

Nitroplast: A New Entrant to the Organelle Club

TWO recent publications in the prestigious journals *Science* (April 2024) and *Cell* (March 2024) have provided concrete evidence that a nitrogen-fixing cyanobacterium *Candidatus Atelocyanobacterium thalassa* (UCYN-A), known to survive inside a marine alga (*Braarudosphaera bigelowii*) symbiotically, has integrated itself with the host and evolved into an organelle, named Nitroplast.

Nitroplast is likely to join the ranks of mitochondria and chloroplasts, the two important organelles in cells of higher life forms. According to one of the authors, Tyler Coale, “It is the first known nitrogen-fixing organelle and could be the key to the success of these algae.” The alga containing nitroplast is widely distributed in seas around the world. The work hails as a breakthrough with immense potential in agriculture.

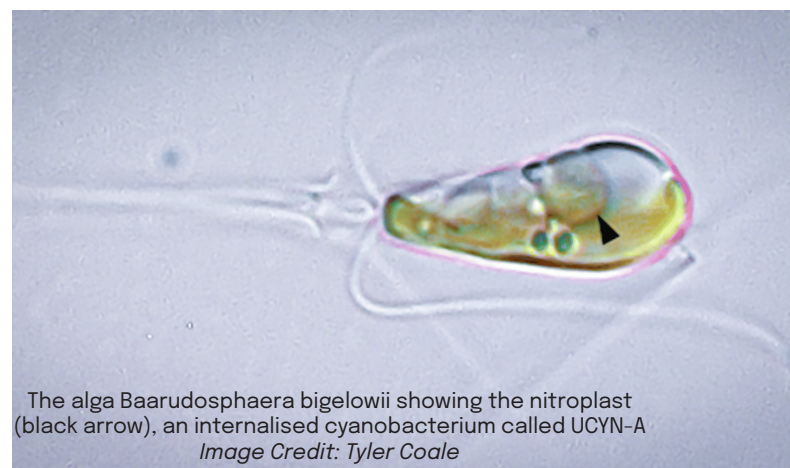
Life originated on Earth about 3.5 billion years ago in the form of simple unicellular organisms like bacteria and archaea, which evolved over millions of years into complex life forms. Evolution proceeds mostly *via* mutations and other changes in genetic material, bifurcation of the lineages and emergence of new species. Very rarely, however, the merging of two different lineages beginning through a process called endosymbiosis (mutual association where one organism is living inside the other) results in the advent of novel and robust forms of life.

In most instances, the endosymbiotic partners represent distinct domains (one prokaryote and another eukaryote) of life and retain their abilities of independent survival under favourable conditions. In extremely rare situations, the relationship progresses further and results in endosymbiont integration into the architecture of the host cells, forming

inseparable entities designated as organelles. Such mergers are so rare that only three instances — mitochondria, chloroplast and chromatophores, have been identified over the half-billion years of life on Earth.

Nitrogen is indispensable for all life forms, constituting various biomolecules, including proteins and nucleic acids. While the Earth’s atmosphere is very rich in nitrogen (78%), the bimolecular gas is extremely inert and requires enormous energy for conversion to ammonia and other forms of nitrogen that living organisms can use. Some microorganisms, the nitrogen fixers, acquired the ability to convert atmospheric nitrogen to ammonia very early during evolution catalytically. They are directly and indirectly responsible for all the organic nitrogen in biomass and the nitrates and nitrites in the soil and waters. It is well known that some plants, like legumes, engage nitrogen-fixing organisms in endosymbiotic relationships to address their nitrogen requirements. Similarly, some marine algae depend on nitrogen-fixing microbes living inside their cells.

The symbiotic association between the unicellular marine algae *B. bigelowii* and the cyanobacterium UCYN-A, has been known for several years. The relationship is perfectly mutualistic; the cyanobacterium cannot photosynthesise



The alga *Braarudosphaera bigelowii* showing the nitroplast (black arrow), an internalised cyanobacterium called UCYN-A
Image Credit: Tyler Coale

A Leap toward Carbon Neutrality CO₂ to Methanol

RESearchers at the University of Michigan have developed a catalyst known as cobalt phthalocyanine that converts carbon dioxide — a significant driver of climate change — into renewable fuels such as methanol.

