Active and Adaptive Wood Materials

Of Microbes and Wood

From microbial wood decay to microbial wood engineering

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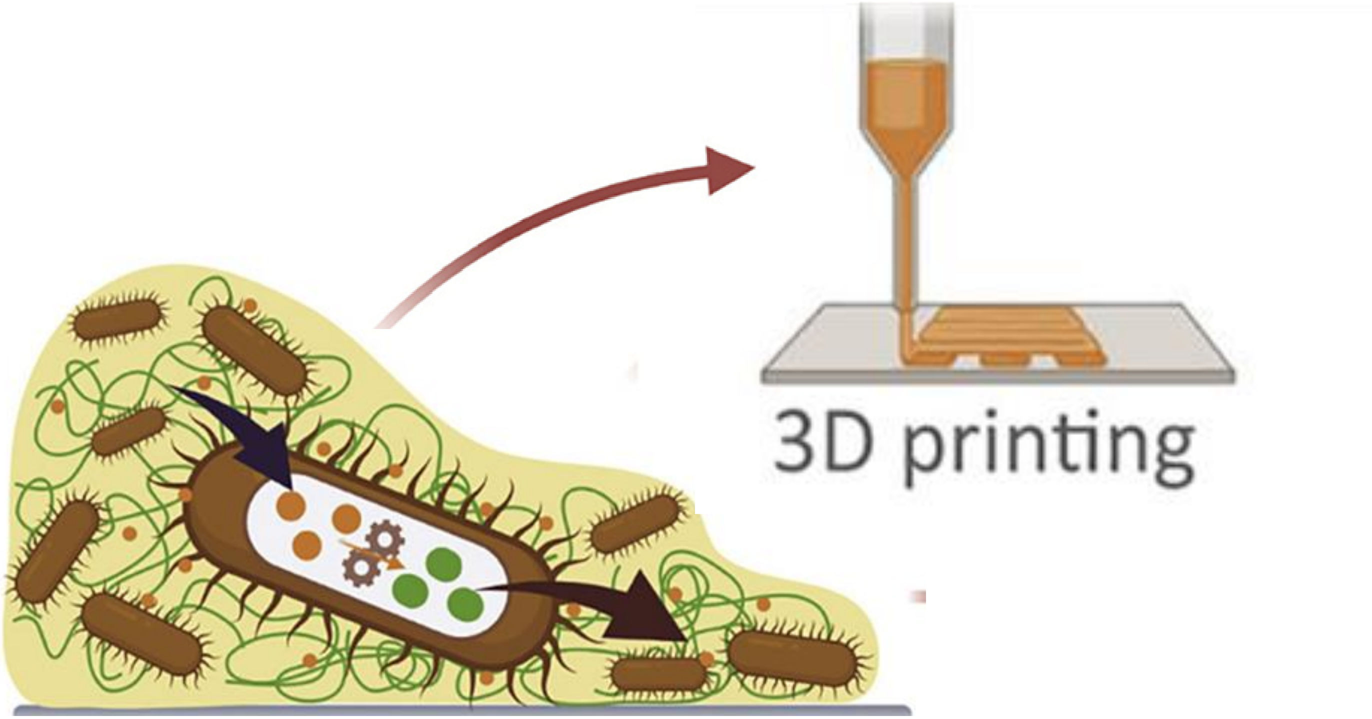
https://www.deviantart.com/boldfrontiers/art/Happy-Wood-Decay-freebie-656642745

D BAUG

IfB Institut für Baustoffe
Institute for Building Materials

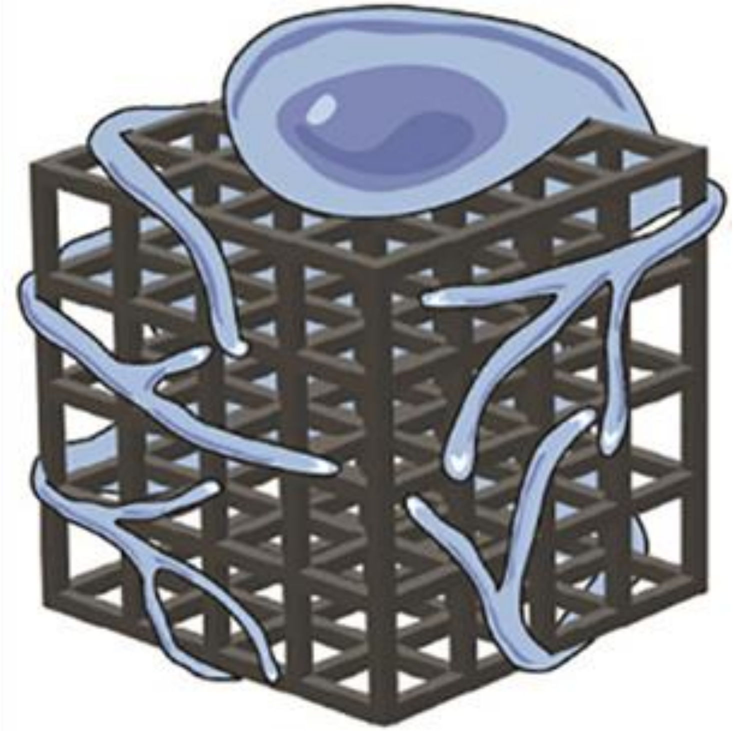
Engineered Living Materials

Biological Engineered Living Materials (Bio-ELMs)



Biofilm

Hybrid Living Materials (HLMs)



Cells cultured on abiotic scaffold

▼

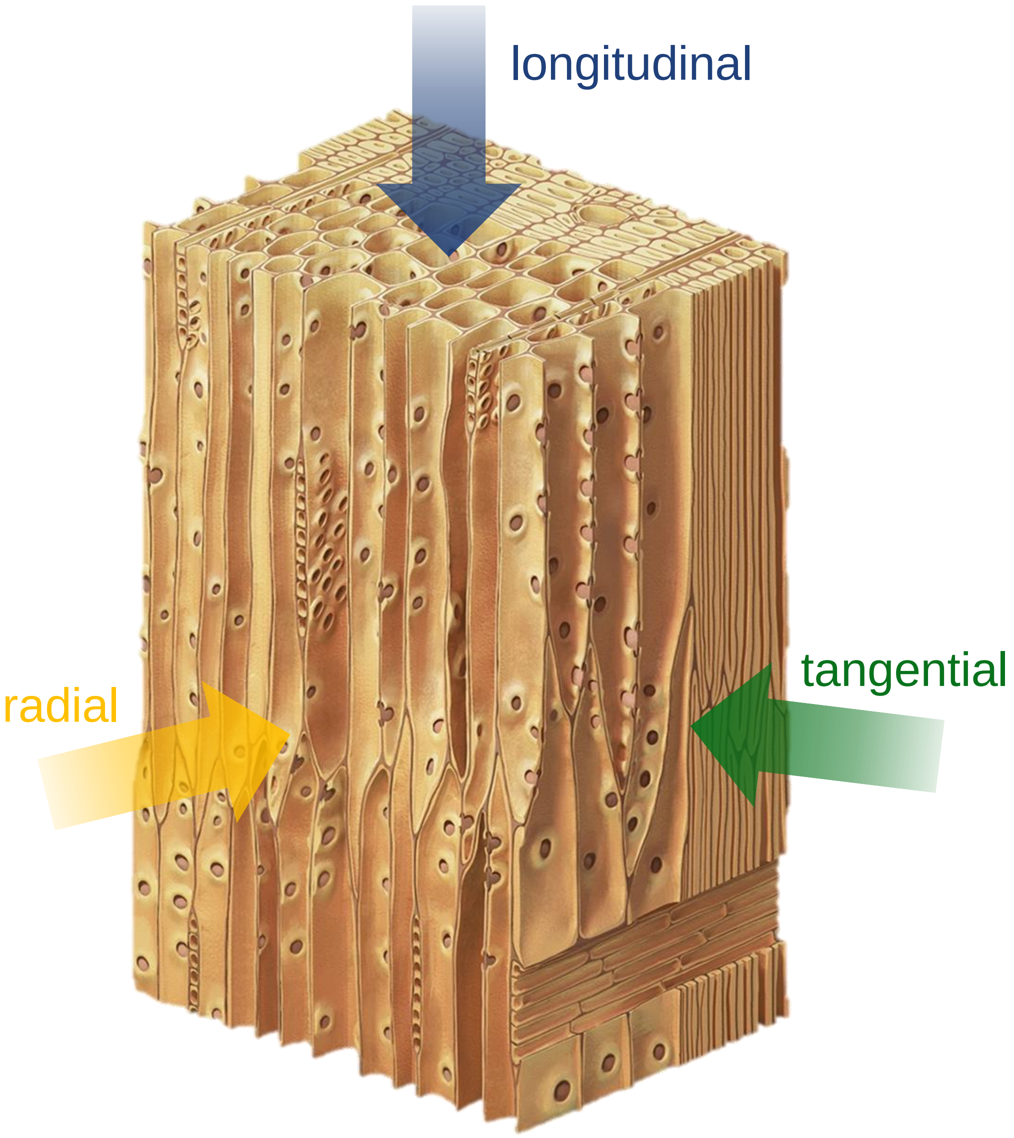
Wood

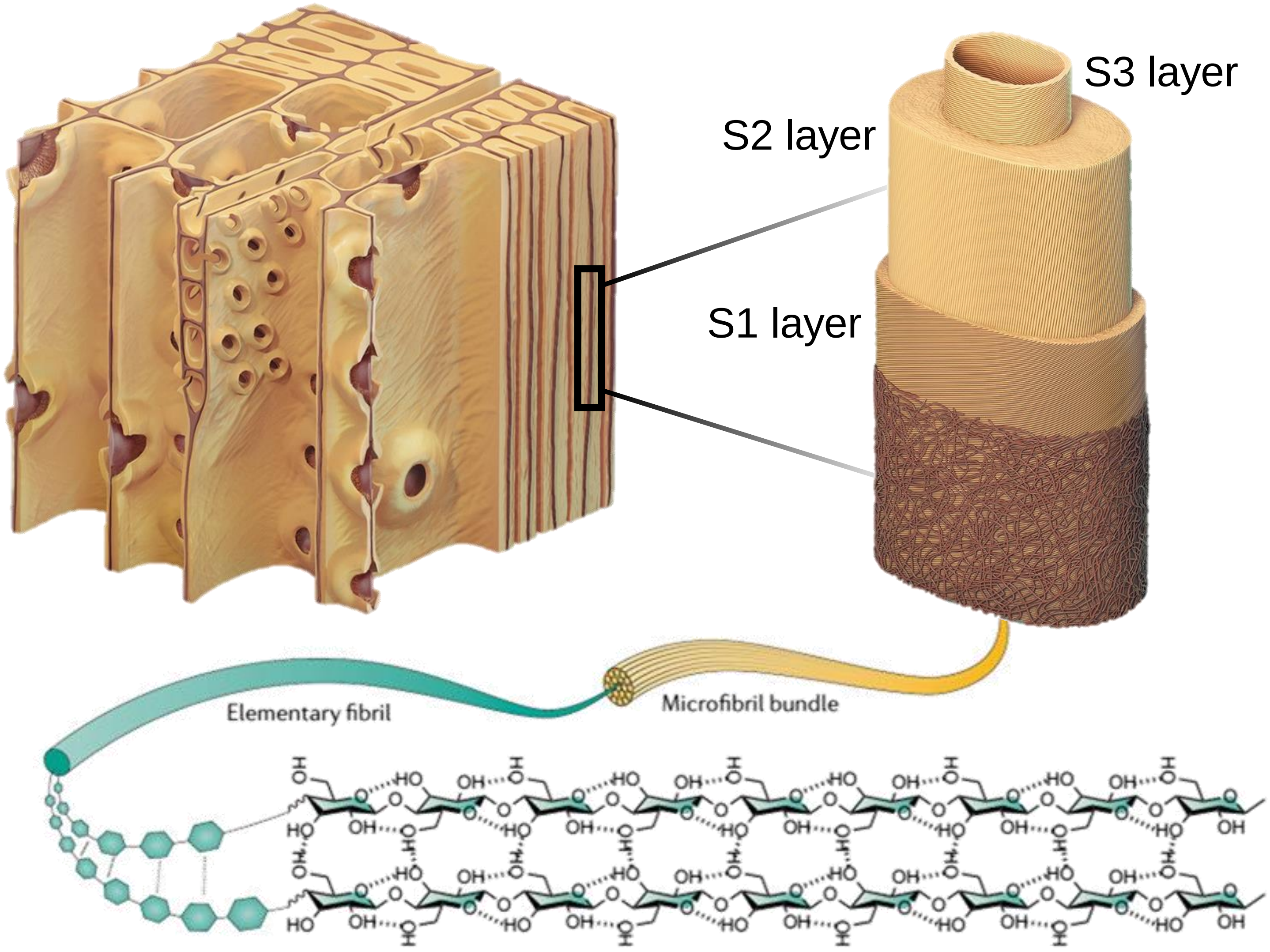
Lantada et al. *Cell Rep. Phys. Sci.* **2022**, *3*, 100807

Wood

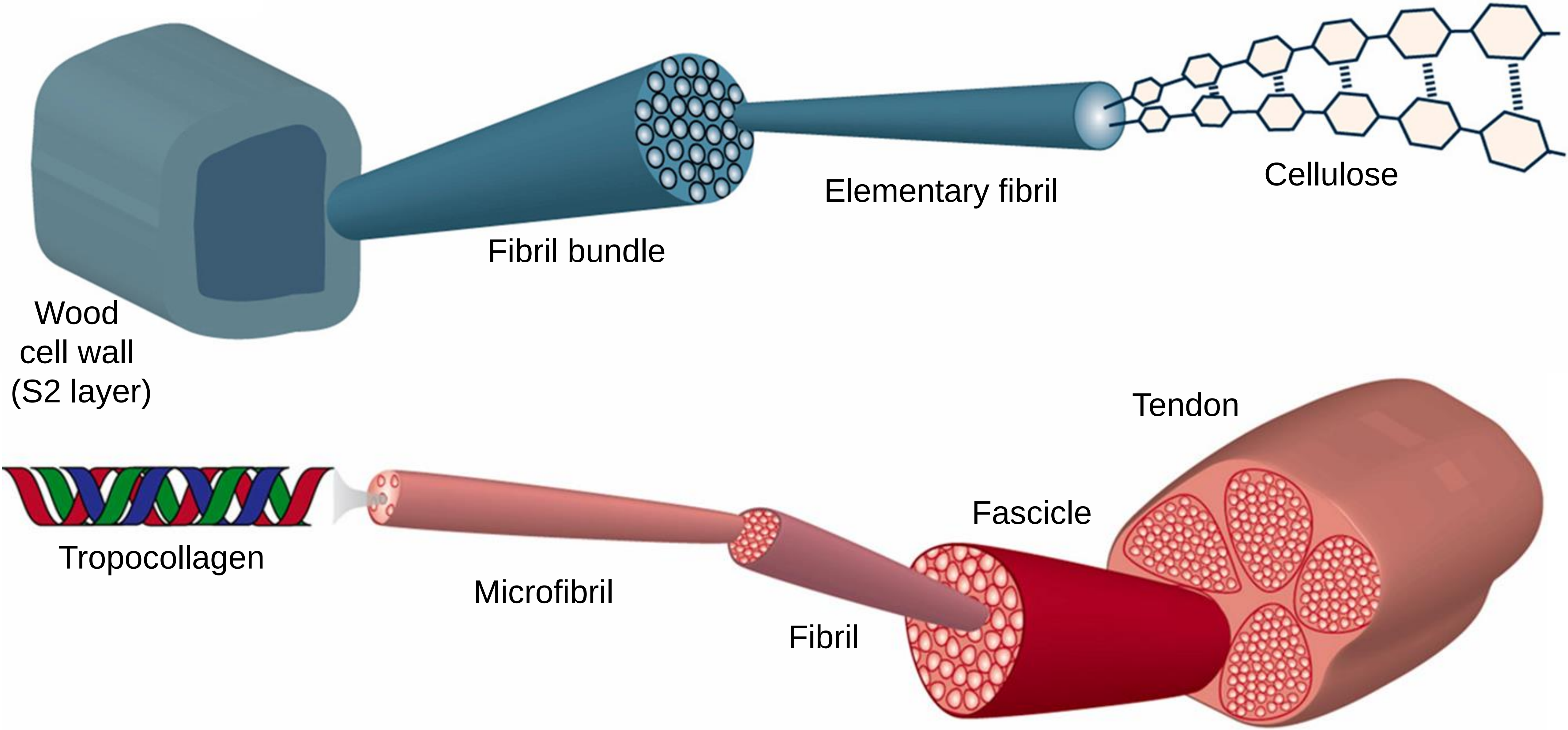
https://www.hdwallpapers.in/sand_path_between_trees_wood_logs_forest_scenery_background_4k_5k_hd_nature-wallpapers.html

