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you migranes? pg. 01

The blood test that can help  
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Pee Power: Could urea fuel be the  
future of sustainable energy? pg. 23

# ScienceMind

WINTER 2023

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# THIS ISSUE



Dear Reader,

Welcome to our Winter 2023 issue! This issue has articles in the categories of cardiology, neuroscience, medicine, pharmacology, business/law, technology, chemistry, and biology. We also present a special interview with Professors Martin Giurfa and Albert Cardona, who take us on an insightful journey into the mind of an insect.

At ScienceMind, we strive to keep informed on the latest developments in STEM. Hence, we couldn't help but notice the attention surrounding generative AI and the impact it's already making on all aspects of humanity. In an effort to embrace this new and powerful technology, our editorial team has decided to let OpenAI take the lead in designing our cover!

Moreover, we have exciting news! The articles in this issue will decide the winners of the first-ever **ScienceMind Awards**. Make sure to sign up to our mailing list and stay tuned on social media for more information regarding nominations, voting, and of course, the awards party!

*If this is your first time reading our magazine...*

ScienceMind is the award-winning, student-led science magazine of King's College London. We report the latest findings in STEM to students and the wider community. We showcase and develop the written and oral communication skills of students interested in STEM by concisely explaining complex scientific concepts in the form of lay articles and by conducting interviews. Authors can also broaden their knowledge by writing articles for different sectors between issues.

Articles have difficulty levels. There's something for everyone!

**Shallow dive:** Secondary school level

**Treading water:** A-level to undergraduate level

**Deep dive:** Final year undergraduate, postgraduate, professor level

*ScienceMind is ever growing, join the new age of science media.*

Kind regards,

*Olivera Mitevska*

**The Deputy Editor-in-Chief**  
**Olivera Mitevska**



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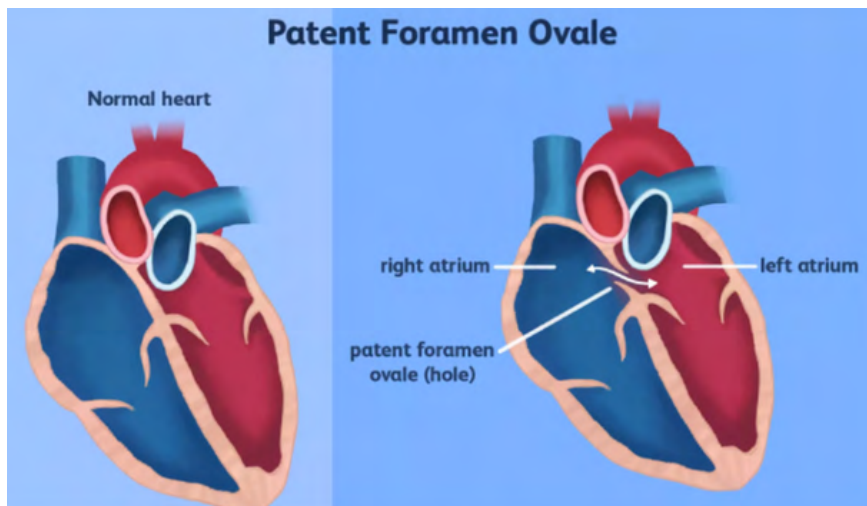
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# IS YOUR HEART GIVING YOU MIGRAINES?

**M**igraines are a neurovascular disorder characterised by recurrent headaches associated with autonomic symptoms, with estimates placing migraines as the **sixth highest** cause of years of life lost due to disability. Approximately 12% of the population of the western hemisphere suffer from migraines, and, although the aetiology (the cause) can vary, a recent link has been established between migraines, and a condition called the patent foramen ovale (PFO).

The **foramen ovale** is an opening in the wall separating the left and right atrium of the heart, which is functional in the foetus but closes shortly after birth (**Figure 1**). The patent foramen ovale (**PFO**), is when the hole in the heart did not close the way it should have after birth. The presence of this PFO means that blood from the right and left sides of the heart, which should not come in contact after birth, continue to be mixed, which affects blood oxygenation and blood pressure throughout the body, amongst other consequences.



**Figure 1:** Patent Foramen ovale (right) is when the hole between the right and the left atrium remains open in a child after birth. This hole can remain open and relatively symptomless all the way into adulthood, but may predispose, to certain conditions, including **migraines**.

A **2008 meta-analysis conducted by Schwedt et al.** confirmed that the incidence of PFO in patients suffering from migraines was **39.8-72%**, and that, similarly, the prevalence of migraines in patients with PFO was **22.3-64.3%**.

About **20-25%** of the adult population has PFO but the incidence of PFO increases to **30-50%** amongst people suffering from migraine with aura (a classic migraine).

There are multiple proposed mechanisms by which PFO causes migraines, which may act in parallel. The first is **the theory of abnormal thromboembolism**, proposing that tiny venous clots and platelet aggregates, which are normally filtered in the lungs, bypass the pulmonary circulation via the PFO, allowing them to directly enter the arteries. This causes occlusion of these vessels, leading to hypoperfusion and thus symptoms of migraine, including the characteristic unilateral throbbing pain and extreme sensitivity to light and sound. The successful treatment of some migraines with antiplatelet therapy, such as aspirin or clopidogrel support this hypothesis. However, many migraines are resistant to this line of therapy, suggesting that other pathways may also be at play.

The second hypothesis involves **vasoactive substances**, including serotonin and calcitonin-derived gene-related peptide. These can transmit pain signals and may thereby be implicated in symptoms of migraines.

Normally, these substances are broken down by monoamine oxidases in pulmonary capillaries. In patients with PFO, they can bypass the lungs, and are no longer broken down. They subsequently migrate to arterial vessels entering the brain where they can effectuate their pain-mediating actions by acting on trigeminal ganglion cells that are involved in the dural neurogenic inflammatory response.

Other studies have proposed a genetic link between migraines and PFO, showing that atrial shunts can be inherited in an autosomal dominant fashion, and that migraine with aura was inherited in a similar way in some families.

Despite the pathogenesis being uncertain, **Elbadawi et al.** showed an improvement in migraine symptoms after transcatheter PFO closure. This is a surgical procedure in which a thin tube (catheter) is inserted into a blood vessel in the groin and guided to heart via this vessel. There, it fixes the hole, before removing the catheter. Although a promising discovery, it is important to consider that only single-centre observations have shown a beneficial role of PFO closure on migraine prevention, whereas large, randomised control trials (**MIST, PRIMA, and PREMIUM**) reported negative results. Nevertheless, a 2021 meta-analysis by concluded that PFO closure was a safe procedure and could significantly reduce the mean number of migraine days and attacks, with numerous patients experiencing complete migraine cessation.

To consolidate the differential findings of previous studies, **Zhang et al. carried out a meta-analysis in February 2022** looking at 3 randomised controlled trials (RCTs) and 8 retrospective case series (RCSs) with **1165 subjects**. The results of this meta-analysis demonstrated a **50% reduction** in monthly migraine attacks and migraine days after PFO closure (**p=0.0295**). Complete resolution did not reach statistical significance, likely due to insufficient studies included in the analysis.

Nevertheless, the higher the incidence of aura in these patients, the greater the reduction in migraine attacks and days, and the higher the incidence of complete cessation of headaches after PFO closure. This suggests a promising new therapeutic approach to treating severe migraines with aura.

In patients **without aura**, some did have **statistically significant reductions** in migraine attack. Nevertheless, incidence of migraine days and headache reduction in these patients was not statistically significant, questioning the therapeutic potential of this intervention. Moreover, some patients experienced more frequent migraine attacks within the 4-week period after PFO closure, with symptoms persisting for several weeks. This may be due to the activation of endothelial cells in the left heart after PFO closure, which activates platelets. Platelet activation triggers their release of serotonin **which may thus perpetuate migraines**.

If serotonin is indeed the cause for these patient's headaches, then antiplatelet therapy such as aspirin or clopidogrel may help resolve their symptoms.

Overall, this meta-analysis substantiated findings of previous studies implicating PFO in susceptibility to migraines. Although yielding controversial results for migraines alone, it certainly warrants **re-evaluation** of PFO closure as a therapeutic means for treating episodic migraines, especially migraines with aura.

References






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## UNIVERSE 25:

# Can the growth and demise of rats predict human nature?

WRITTEN BY SHRADDHA GOSATKAR  
 EDITED BY NICOLA ALLEN  
 DESIGNED BY ANJA STARC

*A mouse utopia was built by John B. Calhoun, where the animals were provided unlimited food and water, and full protection from predators and disease. In this utopia, the only limiting resource was physical space. Calhoun, the American ethologist and behavioural researcher rose to fame through this gripping project - 'Universe 25'. Theoretically, every whim of the mice was meant to be satisfied but how did it deteriorate into hell? And what does it mean for humans?*

In 1970, Calhoun attempted to conduct a behavioural study of captive mice to explain human society in an “ideal world”. He named his project ‘Universe 25’. The mice were provided a 9-square-foot enclosure which had numerous compartments for the mice to nest and explore. For the first 104 days, Calhoun allowed four breeding pairs of healthy mice to their new, utopian environment. During this time, they marked their territories and birthed pups. Over the 104 days, the population of mice approximately quadrupled! What was interesting was that the mice would huddle together during feed time and crowd in certain areas despite the vastness

in space available. It seemed as though they were living in paradise.

The project took an abrupt turn nearly a year in when the population density began to peak. The population growth greatly slowed due to crowding behaviour, now doubling every 145 days instead of 55 days. When the number of rodents reached 620, mice began to naturally form groupings. Mice that did not fit into any of the groups became severely socially isolated. Mice who are unwelcomed in the population face extreme vulnerability, both for their mental and physical health. In normal circumstances, isolated mice would have immigrated to find



another group, however, within Universe 25, they were starved of this option. There was also a formation of a **hierarchy** between them, and the most dominant mice were extremely aggressive and large, thus called the **“alpha mice”**. These mice began to attack the group, rape, and even practice cannibalism at the expense of their peers.

As a result, **many males began to become negatively impacted psychologically**. They excluded themselves and as a consequence, slept and ate by themselves. **Female mice even began to attack their own pups** as taking care of their nests in the middle of such a violent and chaotic environment was exhausting. Some would completely withdraw themselves from their motherly duties, ignore their pups and quit mating entirely. **The utopia became hellish and showed a breakdown of social order named the “behavioural sink”**.

As a result, a low birth rate was observed and an increase in mortality

in younger rodents. A new class of male rodents appeared which were named the **“beautiful ones”** who had no perception of the “normal” lives that mice led beyond the enclosure. These mice refused to mate with females or to “fight” for their space.

They **were only concerned with food, sleep and grooming**, appearing in perfect health and unruffled. Eventually, most of the population consisted of “beautiful ones” and “isolated females”. During this stage homosexuality was also observed which led to a greater decrease in birth rate. Eventually, **the beautiful ones outnumbered the alpha males, but they continued to exist solely instead of mating or creating new roles**. This paradox of the beautiful ones revealed that self-destructive patterns emerge when living a life without purpose.

Calhoun explained that he observed two stages of the death phase: the **“first death”** and **“second death”**. The first death stage was characterised by rodents being empty of desire to mate, raise young

or establish their role in society. The latter stage was from juvenile mortality reaching 100% and reproduction being 0%.

