Bio-based Materials Research at SML

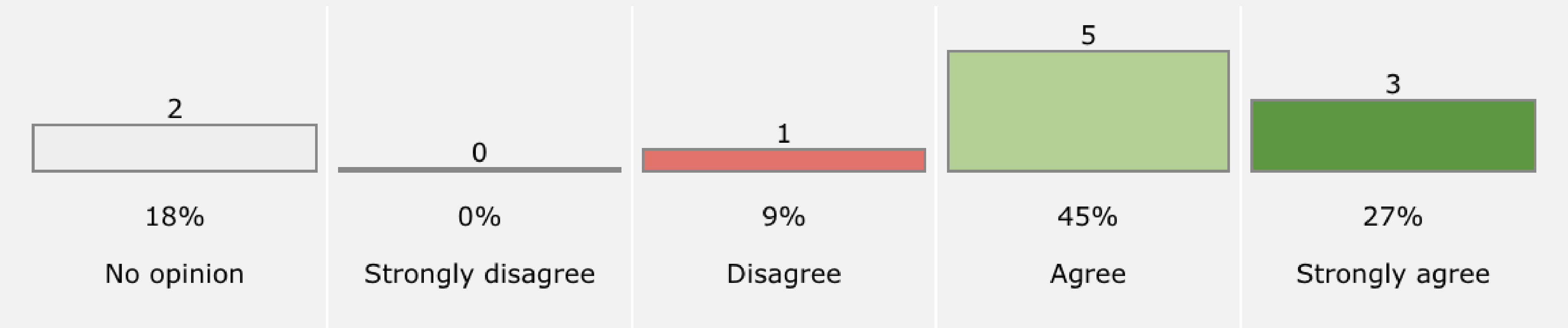
Tiffany Abitbol

2025

Indicative feedback

Year	2024-2025
Course	Sustainability and materials
Questionnaire	Indicative feedback of teaching (since 2022-2023)
Nb Registered	43
Nb Answered	11

The running of the course enables my learning and an appropriate class climate



Indicative feedback

- 10-15 pages looks like a lot for an equivalent of 1 credit
- Complicated course to follow as you speak very quickly, and there is a lot of information, what do we need to know for the midterm?
- Le cours est très interessant. Il me semble indispensable dans notre formation d'ingénieur et la prof est très agréable à écouter / le contenu est pertinent ! Cependant la charge de travail : 1 article de 15 pages à rédiger + 1 mid term + 1 travail de groupe, me semble un peu trop. La charge de travail correspond davantage à un cours à 4 crédits ou + ... Les exercices sont intéressants mais peut être revoir la charge de travail global .
- The class is very good, but I feel like the assignment has taken a lot of time
- The course content is interesting and essential. However, I hope it will not be used by students to engage in greenwashing by using sustainability concepts without actually addressing the problem during their career.
- The course is pretty interesting, however, the assigment is quite time consuming and a lot of research is needed to write 10-15 pages in 3,5 weeks.

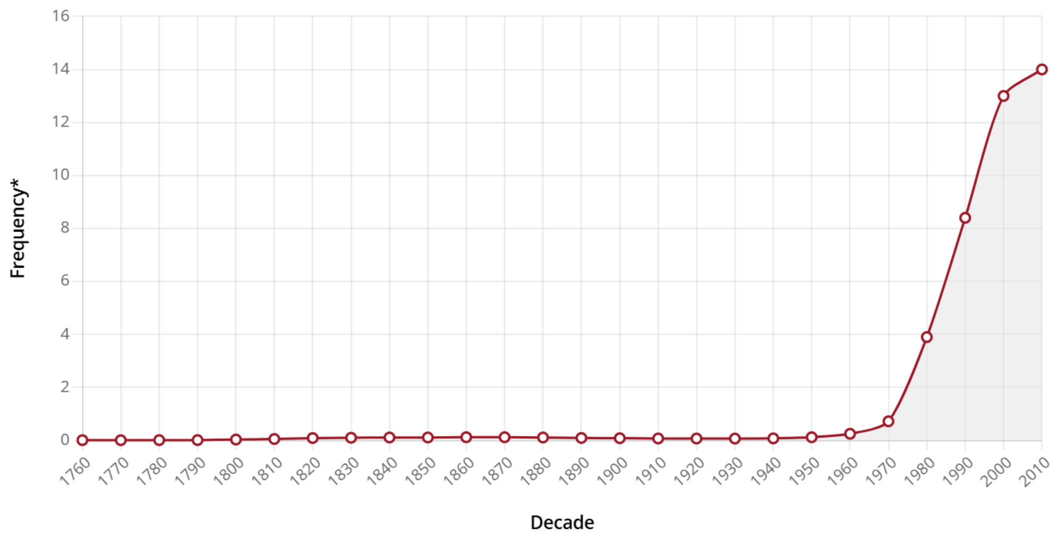
What's coming up

- April 2 - Guest lecture on biomaterials: Wolfram Bruck ✎ *Today – a subset of polymers*
- April 9 - Midterm ✎ *Questions? (no ceramics since we did not discuss; high level of April 2 and guests)*
- April 16 - Guest Activity on Teamwork: Valentina Rossi ✎ *Tiffany is absent. Meant to be in project team.*
- April 23 - Spring Break ✎ *Yay!*
- April 30 -Guest lecture: Padraig Murphy of Logitech ✎ *Tiffany will discuss plastics & composites*
- May 7 - Sustainability at EPFL: Anna Kounina Masse ✎ *Tiffany will discuss ceramics and a fun topic?*
- May 14 - Guest lecture: Glencore! (Elmira Imani and Dr. Marco Billia) ✎ *!!! Please attend !!!*
- May 21 - Final presentations ✎
- May 28 - Final presentations ✎

Remember: you both present and evaluate! Check schedule to avoid conflicts!

Sustainable Materials?

Frequency of *sustainable*, adj., 1760-2010



- About 8 times per million words

SML
SUSTAINABLE MATERIALS LAB

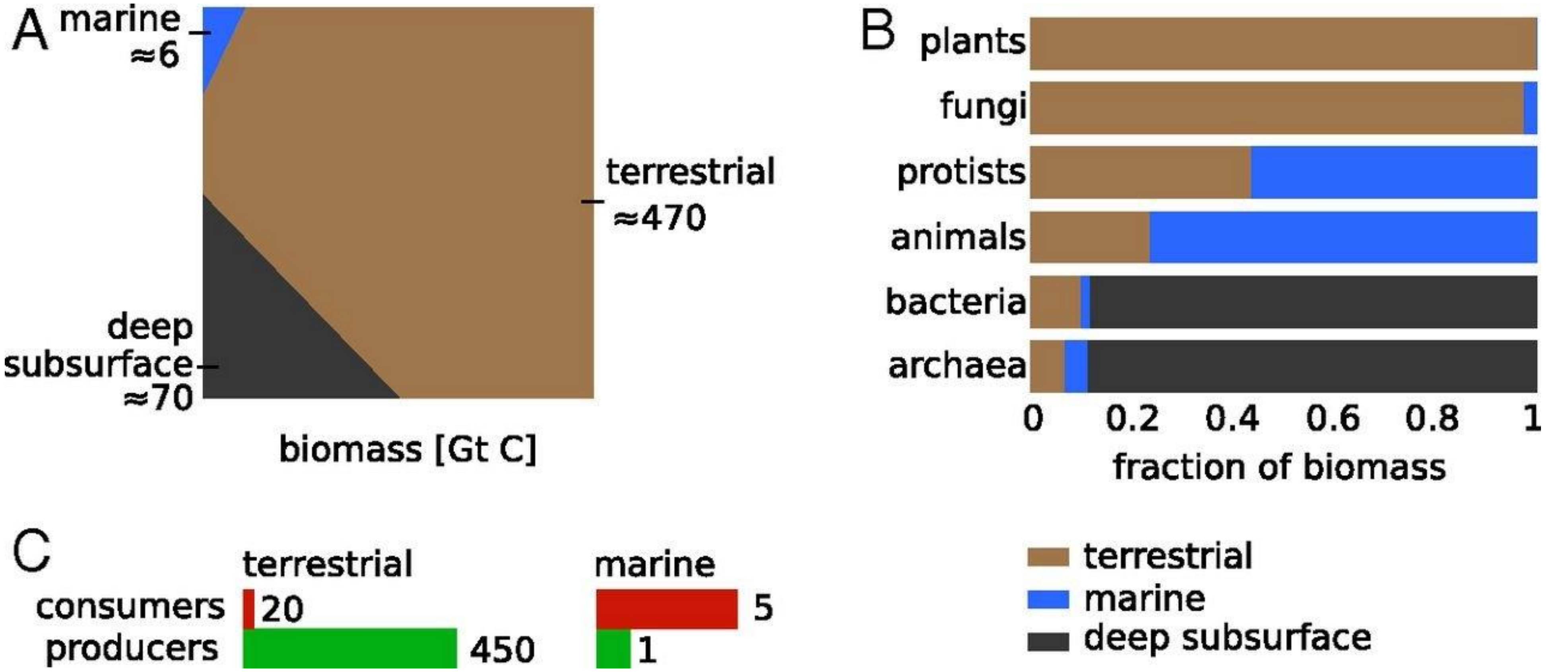
- Materials from renewable resources
- Materials from waste streams
- Biodegradable

[Sustainable from OED]

Outline

- **Cellulose**
- Cellulose nanomaterials
- Example: Cellulose nanomaterial films
- **Mycelium**
- Mycelium in materials science
- Example: Growing a composite from mycelium

Biomass on earth



Bar-On, Y. M., Phillips, R. & Milo, R. The biomass distribution on Earth. *Proc. Natl. Acad. Sci. U. S. A.* 115, 6506–6511 (2018).

Outline

- **Cellulose**
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- Example: Cellulose nanomaterial films
- **Mycelium**
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Cellulose in plants

- Most abundant biopolymer on Earth
- Composite
- Load bearing
- Hierarchical
- Pulp and paper chemistry for isolation of cellulose fibers
- Different plant cell wall components can be extracted and modified in different way

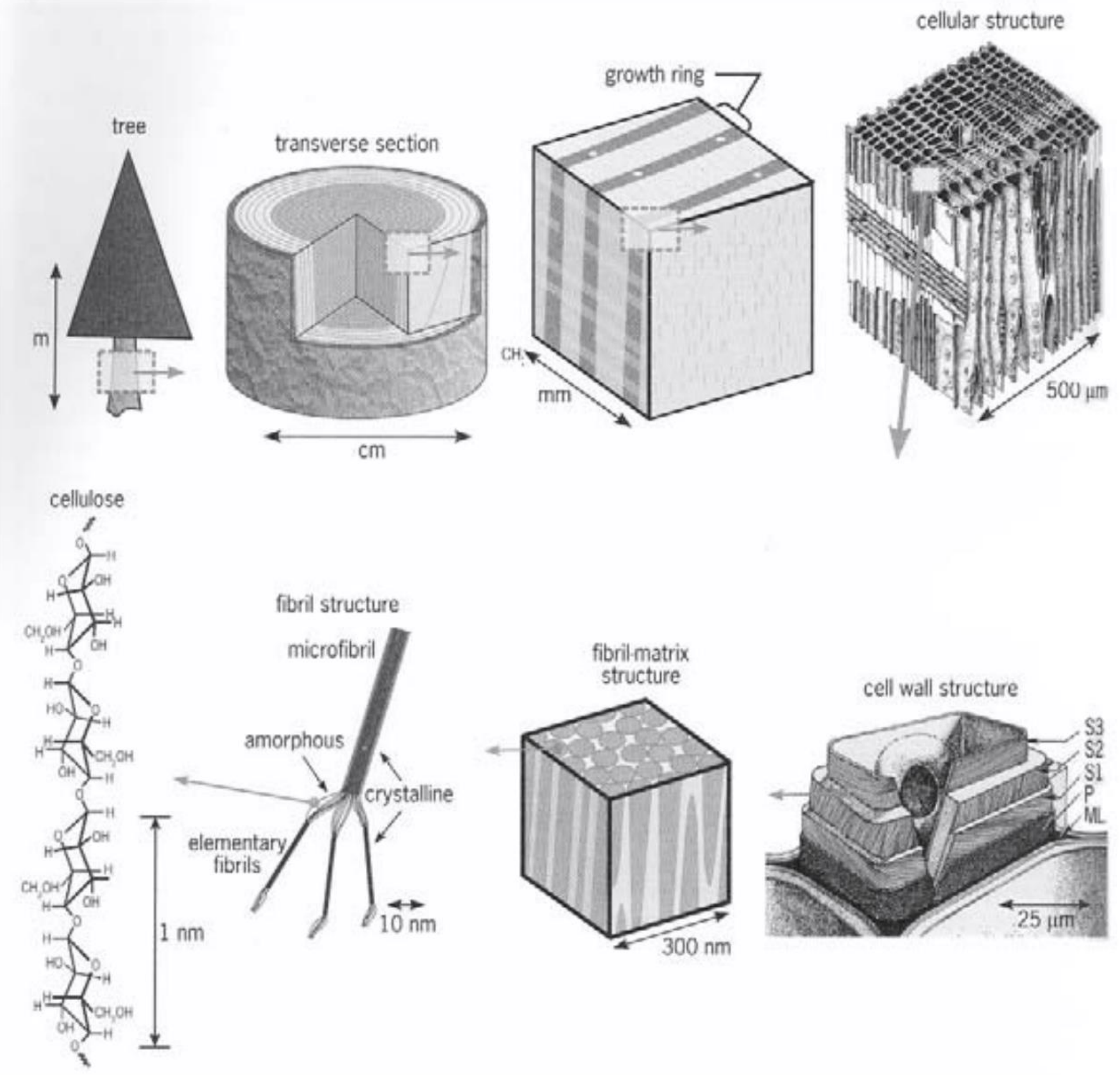
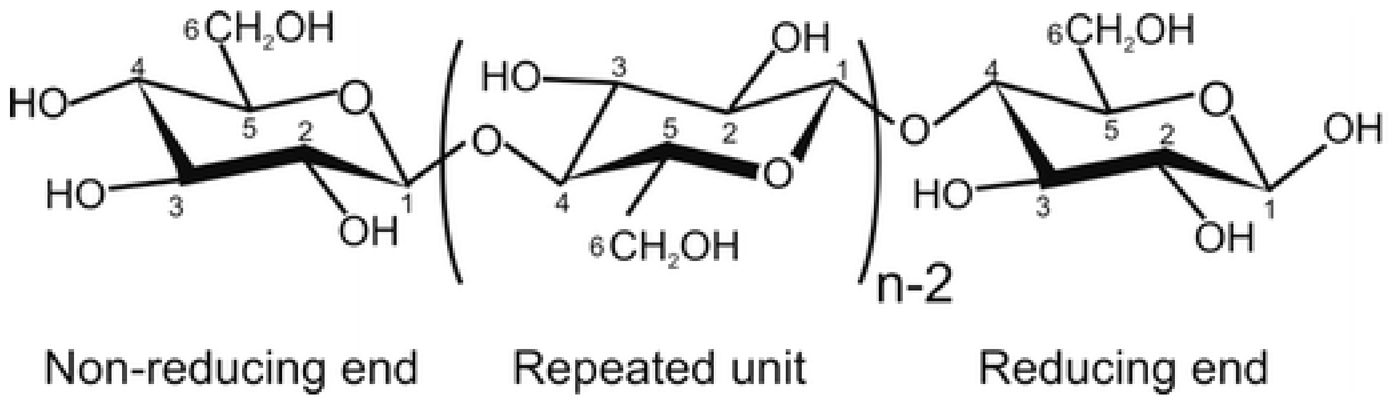