Wood as an abiotic scaffold for Hybrid Living Materials



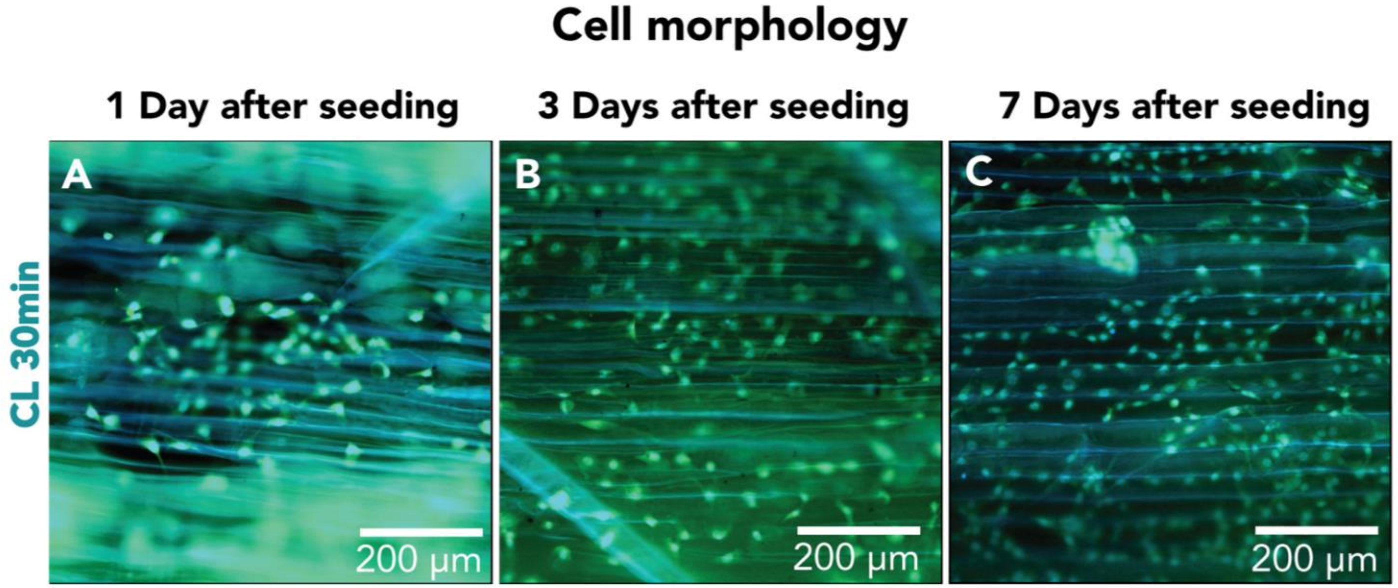


Wood as an abiotic scaffold for Hybrid Living Materials

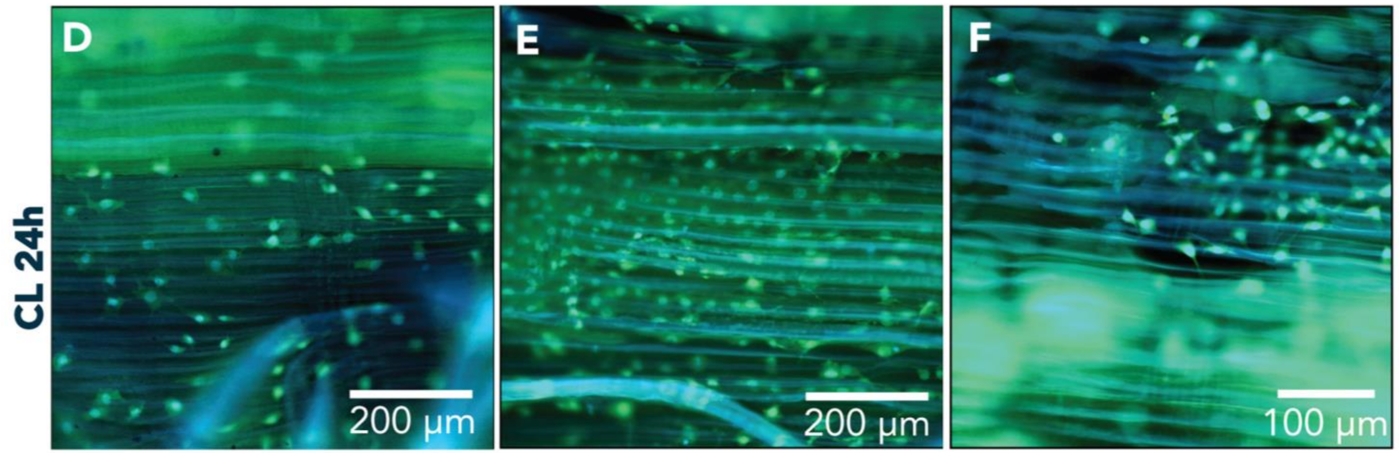


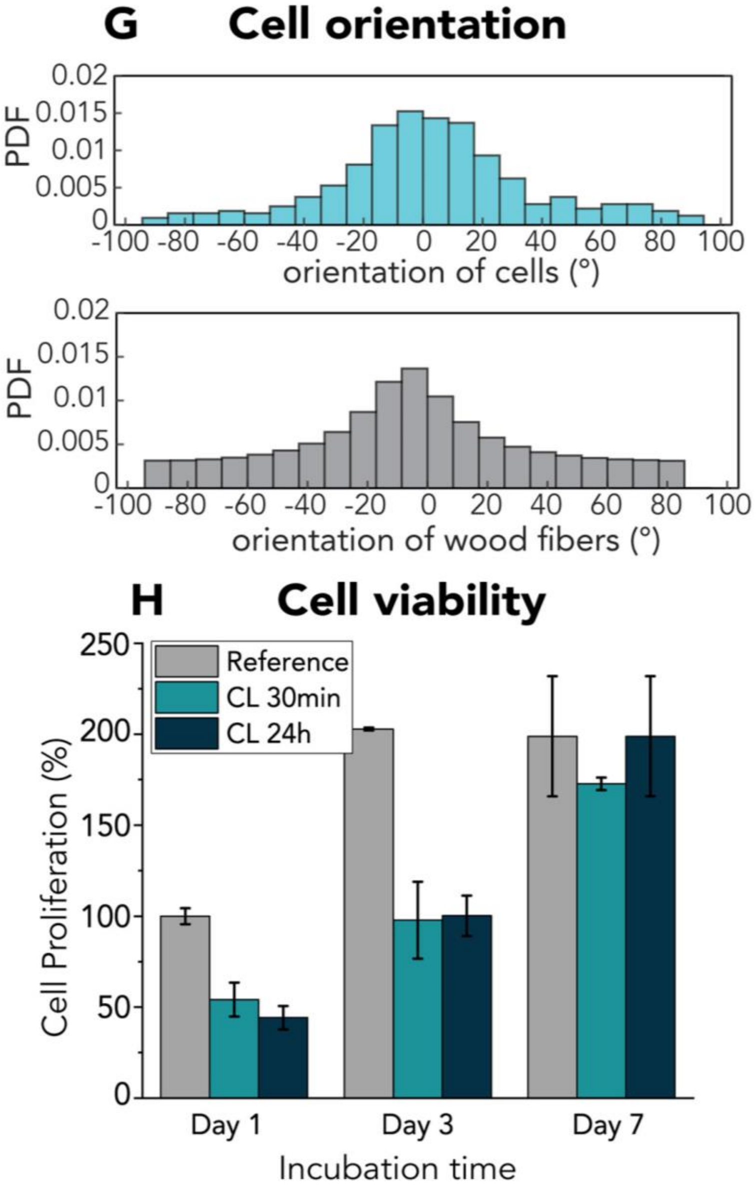
Koch et al. *Mater. Today Bio* **2023**, *22*, 100772

Wood as an abiotic scaffold for Hybrid Living Materials



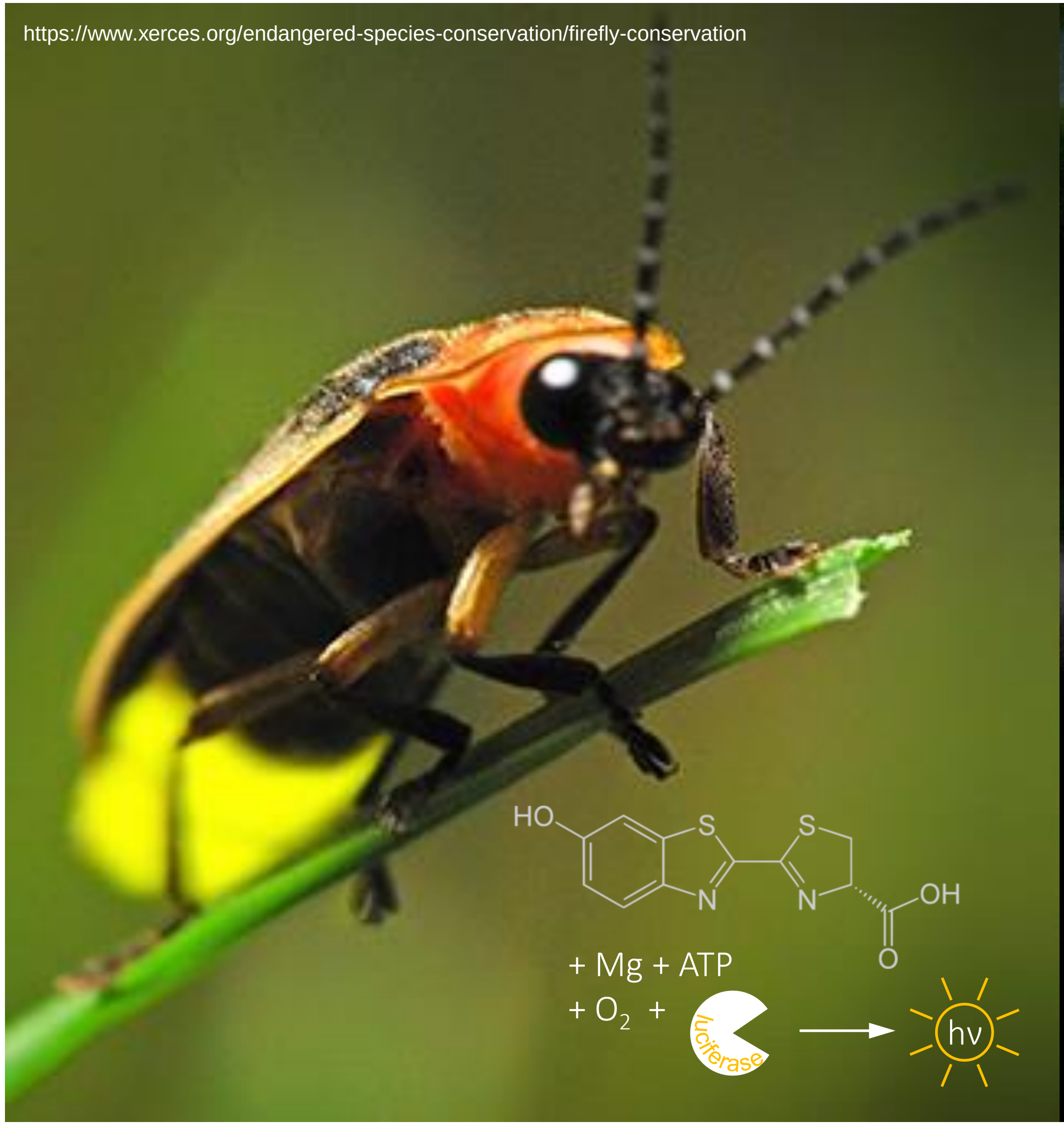
Murine NIH3T3 fibroblasts cultivated on gelatin-impregnated, delignified wood

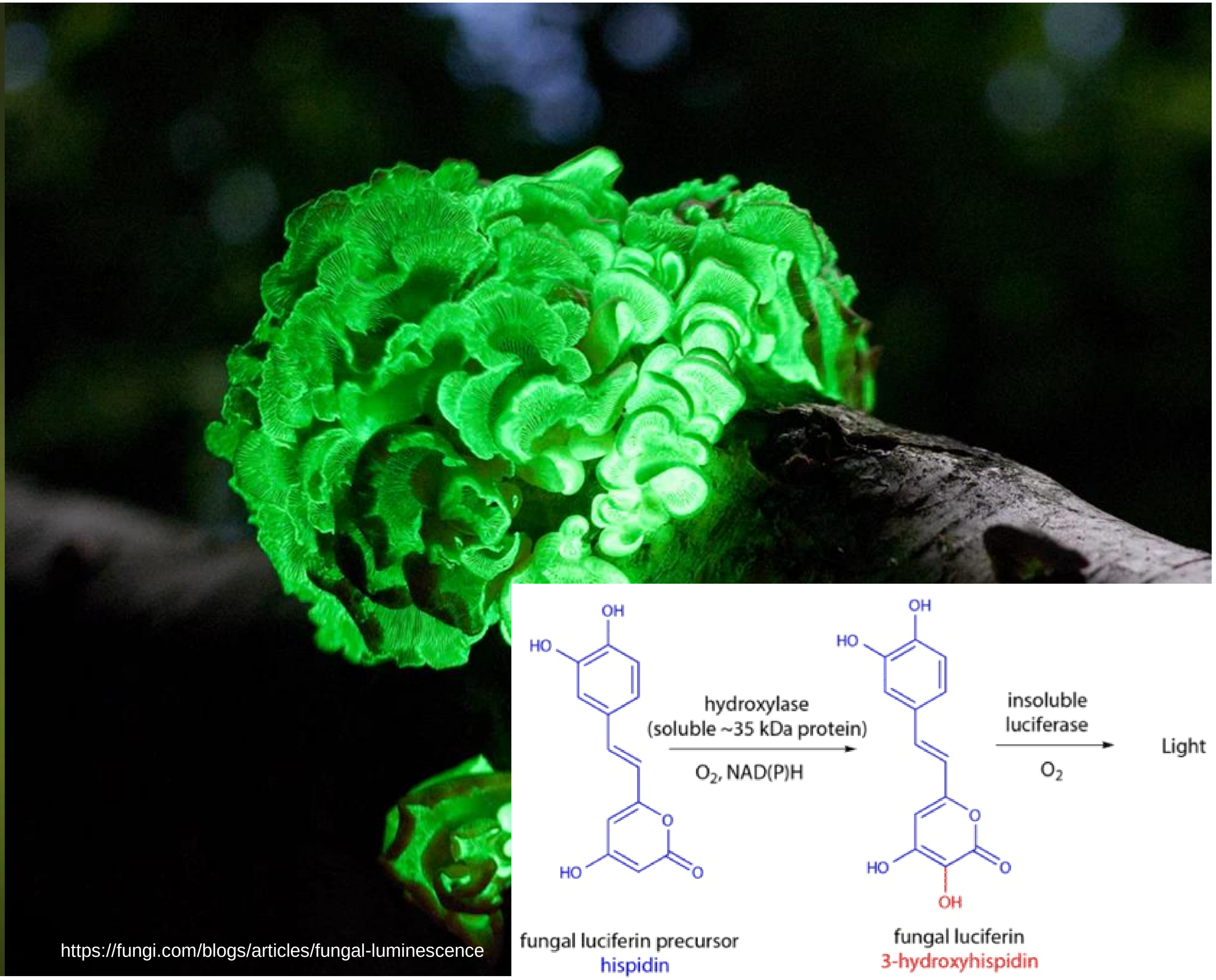




Koch et al. *Mater. Today Bio* **2023**, *22*, 100772

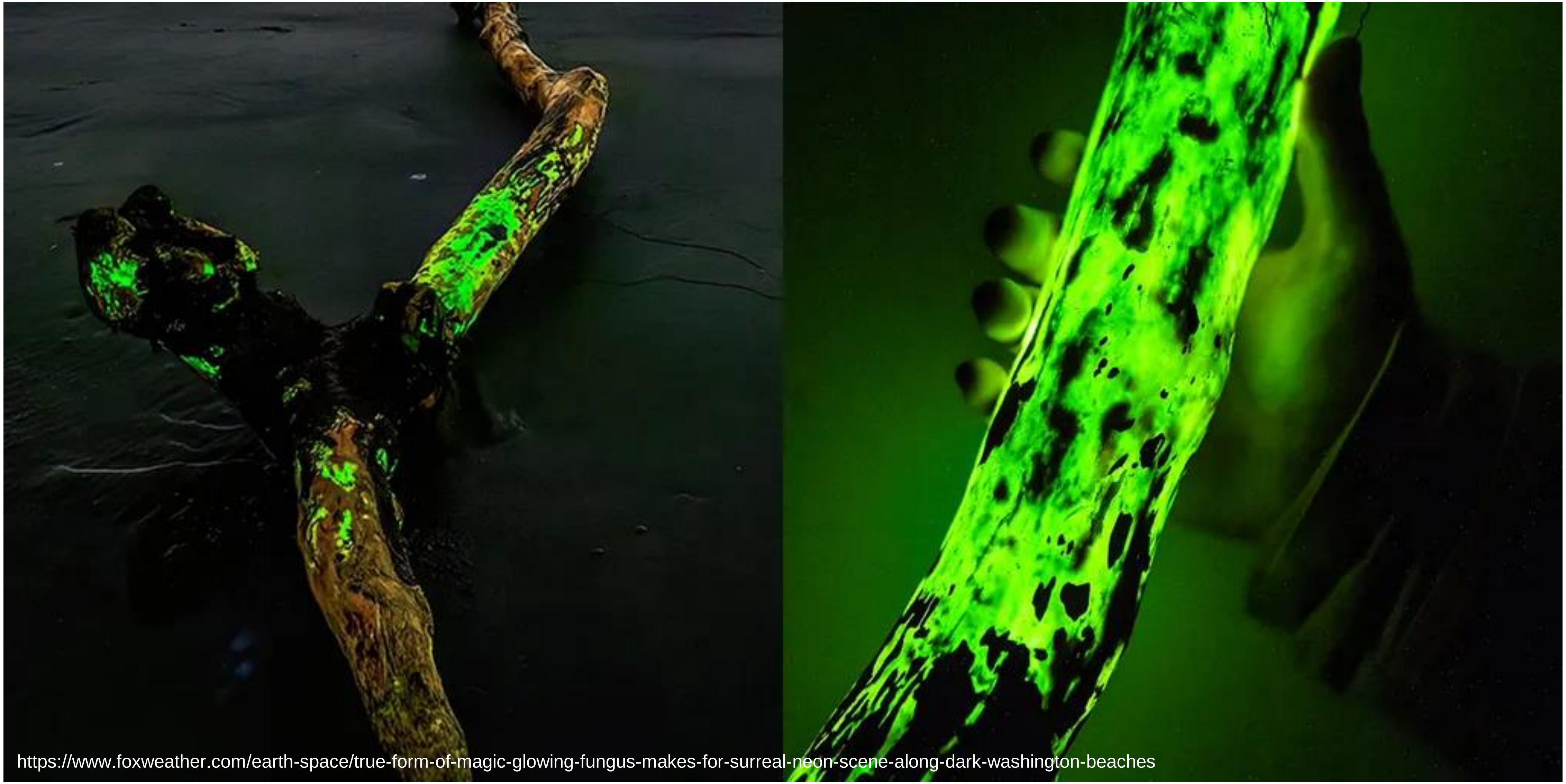
Fireflies and Foxfire





Kaskova et al. *Sci. Adv.* **2017**, 3(4), e1602847

Bioluminescent Wood: a naturally-occurring Hybrid Living Material



https://www.foxweather.com/earth-space/true-form-of-magic-glowing-fungus-makes-for-surreal-neon-scene-along-dark-washington-beaches

Bioluminescent wood

« The chemical reaction [responsible for light emission] has not been artificially induced in wood through manipulation of the conditions for fungi to glow.

The main reason for this is that <u>the balance between the choice of fungal species, wood species, its moisture content and the environmental conditions required to produce bioluminescent wood is very challenging</u>.