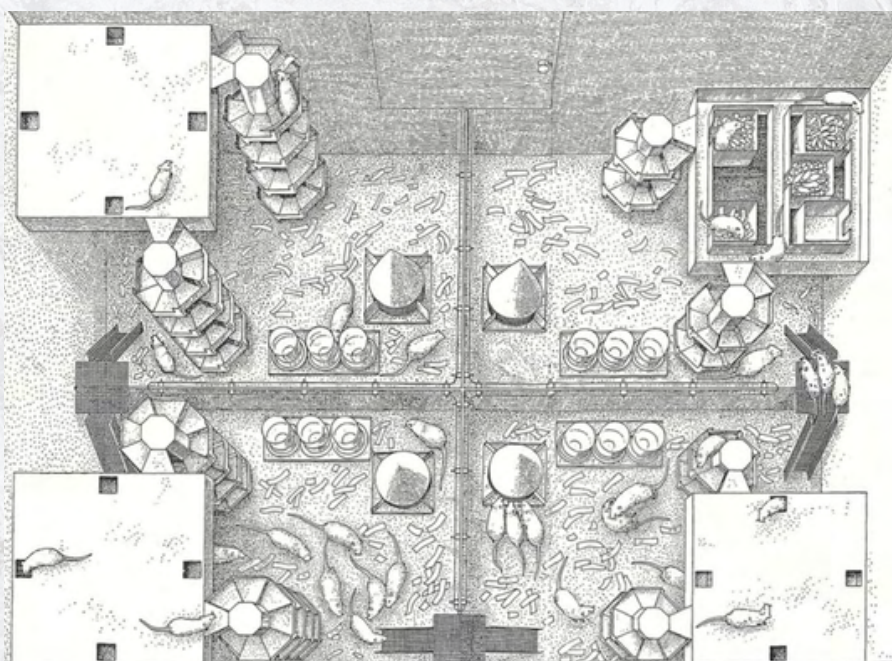


Figure 1: An image picturing a rat habitat from Calhoun's 1962 article.

Taken from:  
<https://www.sciencehistory.org/distillations/mouse-heaven-or-mouse-hell>

Over the course of the 25 repeated experiments, the same sequence of events would occur:

- The mice would meet, mate and breed in large quantities.
- The number of mice began to plateau, rather than increase.
- Increasing pressure caused by reduced space led to rodents developing hostile and/or anti-social behaviour.
- The populations would permanently diminish with no recovery,

**What if Universe 25 was applied to humanity? Would humanity suffer the same fate?** This project was wildly controversial when first made public as Calhoun's theory raised concerns that social breakdown seen in Universe 25 could be a metaphor for the fate of humanity. Thus, Universe 25 has been an interest of city planning councils, architects, and government agencies around the world.

However, Calhoun did not believe that humanity was doomed. In some of his experiments, **rodents developed innovative tunnelling behaviours or adding more rooms** allowed animals to live in high-density environments without being forced into unwanted contact with others. Writing in a report summary in 1979, Calhoun noted that **"no single area of intellectual effort can exert a greater influence on human welfare than that contributing to better design of the built environment."**

Universe 25 offers an important insight into how humankind could demise. The "beautiful mice" particularly show that if individuals do not obtain a productive role in

society, and if they do not have established relationships and role models in their environment, **people could lose their purpose in life.**

Most importantly, Universe 25 was a utopian environment made to test the potential problems of crowding, something that the modern world is rapidly reaching. However, this means that to replicate it in humans, we would have to ensure the end of disease, hunger, and natural disasters. Thus, it is not currently a perfect parallel to humanity. Furthermore, critics have also argued that the end of the mouse utopia may not have created an overpopulation problem but an environment where more aggressive mice were able to control the territory and dominate other rodents. Thus, the issue was more so with how the area was controlled rather than lack of area for the rats.

***With modern century ideals, do you think Calhoun's experiment could apply to humans?***



References





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# WRITERS

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## DEEP DIVE

# WHAT IS IT LIKE TO BE AN INSECT?

WRITTEN BY ALEXI MERY  
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For a long time, insects were thought to be mechanical machines. Beings that act based on cold instinct and with little to no subjective experience. We now know that this is simply not true. Social insects in particular such as ants or bees seem to be almost magical in their ability to do extraordinary tasks with brains the size of a pinhead or less. To understand how scientists are peering into the minds of insects, I interviewed two leaders in the field: Professor Martin Giurfa from the University of Toulouse and Professor Albert Cardona working at the laboratory of molecular biology (LMB) in Cambridge. This article will focus primarily on members of the Hymenoptera order, the largest order in the insect class.

## MARTIN GIURFA

**M**artin Giurfa is a scientist with an extraordinary story. Born in Argentina in 1962,

he studied biology at the University of Buenos Aires during the reign of the National Reorganisation Process, a brutal military dictatorship which persecuted left-wing political opponents. In protest, Giurfa chose to join the left-wing party 'Partido Intransigente', where he had quite an influential role. This would eventually allow him to meet Prof. **Josué Núñez**, a founder of the field of **behavioural physiology** in Argentina. Giurfa has spent much of his career studying bees, in particular **honeybees** (*Apis Mellifera*). An important contribution

he made to the field of insect was his discovery that **honeybees mark flowers they have already visited with a specific pheromone so as to not visit the same flower twice**. Giurfa is currently a Professor at the University of Toulouse.

Professor Núñez would prove to be a very useful connection for Giurfa since he knew Professor Randolph Menzel well. Menzel was a student of Martin Lindauer, a pioneer of the ethology field who specialised in learning and memory. Lindauer was one of the students of Karl von Frisch, one of the first scientists whose work on bees was seen as so important that it was awarded the Nobel Prize in Physiology

or Medicine in 1973. We shall explore Martin Giurfa's career and contributions to the field of insect cognition a bit later in the article.

Bees are members of the Hymenoptera order which is itself composed of bees, wasps and even ants (see figure 1). However, in many ways, bees are the insects capable of the most complex of behaviours and thus if one could understand how bees perceive the world, that would go a long way towards helping us see how all Hymenoptera members might think. Let us first delve into the evidence that proves that honeybees have an intricate, subjective experience of the world around them.

One of the most fascinating behaviours honeybees can carry out is the **construction of intricate combs both to store food and to house larvae**. In fact, Charles Darwin called the ability of bees to make combs as "the most wonderful of all known instincts". These combs are very mathematically peculiar since the hexagonal hive construction is the architecture which allows space to be divided into the largest area with the smallest perimeter. The proof of this took almost 2000 years to be determined but was finally accomplished in 2001 by the mathematician Thomas C. Hales. Regardless of the mathematical elegance of the comb, the behavioural insight that goes behind it is also fascinating and could be argued to go far beyond just instinct.

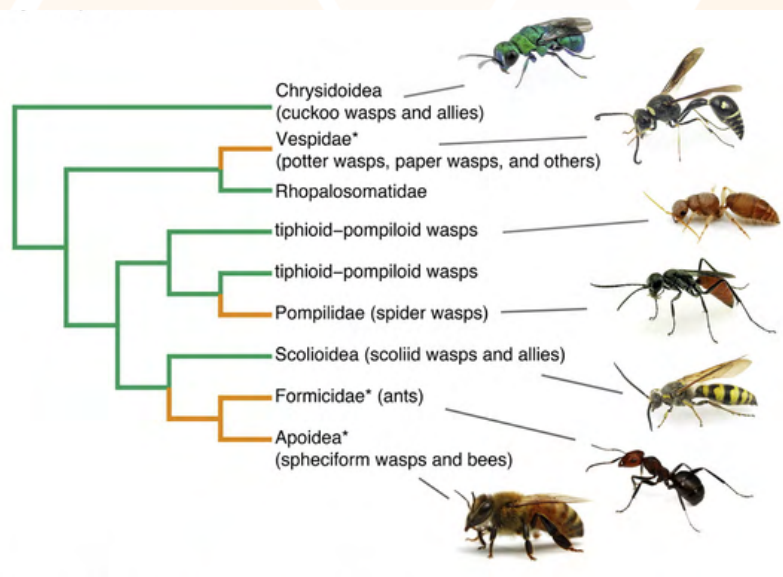
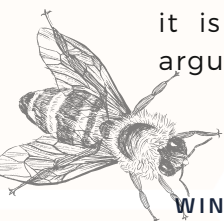


Figure 1: The phylogenetic relationship between different species in the Hymenoptera order.

**Francois Huber was a Swiss entomologist** who spent a large part of his time studying bees. Blind, Huber required the assistance of his wife Marie Aimee Lullin and servant Francois Burnens. Huber and his team were interested in recording details related to honeycomb construction. Even just by observing honeybees as they were constructing their combs, fascinating behaviours could be observed. One such behaviour was that **bees had great flexibility during hive construction, with the ability to change a comb's dimensions depending on whether it was to be used by a drone or the differently shaped compartment used to host a queen**. Moreover, as can be shown in figure 2, bees are able to adapt the construction of the hive depending on the surface they encounter. This is just one small example of the amazing complexity of honeybee behaviour and if a reader is interested to find out more, I would strongly recommend Professor Lars Chittka's book 'The Mind of a Bee'.



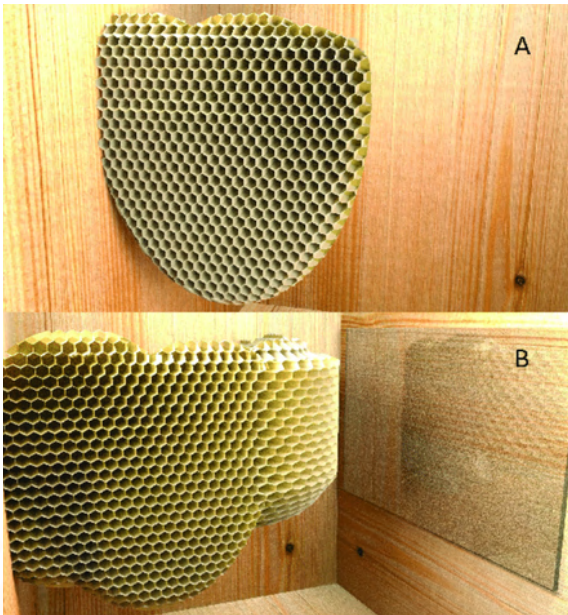


Figure 2: Honeycomb construction on different materials following work by Francois Huber.

Moreover, a fascinating behaviour that only honeybees are capable of doing which is closer to what Martin Giurfa works on is the bee dance also known as the **waggle dance**. First, the performing bee will run a certain distance vertically along the hive. Then she will run in a semicircle to the left and to the right. Aristotle was the first to hypothesise that bees could **communicate the location and distance** where other bees could find flowers using repetitive, choreographed motor movements. This finding was **rediscovered in 1788 by Ernst Spitzner** who interpreted the dance somewhat correctly since he implied that bees used it to communicate the location of a good supply of nectar. However, Spitzner's findings were forgotten. **The scientist who would finally decipher both the function of the waggle dance and the way it encodes information was Karl von Frisch.**

Von Frisch had, since the 1920s, hypothesised that bees could use their 'dance' to communicate to

other bees the location of valuable sources of nectar but he was not sure how this might work. When Von Frisch saw this, he had no idea how this dance might encode information. However, in 1945, he had several breakthroughs. He started changing the distance at which a food source was provided to the hive and observed the response the bees had. He saw that the bees very quickly learnt to look at the new location. Von Frisch therefore wondered whether the waggle dance might be able to encode for distance.