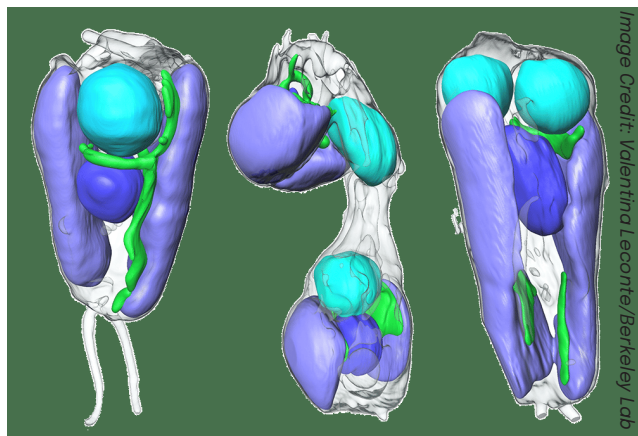
Published in the journal *ACS Catalysis*, U-M researchers studied using cobalt phthalocyanine as a catalyst to convert carbon dioxide into methanol through multiple reaction steps. The first step converts Carbon Dioxide (CO₂) into Carbon Monoxide (CO), and the second converts CO into methanol.

This approach presents a sustainable method for reducing greenhouse gas emissions while offering an avenue to produce clean energy.

Scientists have long tried to find a way to chemically convert CO₂ into fuels like methanol. Methanol could potentially be used to power vehicles in a more environmentally friendly way.

While the conversion of CO₂ to methanol has been industrialised, achieving this transformation on a large scale through electrochemical processes has proven to be a significant challenge.

“Our approach is unique because we are able to bring and bridge all this knowledge that each field has on the same problem. We have scientists and engineers all within one team, brainstorming and gathering insights to design and understand the system in the best way possible,” said



X-ray images of *B. bigelowii* at different stages of cell division. The newly identified nitroplast is shown in cyan, the algae nucleus is blue, mitochondria are green, and chloroplasts are purple.

and depends on its host for the requirements of carbon compounds, while the algae cannot fix nitrogen and seek the help of the bacterium. There have been speculations regarding transforming the nitrogen-fixing bacteria UCYN-A into an organelle called nitroplast in the marine algae *B. bigelowii*. Still, convincing evidence supporting this contention has been lacking thus far. Cultivation of *B. bigelowii* in the laboratory remained a serious hurdle in the study, but the problem was resolved by the painstaking efforts of Kyoko Hagino of Kochi University of Japan, who is one of the authors of the study.

Prof. Jonathan Zehr at the University of California, Santa Cruz, and his international team provided evidence that the merger between *B. bigelowii* and UCYN-A has progressed and resulted in the formation nitrogen fixing cellular organelles, the nitroplast. The following features of the nitroplasts suggested that UCYN-A has completely integrated with the algal cell machinery in the form of an organelle.

1. The genome of UCYN-A (nitroplast) has shrunk with the loss of several essential genes.

2. Three-dimensional subcellar images obtained using X-ray tomography showed excellent coordination between the algae cell division and the nitroplasts' division. The nitroplasts are cleaved into two during the algal cell division initiation and passed on to the daughter cells like other organelles.
3. The nitroplasts depend on proteins encoded by the nuclear genome and synthesised in the algal cytoplasm. These are directed specifically to the nitroplasts with the help of specific labels on them, the transport peptides. Twenty-eight per cent of the protein in the nitroplasts, including those involved in nitrogen fixation, originate in the host algae.

Considering the importance of nitrogen fixation for all living beings, it was predicted that some photosynthesising eukaryotes may also have evolved organelles for efficient nitrogen fixation. Studies of Zehr and coworkers have furnished concrete evidence in this regard. Thus far, nitroplasts have been observed only in the family of the marine alga *B. bigelowii* (Prymnesiophytes). It is estimated that the merger of the alga with the cyanobacterium occurred about one hundred million years ago, much later than when mitochondria and chloroplasts came into being.

Besides establishing an organelle-like structure for nitrogen fixation in the algae, the work has important implications in agriculture. Agricultural crop yields are restricted by the availability of usable assimilable nitrogen, making nitrogen fertilisers like those containing urea indispensable. Additional understanding of the algal nitroplasts will likely lead to a technology by which plants can be armed with nitrogen-fixing organelles and reduce their dependence on nitrogen fertilisers. It is a long way to go, but the rewards will be immense if the attempts succeed.