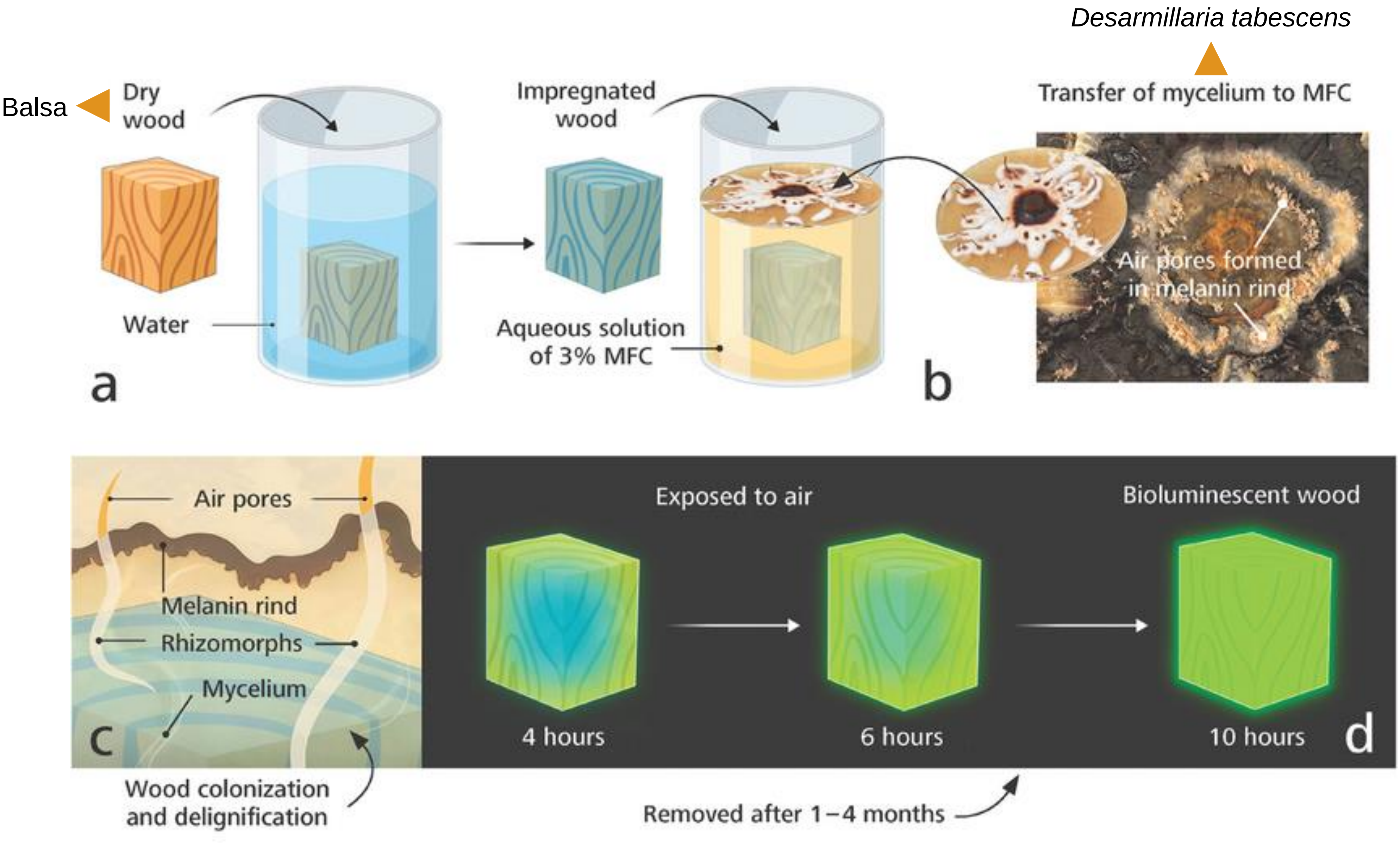
Investigating the production of bioluminescent wood, we hypothesized that using the white rot fungus *Desarmillaria tabescens* will lead to bioluminescence, because of its ability to colonize and degrade lignin in wood with a very high moisture content.

The hybrid material with the highest bioluminescence is produced by soaking the wood blocks before co-cultivating them with the fungus for <u>3 months</u>.

Regardless of the incubation period, the strongest bioluminescence is evident from balsa wood blocks with a <u>moisture content of 700–1200</u>%, highlighting the fundamental role of moisture content for bioluminescence production. »

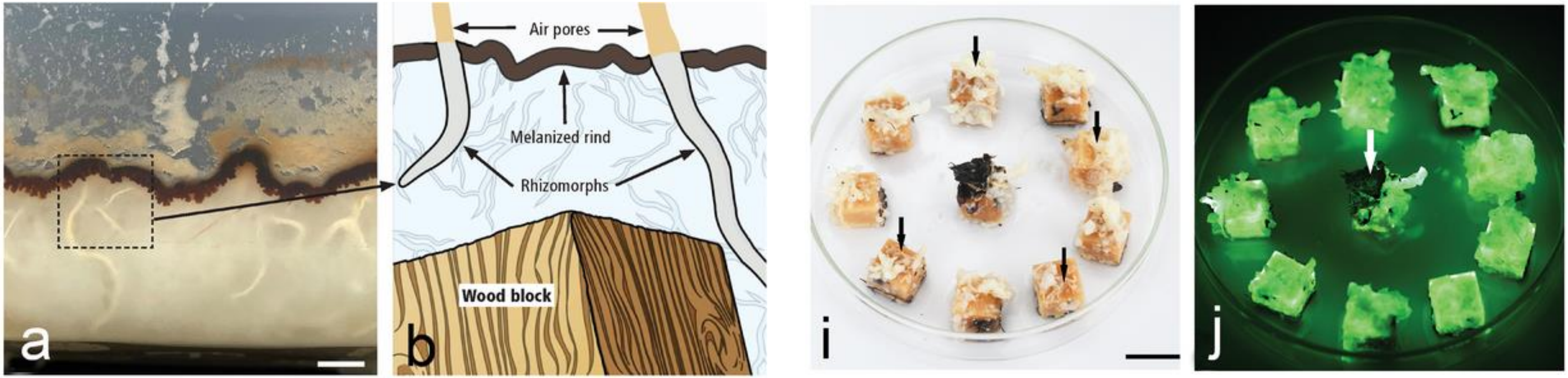
Schwarze et al. *Adv. Sci.* **2024**, 2403215

Artificial Bioluminescent Wood



Schwarze et al. *Adv. Sci.* **2024**, 2403215

Artificial Bioluminescent Wood

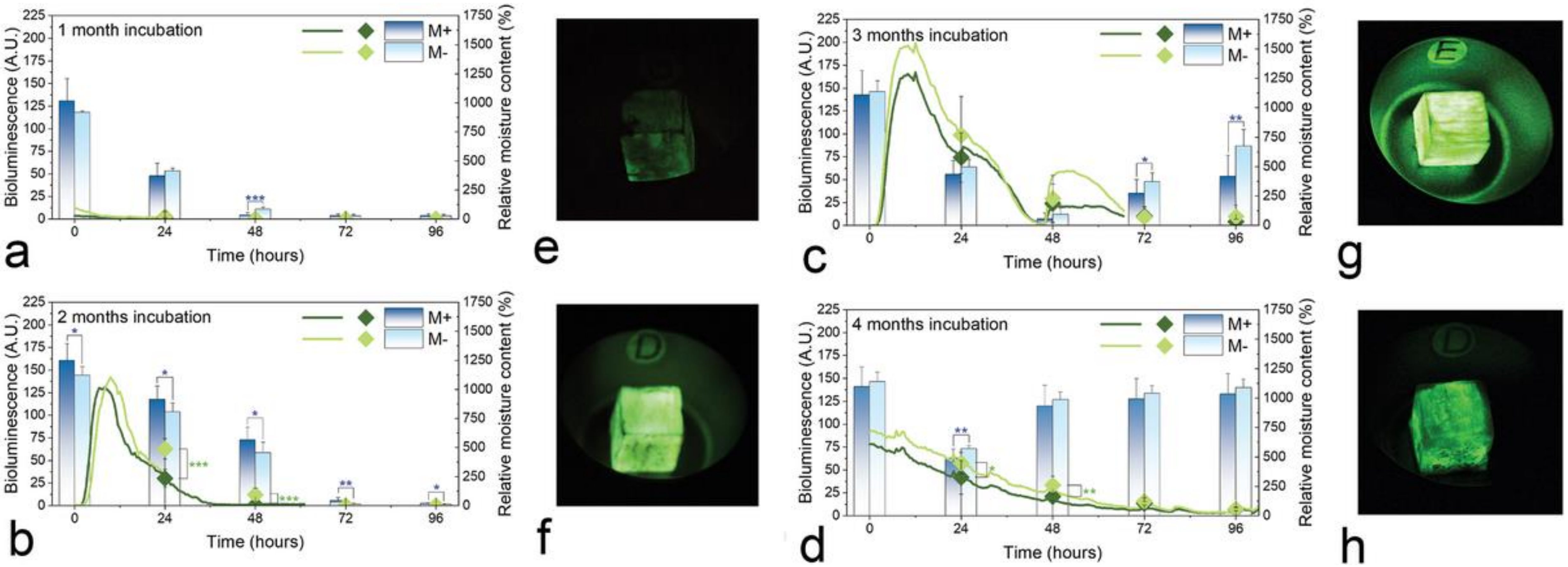


Incubation of wood blocks in 3% MFC with *D. tabescens* for producing bioluminescent wood. a) Non-melanized rhizomorphs (arrow) colonize MFC and the submerged wood blocks. Scale bar = 1 cm. b) Illustration showing wood blocks submerged in MFC and the connection of rhizomorphs and air pores (arrows). At the substrate-air interface, MFC is covered by a melanized rind (arrow). i) Balsa wood blocks incubated for 3 months with *D. tabescens* and exposed to light. Note abundant rhizomorphs (arrows) of *D. tabescens* have strongly colonized balsa wood blocks (scale bar = 1.5 cm). j) Wood blocks in i) exposed to air in the dark showing strong bioluminescence induced by D. tabescens. Note dark melanin rind (arrow) absorbing bioluminescence emitted from wood (scale bar = 1.0 cm).

Schwarze et al. *Adv. Sci.* **2024**, 2403215

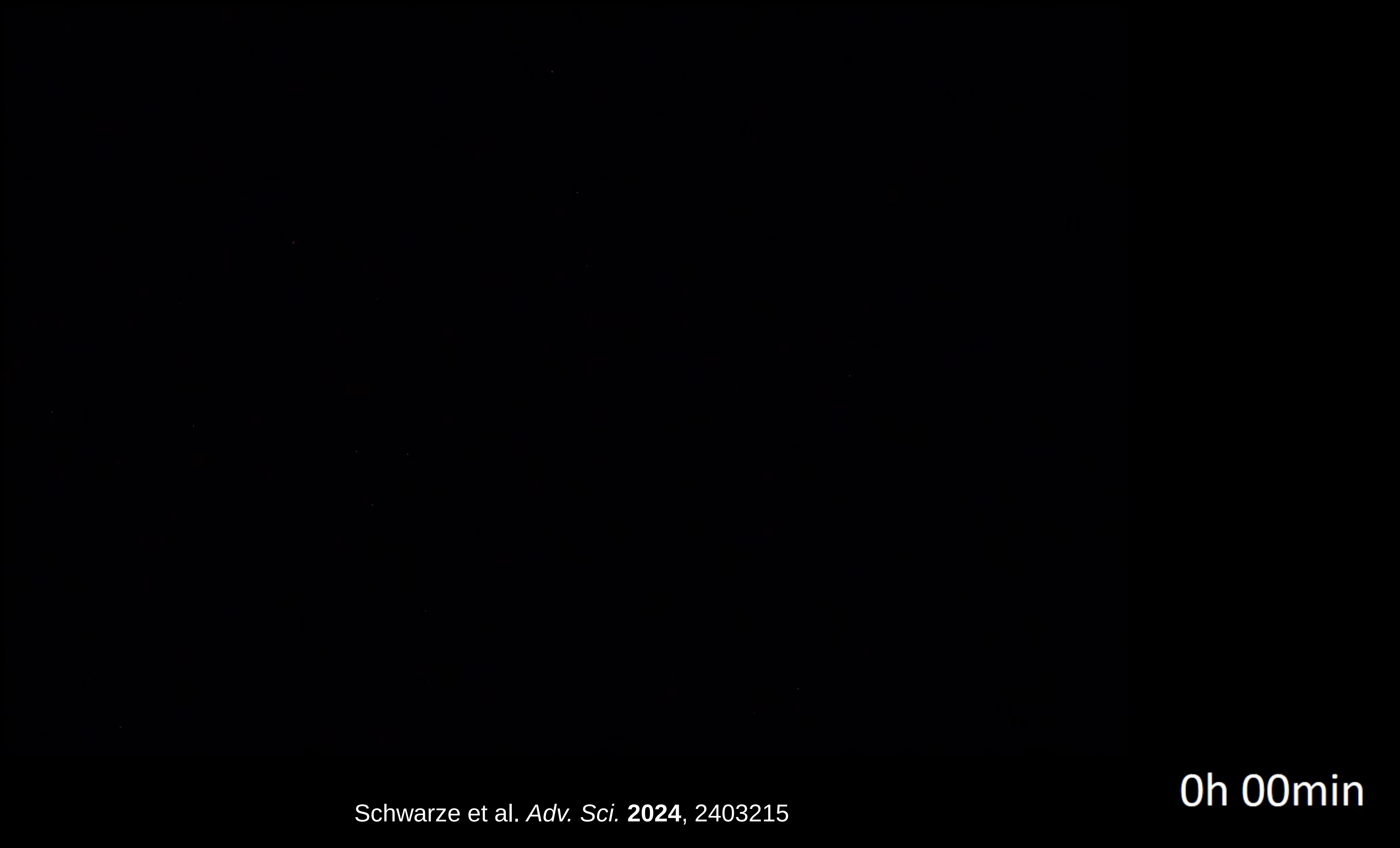
Artificial Bioluminescent Wood

Relationship between bioluminescence and moisture content of wood blocks (incubated for 1, 2, 3, and 4 months) over 96 h in a dark room at RT ([M+] = with malt, [M-] = without malt).



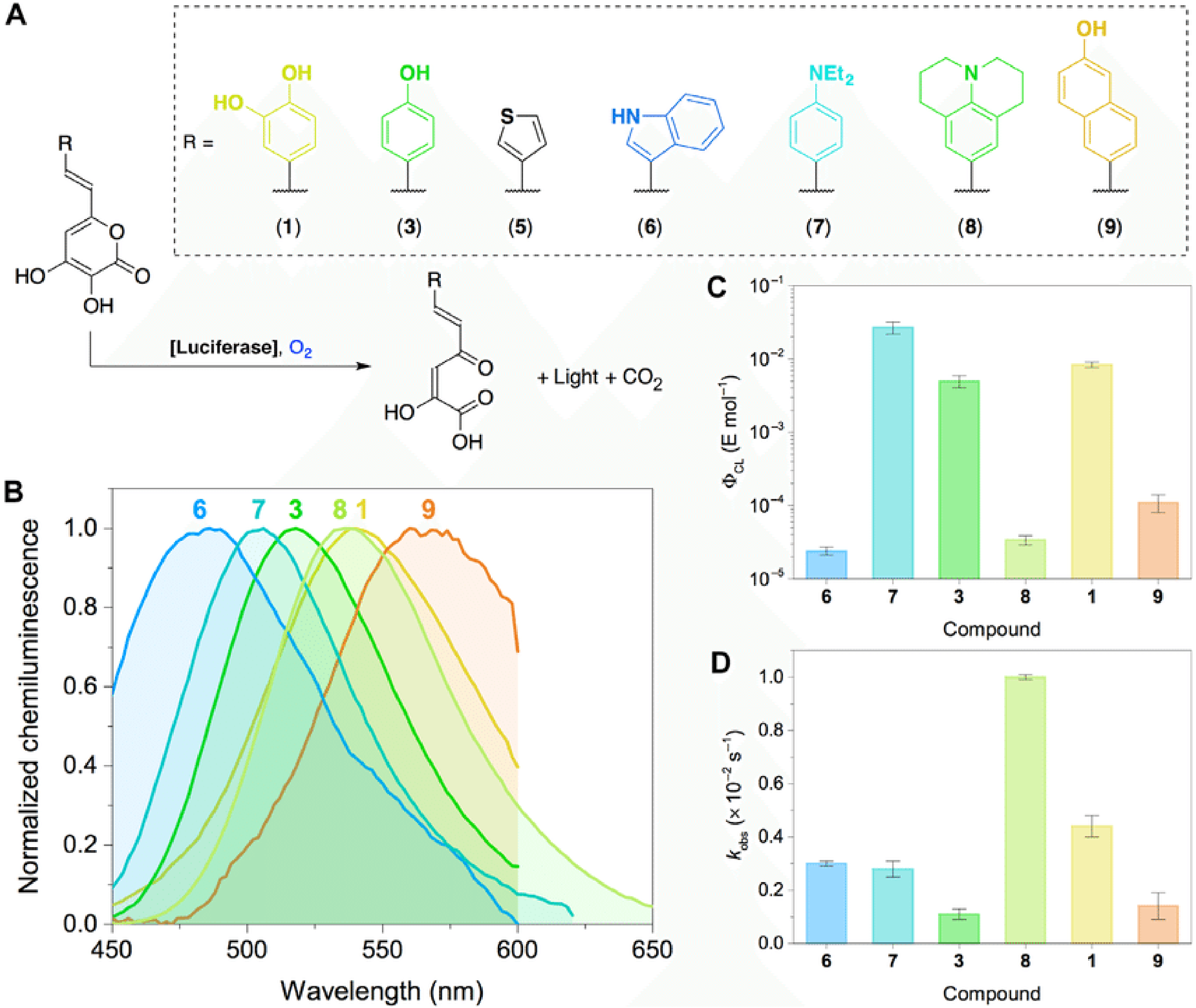
Schwarze et al. *Adv. Sci.* **2024**, 2403215

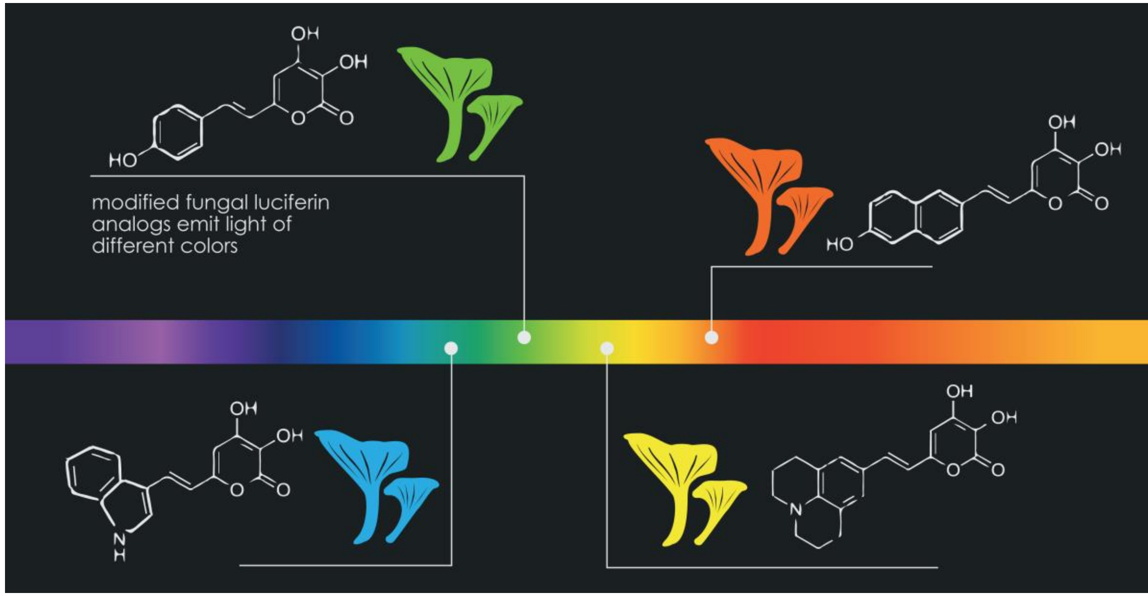
Artificial Bioluminescent Wood



Schwarze et al. *Adv. Sci.* **2024**, 2403215

Artificial Bioluminescent Wood: expanding the color palette





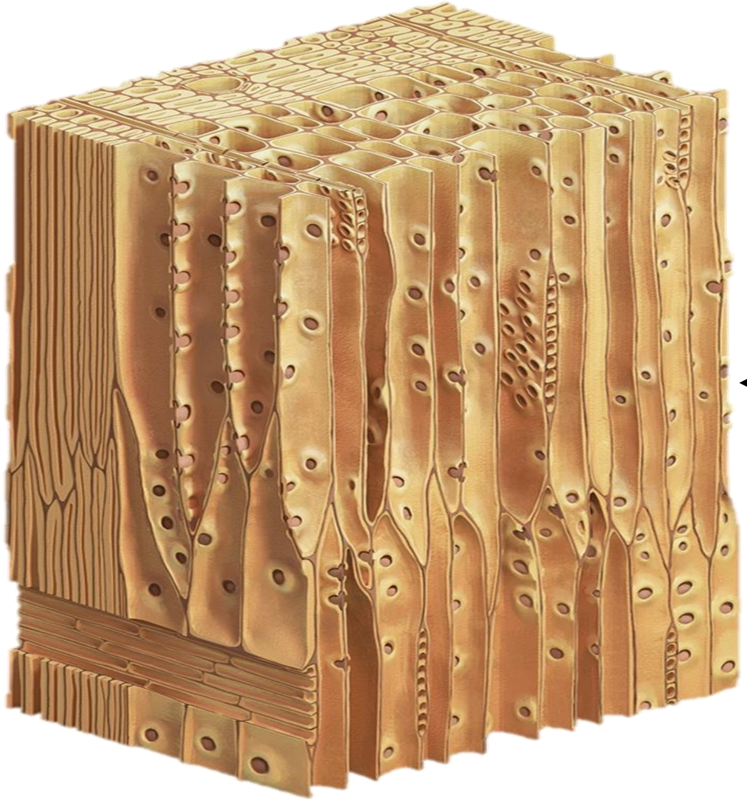
Kaskova et al. *Sci. Adv.* **2017**, 3(4), e1602847

Chemiluminescent Wood

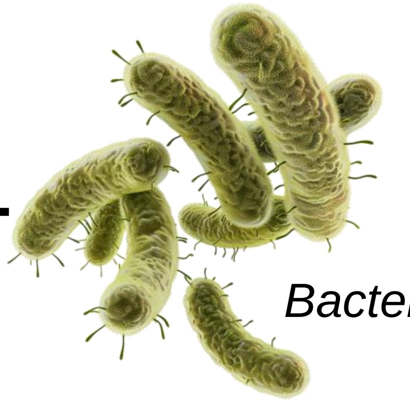
Ritter *et al. Carbohydrate Polymers*, **2024**, *339*, 122166

Engineered Living Wood Materials: is it all that easy?

