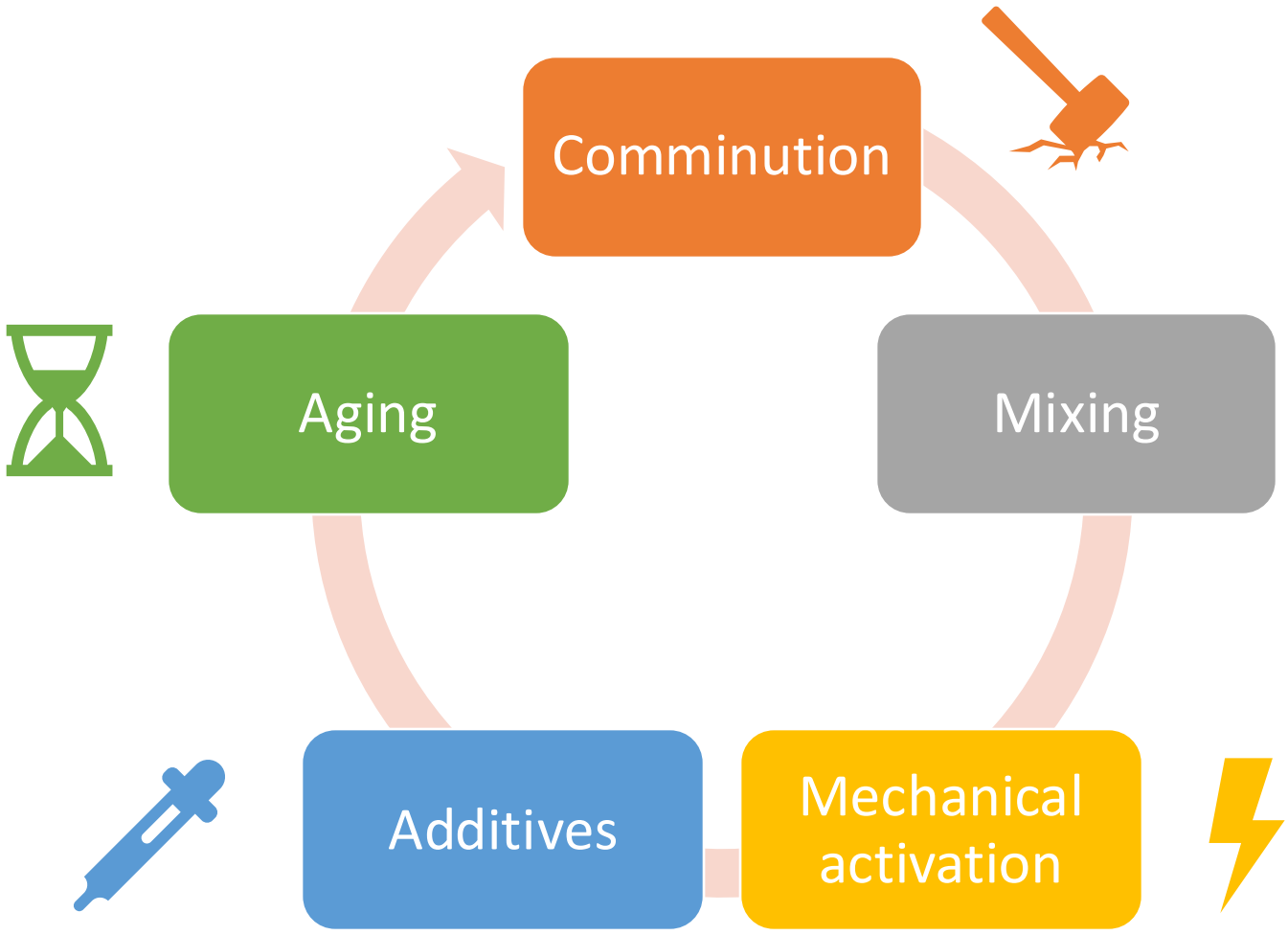






Caffeine + anthranilic acid

Mechanochemistry



Aging



Cite this: *Chem. Sci.*, 2012, **3**, 2495

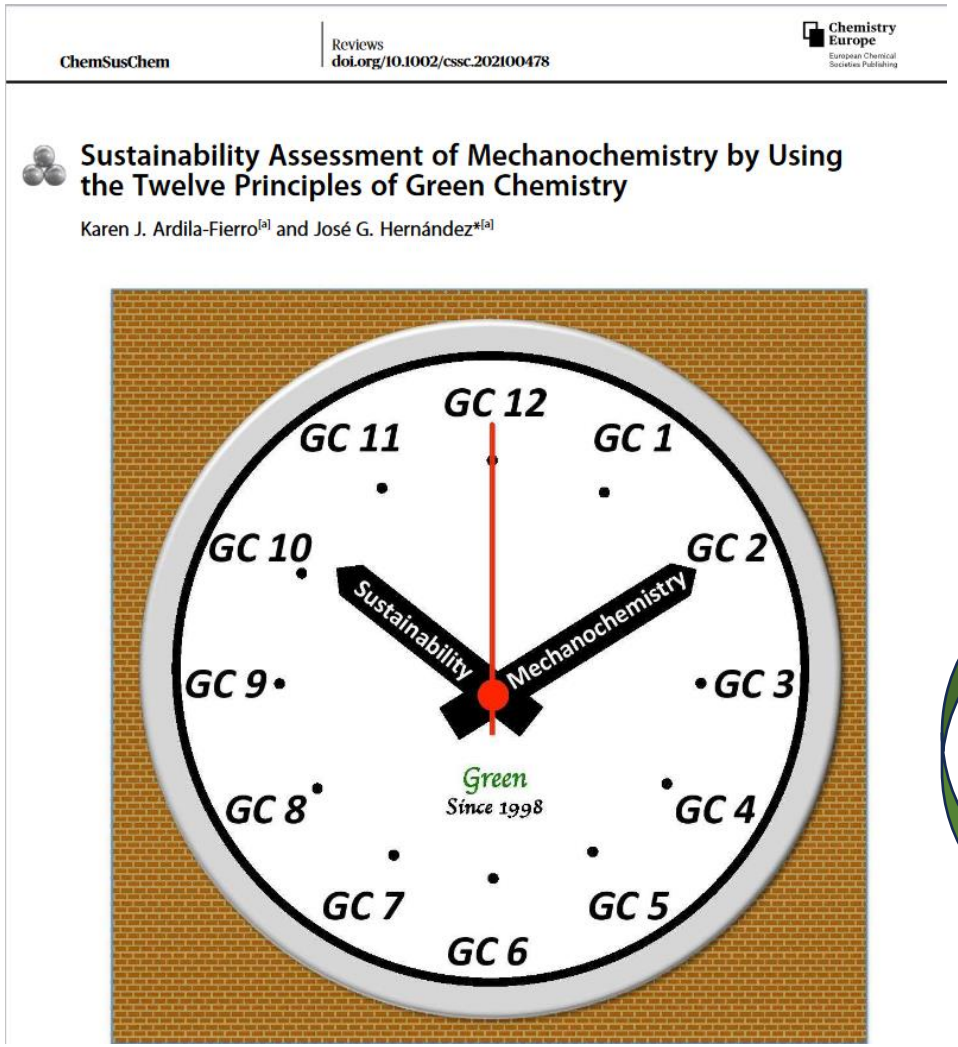
www.rsc.org/chemicalscience

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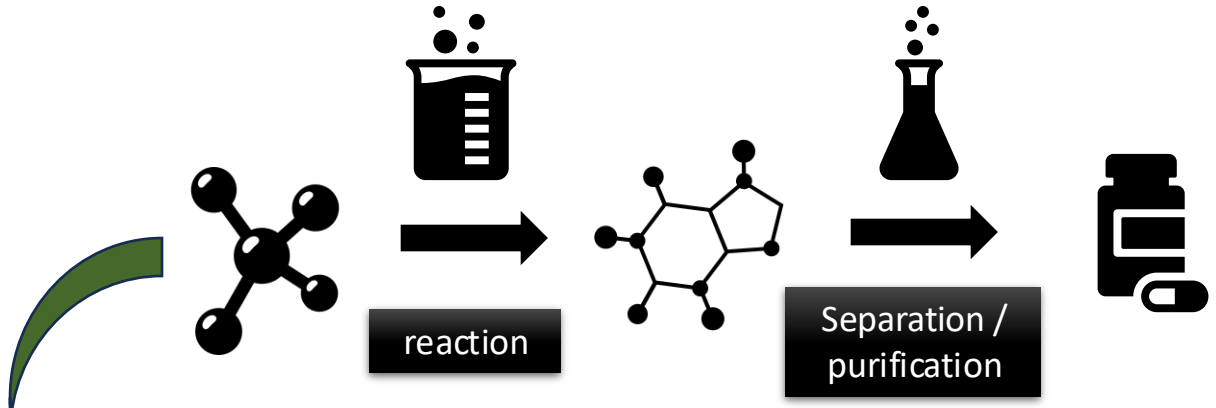
Accelerated aging: a low energy, solvent-free alternative to solvothermal and mechanochemical synthesis of metal–organic materials†

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Mechanochemistry and Assessment



"The association between mechanochemistry and Green Chemistry often originates from the solvent-free nature of most mechanochemical protocols, which can reduce waste production. However, mechanochemistry satisfies more than one of the Principles of Green Chemistry."



1. Solvent use reduction (reaction, for separation maybe)
2. Energy can be lowered
3. Safer chemicals
4. Other benefits

1. Thermal energy reduction
2. No need to remove the solvent

K. J. Ardila-Fierro, J. G. Hernández, *ChemSusChem* **2021**, *14*, 2145.

It’s important to use metrics for mechanochemistry



Mechanochemistry is in a Green Chemistry toolbox

Mechanochemists must demonstrate their method is better in the context of their work



Metrics



Weigh the importance of improvement