He found that indeed, **bees that were exposed to food sources far away had a different looking waggle dance than those exposed to food close.** The distance is encoded by the length of the straight line bees run. Von Frisch also discovered that the orientation of the dance does not stay constant. It **follows the direction of the sun, which allows bees to also know which direction to go in to find the food source.** This is particularly useful since bees can detect polarised or directional light and the pattern of polarisation is different depending on where one looks in the sky, allowing bees to orient themselves very rapidly. **What is really amazing is that honeybees can adapt the bee dance to different contexts and situations, such as finding a new place to build a hive.** This capacity for abstractness is a major reason for why many people consider the bee dance as a language - one of the most intricate known to Man.

Let's now get back to Martin Giurfa and his contributions to the field of insect neuroethology. Giurfa made a





landmark discovery that **bees can understand several key concepts such as the concept of 'sameness and difference' but also of 'up' and 'down'**. This paper was really groundbreaking and showed the extent to which bees are capable of conceptual learning, the ability to categorise objects. In fact, when I asked Giurfa what his most surprising discovery was, he mentioned this one (although his first answer was to say, 'everything'). However, Giurfa did not stop there. He also made seminal contributions to our understanding of the importance of pheromones in guiding bee behaviour and has done extensive work on olfaction in honeybees.



they are multimodal whereas the mushroom bodies of fruit flies (*Drosophila melanogaster*) are unimodal (only respond to olfactory stimuli). **The mushroom body is what allows honeybees to perform conceptual learning.**

However, an important question still remains. **Why are the honeybee mushroom bodies so much more developed and complex than that of other insects?** And why is it that honeybees and bumblebees are capable of such complex behaviours. **A central hypothesis might be that it is due to the social nature of these insects.** However, solitary bees also require large behavioural capacities, in particular when it comes to navigation since if a honeybee colony loses one individual, that is not very important but if a solitary bee cannot return to her hive, that bee's progeny will not survive either. In fact, even the microscopic bee *Nomioides minussimus* possesses a complex homing behaviour. In order to show that the social nature of insects is a key indicator as to how complex that insect's behaviours can be, more behavioural research needs to be done on other Hymenoptera, such as other bee, wasp and ant species.

Martin Giurfa's interest in the molecular mechanisms of insect behaviour has led him to explore the mushroom bodies and we spent a long time discussing their extraordinary structure. **The mushroom body is found in all insect brains and is in many ways homologous to our hippocampus and association areas.** The mushroom bodies of honeybees are particularly interesting since they respond to different sensory information or modalities such as taste, smell and vision. In other words,

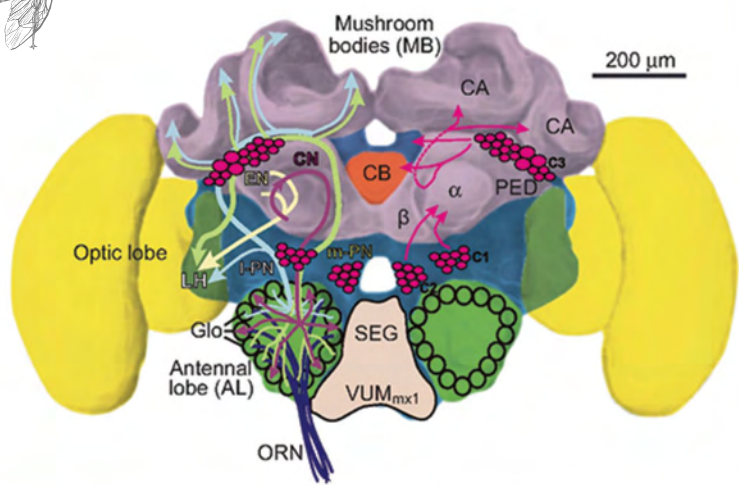
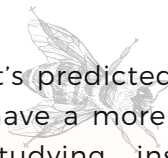


Figure 3: Computerised model of a honeybee brain.

A useful way of achieving this might be through the use of new **electrophysiology protocols** enabling us to very rapidly assess whether different insects possess different neuronal pathways. Martin Giurfa has very much pioneered this idea to understand complex behaviour by using a virtual reality protocol to allow bees to remain still whilst they perform complex tasks. Doing this allows Giurfa to keep a bee's head still, thus allowing electrodes to be implanted into the bee's brain.




It's predicted that this will allow us to have a more comparative approach to studying insect behaviour. Another method that could allow us to better understand insect brains are **connectomic methods**. This method involves imaging synaptic connections between neurons and using them to create a computerised map that can be used to understand the different neuronal circuits found in the brain.

### ALBERT CARDONA

Cardona did his PhD at the University of Barcelona **looking at the development of planarians**. For this work, Cardona had to make extensive use of the electron microscope. This microscope works in a similar way to a classic light microscope except that it uses a beam of electrons instead of photons. This method permits for both a higher magnification and resolution. In fact, samples can be magnified by up to 2 million times.

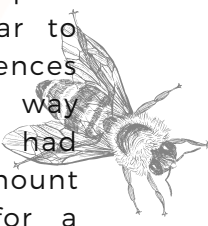
There are several different types of electron microscopy. The one most commonly used for connectomics research is the **transmission electron microscope or TEM**. This EM method is very powerful since it allows for parallel image acquisition and thus speeds up imaging time. The rate limiting step with this type of imaging is that extremely fine slides are needed and handling of these slides needs to be extremely gentle. TEM has been used since the start of the connectomics field since the first organism to have its nervous system mapped was *C. elegans* in 1986 which was done using TEM. TEM imaging can now be done very rapidly using GridTape, for instance, as a method to automate imaging.

Interestingly, the term 'connectomics' was only coined in 2006 by Olaf Sporns in the context of mapping all the neurons in the human brain using methods such as Diffusion Tensor Imaging or viral tracing. However, the resolution provided by DTI is far smaller than that provided by TEM and this means that DTI can only really be used to trace large neuronal tracts. Viral tracing also takes longer than using EM and is less precise. Another method currently used for connectomics is **brainbow**.



Albert Cardona, first at Janelia farm in the US and now at the LMB in Cambridge, has been central in **mapping a large amount of *Drosophila Melanogaster* larvae's 9000 neurons**. However, he did not do this alone. Dozens of labs around contributed too, using the computer program CATMAID (collaborative annotation toolkit for massive amounts of image data) to sift through all the data and arrange it in a coherent way. The reason why Albert chose to work on *Drosophila* is that a vast array of molecular tools are available to scientists to label and manipulate individual neurons but also because almost all the different neuronal cell types have been categorised.

Albert's lab, working with collaborators from around the world, started publishing the reconstructed nervous system data from 2016 onwards and made a massive impact when it occurred. It was clear to many neuroscientists at conferences where Albert spoke that the way neuroscience would be done **had changed forever**. The sheer amount of data is enormous. Just for a microscopic *Drosophila* fly larvae, the imaging data alone takes about 8 terabytes of storage space.





The kind of resolution one can get by using the EM approaches for neuronal tracing is quite astounding, as shown in figure 4. This neuron is called a **kenyon cell and is the output neuron of the mushroom body**. In order to find such kenyon cells, another researcher at the LMB, Gregory Jefferis, developed a set of tools and placed them in an R package called NBLAST. Using NBLAST, connectomic data can be used to identify specific neurons, look at their pre- and post-synaptic connections and observe where neurons are found relative to the rest of the *Drosophila* CNS.

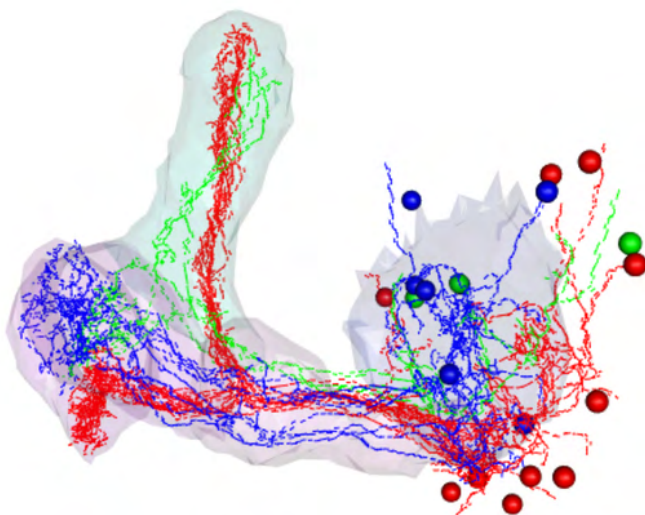


Figure 4: A kenyon cell reconstructed using NBLAST.

Connectomic data needs to be placed in a functional context, however, so that one can understand which neural circuits might be involved in which behaviours. One of Albert's collaborators, Professor Marta Zlatic is trying to do exactly this. She **uses Calcium imaging or GCaMP to visualise neuronal activity and thus determine which neurons are active during what behaviours**. Connectome data allows her to predict how the neuronal circuits

responsible for action selection work, for instance, if the connectome shows two connections to be inhibitory, one might suggest a model where disinhibition occurs so that an action is selected. This therefore can lead to a testable hypothesis and can help to decipher how a specific part of the nervous system works.

When I asked Albert what he thought it was like to be an insect, he said that first one would either be a parasitic wasp (since most insect species are a type of wasp) or to be an ant (since ants have the greatest biomass of any insect). However, in terms of experience, ants and wasps are very different. Most wasps are solitary whereas ants are found in large colonies. Moreover, both wasps and ants are found in almost every continent in the world and inhabit vastly different climates and habitats. These major differences mean that we are still very far from understanding the subtle differences found between different insect brains. There is one major common point, however, between what Martin and Albert have said: **insects have far richer sensory experiences than we do** and we still have very little idea how this might translate in the insect mind. Connectomics work in other insect species might give us some insights into the kind of behaviours that specific species can or cannot perform.



References



SHALLOW DIVE

WRITTEN BY MIRI FRANKL  
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# The blood test that can help diagnose Alzheimer's



**A**lzheimer's disease is a chronic neurodegenerative disease which causes progressive memory loss. The four main characteristics of the condition are **neurofibrillary tangles, neuritic plaques, the buildup of amyloid beta peptide, and the hyperphosphorylation of the Tau protein in neurons.** (De-Paula et al., 2012)

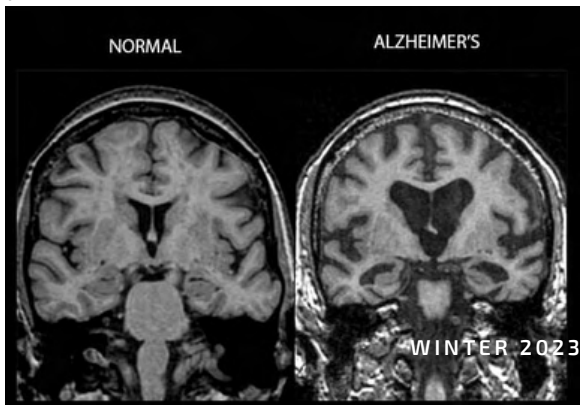
Even though Alzheimer's disease is the most common form of dementia, it takes, on average, **over four months** from onset of symptoms to diagnosis, with some waiting up to two years. This delay in diagnosis leads to people missing out on support and treatment that could improve symptoms. (Alzheimer's Society, 2022) Before the early 2000s, Alzheimer's diagnosis was post-mortem, so although the diagnosis procedure has come a long way, there is still a way to go.


**Currently, the process of diagnosing Alzheimer's is extensive.** After presenting to the GP, the patient will have tests for memory and problem-solving, and a neurological exam.