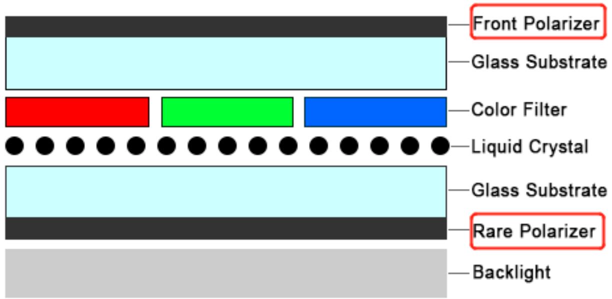
Fig. 1. Hierarchical structure of wood, showing the size scale of each structural feature within wood. The linear polymer chains of cellulose (30% of wood by weight) arrange to form cellulose fibrils, which are the base strengthening component within wood. ***(Adapted from R. J. Moon, C. R. Frihart, and T. Wegner, Nanotechnology applications in the forest products industry, Forest Prod. J., 56(5):4–10, 2006)***

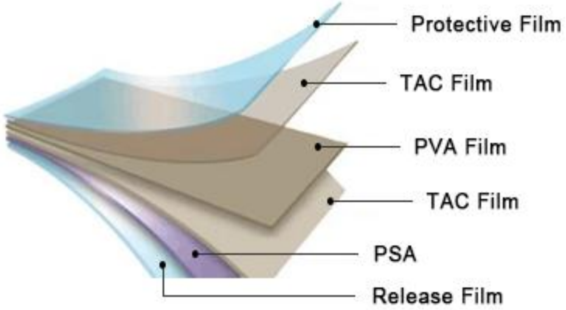
Cellulose



- Glucose is the repeat unit
- Asymmetric
- DP depends on source (e.g.,10000 for wood, 15000 for cotton)
- Crystalline
- Hydrophilic
- **Not easily solubilized, depolymerized, or synthesized**
- **More readily fragmented into nanoparticles**
- *can be modified to give cellulose-backbone polymers

Familiar cellulose products

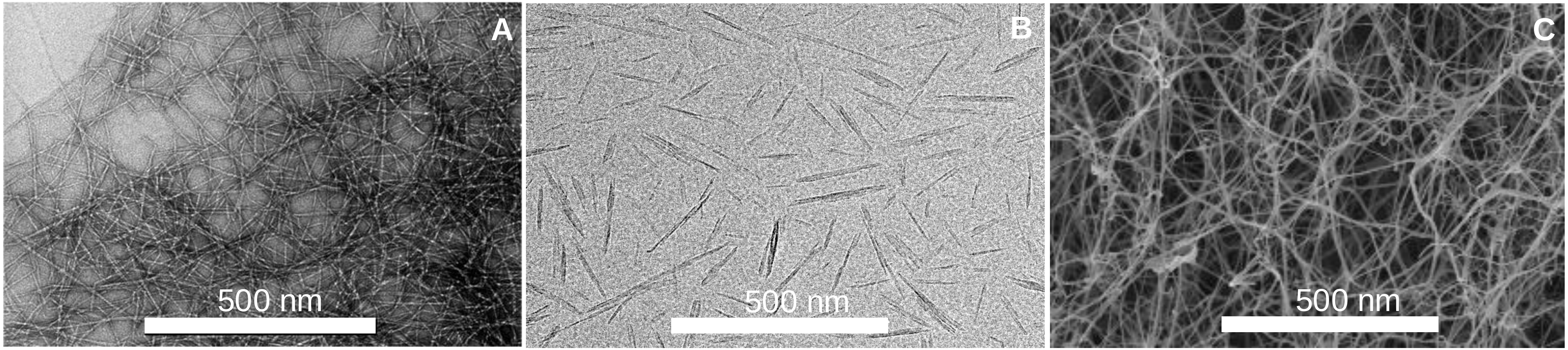




Diverse in form and function!

Nanocellulose

- Generic umbrella word hat encompasses all forms of nanoscale cellulose particles
  - Cellulose nanofibrils (CNF)
  - Cellulose nanocrystals (CNC)
  - Bacterial nanocellulose (BNC)
- Focus on nanocellulose from plants

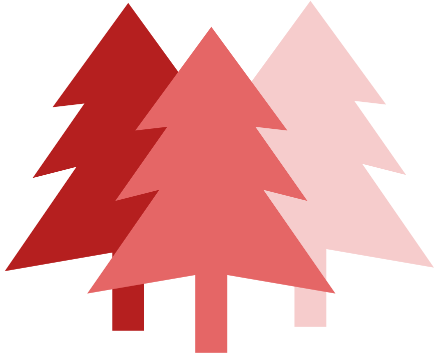


CNF CNC BNC

Klemm DO, Lindström T, Abitbol T, Kralisch D, Chapter 1 - The nanocellulose family, In Micro and Nano Technologies, Nanocellulose Based Composites for Electronics, Elsevier, 2021, Pages 1-14, ISBN 9780128223505,https://doi.org/10.1016/B978-0-12-822350-5.00001-1.

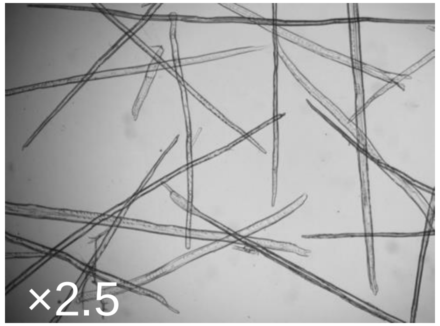
EPFL

Nanocellulose qualities



CELLULOSE CONTAINING BIOMASS

pulping

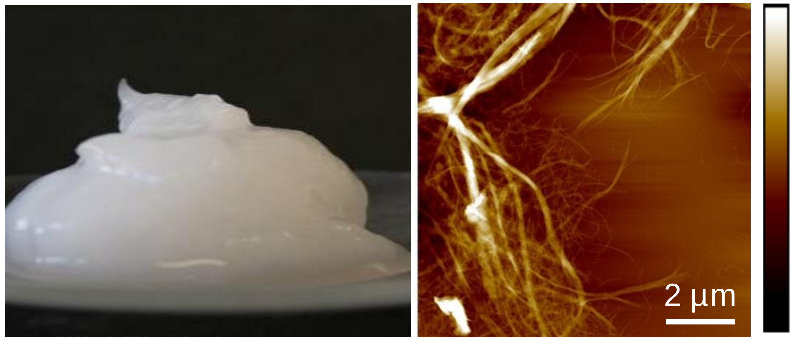


CELLULOSE-ENRICHED PULP

Enzymes & mechanical

ENZYMATIC CNF

150 nm

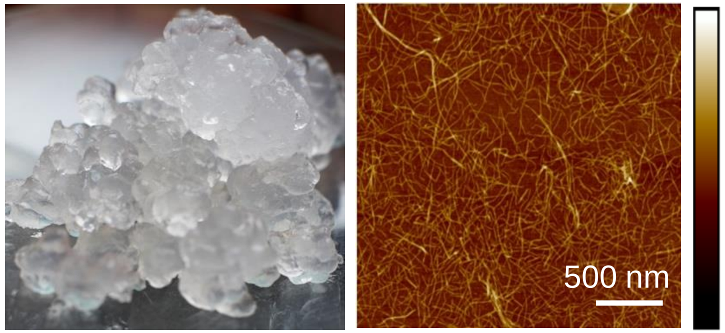


-150 nm

Chemicals & mechanical

OXIDIZED CNF

10 nm

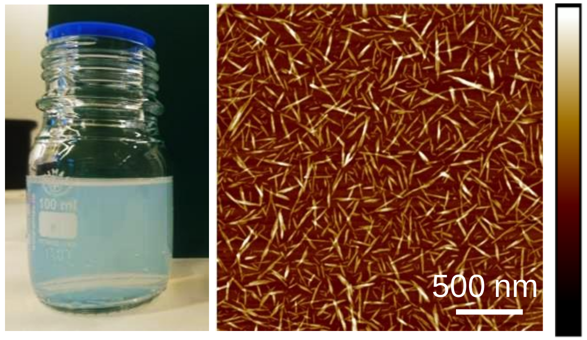


-10 nm

Degradation (usually acid)