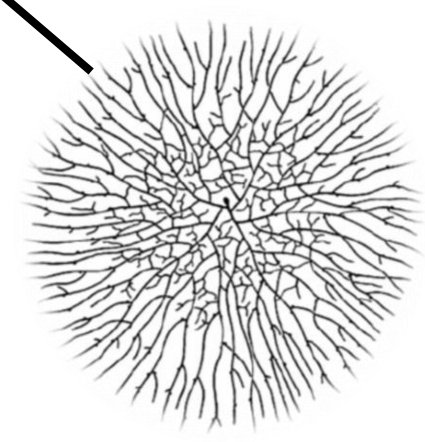
Eukaryotic cells



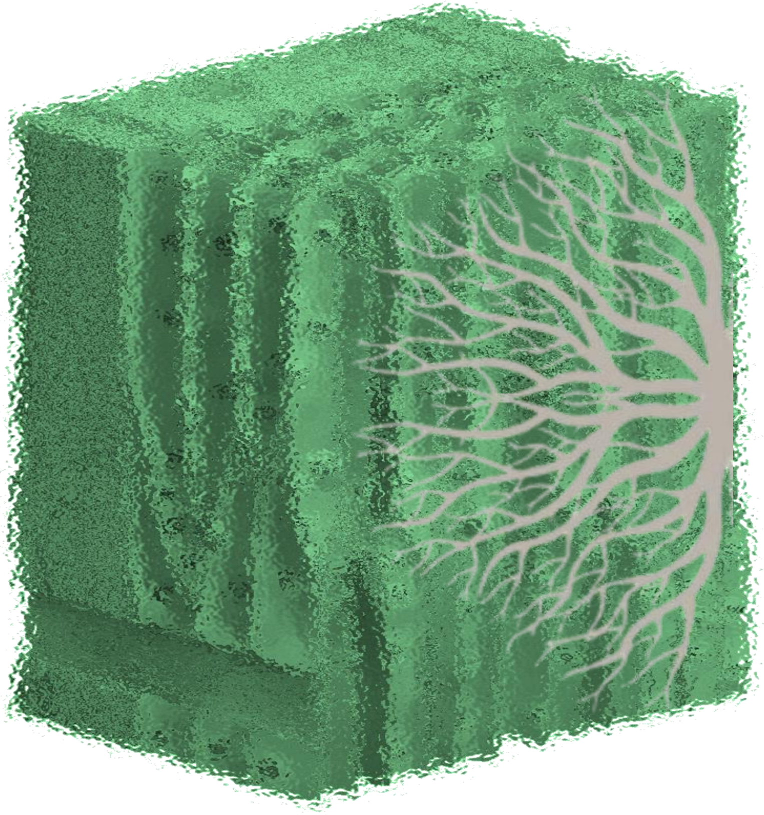
Wood scaffold



Bacteria



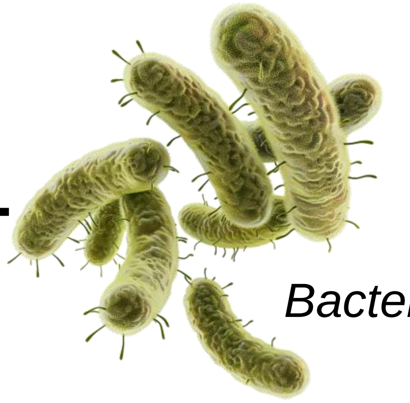
Fungi



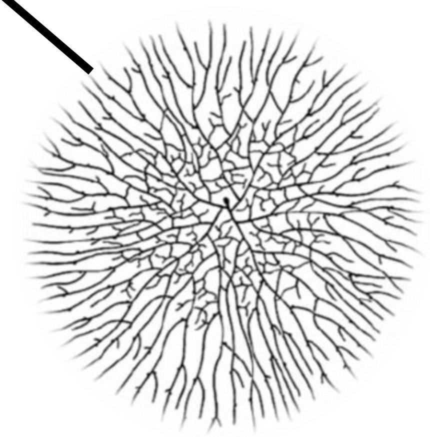
Engineered Living Wood Material?

Engineered Living Wood Materials: is it all that easy? Not really…

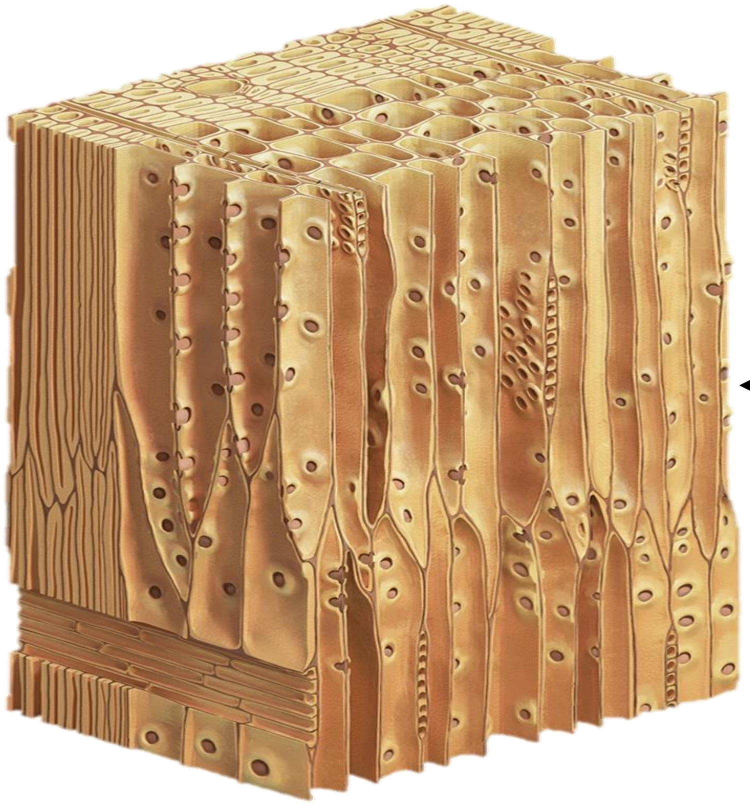
Eukaryotic cells



Bacteria



Fungi



Wood scaffold

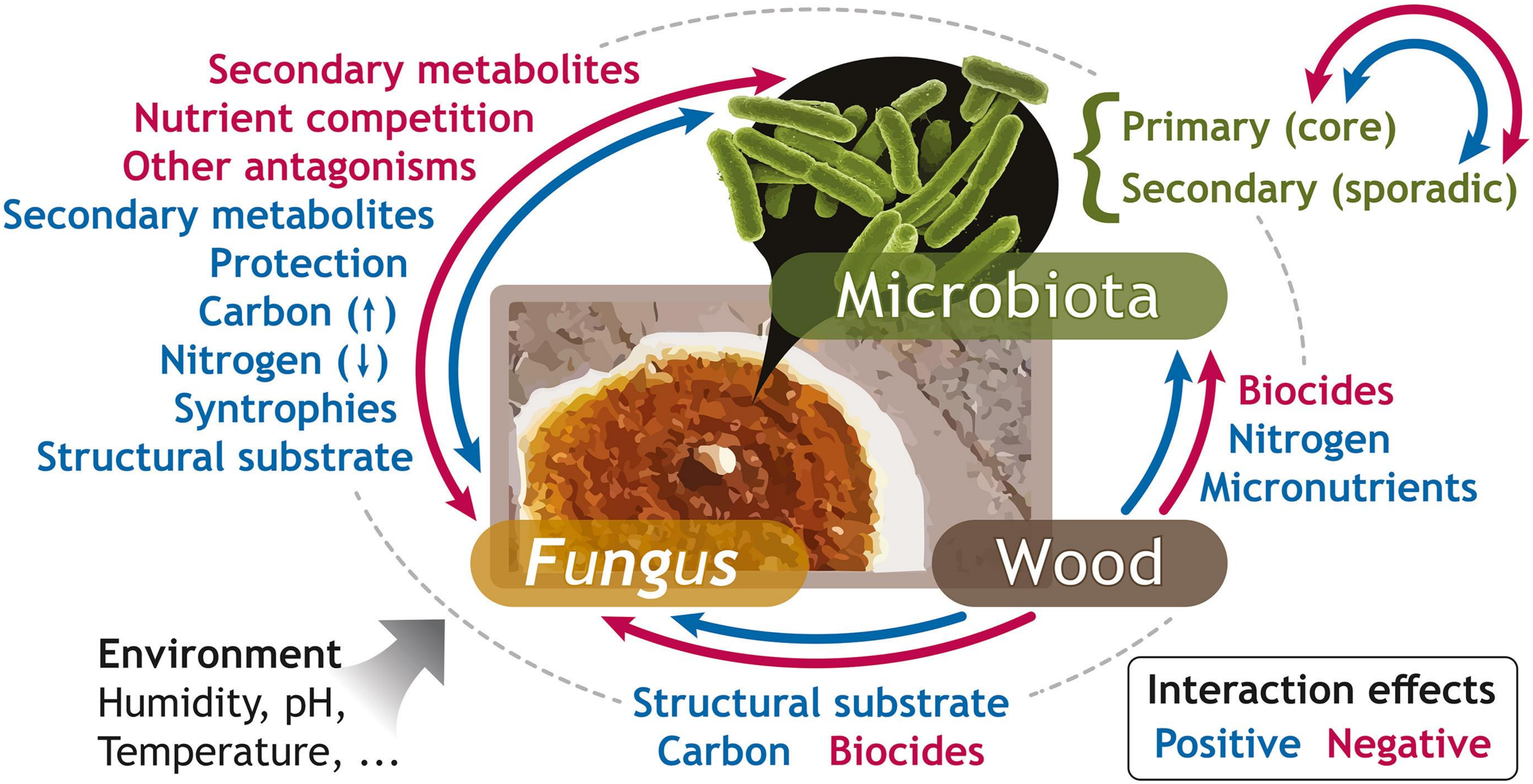
Engineered Living Wood Material???

Wood: radically different perspectives on the same subject

Human perspective

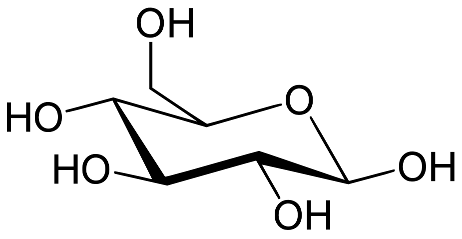
Microbe (e.g. fungi) perspective

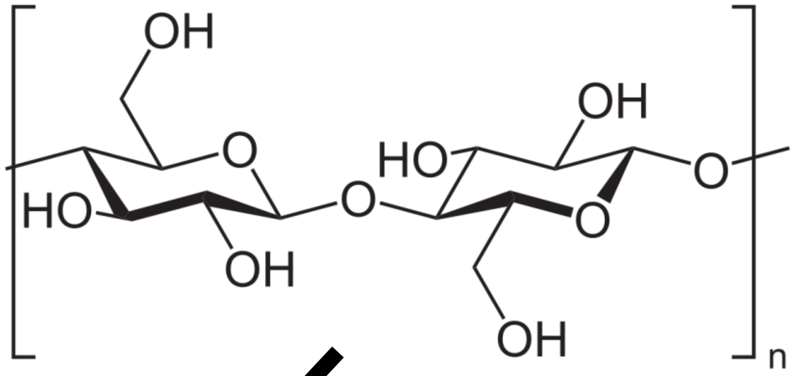
Complex interrelations between wood and microbes

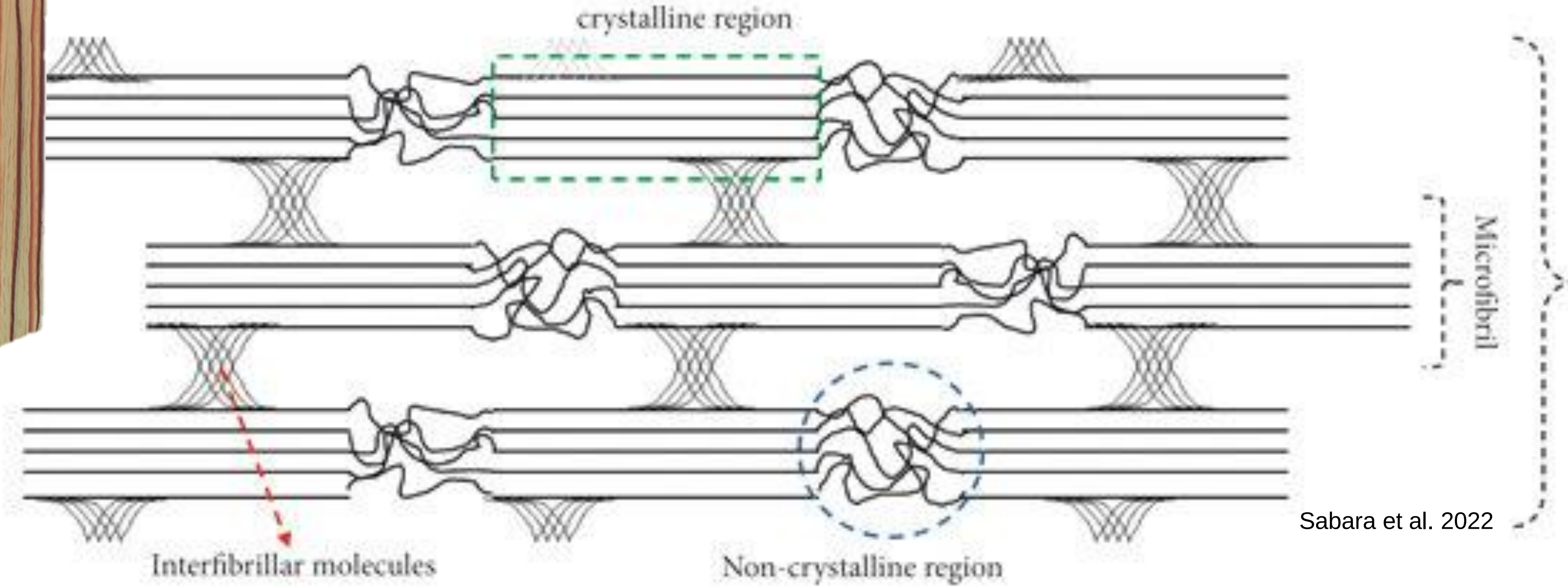


Embacher et al. *Fungal Biology Reviews* **2023**, *45*, 100305

Why do microbes eat wood?



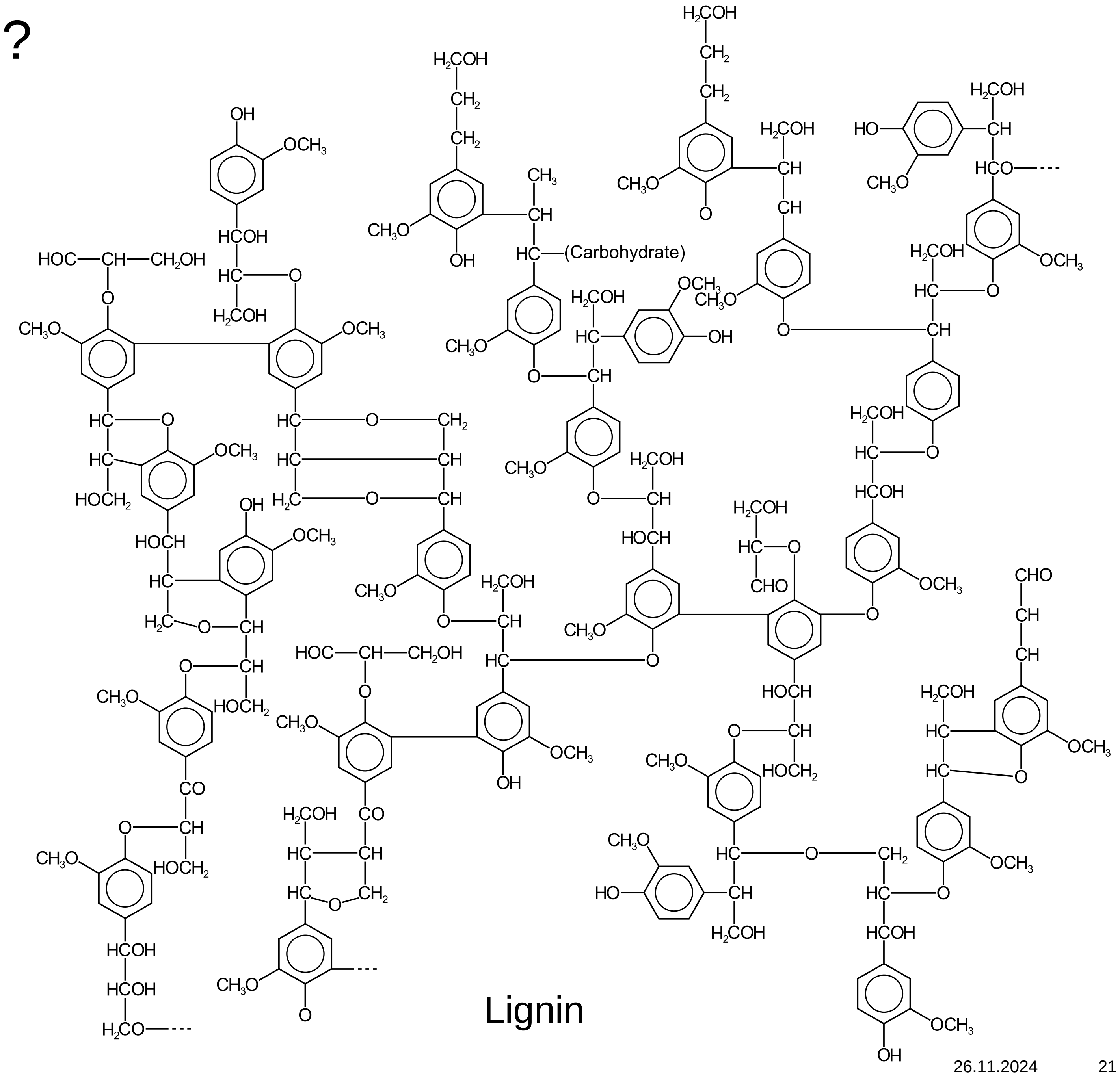




Sabara et al. 2022

Cellulose

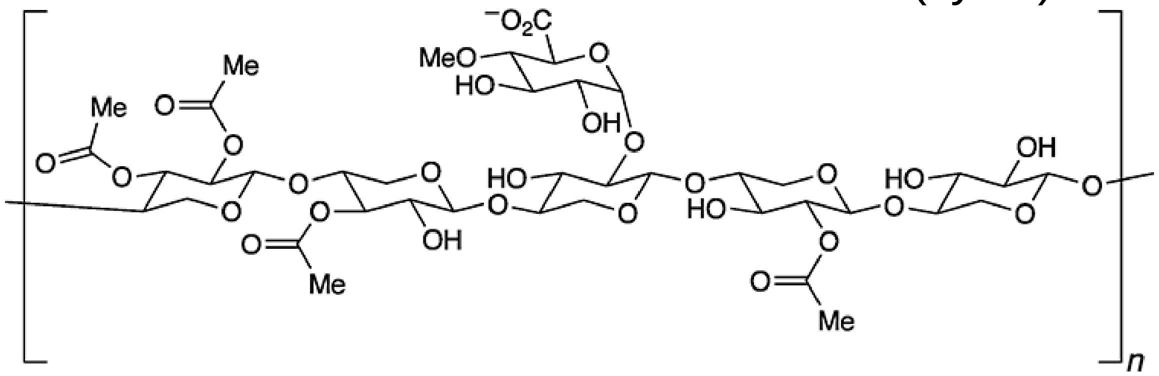
Why do microbes eat wood?