This will often be followed by excluding other conditions that can lead to dementia-like symptoms, such as delirium, depression, thyroid problems, or excessive alcohol consumption. The patient may then have a lumbar puncture to measure the level of change in tau and beta-amyloid in the CSF. Brain scans such as CT, MRI, or PET scans can support the diagnosis or help to rule out other causes for symptoms.

**The journal article titled "Brain-derived tau: a novel blood-based biomarker for Alzheimer's disease-type neurodegeneration" forms the basis of this article.** In their paper, they explained how previous use of blood-based or plasma-based biomarkers for amyloid beta and phosphorylated tau can be useful in looking for Alzheimer's but are not specific to Alzheimer's disease.

Fig 1. MRI scan showing neurodegeneration in a normal brain versus a brain with Alzheimer's (Butch, 2017)





This means they can not be used as diagnostic tools. Their research project aimed to create an anti-tau antibody that only binds to brain-derived tau, in the hopes that this would be more specific to Alzheimer's. **If the biomarker is specific to Alzheimer's, this means that it can be used as part of a screening tool.**

They found that the brain-derived tau was **significantly correlated** to the presence of Alzheimer's, whilst the previously used blood-based tau was not. This means that the blood-based tau, whilst useful, has a large overlap with other diagnostic groups, meaning it is difficult to confirm a single condition - leading to poor diagnostic utility. The brain-derived tau was also able to identify Alzheimer's disease in an autopsy, even in comparison to other neurodegenerative conditions. It was found to correlate to global neuritic plaque counts found in patients with Alzheimer's post-mortem. Examples of the neurodegenerative conditions that the brain-derived tau could distinguish between were brain degeneration, parkinsonian disorders, and healthy controls. **This means that different results in levels of brain-derived tau were present in each of these groups, leading to an easier path to diagnosis.** The brain-derived tau was also found to have an inverse relationship to the progression of cognitive performance.

The conclusion from their project was that the blood-derived tau is a tool that shows specificity to Alzheimer's disease, and therefore **has the potential in the future to be used as a diagnostic tool in the future.** A reason that the brain-derived tau was able to be more specific than the blood-based tau was due to the suggestion of lack of interference from peripheral tau. (Gonzalez-Ortiz et al., 2022)

At the end of the day, there is an **urgent need for a simple diagnostic tool for the diagnosis of Alzheimer's.** A blood test would allow for earlier detection and diagnosis, meaning that treatment can be started quicker for patients. The time between the onset of symptoms and diagnosis is a critical period. Most of the treatments available for Alzheimer's have a significantly better outcome when started earlier, and may stabilise the patients for longer, leading to a better quality of life for an extended time. A blood test also makes diagnosis more accessible, both economically and in more diverse populations. Especially in countries with private healthcare services, where many people do not have health insurance, a diagnosis can be incredibly costly, with several procedures and scans to come to a conclusion. By providing a simpler diagnostic tool, a significantly large number of people would have access to a diagnosis. (Alzheimer's Association, 2023)

At the moment, no available single test can diagnose Alzheimer's, despite several click-bait type articles being put on the internet, and several self-diagnosis tests marketed to consumers. Diagnosis of the disease should only be carried out by the set procedures carried out by doctors. **However, the future of diagnosis is through developments such as brain-derived tau.** The next steps for the biomarker will most likely be validation through a broader range of patients, before being used in conjunction with current procedures.

References



# Poppies to Pills

## THE DEVELOPMENT OF SYNTHETIC OPIOIDS

Opium derivatives have an illustrious history in pharmacology and have been used in medical treatments since their legalisation in 1775. Despite their effectiveness at reducing pain signals, there have always been two sides to the use of opioid medications. In the operating theatre, early opioids were used to manage acute pain. On the other hand, opium has been recreationally used since 3400 BC. Interestingly, people believed that pain was deeply linked to our spirituality and drug use elicited a **'supernatural' experience**.

The first actual developments in opioid synthesis aimed to produce sedation with intense analgesia. Drugs at the time only caused partial analgesia and had many side effects, most notably intense respiratory and cardiac depression which increased the number of complications in post-operative recovery. In 1953, Paul Janssen, a Belgian chemist, was working on new painkillers to find more molecules with higher potency and specificity than the ones before. He speculated that with increased potency and increased specificity would come increased safety. In addition, he hoped to reduce the harmful side effects as well as the addiction that often came as a dependency on the drug forms.

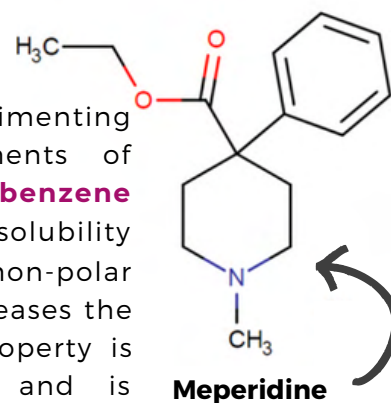
The side effects and potency go hand in hand with the stereoisomeric structure of the compound. The analgesic nature of the drug is intimately related to its 3D shape, therefore, minor changes in the conformation of a narcotic molecule may significantly alter the pharmacologic activity. At the time, the main opioids available,

**morphine and meperidine**, were less optimal at crossing the blood-brain barrier and stimulating opioid Q receptors.

Furthermore, meperidine is an **addictive substance**.

This is because the same decrease in dopamine and noradrenaline that helps with pain relief is associated with feelings of numbness and relaxation. After taking meperidine and other opioids, jitteriness and anxiety are common due to the body compensating by raising noradrenaline levels.

Chemists began experimenting with different arrangements of meperidine by adding **benzene rings** to increase lipid solubility due to their non-polar characteristics, which increases the analgesic activity. This property is known as **lipophilicity** and is particularly relevant to opioids as they have to cross the blood-brain



barrier. However, the change in 3D shape due to the phenyl groups made the interaction with receptors less optimal.

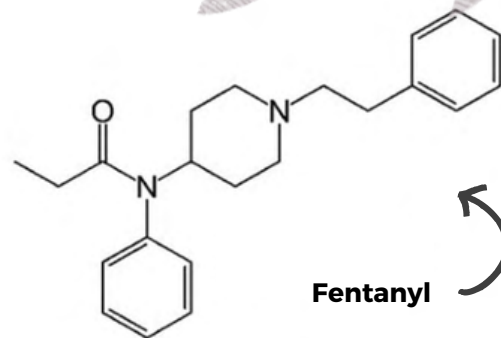
It was found that by separating the phenyl group bonded to a carbon on N-methylpiperidine by three carbons and adding a hydroxyl group to the third carbon a new compound could be produced called **phenoperidine**. This

compound was 20 times stronger than morphine. Continuing attempts eventually resulted in the arrival of **fentanyl, the strongest synthetic opioid, with a 100-300 times greater potency than morphine**.

It binds mu-opioid G- protein-coupled receptors, which inhibit neurotransmitter release, decreasing calcium ion concentration. The binding effectively **blocks nociceptive afferent nerves**, reducing sensations of pain.

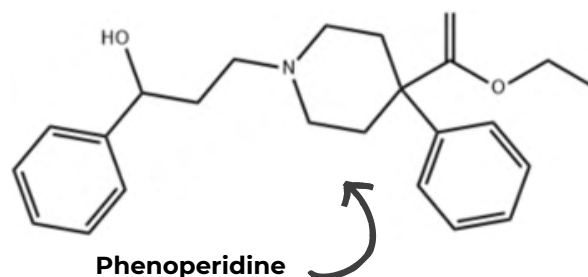
Postsynaptically, potassium channels are opened, which hyperpolarize the membrane, resulting in a **greater threshold** for an action potential to form. Various Opioid agents, of which fentanyl is the most prominent, can decrease serotonin reuptake and increase the release of intrasynaptic serotonin.

Due to its potency and speed, it is often used in combination with other anaesthetic drugs, such as propofol, to reduce the intense stimulus of surgical pain. Fentanyl has quickly become the industry standard, but is this the **best decision to make?** The analgesic and euphoric effects are short-lived, short term



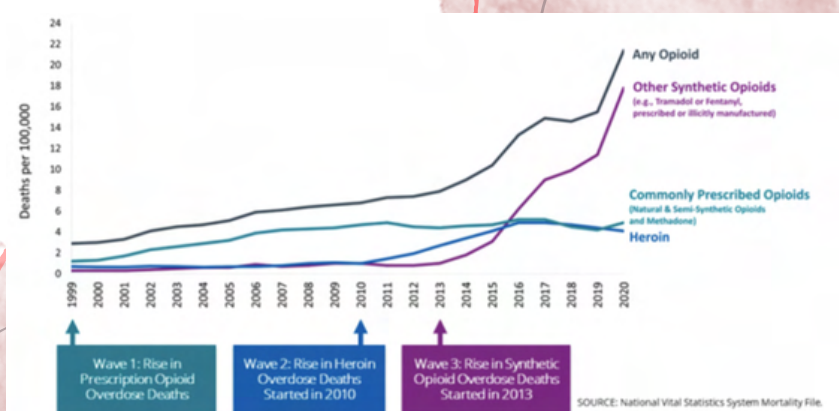
exposure is less likely to cause addiction. However, these same fleeting effects lead to an increased number of overdoses. The highly publicised death of the artist **Prince** due to an accidental overdose brought the topic under the spotlight. Ever since, the number of **overdose deaths has been increasing** as fentanyl is cut into other opioids on the street, such as morphine and heroin. It is cheap to synthesise and as a result, is readily accessible and well-stocked.

Opioid-induced hyperalgesia is a phenomenon **not entirely understood** by academia. Treating pain with opioids can result in increased sensitivity to nociception. When patients receive opioids under anaesthesia, several studies have demonstrated increased opioid requirements after surgery and worse pain scores. Short-acting opioids such as fentanyl may provoke OIH more than longer-acting ones, as OIH increases when pain relief wears off and opioid doses must be repeated.

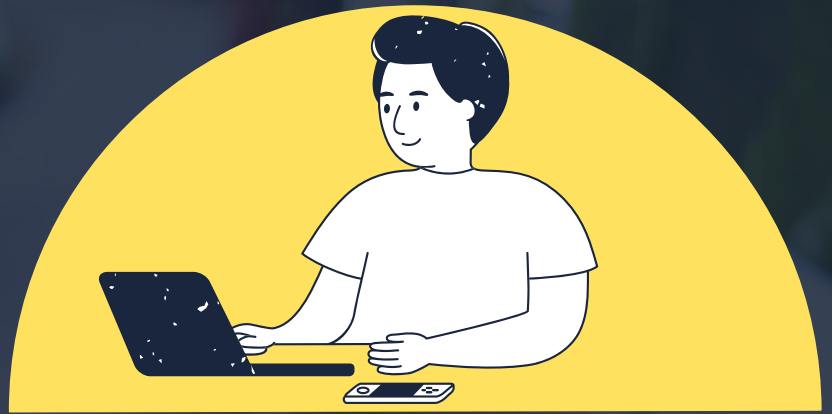


Since the introduction of synthetic opioids into the marketplace, American overdose deaths have almost tripled. This is largely due to the **over-prescription of opioids** by American doctors and incentivisation by insurance companies to make expensive pain medication more common. Some anaesthetists are opting to remove fentanyl from their operating theatres completely, choosing instead to use regional nerve blocks such as **lidocaine and epidurals**. It is apparent that the danger to society that synthetic opioids pose is vastly underappreciated. Although the literature is united on the safe doses and administration of fentanyl, there is still more to be uncovered about the long-term medical and social impact of such a powerful drug.