CNC

10 nm

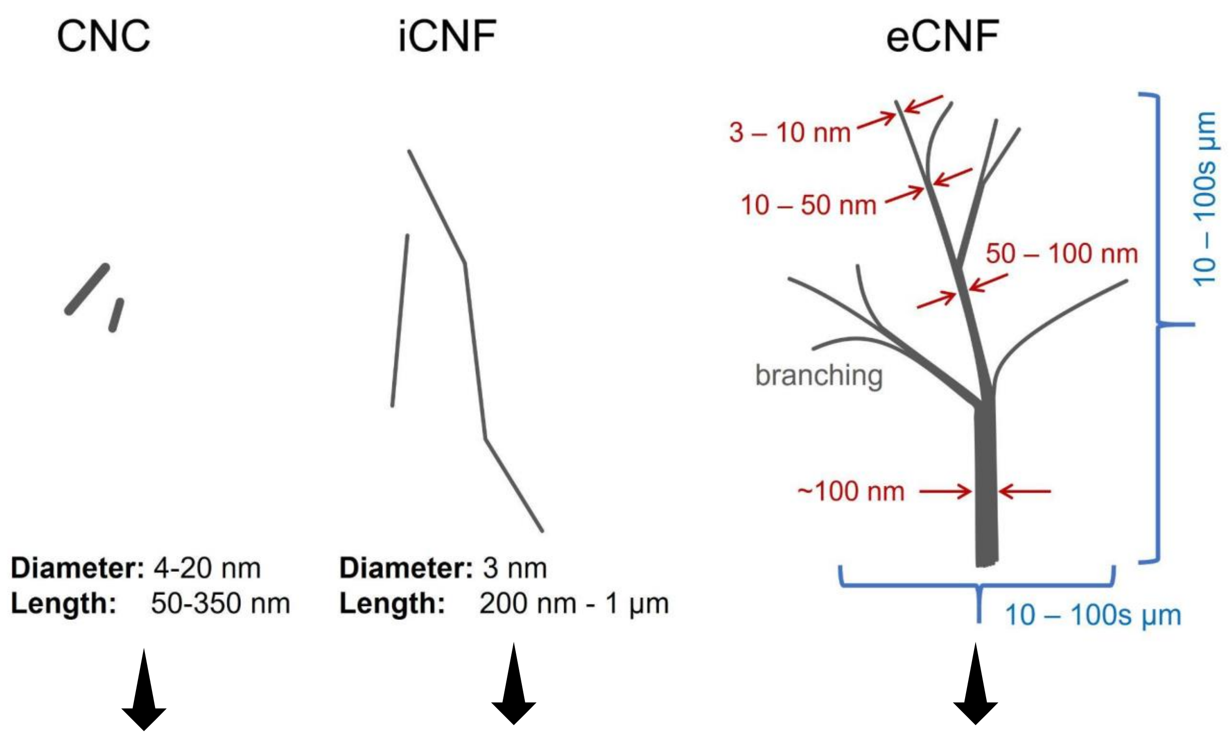


-10 nm

CNF = cellulose nanofibril
CNC = cellulose nanocrystal

Nanocellulose

- Individualized versus bundled or entangled particles



Usually acid hydrolysis, usually sulfuric acid

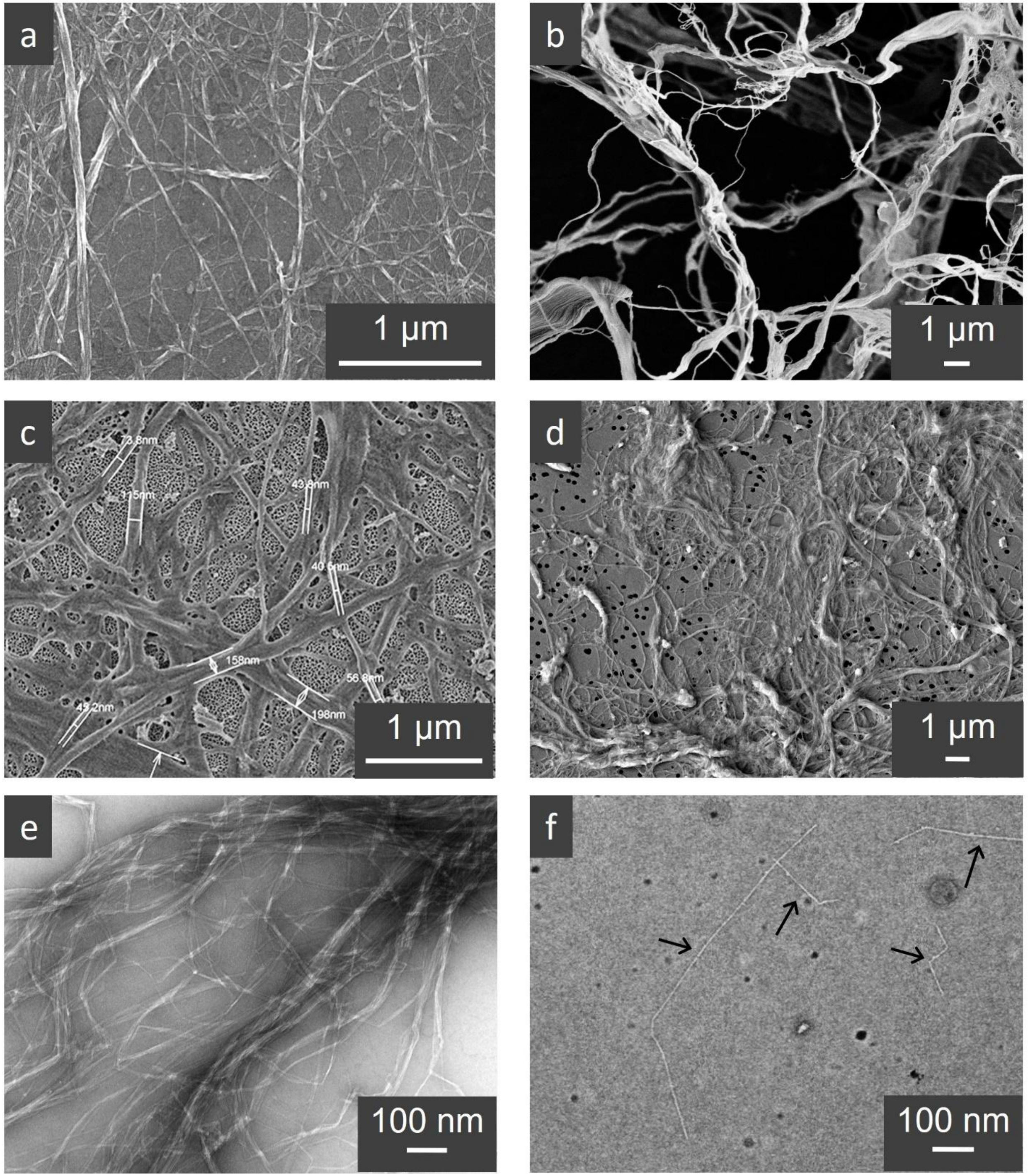
Chemical pretreatment, usually oxidation

Mild or no pretreatments, enzyme pretreatments

From: Setting priorities in CNF particle size measurement: What is needed vs. what is feasible, under review at TAPPI Journal 2022.

CNFs

- Material diversity across and within different preparation approaches
- Characterization is not straight-forward
- Individual or entangled
- Combination of techniques needed to describe the material

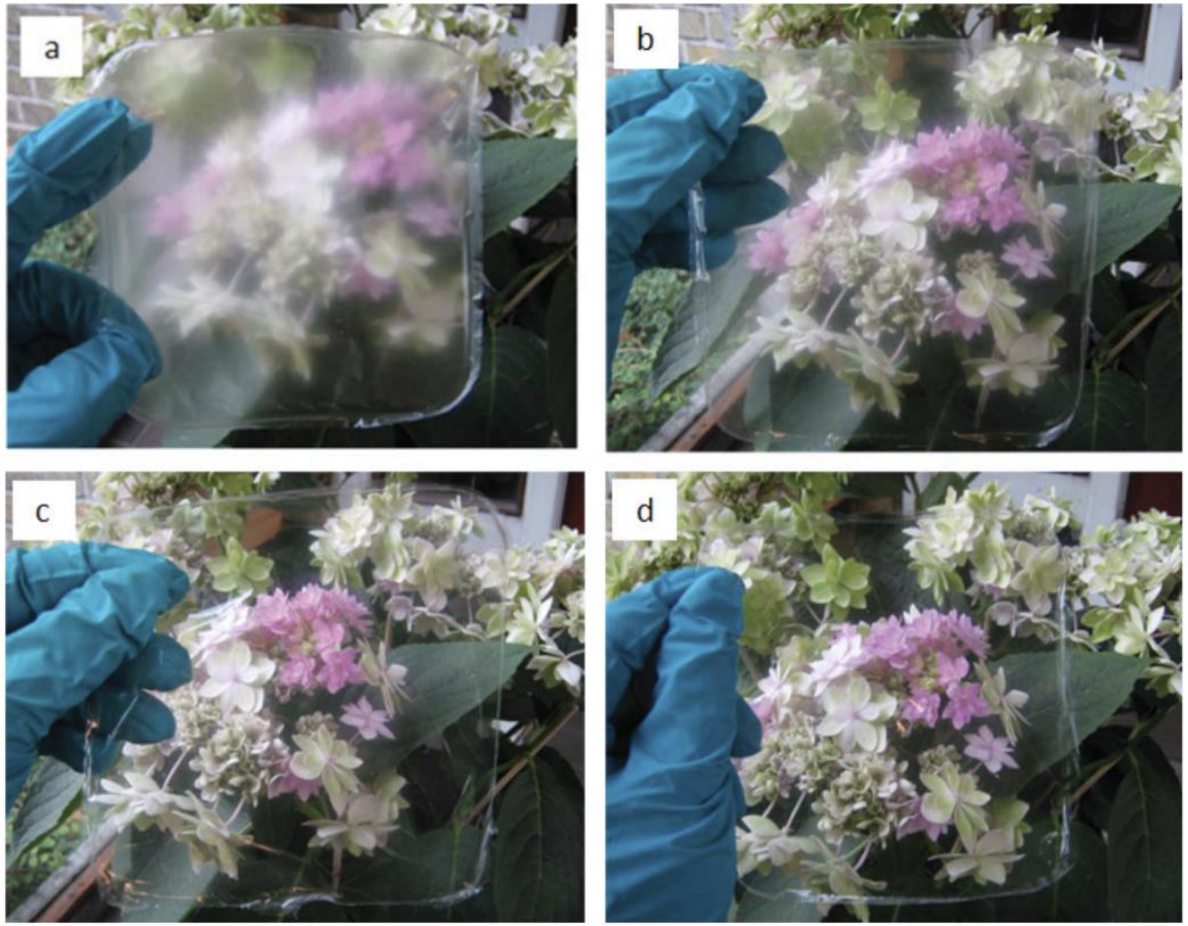


From: Setting priorities in CNF particle size measurement: What is needed vs. what is feasible, under review at TAPPI Journal 2022.

CNF films

- High strength
- Optically tunable
- Water holding and responsive
- Shear alignment
- Gas/grease barrier

Fine points depend on – fibrillation (surface area, nano-yield, aspect ratio) and colloidal stability (surface charge)

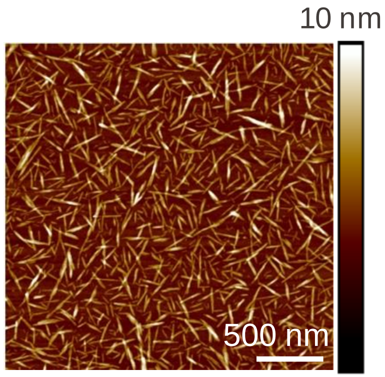


Carboxymethylated CNF:
(a) 0p
(b) 1p
(c) 2p
(d) 3p

J. Appl. Polym. Sci., 119 (2011), pp. 2652-2660, 10.1002/app.32831

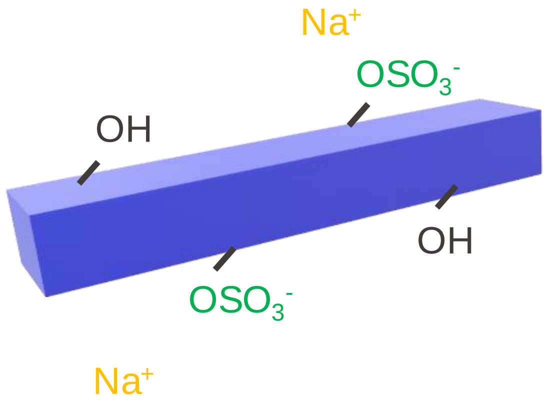
CNC properties

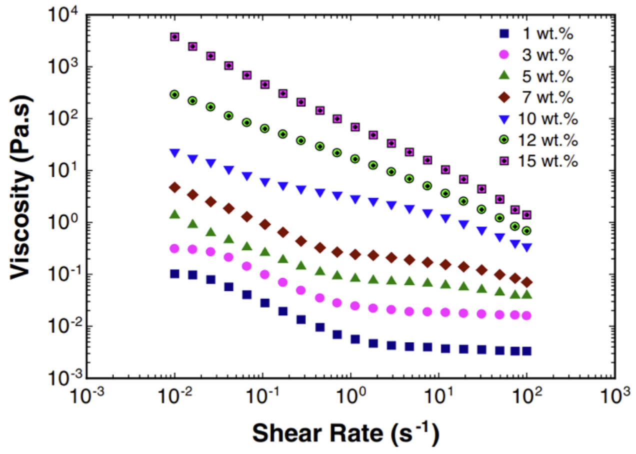
- High crystallinity
- High Young's modulus
- 100% nano-yield
- Hydrophilic
- Surface charge groups
- Colloidally stable in water
- Chemically modifiable
- Shear thinning viscosity
- Alignment in external fields
- Liquid crystalline self-assembly



100% nano

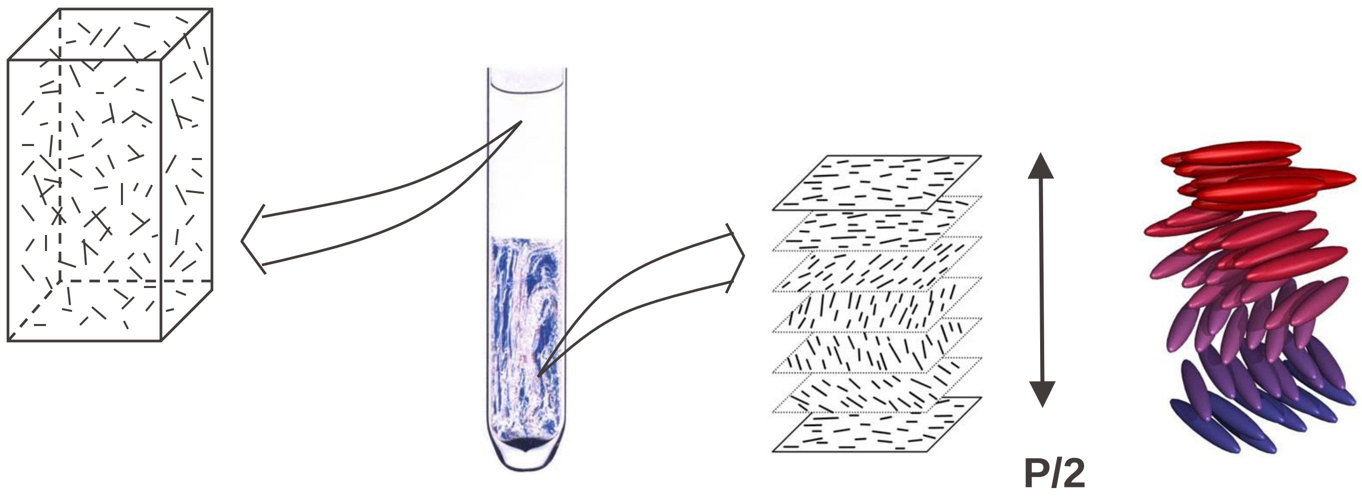
CNC = a bundle of cellulose chains with non-native surfaces





Shafiei-Sabet *et al.* Cellulose 2014, 21, 3347–3359.

Liquid crystalline self-assembly in suspension

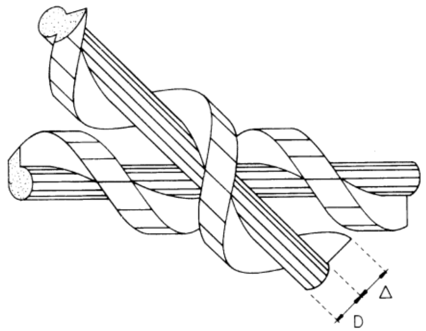


- Water
- Concentration driven
- Onset @ c*
- Always left-handed

Dong et al., Langmuir **12**, 1996, p.2076

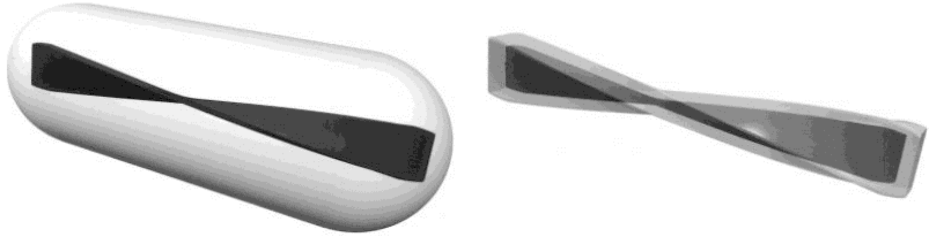
Why?