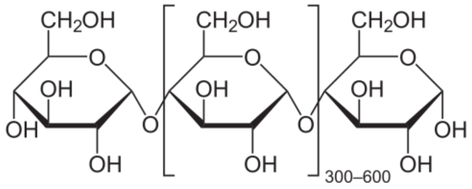


Lignin

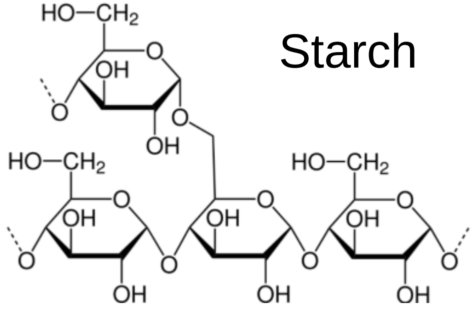
Why do microbes eat wood?

Hemicellulose (xylan)

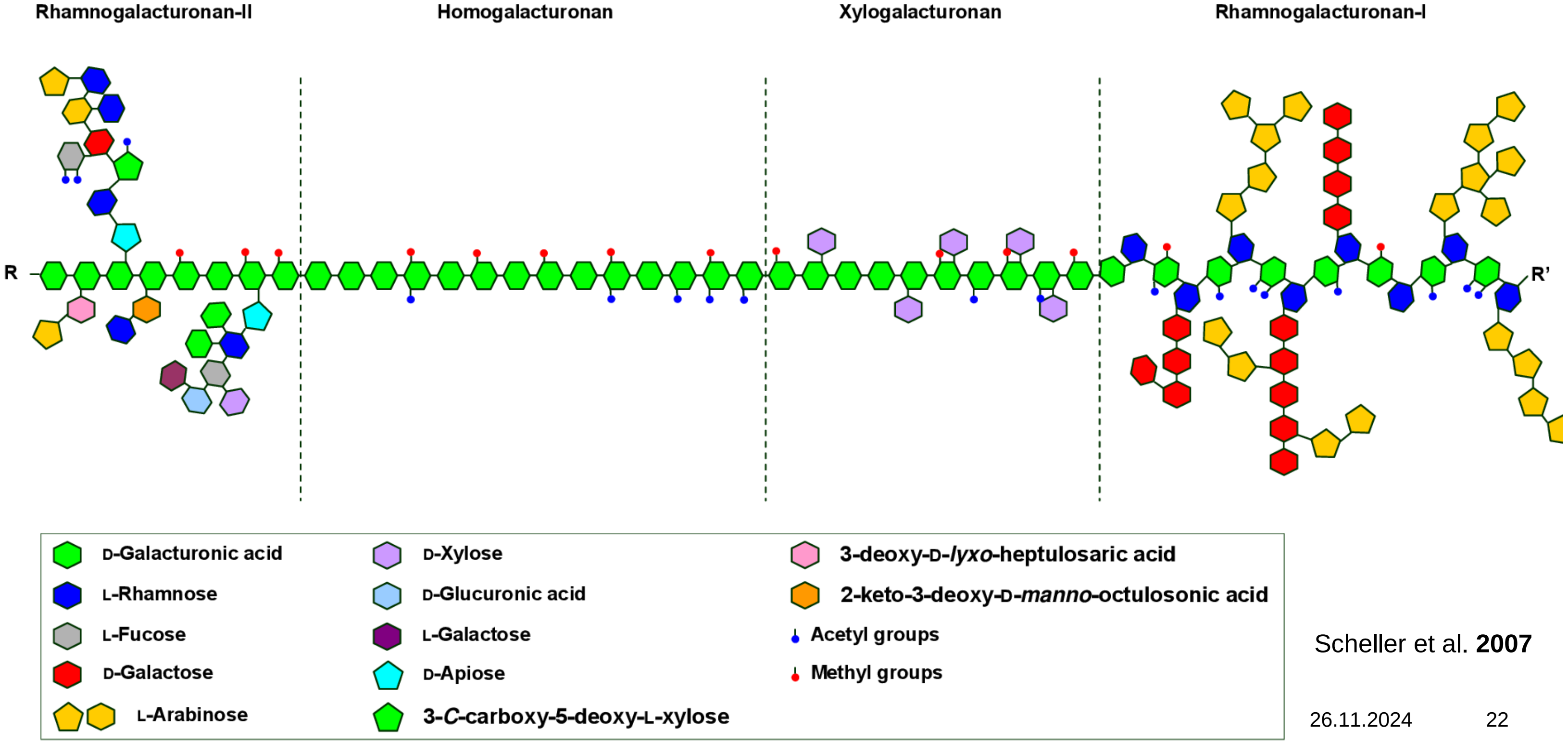




Starch

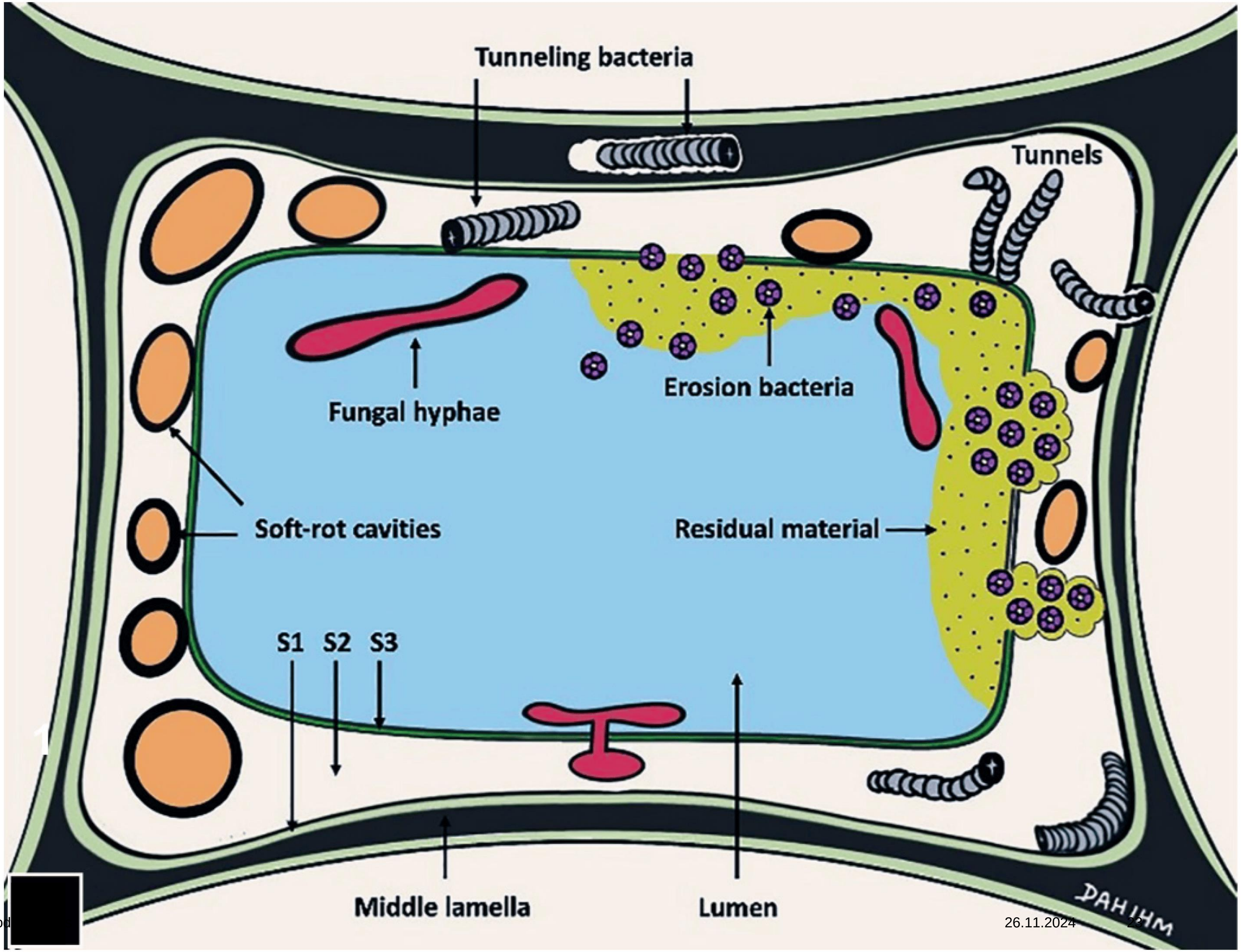


Pectin



Scheller et al. **2007**

Microbial wood degradation



Singh et al. *Forests* **2022**, *13*(3), 394

Wood-degrading fungi

Fungi can cause a variety of decay types in wood: mold, blue stain (sapstain), white rot, brown rot, and soft rot.

«White rot»

«Brown rot»

Rate of colonization, decay, and removal of wood structural components varies greatly between rot types, fungal species, and even strains. Variations in the morphology of decay patterns in wood and wood cell walls reflect local variations in the microdistribution of wood chemical components.

NEVERTHELESS:
a certain fungus causes a specific type of decay and the decay will always be the same no matter what wood type.

Can the appetite of microbes for wood be put to good use?

YES!

Variety (of effects) + Consistency = possibility to choose the type of fungi to achieve a certain property!

Back to the past…

R. Hartig, *Lehrbuch der Baumkrankheiten* 1882, Springer (Berlin), p. 98:

Ein allgemeineres Interesse beanspruchen unter den saprophytischen Holzpilzen noch die Peziza aeruginosa, welche zu den Discomyceten gehörend, doch hier schon erwähnt werden möge, da sie die sogen. Grünfäule des Holzes veranlasst. Insbesondere Eichen- und Rothbuchenholz, welches in stark zersetztem Zustande und anhaltend durchfeuchtet auf dem Waldboden längere Zeit gelegen hat, erhält oftmals eine intensiv spangrüne Färbung dadurch, dass das Mycel des genannten Pilzes, welches nebst den schüsselförmigen Fruchtträgern intensiv grün gefärbt ist, den Holzkörper durchzieht und in den Wandungen der Holzelemente ebenfalls jenen grünen, extrahirbaren Farbstoft erzeugt.

Es soll derselbe wegen seiner Unzerstörbarkeit eine technische Verwendung finden, und neuerdings bemüht man sich in Hannover, durch künstliche Züchtung grünfaules Holz in grösserer Quantität zu erzeugen.

Myco-Holz
=
Myco-Wood

(1964)

Original video:
MYKOHOLZ _ MYCOWOOD (2023, DE _ EN)
https://www.youtube.com/watch?v=afUf_6n1BAc

ETH zürich

Myco-Wood

Table 1 Overview of the Myko-Holz (myco-wood) related patents from Walter Luthardt

Year of application	Patent document	Content	Relation to *Myko-Holz*
1944	DD000000000292B1	[DE] Verfahren zur Züchtung holzbewohnender Pilze	Production of edable mushrooms, led to the invention of *Myko-Holz*
1951	DD000000003114A1	[DE] Verfahren zur Herstellung und Handhabung von Impfmaterial in der praktischen Pilzkultur	Preparation of the inoculation paste
1951	DD000000002175A1	[DE] Verfahren zur Veredelung von Holz durch Steigerung verschiedener Eigenschaften, wie die der Schnitz- und Spitzbarkeit, Feuerfestigkeit und Schwimmfähigkeit	Evaluation of potential applications of *Myko-Holz*
1953	DE000000946845B	[DE] Verfahren zur Veredlung von Holz	production of *Myko-Holz*
1953	DE000000932998B	[DE] Verfahren zur Herstellung und Handhabung von Impfmaterial in der Pilzkultur	Production of the inoculation paste
1957	DD000000022628A1	[DE] Schüttelkolben zur Anreicherung von Luftsauerstoff in Nährlösungen	Preparation of the inoculation paste
1958	DD000000021771A1	[DE] Glasform aus Holz	Application of *Myko-Holz* for glass industry
1959	DE000001063336A	DE] Schüttelkolben fuer biologische Zwecke, insbesondere zur Herstellung von Pilzkulturen	Preparation of the inoculation paste
1971	DD000000102553A1	[DE] Verfahren zur Herstellung von Pilzimpfmaterial zur Übertragung von Pilzkulturen, insbesondere für Kulturen holzbewohnender Pilze	Preparation of the inoculation paste

"Myco-wood"

The incubation of beech wood with the white-rot fungi *Pleurotus ostreatus* and *T. versicolor* has been applied to produce so-called "myco-wood" (Luthardt 1963; Schmidt 1994; Unbehaun et al. 2000). Depending on the incubation time, the fungal treatment reduced the density and loosened the structure of the wood. In consequence, the machinability and rate of water sorption were improved. "Myco-wood" was mostly used for pencils, rulers, drawing tables and wooden forms in the glass industry. During 1958–1965, 55×10^6 "myco-wood" pencils were produced in the former German Democratic Republic. At the moment, this technique is not applied in practice, but production is under consideration by some German pencil producers.

In general, wood mycologically modified by the Luthardt-method is characterized by the following attributes [10]:

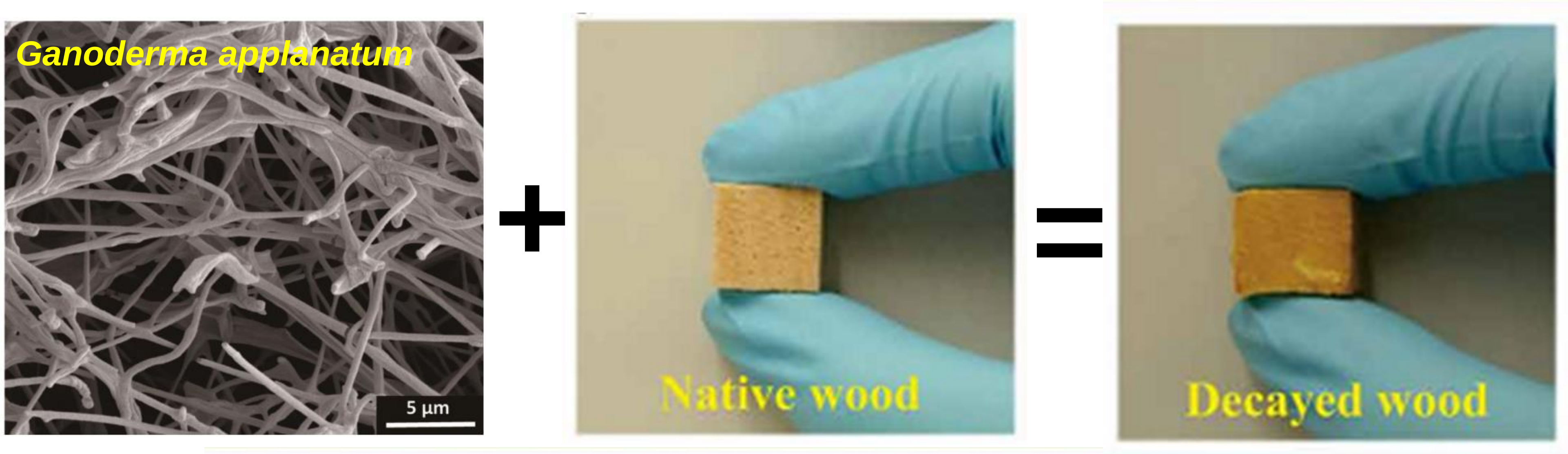
- High and uniform porosity
- Low variation in raw density
- Stressless material (thus low warpage)
- Good insulating properties
- Low swelling
- Good heat and cold insulation
- High sound absorption
- High moisture absorption
- High absorption and good impregnability
- Good sharpenability

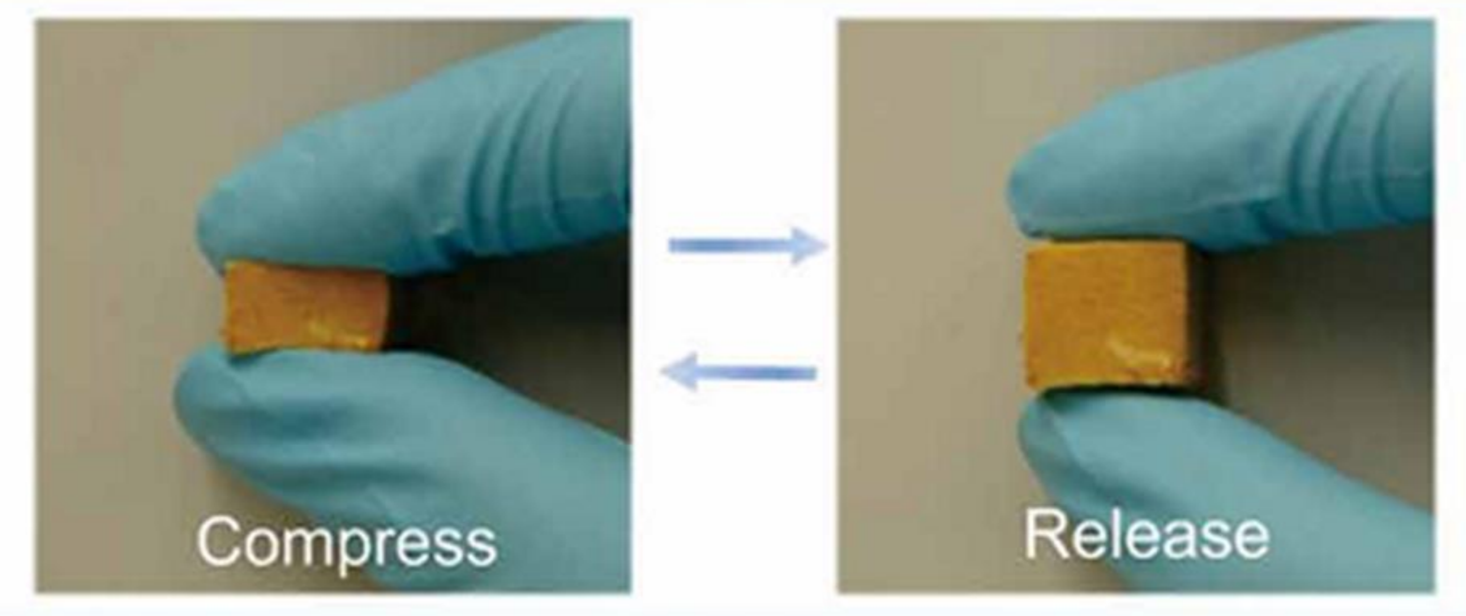
…so, what's the problem?