## References



**Figure 1: Three waves of opioid overdose deaths:** This graph shows the drastic increase in opioid related deaths, specifically due to synthetic opioids



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## SHALLOW DIVE

# THE GREAT UNEQUALISER:

## How COVID-19 Made Health Disparities Worse in the UK

WRITTEN AND DESIGNED BY DORIS YU

EDITED BY OLIVERA MITEVSKA

"It's the great equaliser," proclaimed Madonna in a video posted to Instagram in 2020. Sitting in a rose petal-filled bathtub, the American singer-songwriter delivered a bizarre sermon to her millions of followers about how the novel coronavirus "made us all equal in many ways".

Perhaps in theory, a pandemic could have been just the thing to unite populations and cross societal divides. In some respects, it did. The global research effort to unravel the mystery of this unknown virus led to the **development of vaccines in less than a year**; a process which could previously take a decade.

But you don't have to look too closely to find that the effects of COVID-19 were far from "equalising" (and Madonna's followers were quick to criticise the tone-deaf video, which was subsequently deleted). If anything, **the pandemic shone a light on and exacerbated the existing gaps permeating society**.

In the UK, it was suspected early in the pandemic that ethnic minority communities were disproportionately affected by COVID-19. Researchers from LSE published a study in **May 2020** that found **COVID-19-related hospital deaths in the UK were**

**twice as high** in the **Bangladeshi** population, almost **three times as high** in the **Pakistani** population and almost **four times as high** in the **Black African** population compared to the white British population.

As the virus evolved and infected millions across the country, the **higher mortality rates persisted in ethnic minority communities**. In the **second wave** during the winter of 2020/21, mortality risk was **highest** among people in the **Bangladeshi and Pakistani** groups. The risk **remained high** among people in the **Black Caribbean and Black African** groups but was lower compared to the first wave. In the following winter's **Omicron wave**, **Bangladeshi and Pakistani** mortality rates were **two to three times higher** than in the white British group, while people in the **Black Caribbean and mixed ethnicity groups** also showed **higher mortality rates**.







These statistics could be due to several factors. Firstly, people from minority ethnic communities (particularly those from Black African backgrounds) were **more likely to be employed as key workers in the health and social care sectors** leading to a greater risk of exposure. **Underlying health conditions were also more prevalent** among older people in these communities which made them more vulnerable to infection; this was especially the case for the Bangladeshi population. Ethnic minority communities were also **more likely to live in densely populated areas** compared to the white British group, a condition which would have expedited the spread of the virus. Regardless of the causes, this disparity made it clear that **key societal inequalities were being overlooked** by policymakers in addressing the public health emergency.

The **introduction of vaccines did help to reduce mortality rates** to some degree: it was estimated to have prevented over 150,000 hospital admissions in England in March 2022. However, **vaccination rates in people from minority ethnic backgrounds were noticeably lower** than rates in the white British group. In the same year, the Health Foundation reported that **those whose main language was not English were less likely to have been vaccinated or received a booster** – only **53.9% had received three jabs** compared to 74.4% of people who primarily spoke English.

They also found that **people across most ethnic minority groups were less likely to have received three doses** compared to the white British group. In London, people from the Black Caribbean community made up the highest proportion of unvaccinated adults (**43.5%**), followed by those in the Black African group (**32%**) and those of mixed ethnicity (**31.8%**).

The prevalence of vaccine hesitancy among ethnic minorities could be attributed to factors such as **mistrust of information** regarding the vaccine's efficacy and the systems delivering it; **inability to access healthcare services**; and a **lack of cultural competency** in the services and information provided. These elements need to be considered in the rollout of the vaccination programme to **encourage its uptake across all communities**.

COVID-19 has spotlighted existing societal inequalities that can no longer be ignored. Ethnicity is only one aspect of the healthcare disparities prevalent in the UK which need to be addressed. We cannot truly declare that we are in a "post-pandemic world" if the issues which made the pandemic so devastating in the first place are allowed to continue. **A longer-term public health strategy that actively considers the diversity of the UK's population must be made to prevent a disaster of this scale from happening again.**

REFERENCES



## TREADING WATER

# Pee Power: could urea fuel cells be the future of sustainable energy?

Did you know that the average adult produces approximately **11 kg of urea each year**? Until the 20th century, this was considered waste. However, over the past several decades, researchers have explored ways to turn what is believed to be a biological commodity into a **next-generation sustainable source of electricity**.

## The origins of 'liquid gold'

Urine in wastewater was first suggested as a renewable energy source in the 1970's but has only gained significant development and critique in recent years. The key component of urine is urea, an organic compound that can be **electrochemically oxidised** to produce carbon dioxide, nitrogen gas, water, and electricity. With the world's increasing population and energy dependence on fossil fuels, urea has been suggested to be a good energy alternative for both finite resources and other sustainable fuels. For instance, while **hydrogen fuel** cells are more environmentally friendly than coal and natural gas, they are **expensive** to manufacture and dangerous to transport.

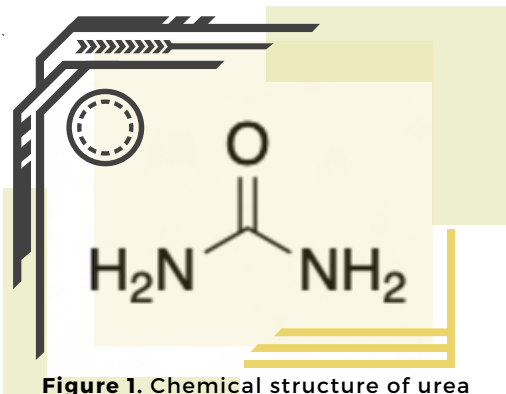


Figure 1. Chemical structure of urea

WRITTEN BY ISABELLA EWELL  
 EDITED BY SAMUEL GINZBURG  
 DESIGNED BY YASMIN MARZIAKHALL

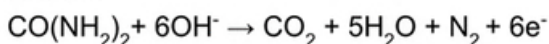
There are many examples of fuel cells being used to generate electricity today, such as direct **methanol fuel cells** and **phosphoric acid fuel cells**, but direct urea fuel cells (DUFCs) have shown incredible **technological potential**. Urea can serve as an excellent source of electricity and is described as a hydrogen-rich chemical fuel, with a **6.67% wt** hydrogen. Luckily for us, it is infinitely available. It can be oxidised in acidic, alkaline, or neutral conditions, allowing for different fuel cell designs to be possible. For example, in a neutral-medium DUFC, a very simple electrolyte of sodium chloride (NaCl) is used. In essence, this means electricity can be generated from precise combinations of urine and table salt! In this reaction, chloride ions are oxidised to form chlorine gas, which then undergoes disproportionation, meaning the chlorine gas is both oxidised to form hypochlorous acid (HOCl), and reduced to form chloride ions (Cl<sup>-</sup>). This reaction generates hydrogen ions, so an acid-resistant catalyst must be used, such as a titanium-coated metal. Interestingly, unlike other biocatalysts, DUFCs can work with natural organisms found in soil, compost, and urine to carry out nitrification and denitrification processes to generate electricity.

## How do direct fuel cells work?

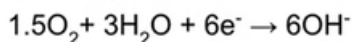
Structurally, DUFCS are constructed from **two electrodes**, an **anode** (positively-charged electrode) and a **cathode** (negatively-charged electrode). The charges of these electrodes are vital for producing electricity, as they determine which species will be attracted to the electrodes in order to be oxidised or reduced by the loss or gain of electrons, respectively.

The generation of electricity using urea works on this simple premise of reduction and oxidation, commonly referred to as **redox**. The most common type of urea fuel cell is alkaline, as it is less susceptible to corrosion than acidic ones. In alkaline fuel cells, urea is oxidised at the anode to produce **N<sub>2</sub>, CO<sub>2</sub> and H<sub>2</sub>O**, and **oxygen** is reduced at the cathode to form **hydroxide (OH<sup>-</sup>) ions** which travel through an anion exchange membrane. The transport of these OH<sup>-</sup> ions completes the electrical circuit, generating electricity.

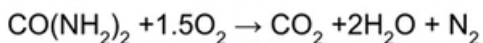
### Anode:



### Cathode:



### Overall:



**Figure 2.** Chemical equations for the electrochemical oxidation of urea in alkaline conditions

## Increasing efficiency: introduction of novel fuel cell catalysts

While DUFCS display an exciting potential, there are various aspects of their design which need to be enhanced in order to make them viable for industrial use. A major example of this are the designs of the electrochemical catalysts used in the fuel cells. The catalysis utilises transition metal complexes which are **highly porous** to allow a **large surface area** for the redox reactions to take place. More precisely, transition metals increase the redox reactions taking place in the fuel cells without being used up or damaging themselves.

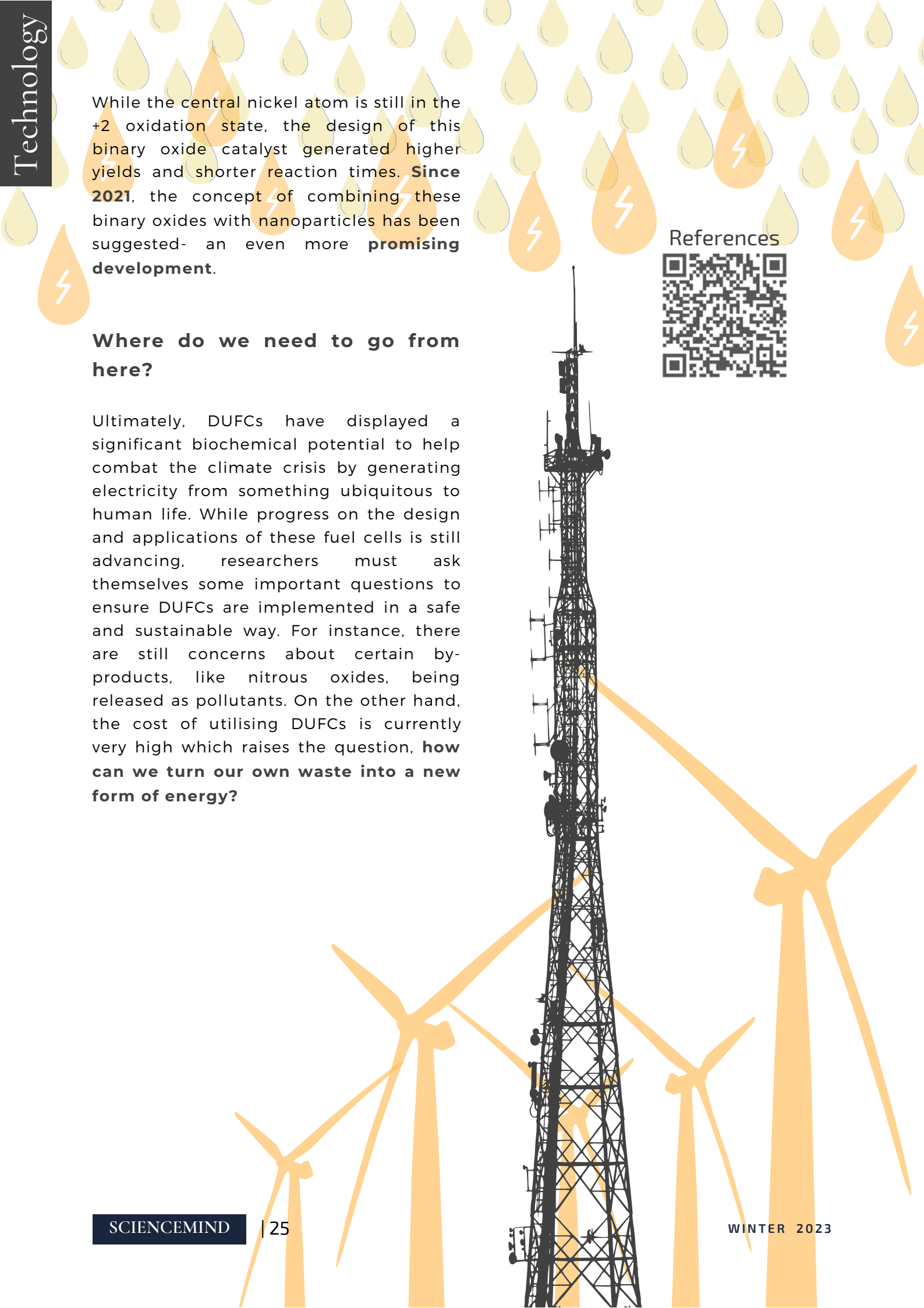
The most common catalyst in alkaline fuel cells designs is **nickel**. It is an ideal catalytic candidate because it is readily oxidised to its +2 oxidation state in an alkaline medium to form Ni(OH)<sub>2</sub>. This ability to form multiple oxidation states quickly means nickel complexes can donate or accept electrons from urea with ease, accelerating the rate of urea oxidation. However, just as with the developments in the fuel cell's technological design, there have been significant breakthroughs with the designs of novel catalysts. For example, in 2018, scientists developed a **nickel molybdenum oxide catalyst** with a **much higher efficiency** than traditional (and expensive) fuel cell catalysts, like platinum, which was able to oxidise urea at much lower energy costs.