- Particle shape



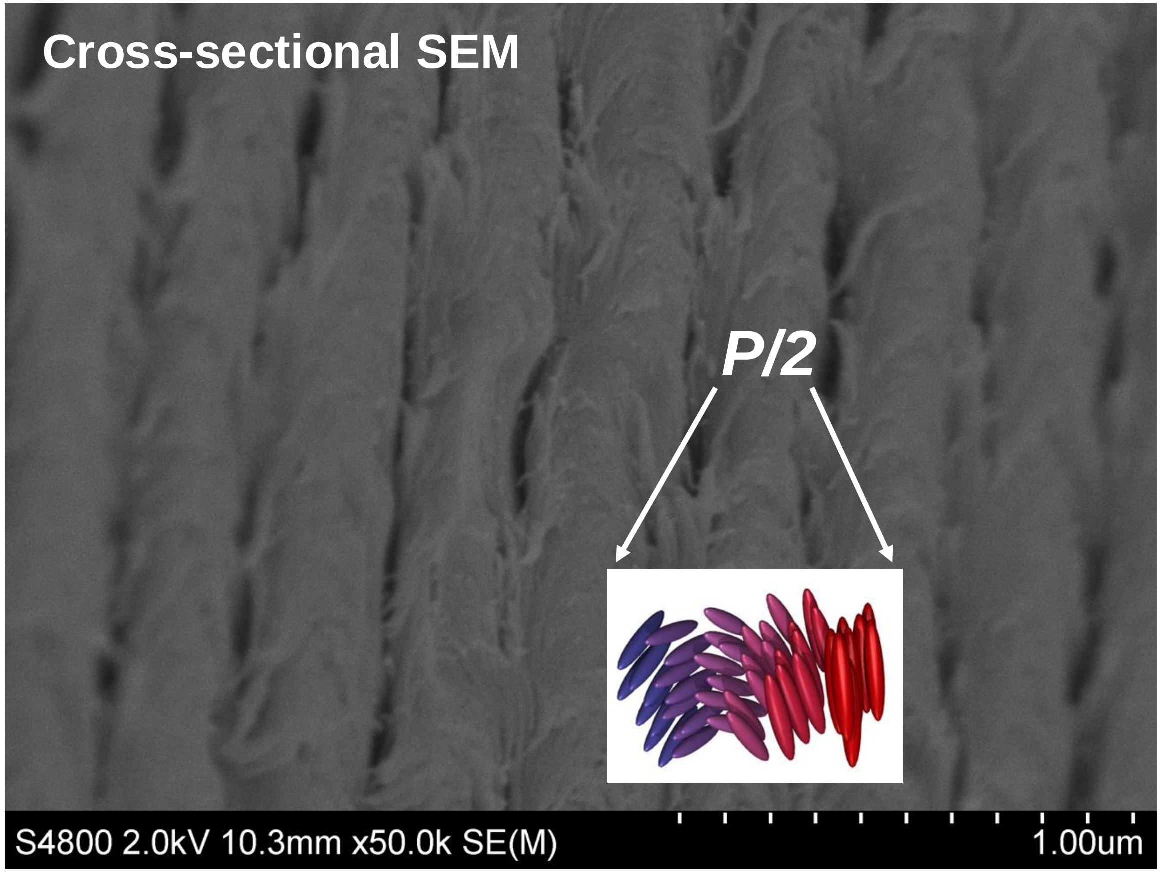
Straley, Phys. Rev. A **14**, 1976, p.1835

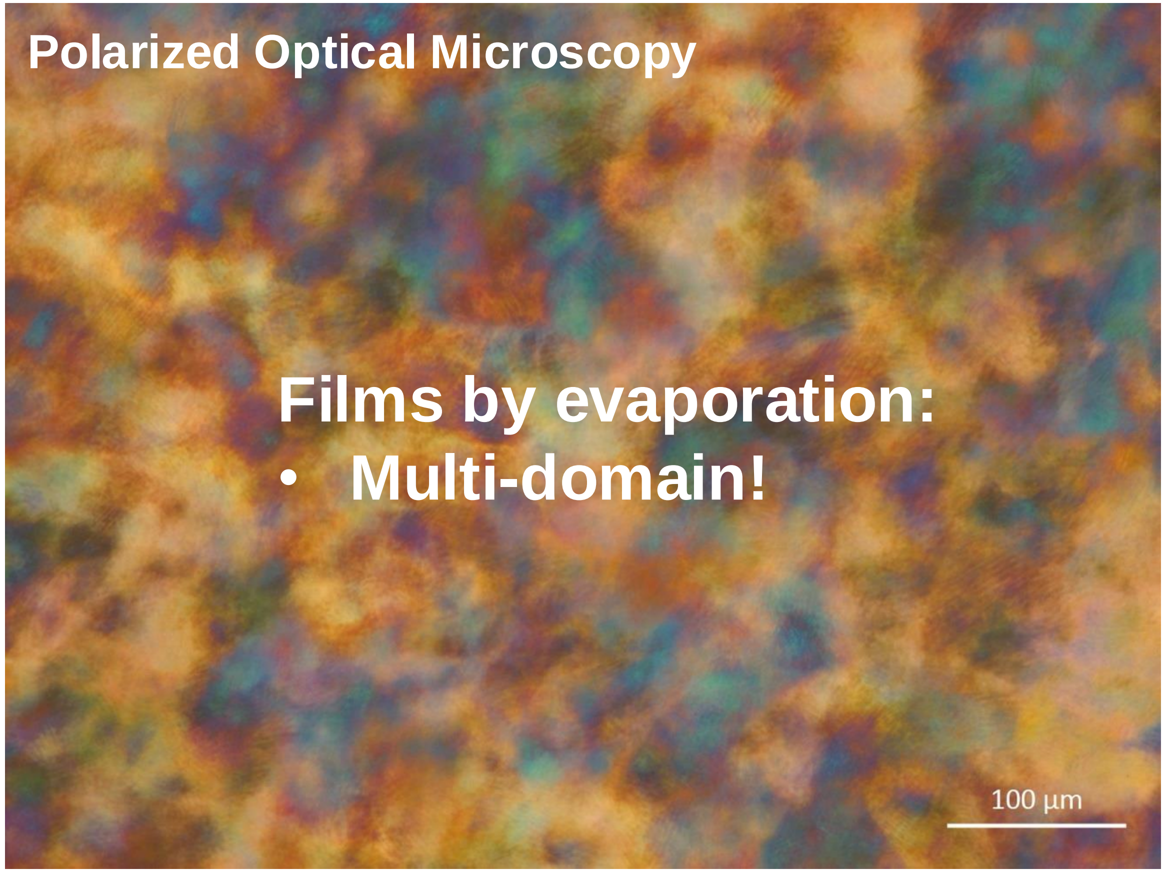
- Electrostatic double layer/screening effects



Araki & Kuga, Langmuir **17**, 2001, p. 449

Chiral nematic films





Structure color films

$\lambda = n P$ (90° to surface)

Transparent or colored and iridescent

- [CNC]
- [electrolyte]
- [additives]
- Sonication energy
- Evaporation rate
- …

Take aways on cellulose films

- Many different types of materials fall under the nanocellulose category
- By breaking down cellulose fibers into nanomaterials, we can work with them in liquid suspensions
- The properties of the suspensions and the materials that they form are highly dependent on the properties of the nanomaterials

Outline

- **Cellulose**
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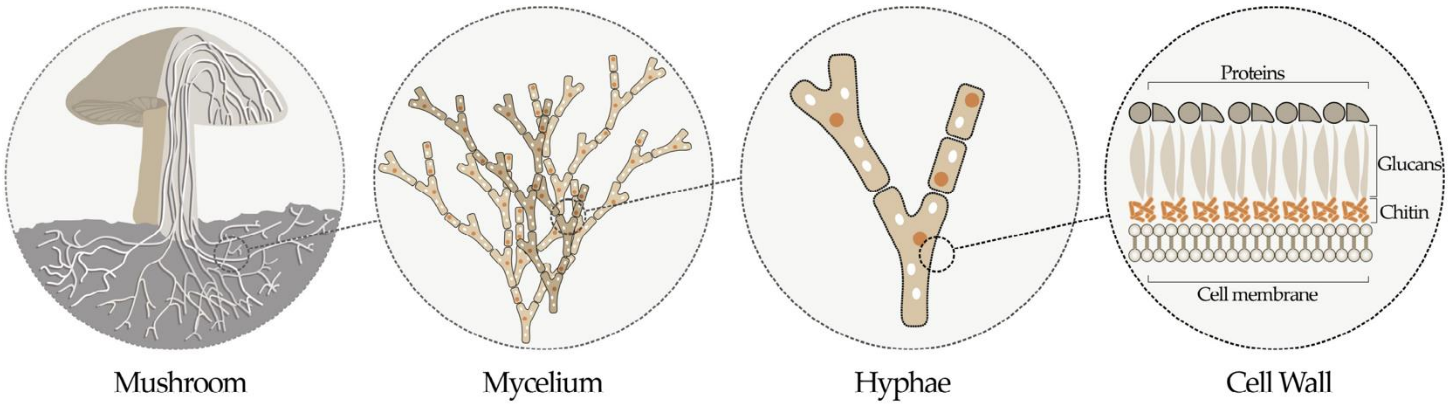
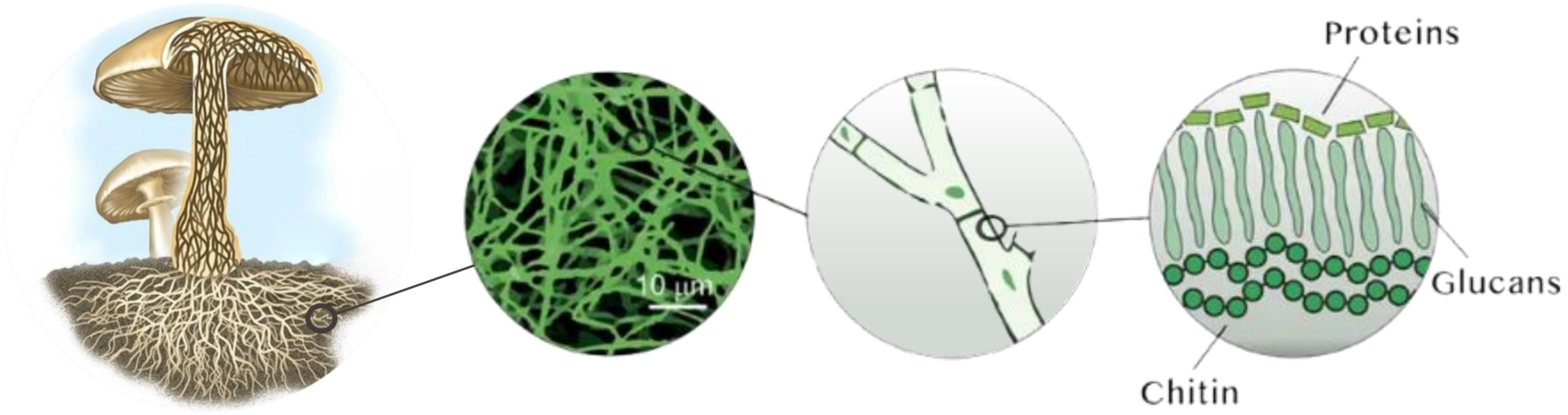
Mycelium cell wall



- Filamentous fungi are composed of elongated cells (eukaryotic) called hyphae
- A network of hyphae is referred to as mycelium
- Fungi are heterotrophs
- Like plant cells (and algae and bacteria), hyphae have a cell wall that serves as structural support: the cell wall is critical in withstanding the effects of osmotic pressure, exerting an opposing force, called **turgor pressure**, that prevents excessive swelling of the cell and lysis

Mohseni et al., Biomimetics **14** (2023).

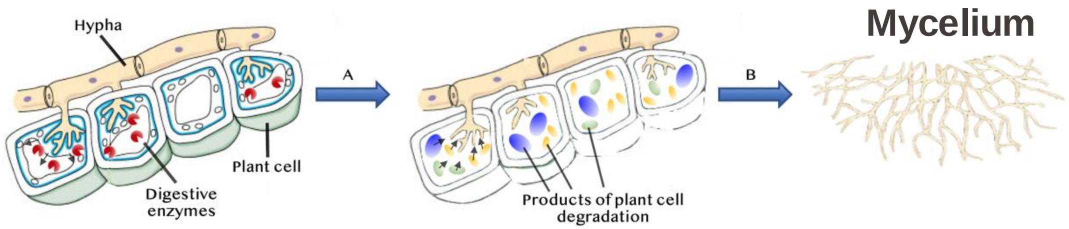
Mycelium cell wall

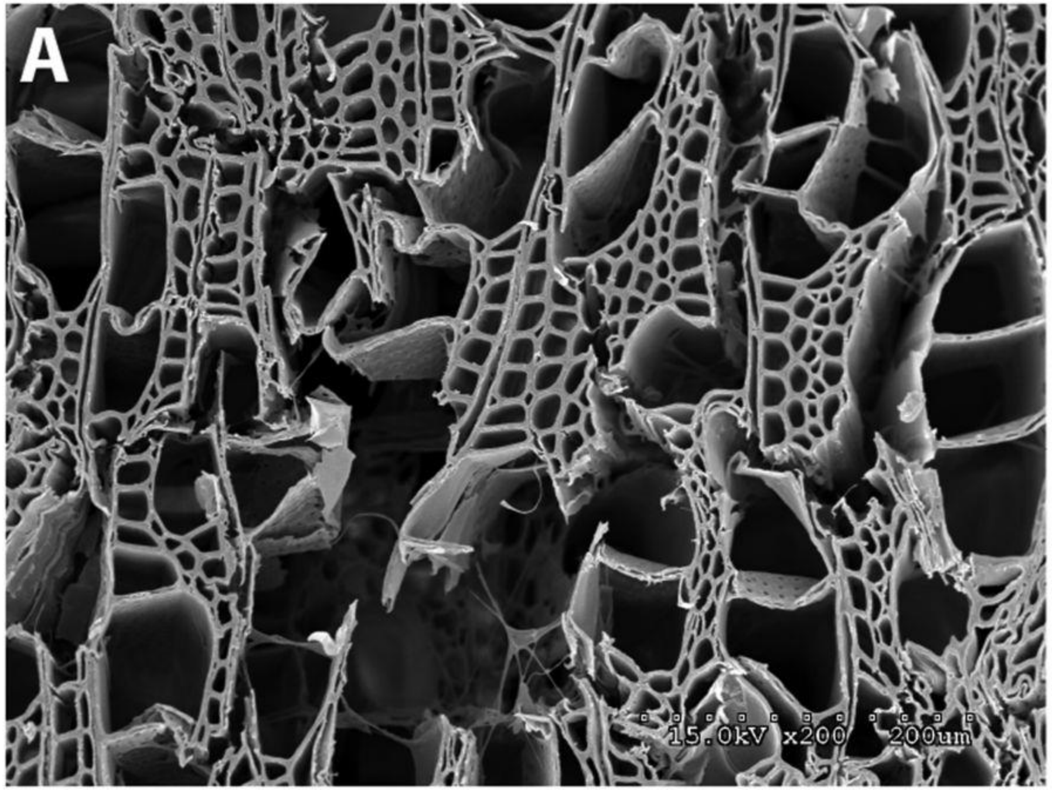


- Fungal cell wall components can be extracted
- Chitin and glucans are useful biopolymers: e.g., used to produce chitosan
- Chitin is insoluble in water but can be broken down into water-dispersible nanomaterials: ChNC and ChNF (chitin nanomaterials)
- The quality (purity, crystallinity, DP, size, rheology, etc.,) of these materials depends on source and extraction treatments