TIME!

(AND fungi stability, biosafety, energy consumption → climate chambers…)

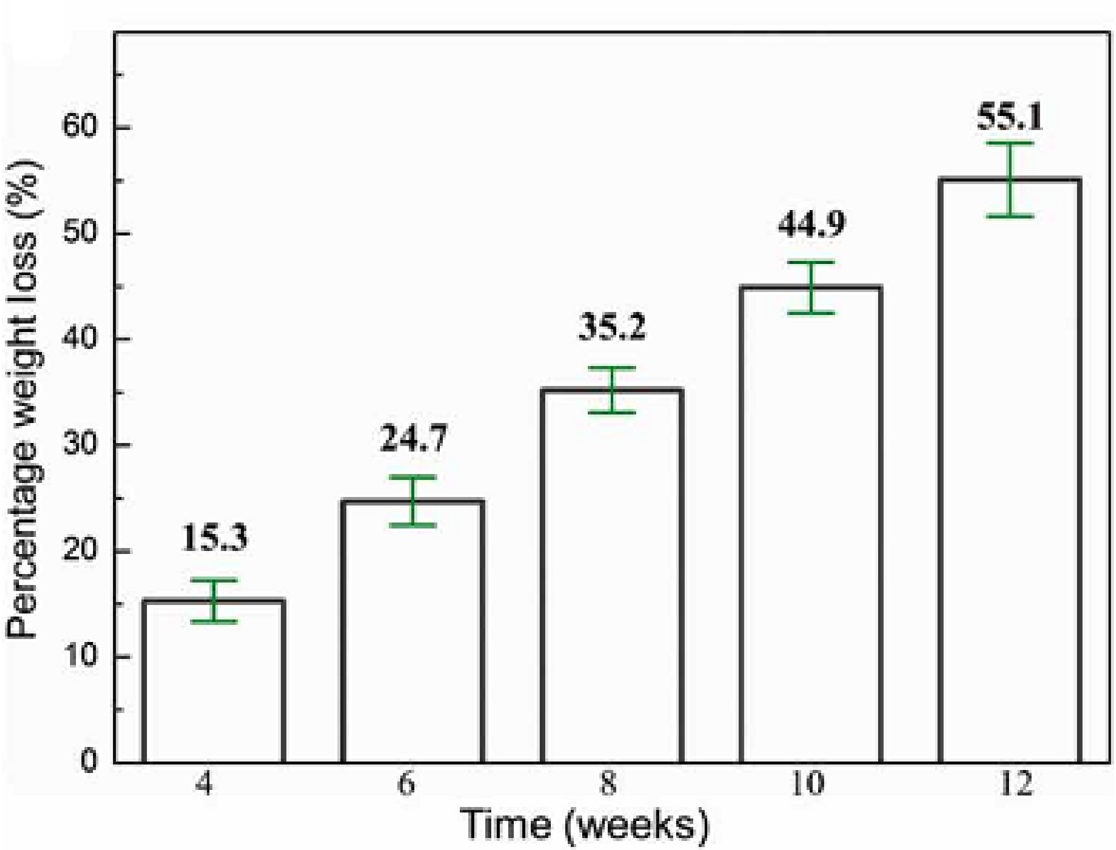
White rot-degraded balsa wood

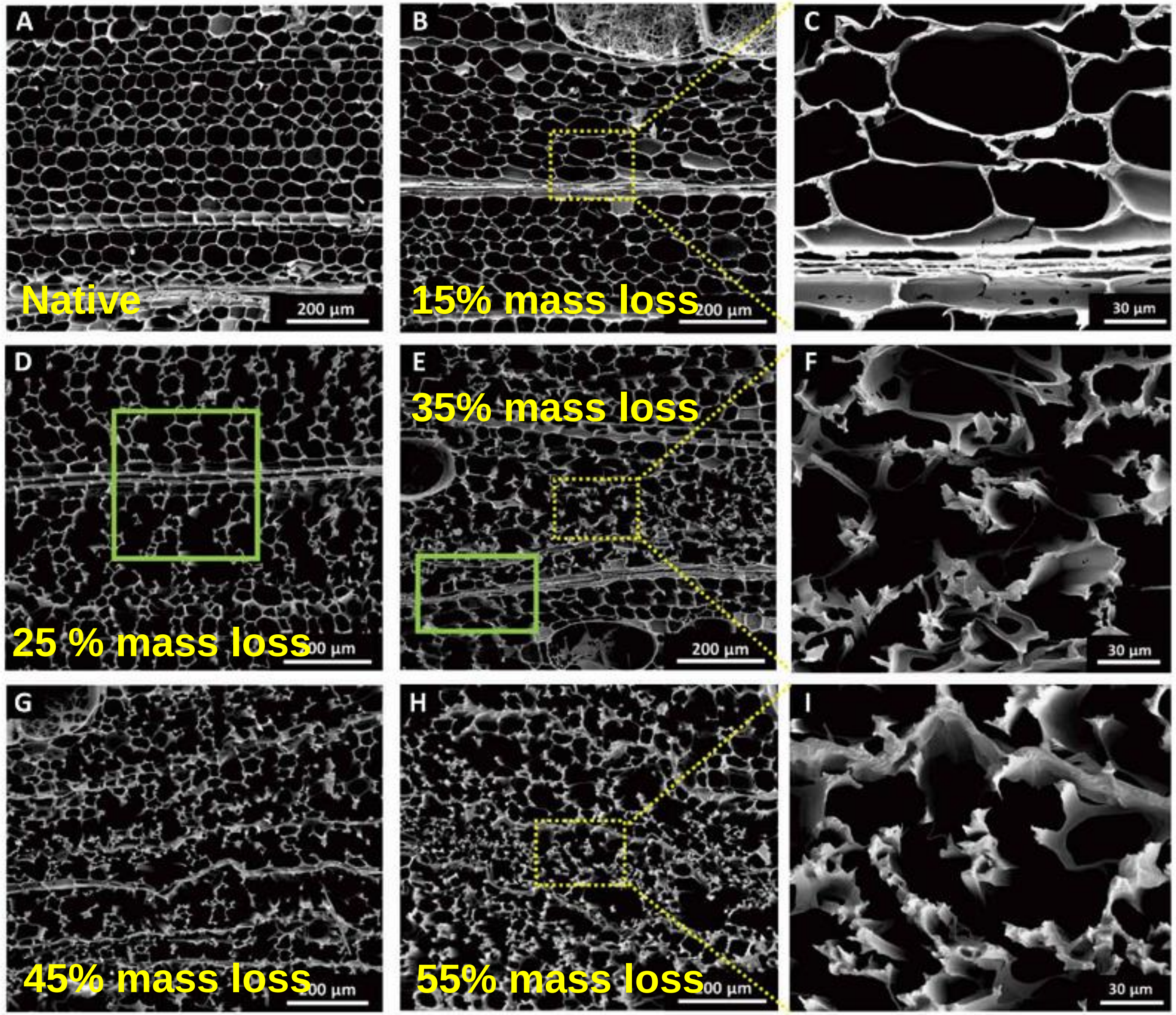




Sun et al. *Sci. Adv.* **2021**, *7*, eabd9138

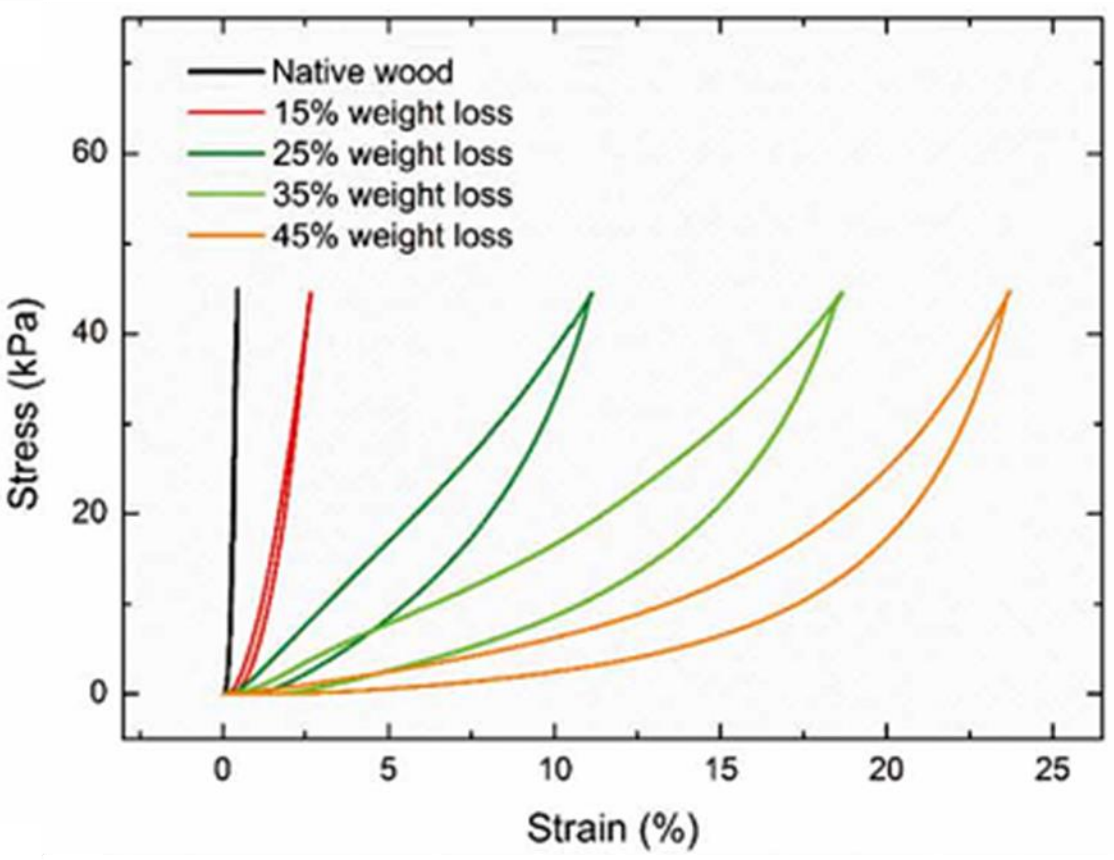
White rot-degraded balsa wood

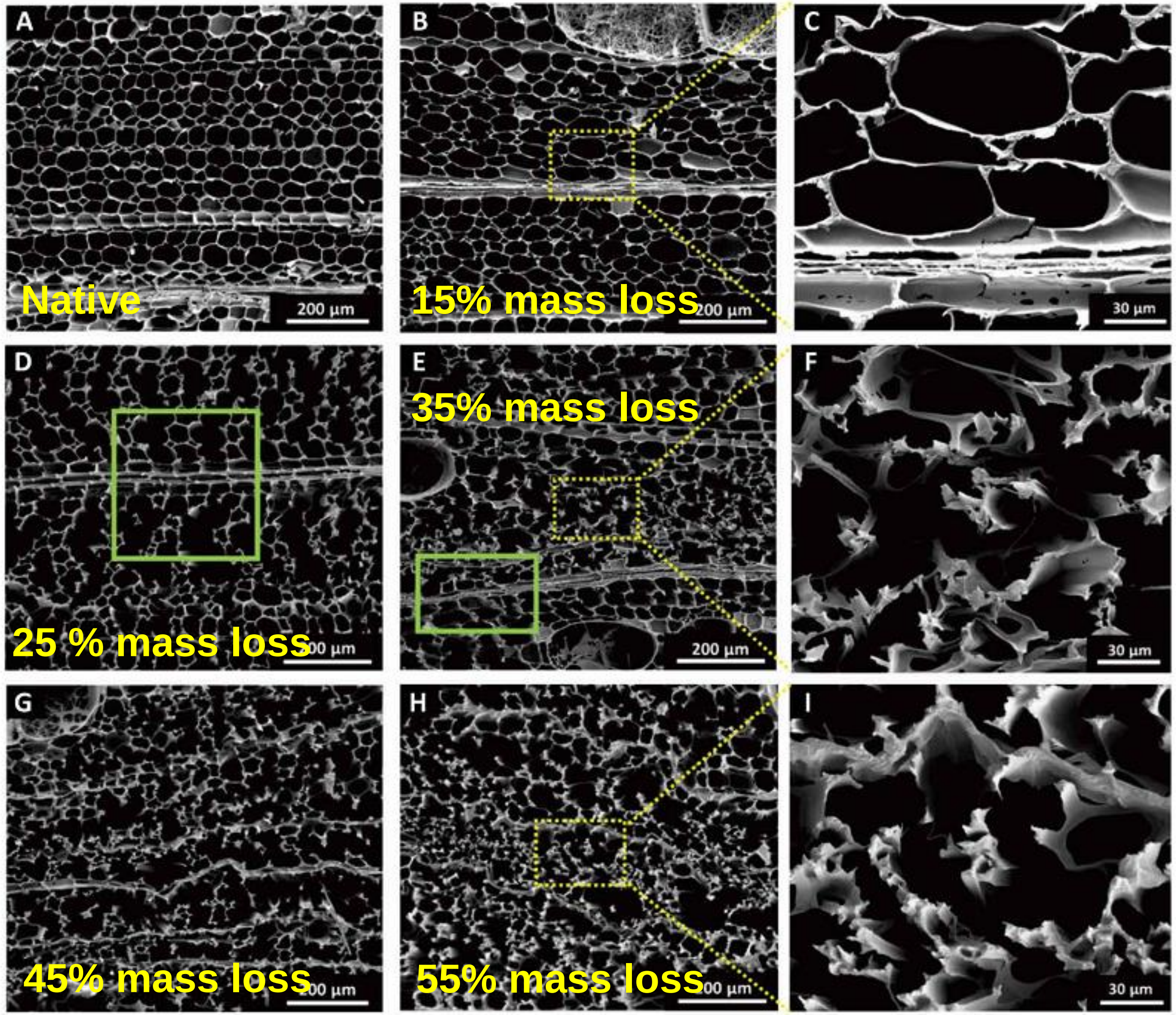




Sun et al. *Sci. Adv.* **2021**, *7*, eabd9138

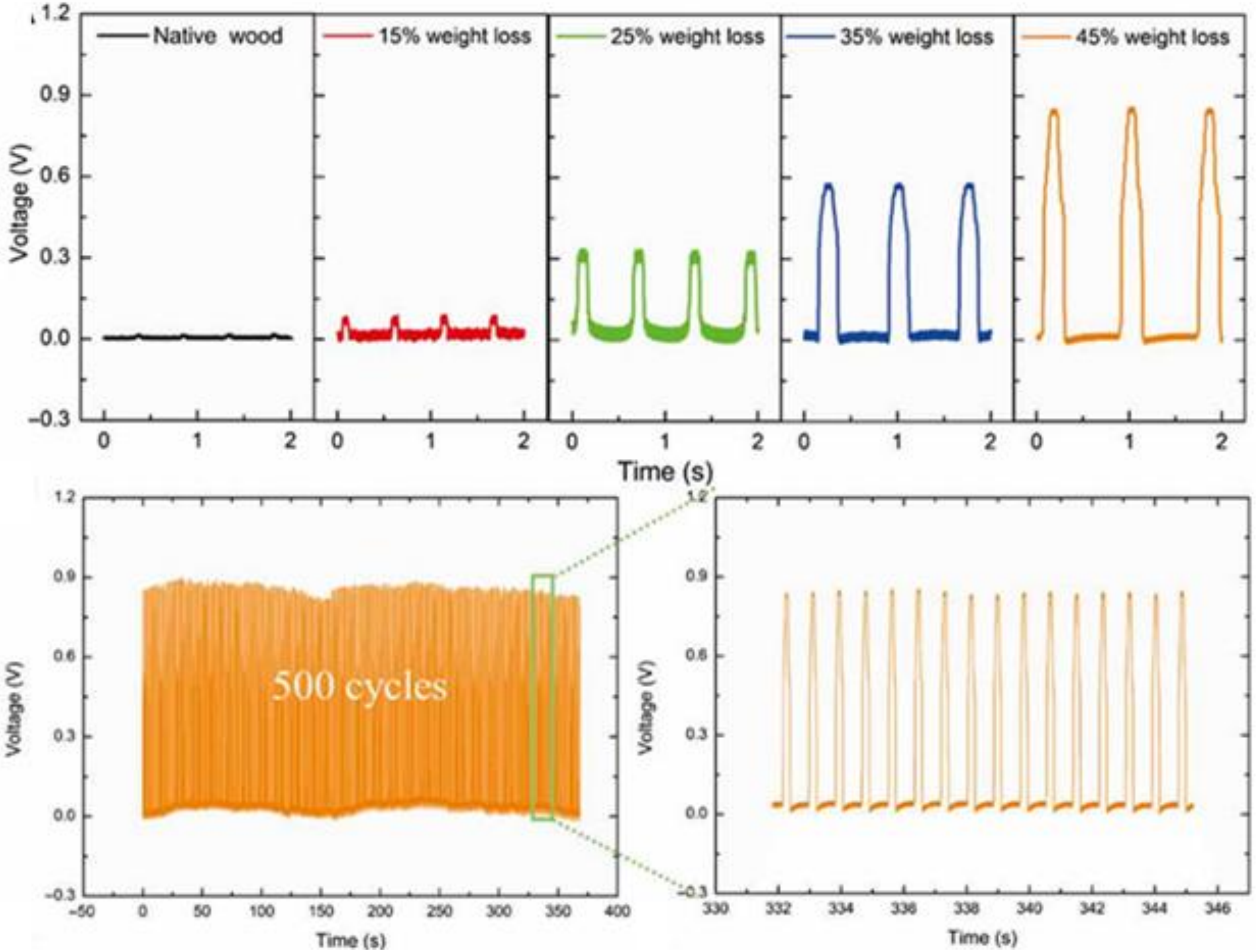
White rot-degraded balsa wood





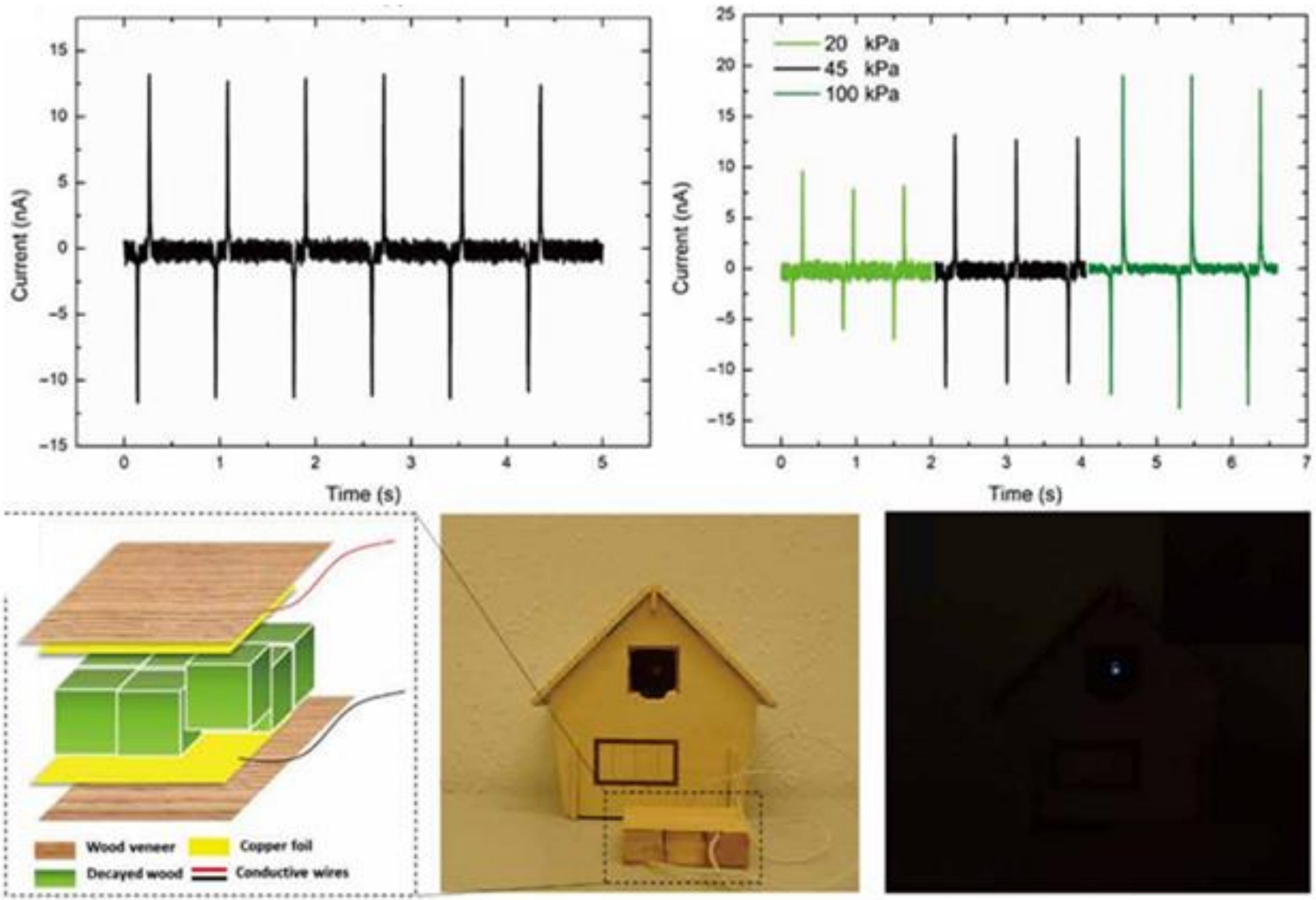
Sun et al. *Sci. Adv.* **2021**, *7*, eabd9138

Piezoelectricity from white rot-degraded balsa wood