While the central nickel atom is still in the +2 oxidation state, the design of this binary oxide catalyst generated higher yields and shorter reaction times. **Since 2021**, the concept of combining these binary oxides with nanoparticles has been suggested- an even more **promising development**.

### Where do we need to go from here?

Ultimately, DUFCS have displayed a significant biochemical potential to help combat the climate crisis by generating electricity from something ubiquitous to human life. While progress on the design and applications of these fuel cells is still advancing, researchers must ask themselves some important questions to ensure DUFCS are implemented in a safe and sustainable way. For instance, there are still concerns about certain by-products, like nitrous oxides, being released as pollutants. On the other hand, the cost of utilising DUFCS is currently very high which raises the question, **how can we turn our own waste into a new form of energy?**

### References





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# Metal Organic Framework Based Materials for Next-Generation Energy Applications

TREADING WATER

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EDITED BY ELINA SUTER

DESIGNED BY SICHUN YAO



Increased global energy consumption drastically affects environmental changes and climate issues, requiring extensive research to develop **new, renewable,** and **efficient** energy sources. As conventional lithium-ion batteries (LIBs) reach their energy density performance limit, developing **new electrodes** and **storage materials** remains one of the most significant difficulties in energy development. Various next-generation batteries, such as **Lithium-sulphur batteries** (LSBs), drew the attention of many scientists due to their high theoretical specific energy (2,500 Wh kg<sup>-1</sup>) and specific capacity (1,675 mAh g<sup>-1</sup>) when compared to LIBs (270 Wh kg<sup>-1</sup>). Moreover, the low cost and high abundance of nontoxic sulphur increase the potential for LSBs production.

While Lithium-sulphur batteries seem to be a promising candidate, they proved to have a significant challenge. Firstly, inert electrochemical reactions occur due to the insulating properties of sulphur and insoluble Li<sub>2</sub>S(2). Secondly, anode corrosion, poor cycling stability, and high self-discharge rates are some of the “**shuttle effect**” results. Upon dissolution of polysulfides, the physical state of sulphur in the discharging/charging process will undergo a solid-liquid-solid transition. When sulphur in a solid state is discharged to higher order polysulfide, low-order polysulfides will be produced due to the reaction of dissolved sulphur with lithium anode. As a result, the low-order polysulfide will diffuse back to the cathode to create high-order polysulfides. Hence, diffusion back and forward of a different order of polysulfides between the anode and cathode will occur continuously because of the shuttle effect (figure 1). To overcome these difficulties in each system, a primary requirement is to develop structurally stable electrode materials with good physical and electrochemical properties.



### Metal-organic frameworks (MOFs)

act as a novel class of porous materials with possible “post-synthetic modifications” with the potential in numerous chemical applications. MOFs are composed of secondary inorganic units: “**nodes**” and organic “**linkers**”. Structurally, the nodes are metal ions or clusters coordinated mainly through nitrogen or oxygen atoms. Interestingly, these materials proved their potential over other porous solids (such as zeolites, by considerably larger pore size and volumes). Therefore, while merely sterically unhindered small molecules fit the pores in zeolites, MOFs possess the advantage for **selective** catalysis reactions with more **bulky** compounds. In terms of variations of the metal centre, such as by substitution of secondary organic units with an identical linker, yield various geometric differences in MOFs (figure 2). The geometric alteration in MOFs depends on the arrangement of the linker substituents which is followed by a change in symmetry and pore size.

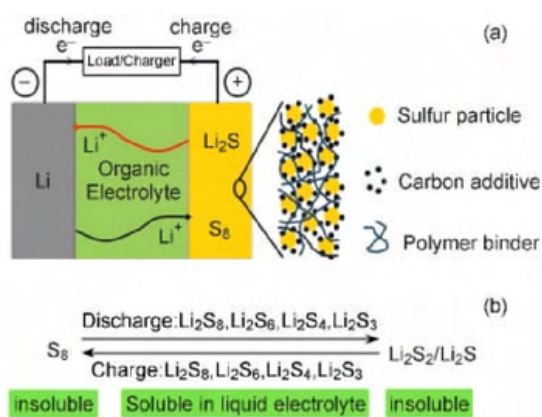


Fig 1. A schematic illustration of the “shuttle effect”. A transition between solid-liquid- solid state occurs between Sulphur species in Li-S batteries (Ren et al., 2019)

In polysulfide encapsulation, the ability to control **porosity** and **chemical environment** in MOFs directly impacts the electrochemical process. Their varying pore geometries facilitate ion diffusion, which is essential for **fast discharging/charging** processes. When applied to Lithium-sulphur batteries, MOFs can store the large expansion of sulphur upon reduction to  $\text{Li}_2\text{S}$ . One of the significant drawbacks in the utilisation of MOFs for LSBs batteries is the **poor electrical conductivity** which leads to slow redox kinetics, poor rate capabilities, and cycling stability.

In a recent promising study by Jiang et al. (2018), a combination of conductive polymers and MOFs was used to construct **polypyrrole-MOF** (ppy-MOF), which resulted in significant charge-discharge rates: 1,685 mA g<sup>-1</sup>. Variation of porosity geometry affected ion diffusion, in which cross-linked pores and tunnel MOFs exhibited the best **high-rate performance** with a maximum **specific capacity** of 790 mAh g<sup>-1</sup>. In terms of chemical properties, frameworks with coordinating unsaturated metal ions increase the adsorption of polysulfide anions due to their negative charges and further **stabilisation** of sulphur-MOF interactions by the organic linkers. As investigated by Park et al. (2018), the use of nMOF-867-based electrodes significantly **increased capacity retention** with little loss observed. The potential in MOFs electrochemical properties can be further investigated using Lithium-Oxygen batteries, Sodium-Ion batteries, and even as battery separators.

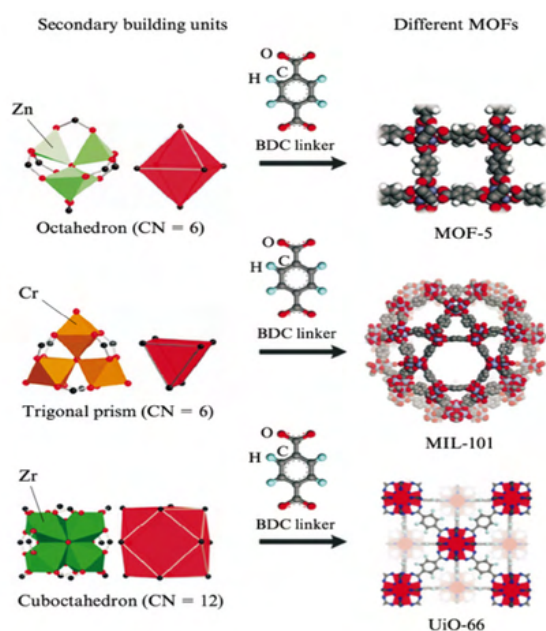
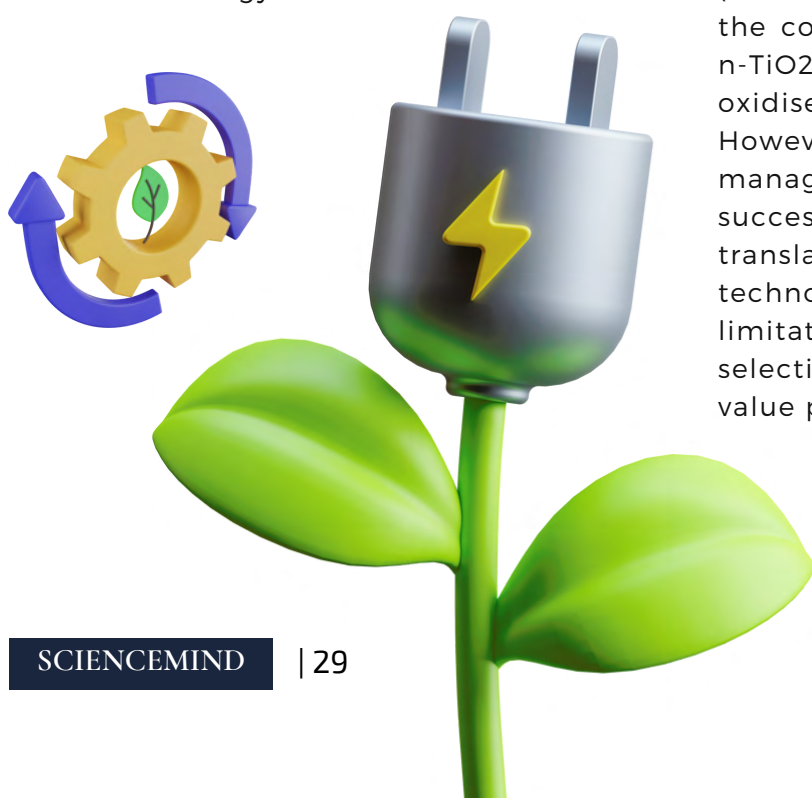


Fig 2. Various geometries in MOF upon reactions of different metal ions with a similar organic linker terephthalate (BDC) dianion. The general shape of the core cluster is a consequence of the spatial arrangement of carbon atoms. The coordination number (CN) refers to the number of linkers coordinating to each cluster (Butova et al., 2016)

While researchers are extensively searching for new renewable, sustainable forms of energy, one of the most fundamental and promising renewable sources is **sunlight**. During photosynthesis, plants store solar energy in **chemical bonds** using **H<sub>2</sub>O** and **CO<sub>2</sub>**. The stored energy can be easily accessed at any time, yielding the advantage of replicating photosynthesis for large-scale solar energy.