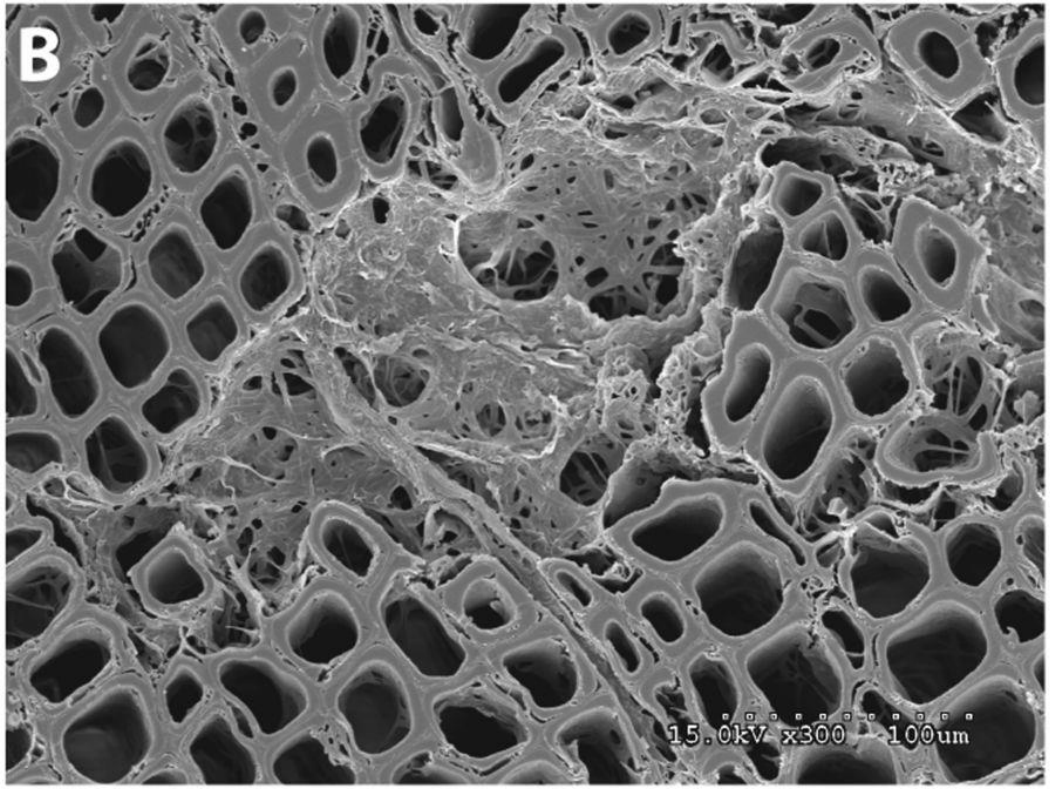
Haneef, M. *et al.*. *Sci Rep* **7**, 41292 (2017).

Wood decaying fungi





(A) *B. botryosum* on aspen wood with vessel, fiber, and parenchyma cell walls degraded. Mycelia are visible growing through the voids.



(B) *J. argillacea on pine showing an area where the fungus has caused a localized simultaneous decay of the cells. Residual cell wall material and mycelia fill the degraded zone.*

Riley et al., Biological Sciences **111** (2014).

Mycelium cultivation

Nutritious woodchip substrate

Radially growing mycelium front

Attias et al., Journal of cleaner production **246** (2019).

- In solid state = **lightweight material** consisting of a filamentous mycelium network and any leftover substrate - *key to mechanical performance*

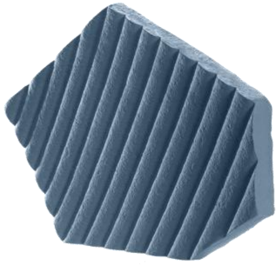
Key attributes for materials:

- **Balance between digestion & binding**
- **Shapeability**
- **Upcycling waste**

Mycelium products

BOLT THREADS

MYCOWORKS

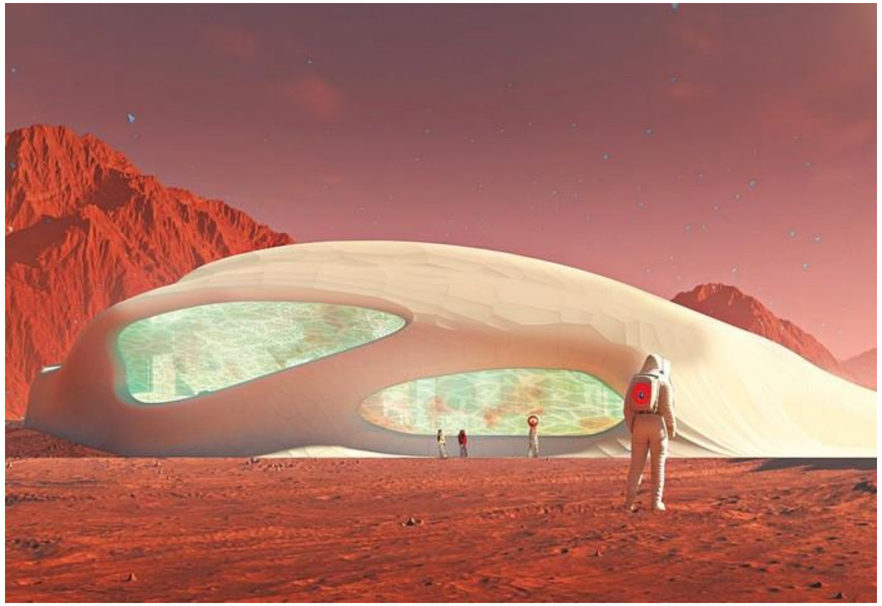


ecovative

mogu
RADICAL BY NATURE

EPFL

Mycelium off planet



Mycotechture

https://cen.acs.org/biological-chemistry/biochemistry/Marvelous-mycelium/102/i32

NASA advances research to grow habitats in space from fungi

by Lynn Rothschild, NASA

Bricks produced using mycelium, yard waste and wood chips as a part of the …

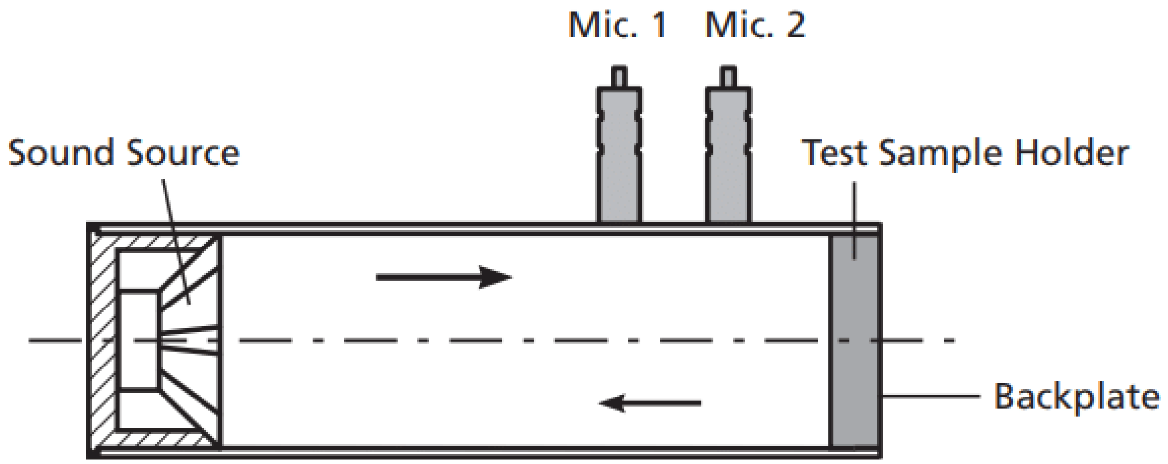
As NASA prepares for long-duration missions to the moon and Mars for the benefit of all, a habitat-growing concept selected Wednesday by the agency could help "grow" homes using fungi for future explorers.

https://phys.org/news/2024-06-mycotecture-planet-en-route-moon.html

Measuring sound: Sound absorption coefficient

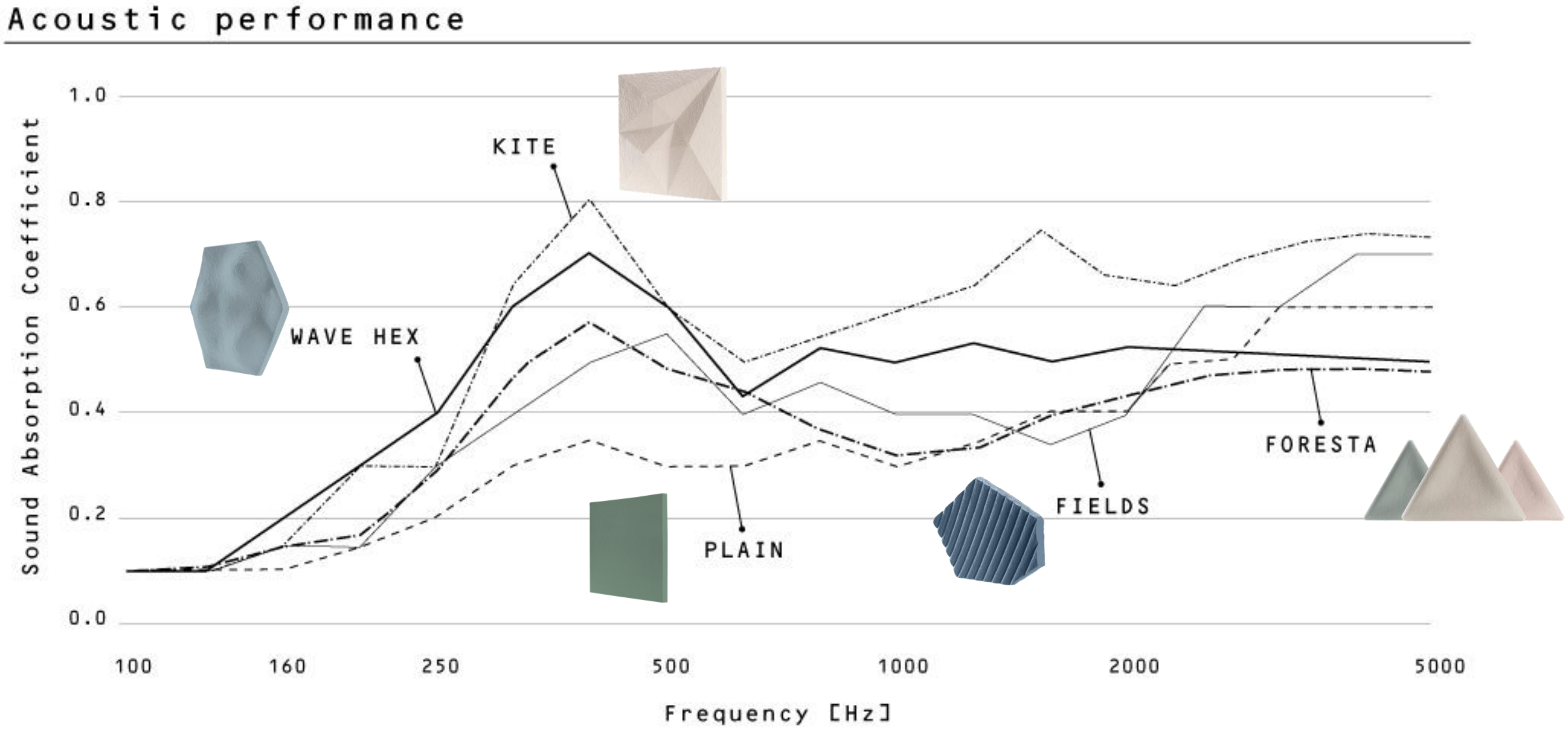
- Ranges from 0 to 1
- Measures how much sound a material absorbs versus reflects
- 0 = total reflection
- 1 = total absorption

- 2 microphone impedance tube set-up
- Sound source at one end and material at other end
- Two mics to measure incident and reflected waves



Lepak et al., Conference proceedings: Acoustic Performance of Additively Manufactured Reeds as absorbers (2018).