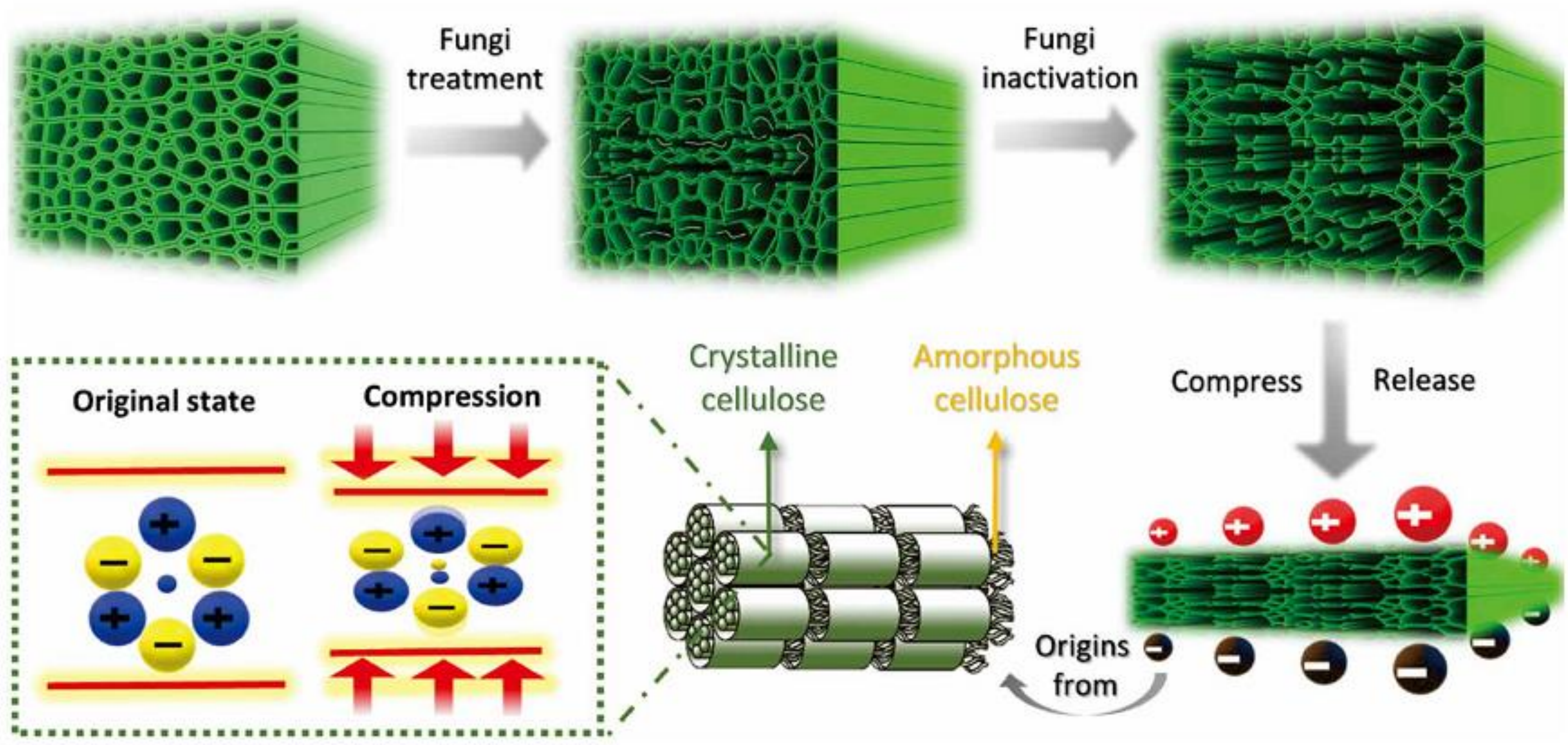
Sun et al. *Sci. Adv.* **2021**, *7*, eabd9138

Piezoelectricity from white rot-degraded balsa wood



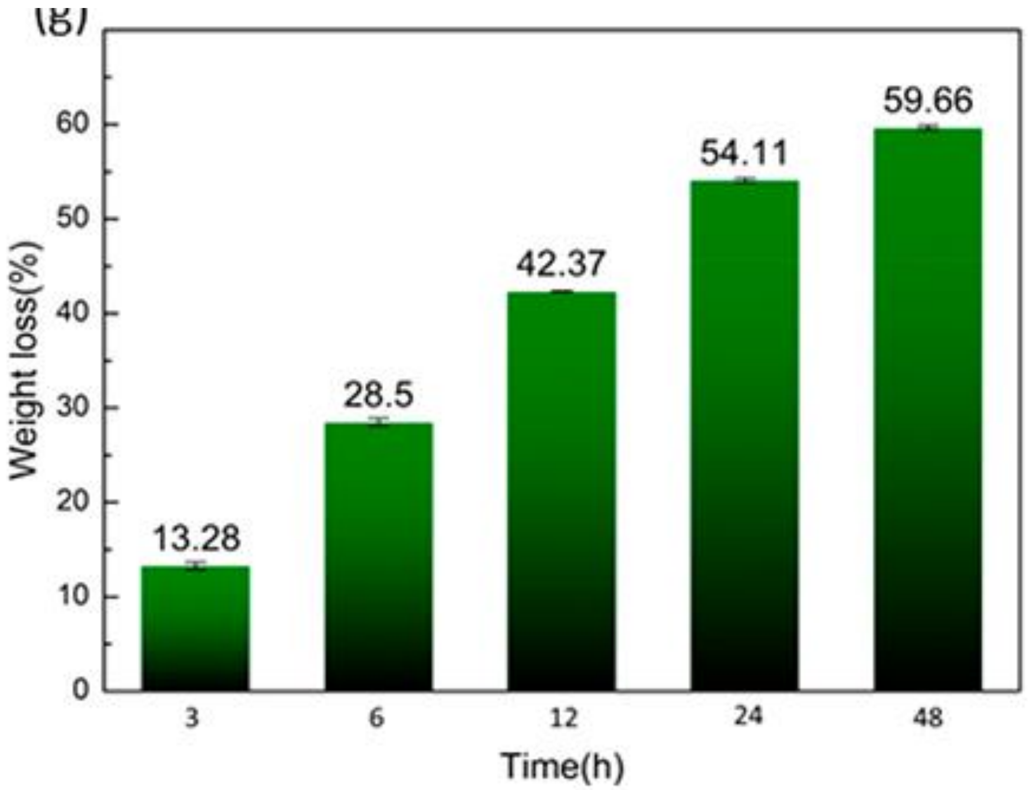
Sun et al. *Sci. Adv.* **2021**, *7*, eabd9138

Piezoelectricity from white rot-degraded balsa wood

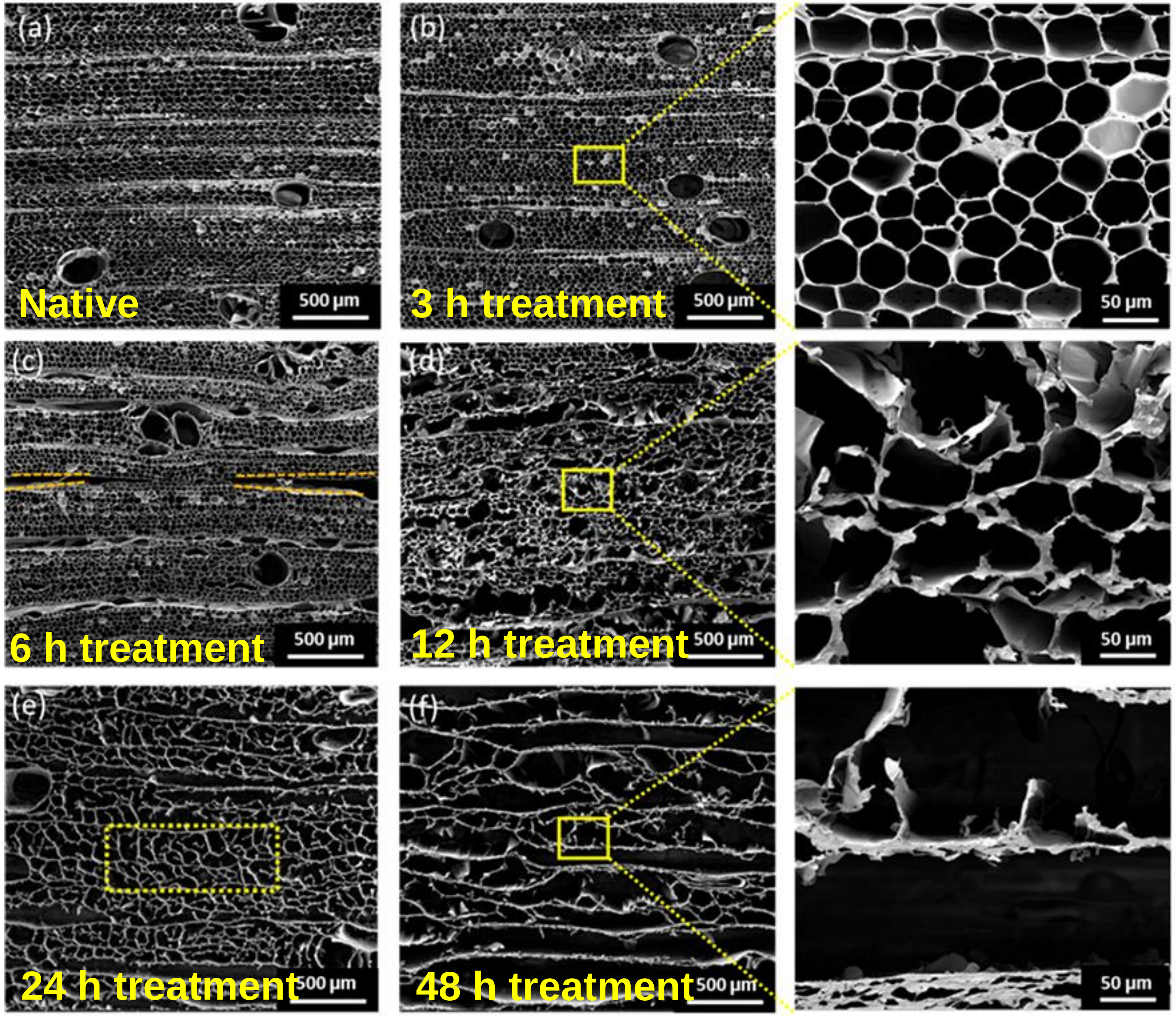


Sun et al. *Sci. Adv.* **2021**, *7*, eabd9138

Piezoelectricity from chemically-delignified balsa wood

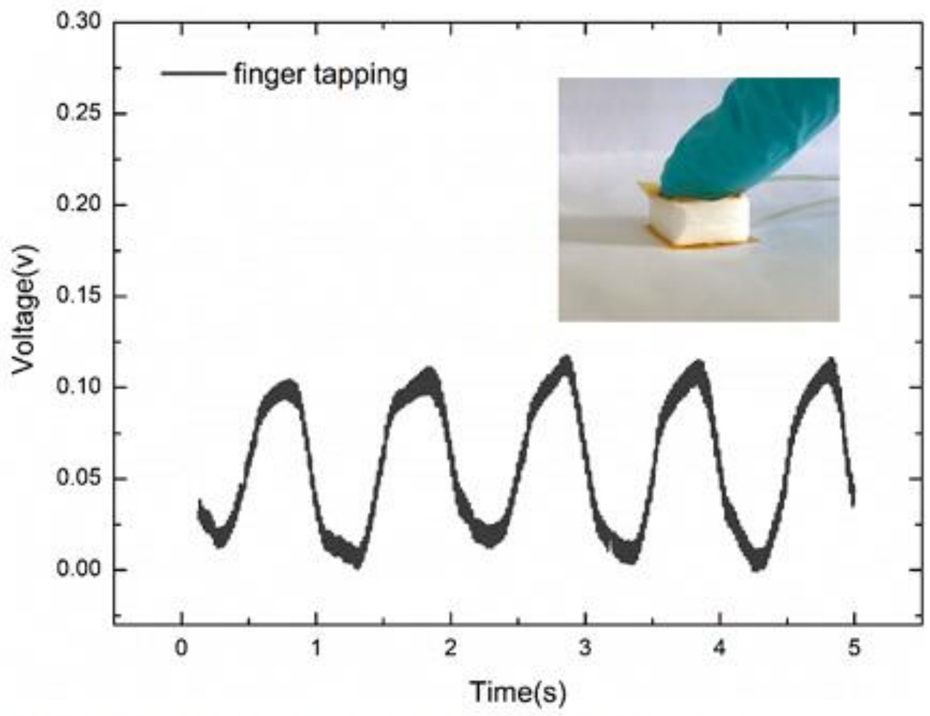


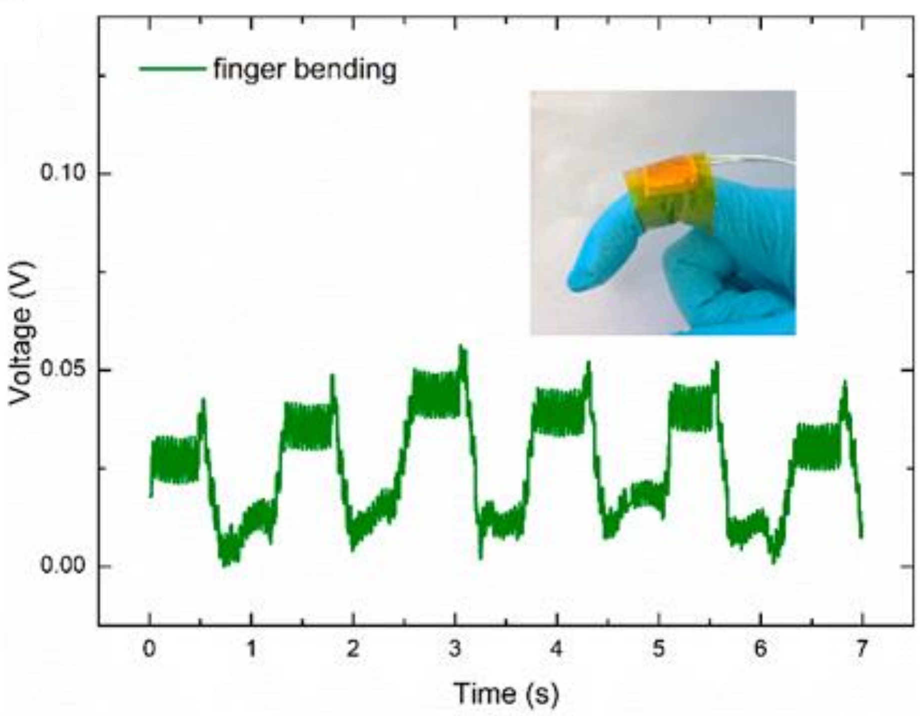
Treatment:
50:50 vol:vol glacial acetic acid and 30% H_2O_2, 80°C