**Artificial photosynthesis** is a large area of research that couples the oxidation of water with the reduction of carbon. It faces many challenges, with a major difficulty in the chemistry of splitting water molecules into H<sub>2</sub> and O<sub>2</sub>. One of the early examples of artificial photosynthetic assemblies includes **dye-sensitised photoelectrochemical cells** (DSPECs). The mechanism involves the coupling of metal oxides: p-NiO, n-TiO<sub>2</sub> with molecular catalysts to oxidise water and proton reductions. However, while the hybrid system managed to generate solar energy successfully, the difficulty of translating the process into daily life technology remained with various limitations: stability to light and pH, selectivity and efficiency, and high-value products.

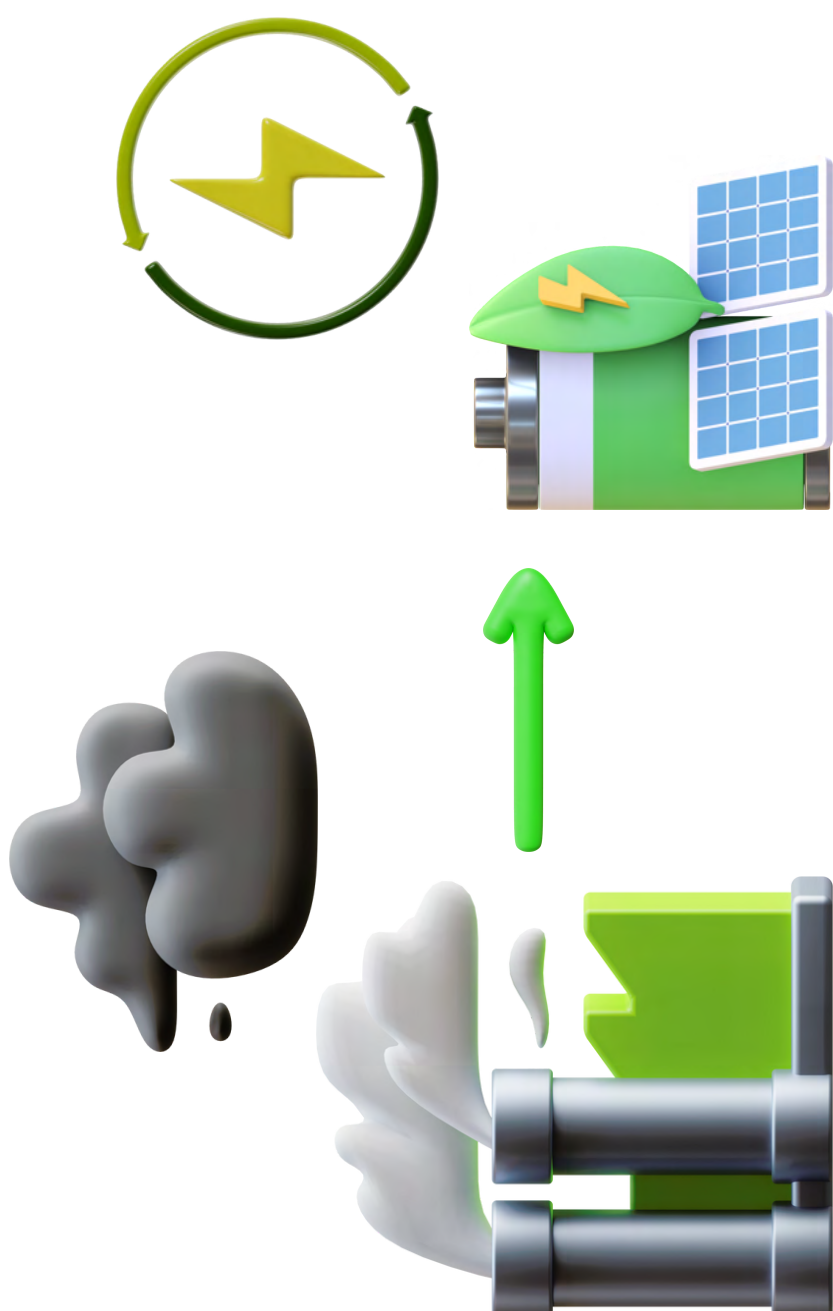




MOFs seem to be a promising solution for artificial photosynthesis. The porosity is crucial as reactions in artificial photosynthesis involve **small molecules**:  $\text{CO}_2$  and  $\text{H}_2\text{O}$  as substrates, and  $\text{O}_2$ ,  $\text{H}_2$ , and  $\text{CO}$  as products. In terms of mass transport in MOFs, the diffusion model is driven by a concentration gradient, and small molecules can **readily diffuse** through the framework. In contrast, larger molecules diffuse slower with lower penetrations to the interior of the framework. While larger pores might improve mass transport into the framework, they might not be efficient enough to overcome diffusion barriers when considering diffusion rates through them. Therefore, the nature of **solvent-MOF interactions** influences diffusion control and is critical for mass transport in artificial photosynthetic processes. For an effective artificial photosynthesis catalysis, it is crucial for the catalyst to be **efficient** towards the reactants and **selective** for the product. Interestingly, MOFs can be highly selective for  $\text{CO}_2$  reduction catalysis with small pores providing uniform adsorption sites and effectively boosting local concentrations of key reactants/intermediates.

While various modifications of MOFs show a range of promising applications in the novel preparation of **Lithium-based batteries** and **energy storage**, more research is needed to improve the current state of knowledge and understanding of these porous materials for future generation applications in **artificial photosynthesis** and **cutting-edge heterogeneous catalysis**.

REFERENCES



# Mycelia: a promising lead to the ecological revolution

TREADING WATER

WRITTEN BY CHELSEA BLAIR | EDITED AND DESIGNED BY SICHUN YAO

Today, the astonishing properties of **mushrooms**, which hold an invisible library of uses which go far beyond the sphere of food, have piqued the interest of a multitude of start-ups, each betting on the use of fungi within our **health** industry but also for **biostimulants**, **biofuels** and **biomaterials**.

## Giant Natural Organisms

The fungal universe is utterly expansive and intriguing to many scientists, considering we are just “barely beginning to understand the complexity and the degree of fungal sophistication”, underlines biologist Merlin Sheldrake in his bestseller *Entangled World*<sup>1</sup>. Not only, but fungal applications could potentially bring a multitude of bio-sourced solutions to many of Earth’s **urgent environmental problems**<sup>2</sup>. Commonly referred to as “mushrooms”, the latter is in fact the only reproductive organs responsible for dispersing the spores of a much more extensive and invisible filamentary entity: **mycelium**.

Those convinced that blue whales or redwood trees are the largest living organisms on the planet will be surprised to learn they’re wrong. As of this year, a mushroom within the *Armillaria Gallica* family whose mycelium extends **over 9 km<sup>2</sup>** and weighs **nearly 400 tons**, has been found in Oregon<sup>3</sup>. Similarly, a boletus mushroom can cover up to **100 m<sup>2</sup>** whilst simultaneously giving dozens of fruiting bodies with help of its hyphae.

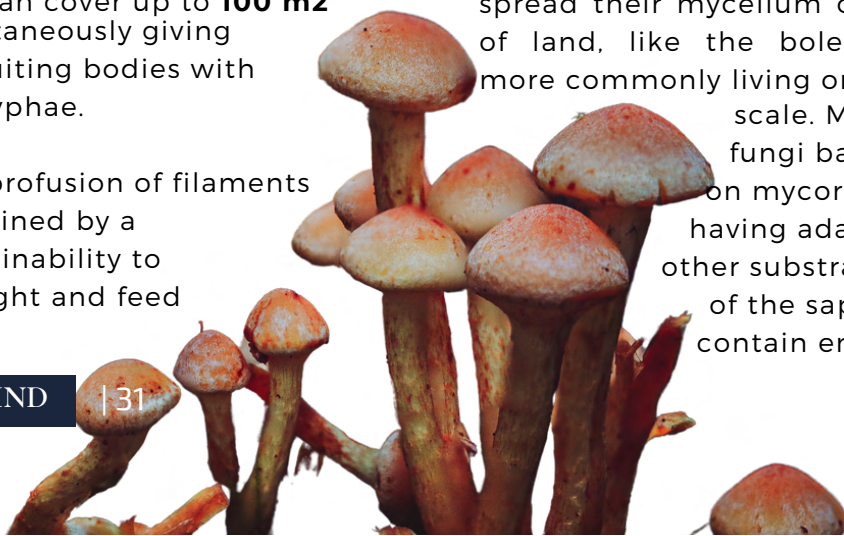
Mycelium’s profusion of filaments can be explained by a mushroom’s inability to synthesise light and feed itself.

Thus, fungi are forced to feed at the expense of another organism and have therefore forged a strategic alliance with most plants on the planet<sup>2</sup>. Mycelium filaments are additionally grafted onto their rootlets, sometimes going so far as to enter their cells and considerably extending their network of roots; a phenomenon known as “**mycorrhization**”.

A perfect example of **sybiotic interdependence** that has shaped our world is the exchange of mineral elements that are pumped from the soil and transmitted to fungi’s hosts, providing the fungi with sugars produced by photosynthesis. In return, it is believed that fungi allowed rootless algae to colonise our soil **over 400 million** years ago!

## The Moldy Phenomenon

Edible or not, macro-mushrooms found within woods represent only a small portion of the fungi kingdom of life<sup>1</sup>. Over **80%** of mushrooms do **not** bear fruit and an even larger number cannot spread their mycelium over large areas of land, like the boletus mushroom, more commonly living on a microscopic scale. Moreover, not all fungi base their survival on mycorrhization, rather having adapted to feed on other substrates<sup>2</sup>. Specimens of the saprotrophs family contain enzymes that are



able to decompose the lignin and cellulose of trees, thriving in particular on dead tree trunks or other forms of biomass. Without these fungi, forests and natural fields would be covered with bio-waste, thus preventing soil regeneration. Also within this family exist several excellent **edible** specimens, such as oyster or shiitake mushrooms. Conversely, other forms of mushrooms have found that in order to satisfy their voracious appetites, they must become **pathogenic**; in other words, killing their host and devouring the latter.