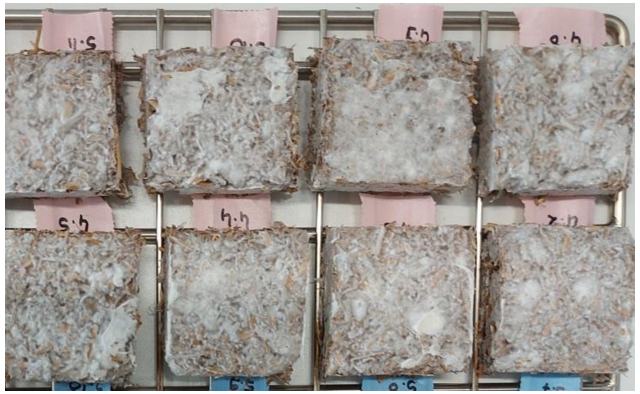
Porous sound absorbers from mycelium

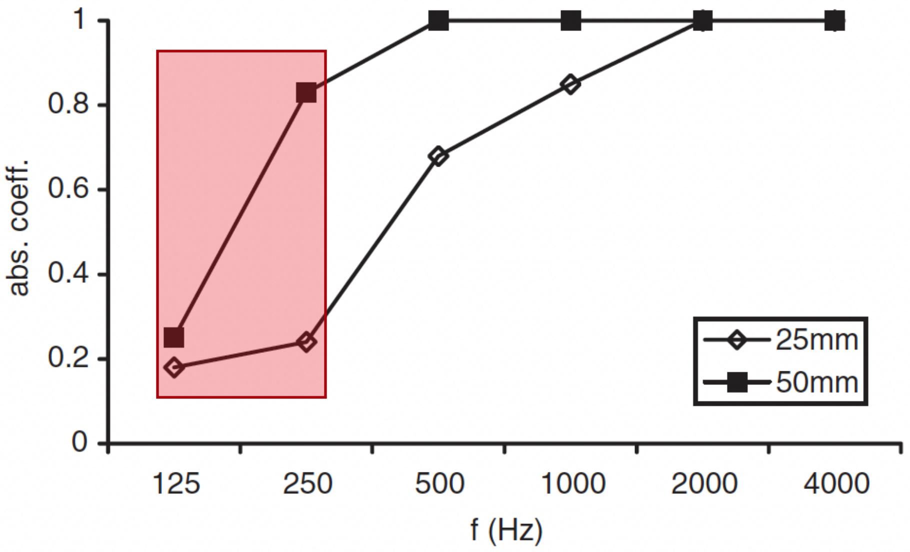


mogu.bio

Porous sound absorbers

- Mycelium-bound composites are porous
- Sound waves move through pores, dissipating sound energy by friction
- Larger cavities have better low frequency absorption (and vice versa)
- Low frequency sounds can be a blind spot for porous absorbers because their pores/cavities are too small



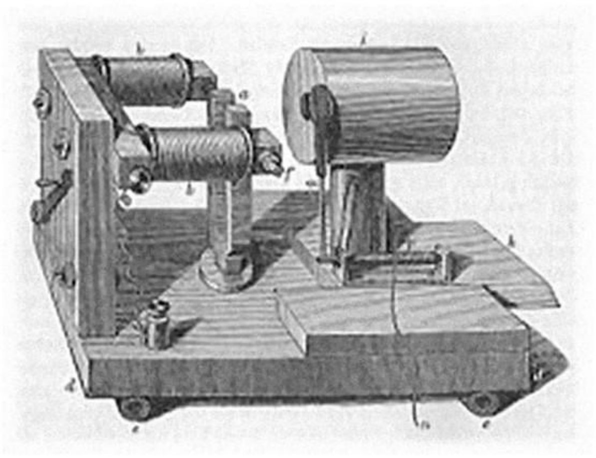


Cox and D'Antonio, 2005

Some examples of low frequency noise:

- Rumbly sounds
- Refrigerators
- Deep voices
- Growls
- Lawn mowers
- Thunder

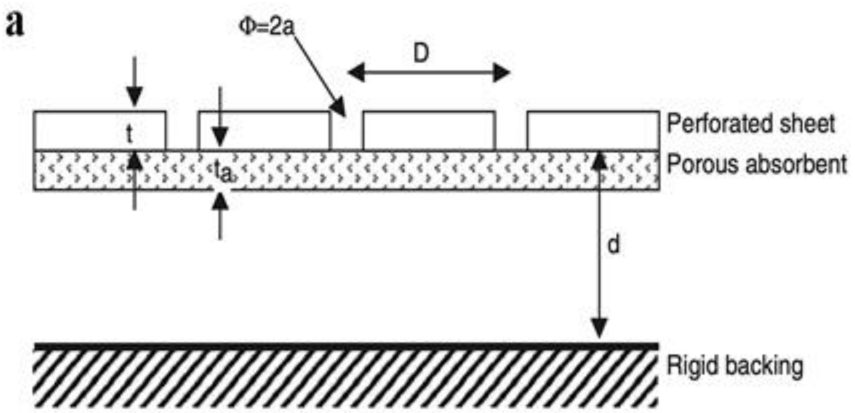
Helmholtz resonance to low-frequency sound absorption



$$f = \frac{c}{2\pi}\sqrt{\frac{S}{lV_0}}$$

Where c = the speed of sound, S = the area of the hole, l = the length of the hole (thickness of wall that the hole penetrates), and V_0 = the volume of the cylinder

Perforated sheets to add Helmholtz resonance to porous absorbers:



- Area, volume, and length of cavity

Helmholtz absorber

Lignocellulose waste converted to sound absorbers

Rye straw

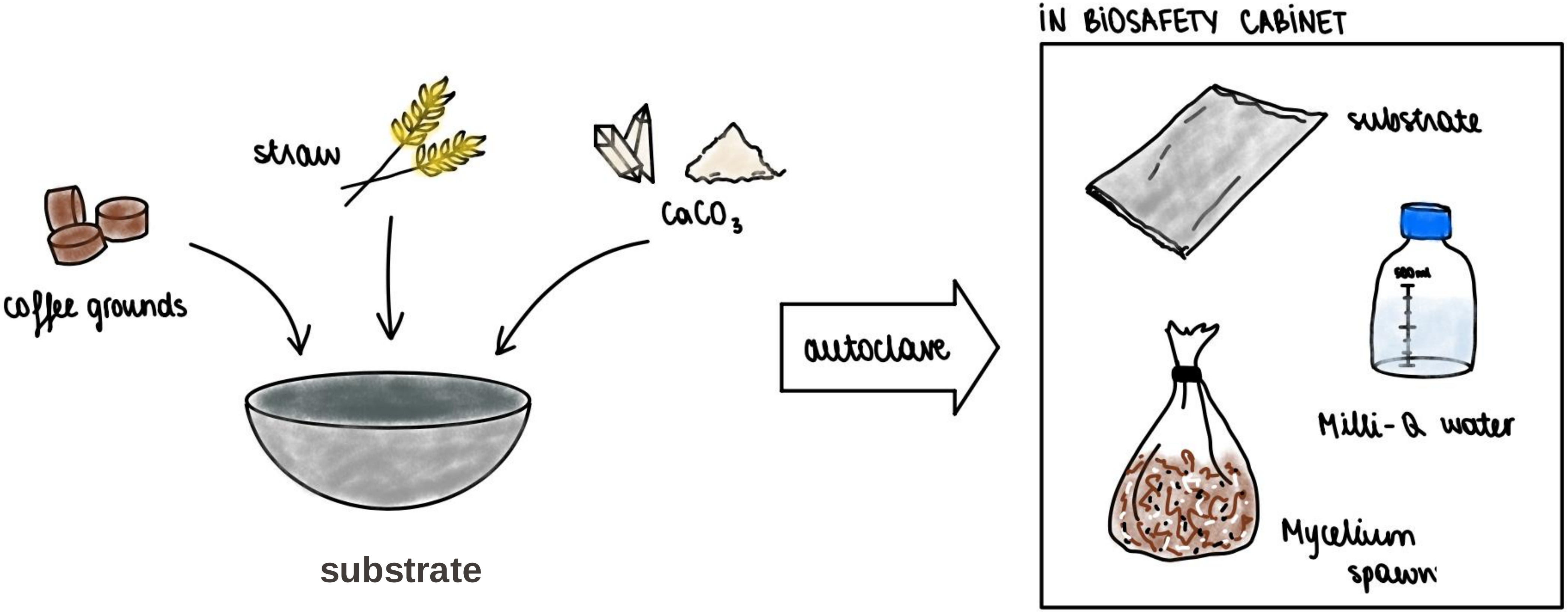
Spent coffee ground

Calcium carbonate

+

Commercial mycelium spawn
Ganoderma Lucidum

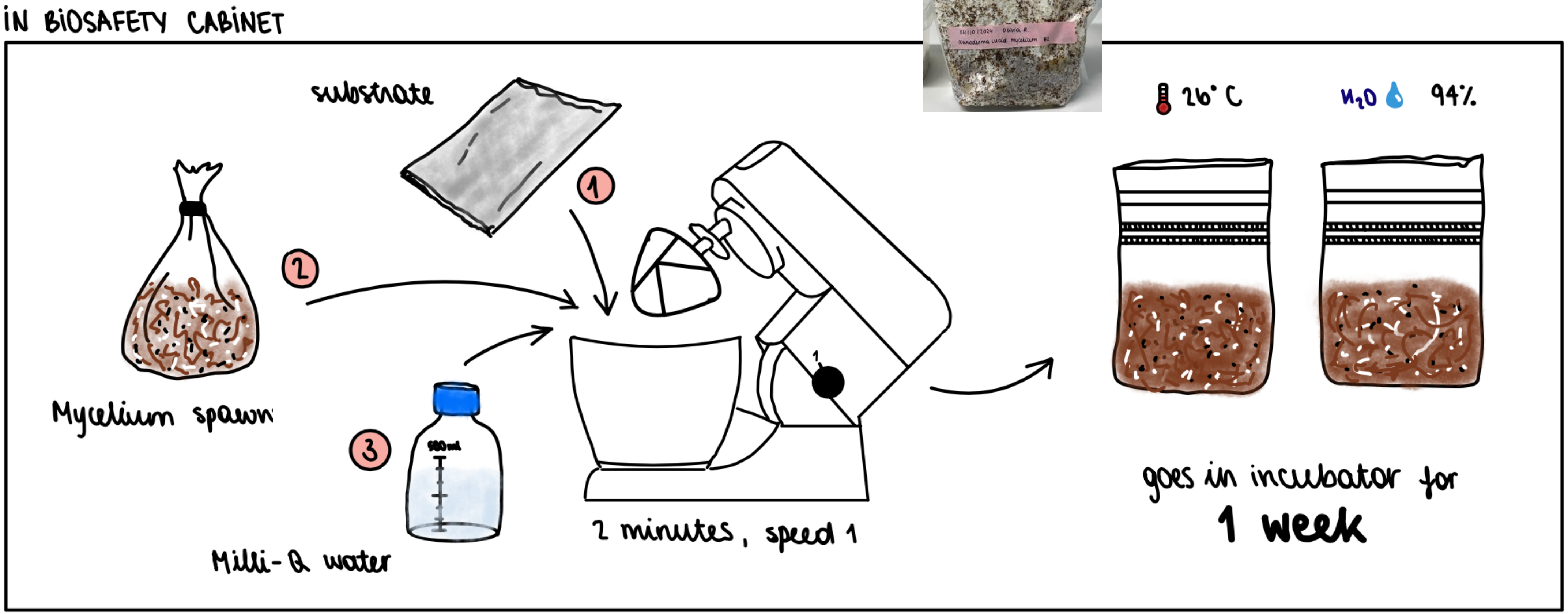
Inoculation



substrate

c/o Olivia Rouiller, EPFL

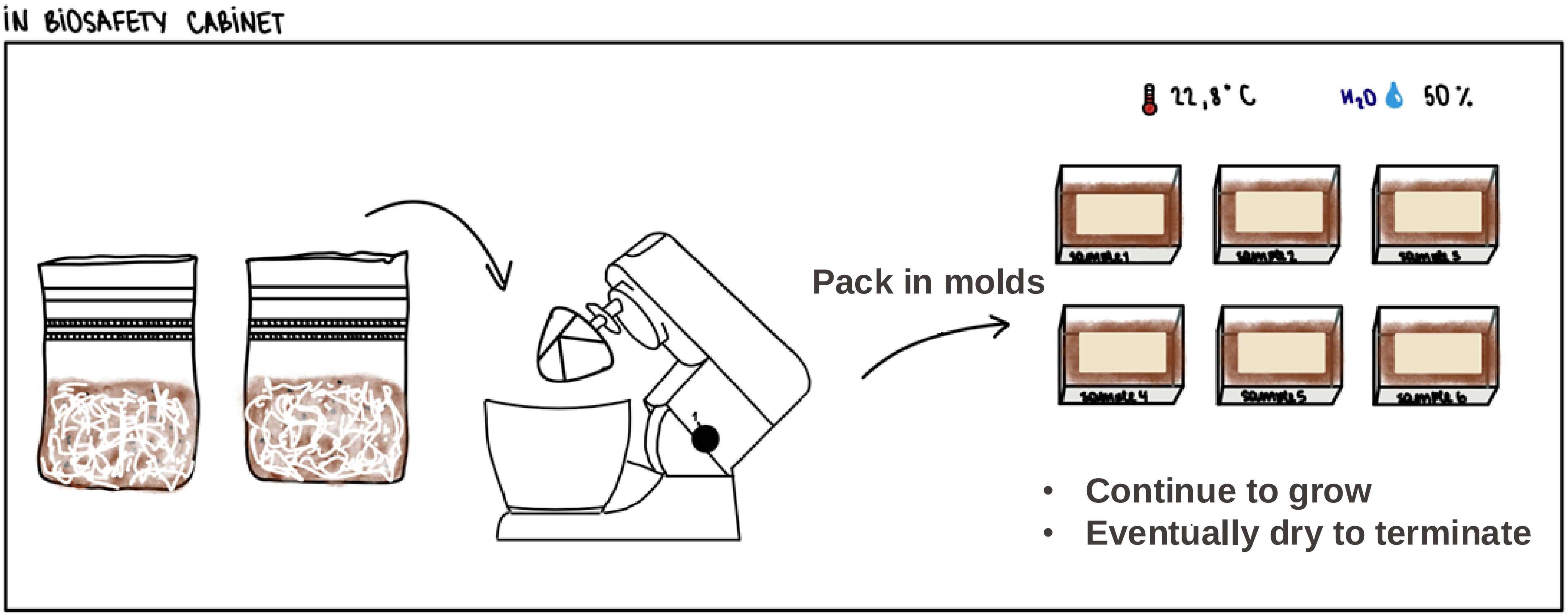
Growth in bag



Pack in molds and continue to grow…

c/o Olivia Rouiller, EPFL

Pack in molds



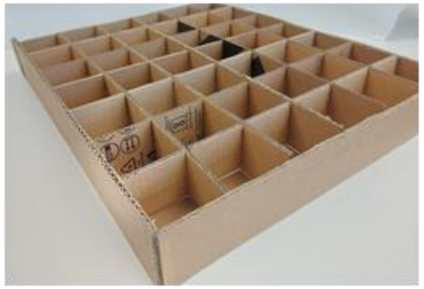
c/o Olivia Rouiller, EPFL

Overall process flow





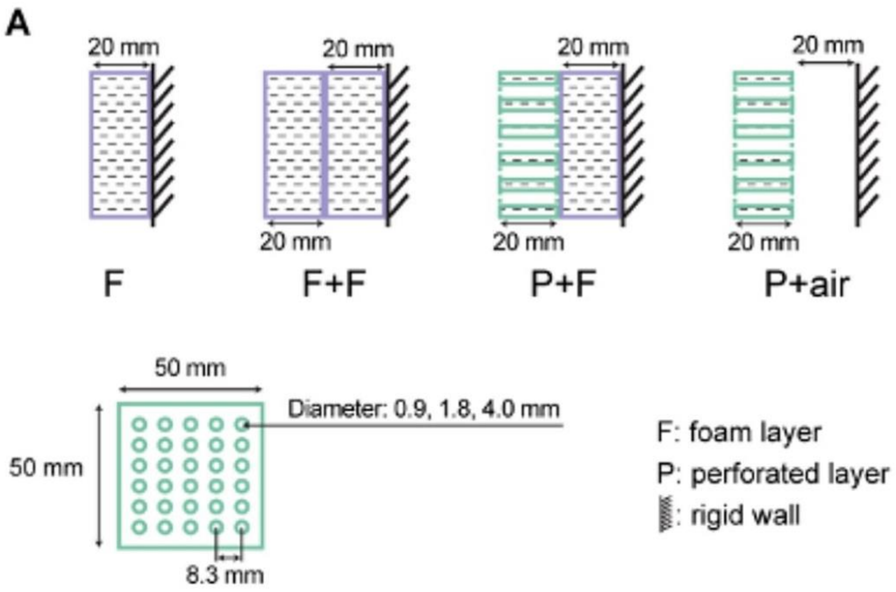
Manual perforations




Precise perforations with 3D printed molds

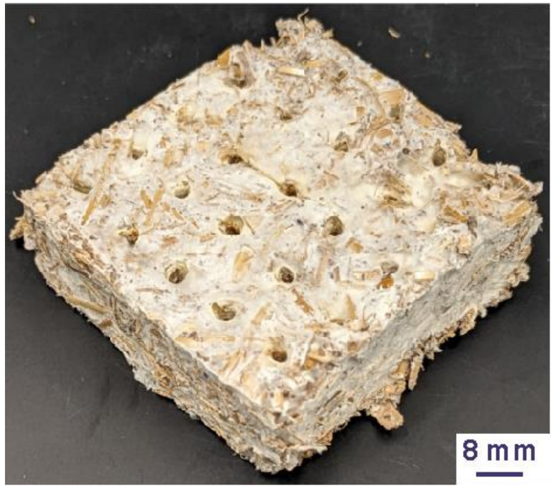
- **1 step to grow an integrated porous absorber with perforated layer**

1st set of experiments: cardboard molds



F = "foam" = porous mycelium-bound composite

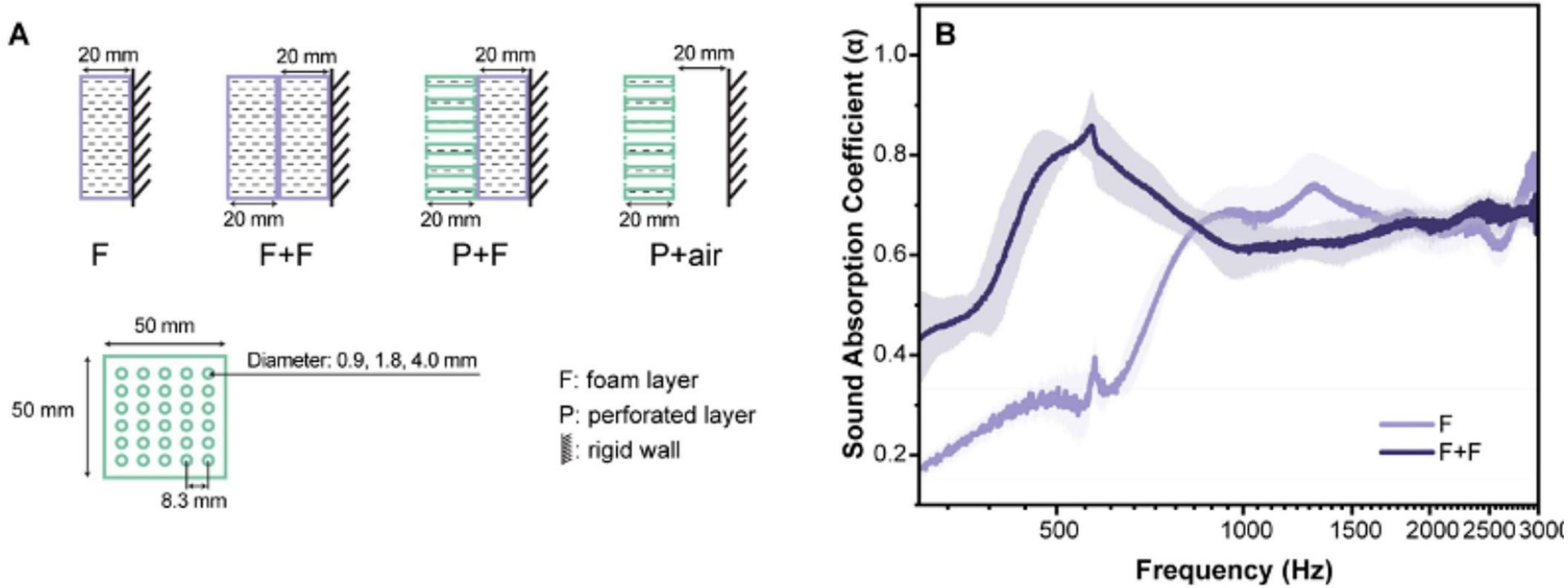
P = perforated layer = layer with holes



- Cavity depth is the same, diameter/volume varied

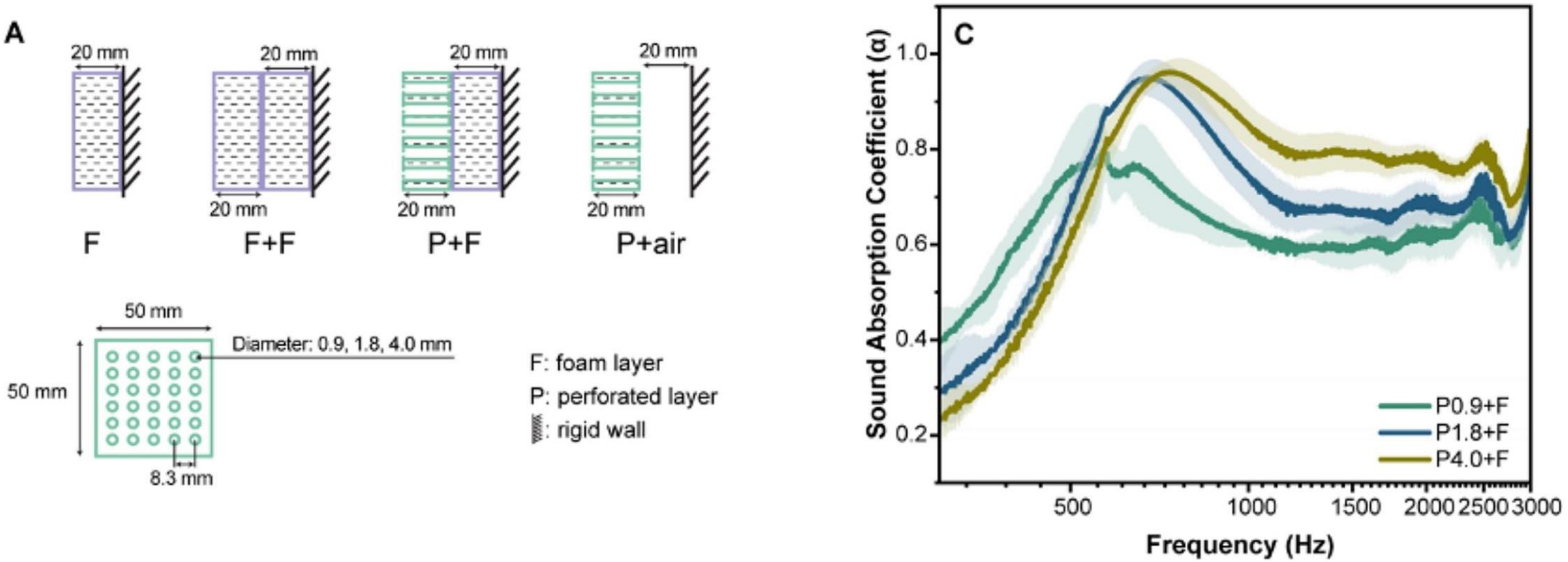
Density range: 145 to 180 kg/m^3

1st set of experiments: cardboard molds



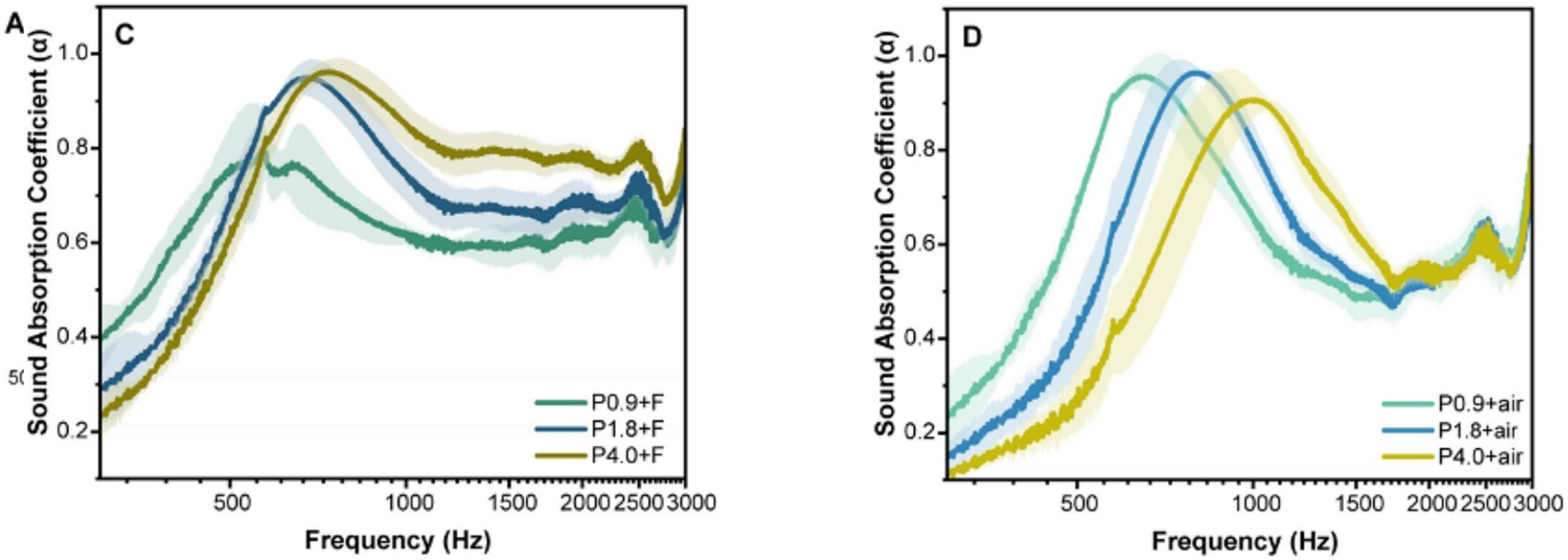
- Consistent with the literature on other mycelium absorbers – “F” increases steadily from low to high frequency and then stabilizes
- Also consistent, thicker layers are better: “F+F” also shows a broad peak at 600 Hz, related to air gaps between layers?