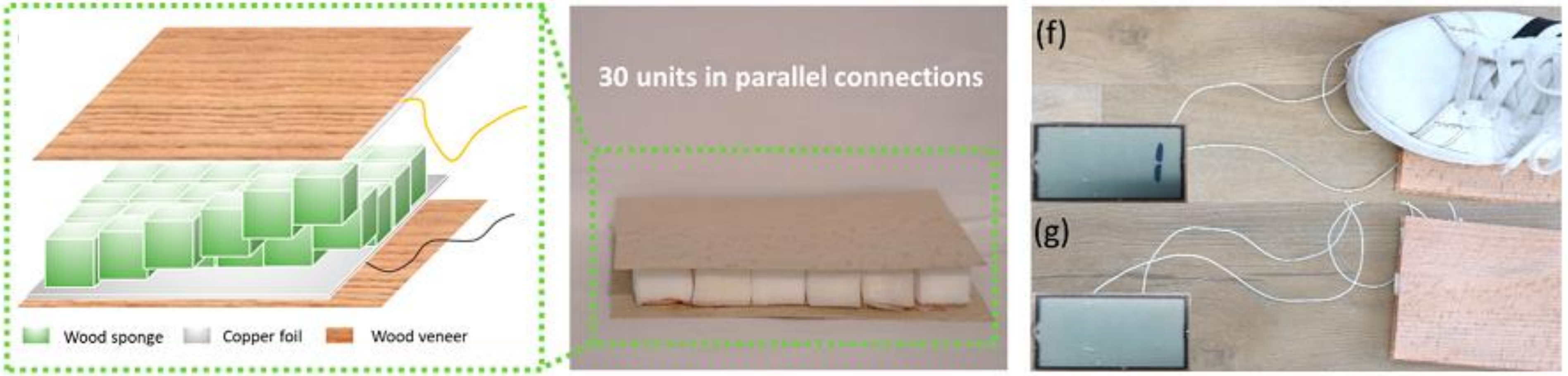


Sun et al. *ACS Nano* **2020**, *14*, 14665-14674

Piezoelectricity from chemically-delignified balsa wood

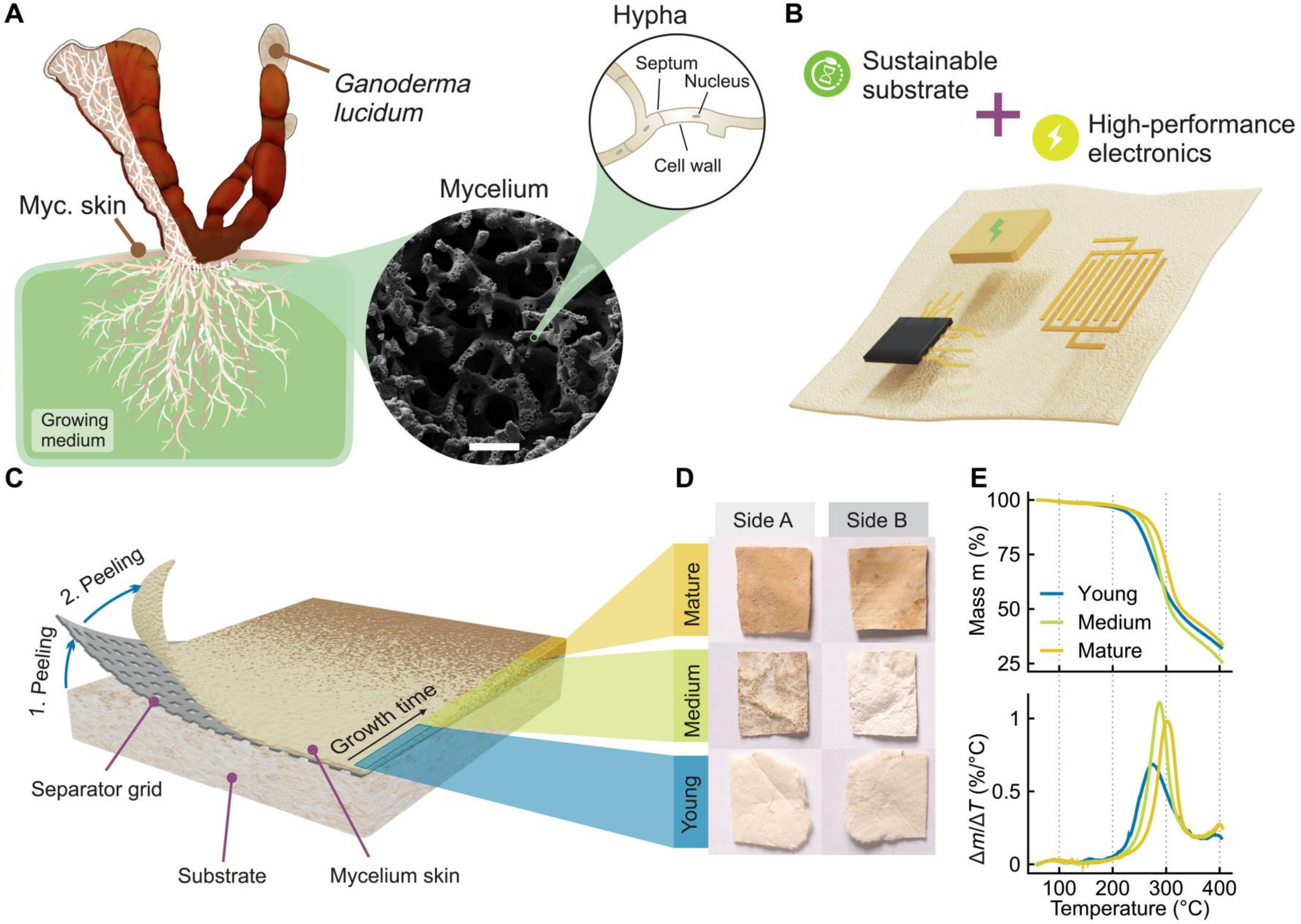






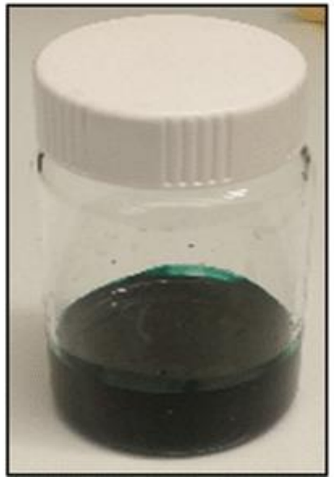
Sun et al. *ACS Nano* **2020**, *14*, 14665-14674

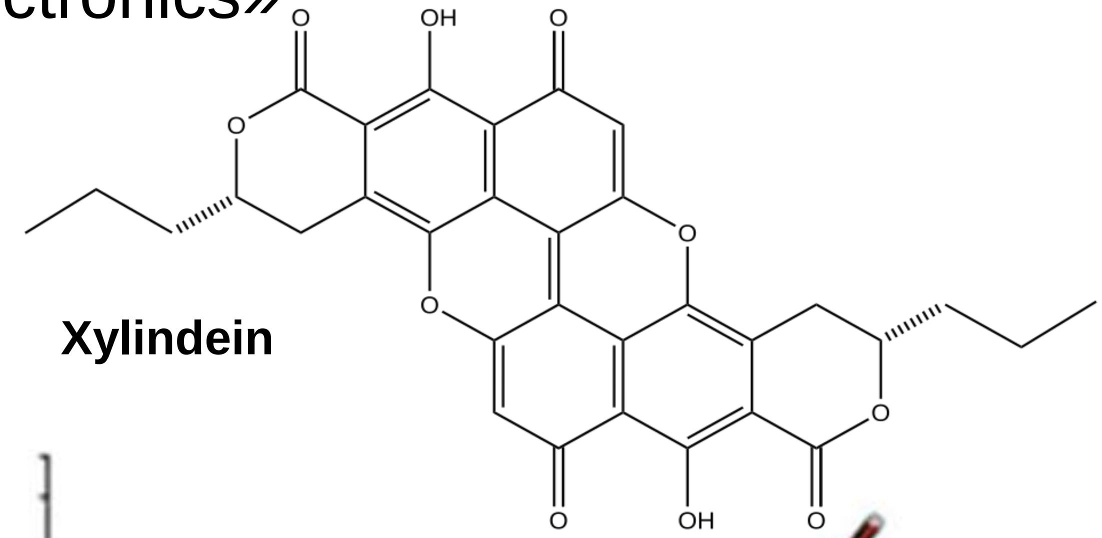
Sci-Fi possibility 1: «wood myceliotronics»



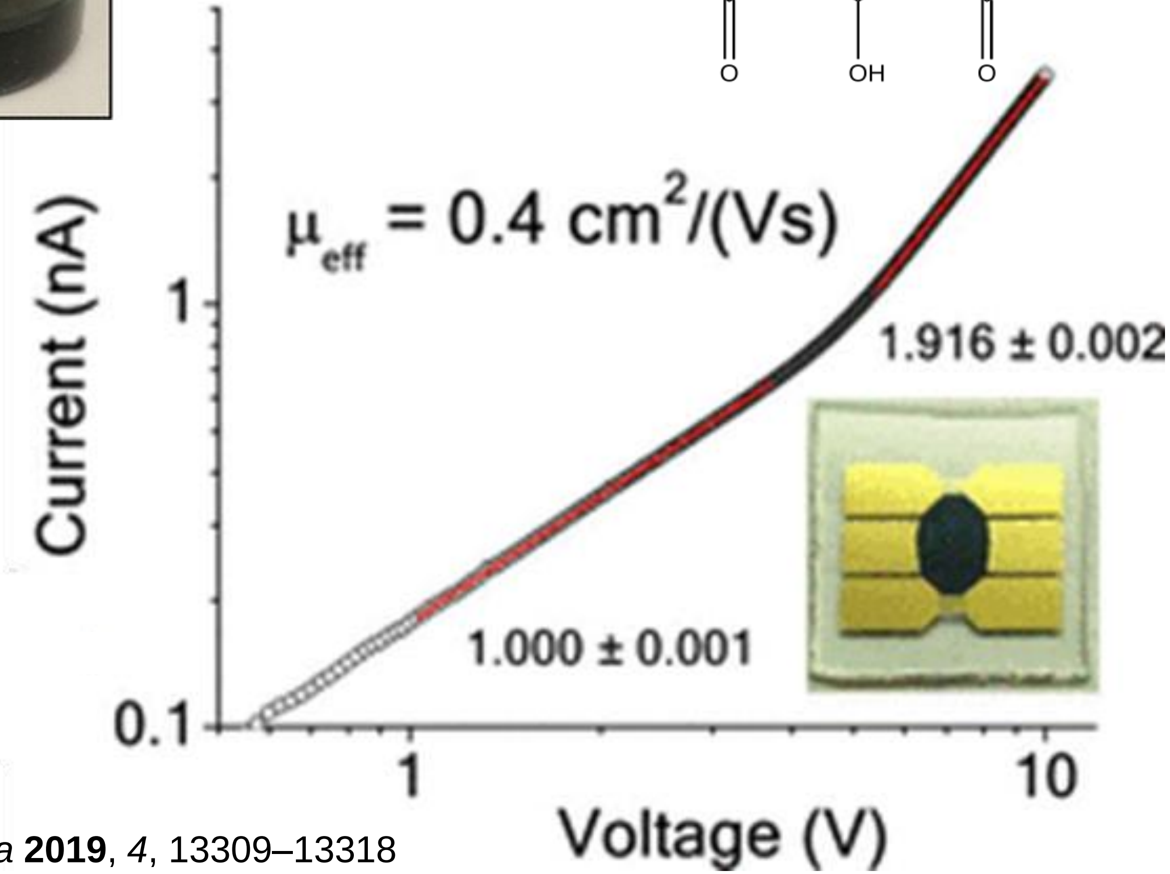
Danninger et al. *Sci. Adv.* **2022**, *8*, eadd7118

Sci-Fi possibility 2: «spalted wood optoelectronics»



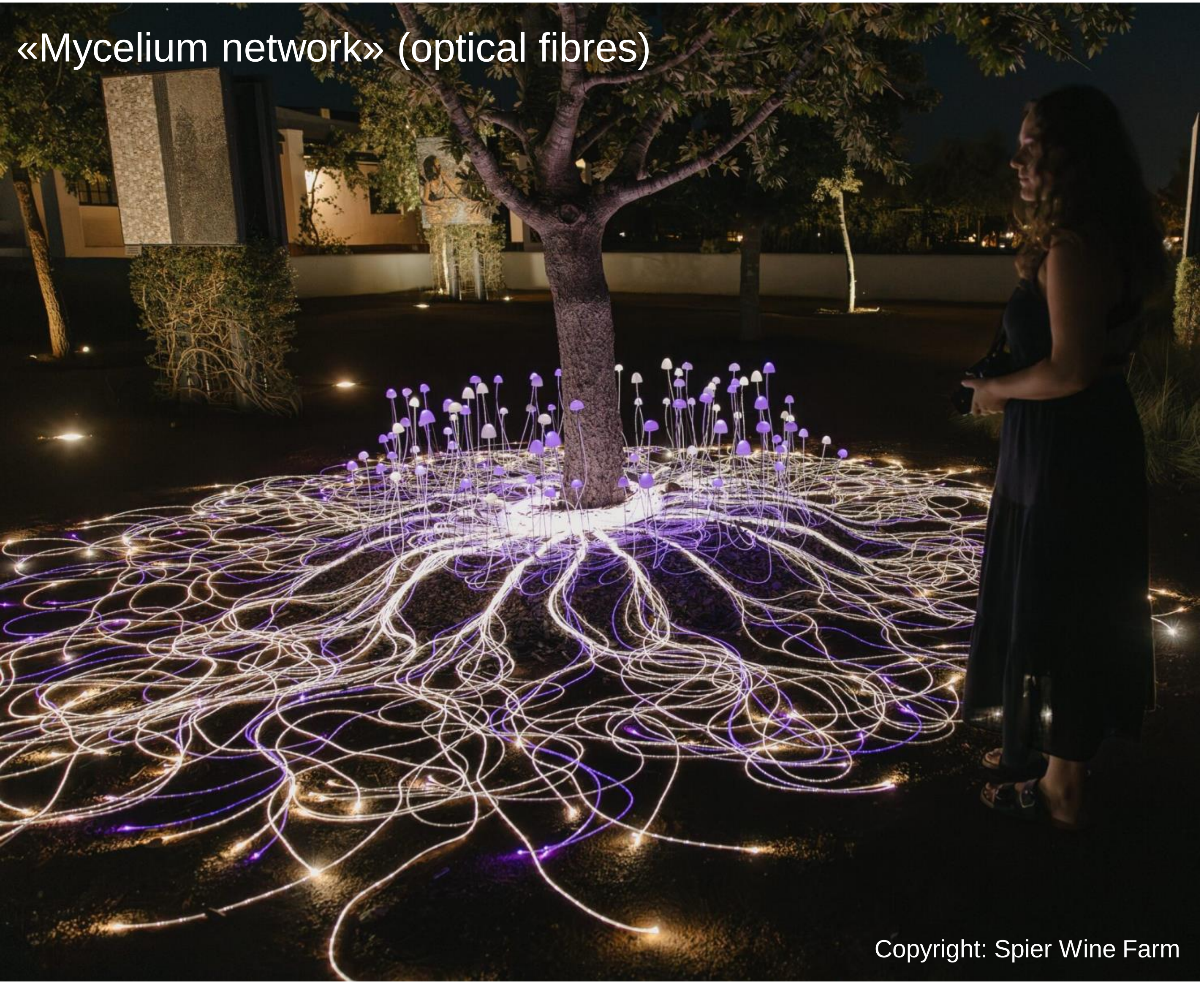


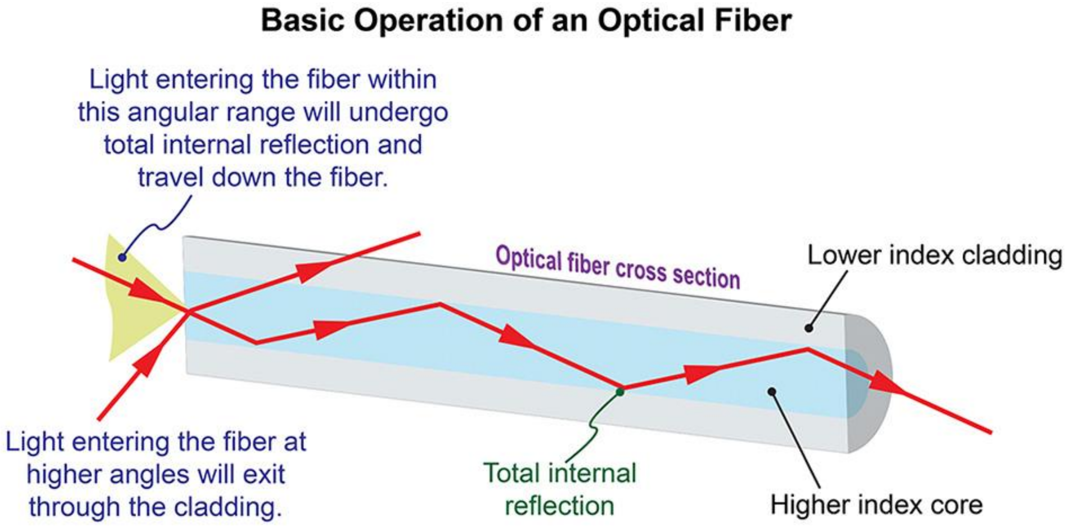
Xylindein

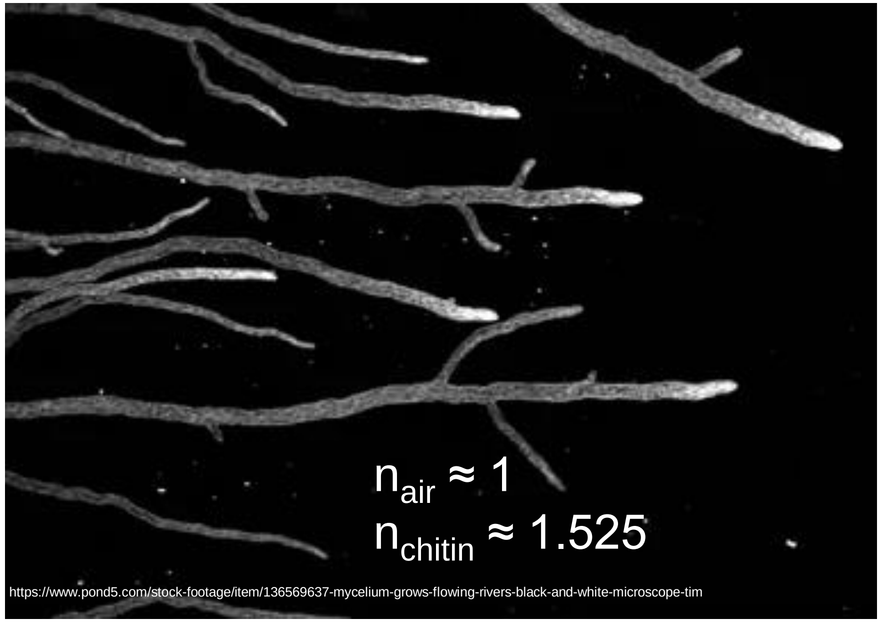


Giesbers et al. *ACS Omega* **2019**, *4*, 13309–13318

Sci-Fi possibility 3: «wood-embedded mycelium optical fibers»







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THANK YOU!

Questions?

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IfB
Institut für Baustoffe
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