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co-primary author Kevin Rivera-Cruz, who recently received a doctorate in chemistry from U-M.

Cobalt phthalocyanine acts as a molecular hook for CO₂ or CO molecules. The arrangement of these molecules around the cobalt metal (the geometry) is crucial because it determines how strongly each gas molecule binds. The problem, they found, is that cobalt phthalocyanine binds much more strongly to CO₂ molecules than to CO molecules. Because of this, once CO is produced in the first step, the CO is displaced by another CO₂ molecule before it can further be converted to methanol.

Using advanced computational modelling, the researchers calculated that cobalt phthalocyanine binds CO₂ over three times more tightly than carbon monoxide. They also confirmed this through experiments measuring reaction rates when varying the amounts of CO₂ and CO.

The researchers showed that the difference in binding affinity has to do with how the catalyst's electrons interact with the CO₂ and CO molecules. To solve this issue, the researchers suggest redesigning the cobalt phthalocyanine catalyst to strengthen how it interacts with CO and lessen how strongly it binds to CO₂.

Resolving this roadblock could pave the way for using catalysts like cobalt phthalocyanine to efficiently convert CO₂ waste into methanol fuel on a large scale.

Reference

Yao L, Rivera-Cruz KE, Zimmerman PM, Singh N & McCrory CC (2023). Electrochemical CO₂ reduction to methanol by cobalt phthalocyanine: Quantifying CO₂ and CO binding strengths and their influence on methanol production. *ACS Catalysis*, 14(1), 366–372.

Source: University of Michigan News

IIT Madras researchers identify the Indian Ocean & Bay of Bengal as Potential CO₂ sinks that decarbonise industrial clusters

INDIAN Institute of Technology Madras (IIT Madras) researchers have identified the Indian Ocean and Bay of Bengal as potential storage sinks for storing large amounts of Carbon Dioxide (CO₂). Called 'CO₂ sequestration,' this process envisages the ocean acting like a greenhouse gas storage reservoir, which will help decarbonise industrial clusters.

The researchers found that CO₂ can be stored permanently in the ocean as a solid hydrate beyond 500 m of sea depth through the liquid CO₂, thereby helping to make our industrial clusters carbon neutral.

The key findings of this research are that it can help devise large-scale CO₂ storage and utilise the fullest potential of oceans to decarbonise the world without harming marine ecology. This research can also help India achieve its National decarbonisation and climate change goals.

The stored CO₂ can create an eco-friendly ice-like substance called 'Gas Hydrates'. One cubic metre of gas hydrate can sequester approximately 150-170 cubic metres of CO₂ under oceanic conditions beyond 500 metres.

Thus, gas hydrates-based storage has huge potential to decarbonise India's industrial clusters. This research will pave the way for developing large-scale sequestration in subsea sediments to help the scientific community fulfil India's net-zero targets.

Highlighting the importance of this research to India, Prof. Jitendra Sangwai, Department of Chemical Engineering, IIT Madras, said, "Methane hydrates have been in the ocean for millions of years without affecting the environment. Methane is a more potent greenhouse gas than CO₂. This attracts researchers to explore the ocean to store CO₂ permanently. Our analysis shows that at above 2,800 m depth, CO₂ is denser than seawater, which offers an additional gravitation barrier for CO₂ to escape."

Prof. Jitendra Sangwai added, "Our dependence on fossil fuels will continue for the foreseeable future till we find a reliable source of energy to replace fossil fuels completely. Thus, CO₂ capture and sequestration are an important precursor to achieving net-zero goals. Once CO₂ is captured from the source, it needs to be sequestered safely. CO₂ sequestration in oceans will be beneficial for India as, according to a conservative estimate, the Bay of Bengal alone can be able to sequester several hundred giga tonnes of anthropogenic CO₂ in oceans and marine sediments, which is equivalent to several years of total GHG (Greenhouse Gas) emission emitted by India. Some European countries (e.g., Norway and Denmark) are working on CO₂ storage in the North Sea."

Once the CO₂ is permanently stored as a gas hydrate, it does not allow any reemission into the atmosphere owing to

the gravitational and hydrate permeability barrier in the subsea sediments.