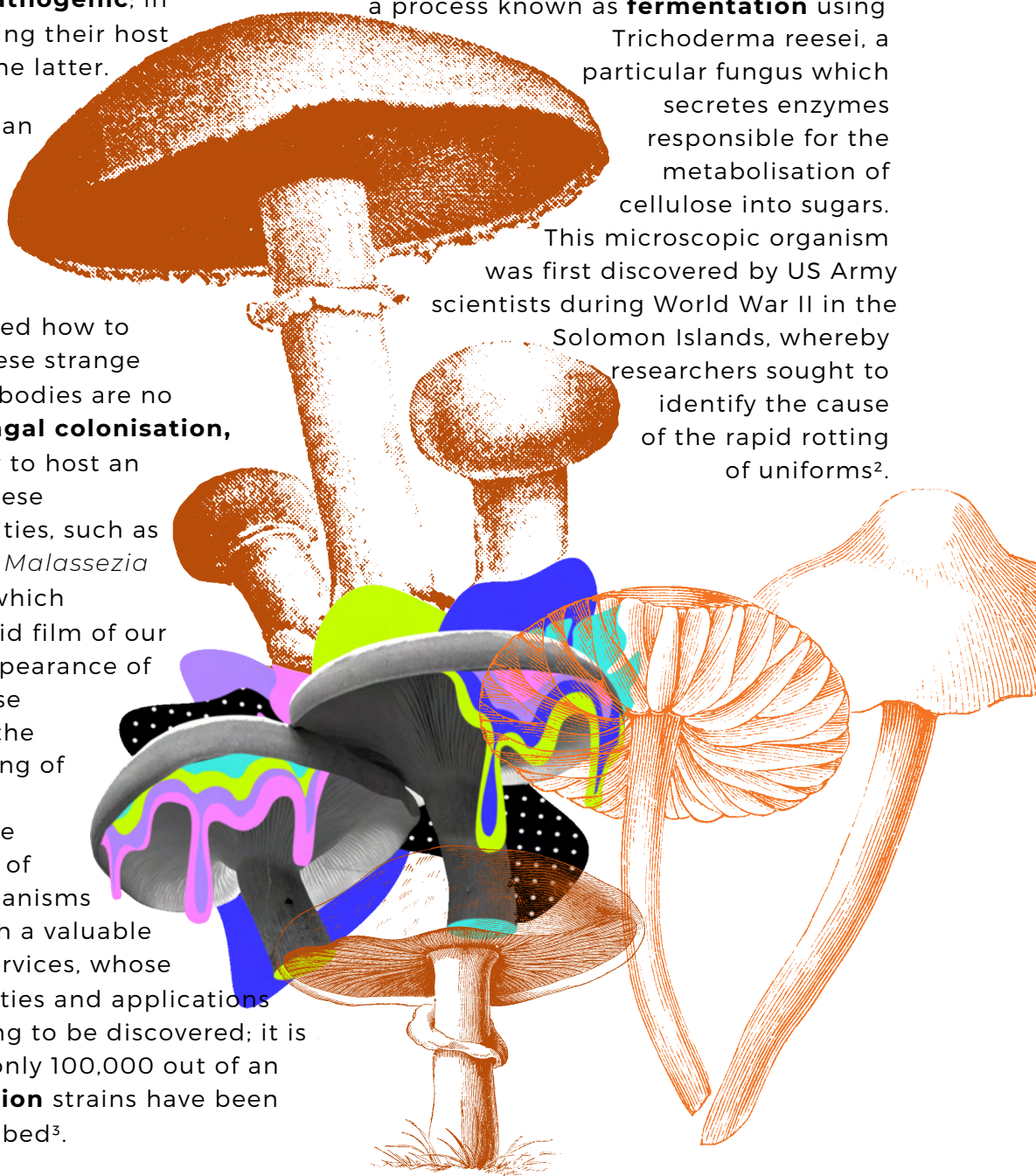
For most of human civilisation, we never understood the mechanisms behind **moulds**, yet we still learned how to **domesticate** these strange organisms<sup>1</sup>. Our bodies are no exception to **fungal colonisation**, with their ability to host an abundance of these microscopic entities, such as fungus from the *Malassezia globosa* family which degrades the lipid film of our scalp (i.e. the appearance of dandruff) or those contributing to the proper functioning of our intestinal microbiota. There exists a universe of polymorphic organisms providing us with a valuable **ecosystem** of services, whose potential properties and applications are just beginning to be discovered; it is suspected that only 100,000 out of an estimated **5 million** strains have been listed and described<sup>3</sup>.

### Eco-Responsible Soil Decontamination

Assisting **soil de-pollution**, certain fungi, such as oyster mushrooms, contain enzymes capable of degrading **harmful hydrocarbons**<sup>1</sup>. Certain companies have achieved successful excavated soil clean-up by coating mushroom spores with algae to better guarantee fungal preservation. Others have developed a way to produce **bioethanol** from biomass waste during a process known as **fermentation** using

*Trichoderma reesei*, a particular fungus which secretes enzymes responsible for the metabolisation of cellulose into sugars.

This microscopic organism was first discovered by US Army scientists during World War II in the Solomon Islands, whereby researchers sought to identify the cause of the rapid rotting of uniforms<sup>2</sup>.



The current lineup of new, innovative **mushroom-based materials** has proved the fungal world's extremely promising future, provoking the question of how best to exploit mycelium's growth capacity, whose envelope is made up of chitin, an organic substance found within an insect's shell with properties similar to that of cellulose<sup>4</sup>. By mixing together agricultural waste-type biomass sawdust with mushroom spores in a mould, one can grow a compact and compostable **biosourced-material** capable of taking on any form in just a few days, requiring virtually no energy expenditure. Nonetheless, the production costs are still **much higher** compared to the polystyrene (plastic) that dominates the mass market.

### Myco-Health, Homes and Leather

Recently, a whole string of small businesses has begun exploring the distant origins of mushrooms, including their **health** benefits, though it is believed the mentioned have been a part of traditional pharmacopoeia in Asia for **nearly three millennia**. In the West, interest developed much later, in particular with respect to Alexander Fleming, who managed to isolate **penicillin** from a fungus back in 1928, giving birth to the first antibiotic<sup>1</sup>. From immunosuppressive cyclosporine to cholesterol inhibitor **statins** to psychiatric **psilocybin**, certain active molecules contained within mushrooms have entered the world of medicine to help orchestrate the proper functioning of the **immune, digestive and nervous systems** alike.

Mycelium's manufacturing process has also been applied to the production of other alternative materials, such as **concrete blocks**. This not only applies to homes on Earth but potentially off-Earth dwellings on **Mars** and the **Moon**<sup>6</sup>. Instead of metal or glass housings, the current modern era of green technology has prompted NASA's Ames Research Center to invest its time in developing **prototype containers** made using the invisible **underground threads** that makeup mycelium. The objective of this project is to ultimately allow individuals to be able to independently cultivate their own habitats using **lighter materials**.

Down on Earth and combining in-depth science with **haute couture design, garments** were recently launched by Stella McCartney, showcasing this next-generation material's fullest potential and paving the way for numerous future commercial offerings. In the midst of the Covid pandemic back in October 2020, Stella McCartney explored the use of Mylo™ material, providing critical feedback and ultimately becoming a part of the exclusive consortium of brands working alongside the mycelium BoldThreads team<sup>7</sup>. The earliest two garments announced by McCartney include a black strapless top and utility pants: both **unique, cruelty-free and effortlessly sensual**. The pieces have been meticulously handcrafted in McCartney's London workshop using panels of **mycelium-based material**, which are then laid atop recycled nylon.



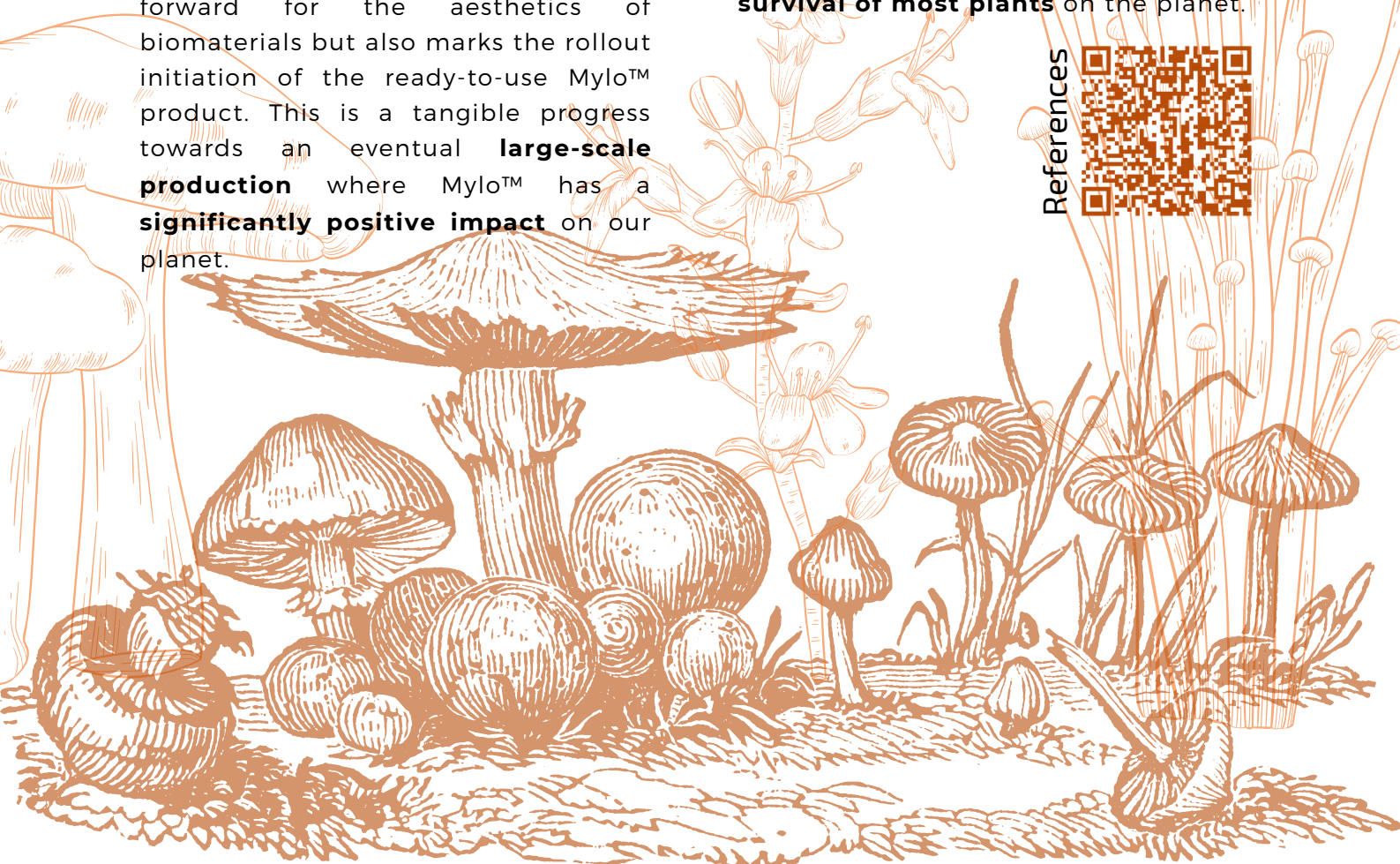
McCartney and BoltThreads have been partners in sustainable innovation since 2017, the Stella McCartney luxury brand taking part in the Mylo™ journey since its grand debut. In fact, the first product ever created using Mylo™ products was a prototype of Stella's iconic Falabella bag. This state-of-the-art design process is **non-petroleum-based**, stipulating the remainder of more underground fossil fuels and less spilled plastic. Consequently, Mylo™ is fabricated to have an extremely **minimal environmental impact** and takes just **several days**, rather than years, to fabricate.

Creating **new, high-quality biomaterials** is a major technological challenge and a huge opportunity for both people and the planet. The material used in her first two garments not only represents a huge step forward for the aesthetics of biomaterials but also marks the rollout initiation of the ready-to-use Mylo™ product. This is a tangible progress towards an eventual **large-scale production** where Mylo™ has a **significantly positive impact** on our planet.

## Earth's Surprisingly Indispensable Vegetative Structure

To close, mycelia showcase an **essential** role within terrestrial and aquatic **ecosystems** by breaking down and converting plant matter into **assimilable nutrients**, not only in an unassisted fashion but also with aid of other plants and subterranean life forms<sup>6</sup>. In addition, mycelia promote the **organic composition** of the soil, their growth also giving rise to atmospheric carbon dioxide and promoting water and nutrient absorption from plants around or in symbiosis with them. Not only this, but mycelia hold the capacity to **protect** plants against certain pathogens that attack their root systems. In short, mycelium is used to feed many invertebrates found in the soil and is thus required for a **functioning agricultural system** and for the **survival of most plants** on the planet.

References





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