1st set of experiments: cardboard molds



- Larger perforation diameters: shift resonance to higher frequency
- Smaller perforation increase SAA at lower frequencies

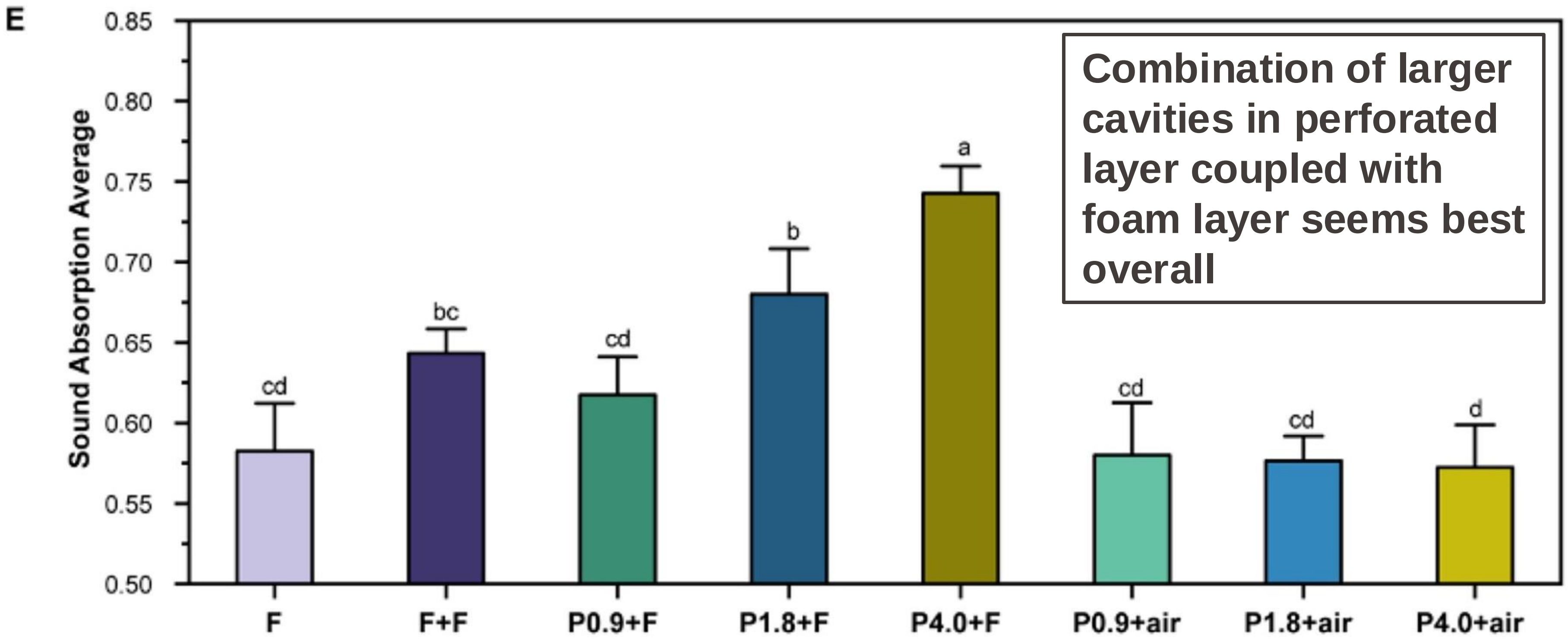
1st set of experiments: cardboard molds



- What's the impact of "F"? Replace with air cavity
- "F" increases absorbance above 1200 Hz, shift resonance to lower frequencies
- With air cavity in place of "F" – resonance frequencies are shifted to higher frequencies (effect of diameter better resolved?)
- "F" layer is critical – added thickness and overall absorption **– even at low frequency!**

1st set of experiments: cardboard molds

- SAA is the mean value of sound absorption coefficients over the frequency range from 200 to 2500 Hz.



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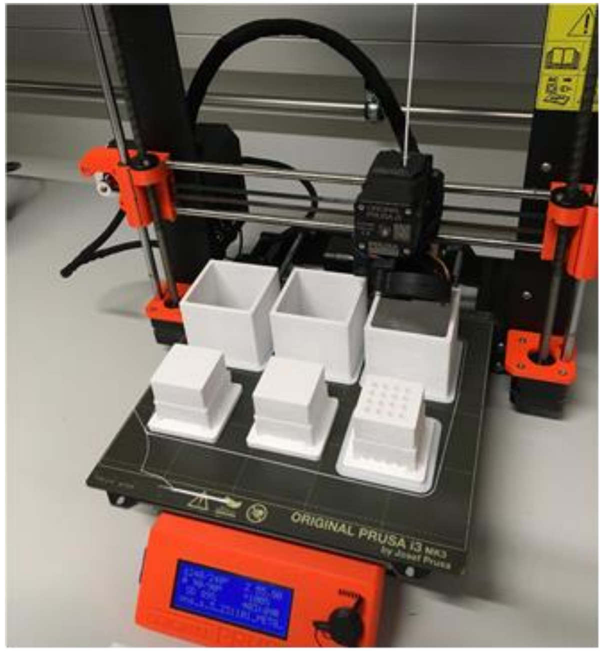
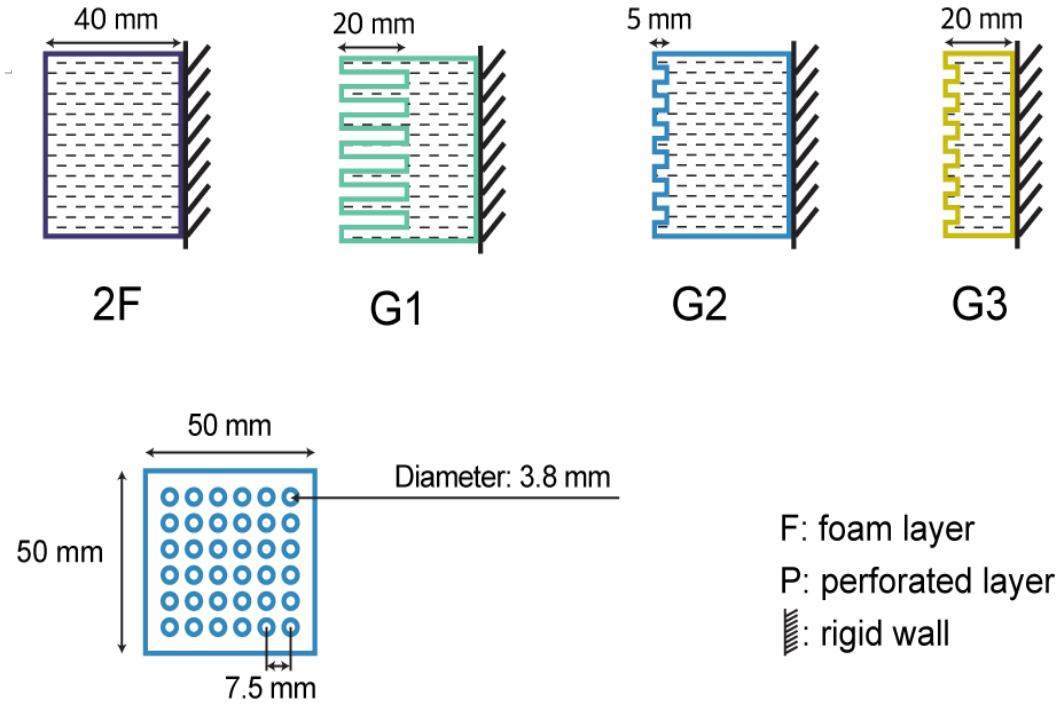
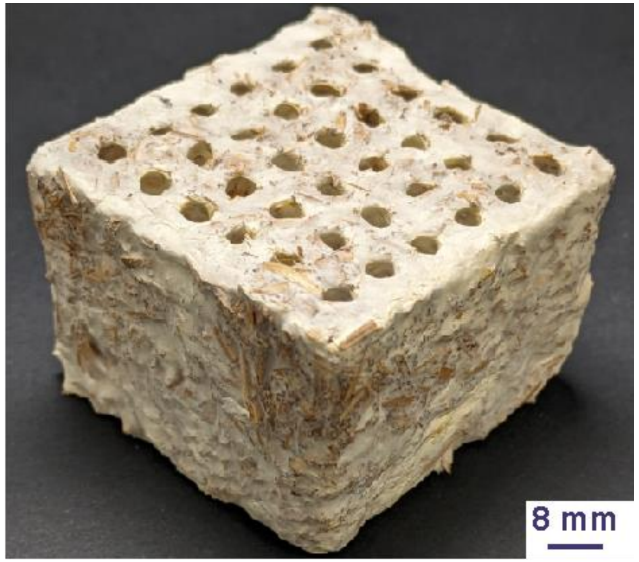
2nd set of experiments: 3D printed molds



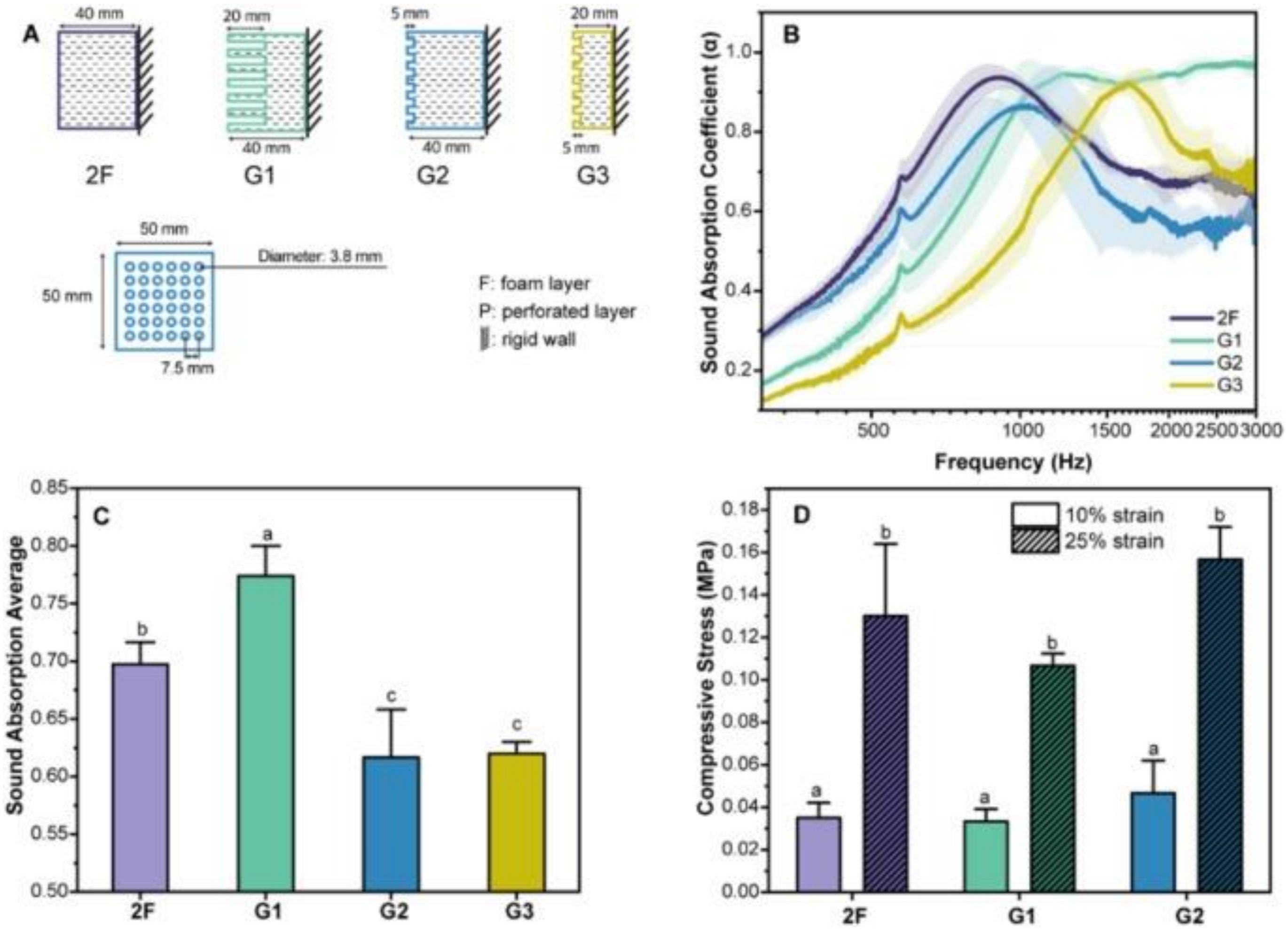
2nd set of experiments: 3D printed molds





- 2F, G1, G2: all 40 mm, with different cavity depths
- G3: same perforation depth as G2, but half the total thickness at 20 mm

Our approach to mycelium materials



- **Same total thickness: 2F, G1, and G2** – resonance seems to shift to higher frequency, with deeper cavities (**G1**) showing better overall absorption at high frequencies

- **Same cavity depth: G2** and **G3** – resonance shifted to higher frequency with thinner sample (**G3**), less absorbance at lower frequency

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Take aways on mycelium absorbers

- It’s complicated
- Helmholtz resonators are usually rigid plates, in this case we have a porous layer with holes/cavities (on top of a porous layer)
- Bright side: we can upconvert lignocellulose into precise geometries and asymmetric structures (especially if we use 3D printed molds) – in one step!
- These geometries show different performance in acoustic absorption (in a range that makes sense for real world applications) – optimistically, we can tune the sound absorption profile based on material design
- The properties we report seem better than what’s out there (but its hard to perfectly compare)
- Open questions: water sensitivity, scale up, shrinkage on drying, etc.,

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Upcycling lignocellulose waste for sound absorption

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Mycelium-Bound composites from agro-industrial waste for broadband acoustic absorption

Wenjing Sun *, Sophie H. Strässle Zúñiga, Valentin Philippe, Louisa Rinaldi, Tiffany Abitbol *

Sustainable Materials Laboratory, Institute of Materials, School of Engineering, EPFL, Station 12, 1015 Lausanne, Switzerland

A R T I C L E I N F O

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Acoustic absorption
Additive manufacturing
Upcycling

A B S T R A C T

This research explores the development of mycelium-bound composites for acoustic applications where natural fungal mycelia is used to bind organic waste into sound absorbing panels. The composites were grown in 3D printed molds to impart precise perforated patterns according to the principles of Helmholtz resonance. This approach led to improvements in sound absorption across a broad frequency range, particularly at low to mid-frequencies. By using agro-industrial waste as the raw material, our approach demonstrates the potential for upcycling while maintaining an entirely biodegradable composition. The study highlights the flexibility in material composition and design, offering a pathway for further refinements to optimize acoustic performance.

Thank you! Questions?