The Key findings of their research include

- Beyond 2,800 m of sea depth, CO₂ liquid is denser than seawater.
- Thus, beyond 2800 m sea depth, CO₂ can be stored permanently in the form of a liquid pool and solid hydrate and
- Due to the gravitational and permeability barrier that subsea sediments offer, it will not permit any reemission into the atmosphere.
- The subsea clay sediments improve gas hydrates' mechanical and thermal stability, which helps achieve long-term CO₂ storage potential.

Elaborating further, Mr Yogendra Kumar Mishra, Research Scholar (Prime Ministers Research Fellow), IIT Madras, said, "There are different ways to sequester CO₂ to reduce its impact on the environment. Using the ocean as a CO₂ storage sink is attractive, but storing CO₂ directly into the ocean at shallow depths can harm marine life. Hence, CO₂ needs to be stored permanently in the ocean in the form of liquid pools or solid hydrates beyond a certain depth."

Further, Mr Yogendra Kumar Mishra said, "Another attractive option is to store CO₂ in subsea sediments as this will have less impact on marine ecology. The subsea sediments have tiny spaces that can hold CO₂ and, over time, stored gas forms ice-like gas hydrate crystals in the pores. This will further reduce the permeability of hydrate-bearing sediments and create a permeability barrier."

The IIT Madras Research team has observed that hydrate formation is more efficient and stable at higher clay concentrations. The clay inclusion in seawater improves the kinetics of hydrate formation compared to seawater alone. Some promoters, such as Tetrahydrofuran (THF), further enhance hydrate kinetics synergistically with clay and will help in large-scale CO₂ storage in subsea sediments.

Studying the concentration of clay, properties of additives, and local bathymetry information of the ocean can help figure out the best way to store CO₂ in the subsea sediments.

Reference

<https://doi.org/10.1021/acs.energyfuels.3c00581>; <https://doi.org/10.1021/acs.energyfuels.3c02311>; <https://doi.org/10.1016/j.fuel.2024.130990>

Source: IIT Madras Press Release

PhD Reimagined: i3C BRIC-RCB PhD Programme Offers a Unique Path to Doctoral Success



Launch of i3BRIC programme by Dr Jitendra Singh, Hon'ble Minister (I/C) for Ministry of Science and Technology (source: PIB)

INDIA of today has the capacity to excel in science, capitalising on its huge demographic advantage for the foreseeable future and thereby serving as a driving force for Nation-building. Exploiting the demographic dividend in the field of Science and Technology requires dedicated efforts to shape the mindset of young researchers early in their careers, encouraging them to think creatively, push boundaries, and tackle real-world challenges. It has been proven time and again that though R&D generates and establishes new ideas, converting them into usable technology needs innovation, entrepreneurial exertions and collaborations among institutions and researchers.

An interdisciplinary PhD programme in life science thus plays a pivotal role in advancing research by breaking down disciplinary silos. Combining insights from diverse fields such as biology, chemistry, physics, and computer science offers a holistic approach to understanding complex biological systems. This fosters creativity, problem-solving skills, and the ability to address real-world challenges with innovative solutions.

These ideas led to conceptualisation and eventual rollout of the i3C BRIC-RCB PhD Programme, aiming to Ideate, Innovate, Immerse and Collaborate (i3C) while pursuing PhD to solve real-world problems employing state-of-the-art technologies and tools with top-notch mentors at premiere institutions.

Dr Jitendra Singh, Hon'ble Minister (I/C) for the Ministry of Science and Technology, launched this five-year programme, which fosters collaboration among three prestigious Department of Biotechnology institutions — DBT-Biotechnology Research Innovation Council (DBT-BRIC), Regional Center of Biotechnology (RCB), International Center for Genetic Engineering and Biotechnology (ICGEB).

One of the highlights of the programme is a unique three-month internship which will immerse scholars in societal challenges, honing their practical skills and preparing them for the professional sphere. This will be followed by highly trained professionals who are trained in high-end scientific equipment. After the training and immersion, the doctoral researcher will be mentored by faculty members of the participating institutions.

By equipping scholars with diverse skills and fostering practical experience, the i3C BRIC-RCB programme is poised to empower the next generation of biotech leaders and propel India towards the forefront of the global biotech landscape.

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