

The Living as Technology

An Introduction to Frugal Biotechnologies

Dear CitEuroPass students,

In preparation for our upcoming session, I would like to share with you an in-depth exploration of "The Living as Technology," a concept that will be central to our work together. This document will provide you with comprehensive background knowledge that will enhance our collaborative experience.

Understanding Biotechnologies

Biotechnology, in its essence, is the use of living systems and organisms to develop or create different products. This field represents a fascinating intersection of biology and technology, where we harness the power of living organisms or their components to create or modify products, improve plant or animal species, or cultivate microorganisms for specific purposes.

The practice of biotechnology is not a novel concept; it has been a part of human civilization for centuries, manifesting in basic forms such as the use of yeast in baking or brewing. However, modern biotechnology has evolved dramatically, particularly since 1973 when Stanley Cohen and Herbert Boyer demonstrated DNA cloning, leading to significant advancements in genetic engineering techniques.

These new techniques have enabled:

- Creation of engineered biological molecules
- Design of genetically modified microorganisms and cells
- Development of methods to discover new genes and determine their functions

Today, biotechnology finds applications across numerous fields:

In Medicine: The biotech industry, with revenues exceeding \$150 billion annually, focuses on the drug discovery pipeline. This involves identifying genes or proteins associated with specific diseases that could serve as drug targets and diagnostic markers. Thousands of chemicals are

screened to find potential drugs that affect these targets, which are then optimized and tested in clinical trials.

In Agriculture: Biotechnology has been leveraged to improve crops and livestock for thousands of years. Modern genetic engineering techniques optimize the genetics of crops and livestock to enhance utility and improve yields, integrating these methods into the research and development programs of established agricultural companies.

The applications of biotechnology continue to expand, providing exciting opportunities for sustainable solutions. For instance, researchers have developed a natural process called microbial induced calcium carbonate precipitation (MICP) to 'grow' bio-bricks using urease-producing bacteria and calcium sources, demonstrating the potential for environmentally sustainable applications.

Biotechnologies in Our Environment

Rather than conventional tools, biotechnology uses microorganisms and biological processes as instruments to solve real-world problems. Here are specific applications in our environment:

Wastewater Treatment

Conventional water treatment relies heavily on physical and chemical processes, which can be energy-intensive and generate secondary waste. Through biotechnology, specific types of bacteria, such as *Pseudomonas* or *Bacillus*, can break down harmful pollutants in water. The use of these bacteria in biofilters allows us to purify wastewater in a sustainable and eco-friendly manner, highlighting the practical applications of biotechnology in environmental remediation.

Agricultural Advancements

Biotechnologies are revolutionizing agriculture. Through genetic modification techniques, crop varieties have been developed that are more resistant to pests, diseases, and extreme weather conditions. This reduces dependency on chemical pesticides, which can have negative environmental impacts, and helps increase crop yields. In a world facing the challenge of feeding a rapidly growing population, these advances are invaluable. Furthermore, the concept of zero waste agriculture demonstrates the potential of biotechnology to contribute significantly to sustainable farming practices.

Environmental Monitoring

Organisms like lichens or specific bacteria can act as bioindicators, signaling the presence of pollution or other ecological disturbances. These bioindicators provide valuable information about the health of our environment and are a powerful tool for scientists and policymakers, enabling them to track and respond to environmental changes.

Biotechnologies are also increasingly used in oceanographic research, although this field is still developing. There is evidence that biotechnologies help investigate marine environments, including microorganisms that thrive in extreme conditions, which may hold keys to new biotechnological applications.

MICP - Turning Bacteria into Builders

Microbially Induced Calcite Precipitation (MICP) is a fascinating biotechnological process where bacteria function as microscale builders. This process leverages bacteria that naturally produce urease, an enzyme that breaks down urea (which can come from various natural and synthetic sources) into ammonia and carbon dioxide. In the presence of calcium ions, this reaction triggers the precipitation of calcite (a form of calcium carbonate), which binds soil particles together, creating a substance similar to natural concrete.

The significance of MICP extends to:

- **Sustainable Building Materials:** It offers an alternative to energy-intensive and environmentally harmful construction materials.
- **On-Site Production:** Since the bacteria used in MICP are commonly found in various natural environments, it presents the possibility of producing building materials wherever needed.
- **Reduced Environmental Impact:** The process occurs at ambient temperatures and utilizes natural biological processes, significantly reducing the carbon footprint compared to traditional concrete production.

While MICP technology is still in early development stages, projects have successfully produced bricks and other building materials using this method. Research continues worldwide to address challenges such as controlling the process to ensure consistency and reliability of the final product.

MICP exemplifies how biotechnologies can help us rethink problem-solving approaches and our interaction with the environment. It represents a symbiotic relationship with nature, where we work in harmony with natural processes rather than against them.



Architectural form made from living building material. College of Engineering & Applied Science, University of Colorado Boulder © Scientific American, Inc

Bioindicators - Lichens and Beyond

Bioindicators serve as crucial markers of ecosystem health. Lichens, in particular, are powerful bioindicators due to their unique symbiotic nature—a partnership between a fungus and an alga or cyanobacterium. These organisms thrive in diverse environments and are highly sensitive to environmental changes, especially air quality.

Unlike many plants, lichens lack a protective cuticle, causing them to absorb water, nutrients, and air pollutants directly from the atmosphere. This characteristic makes them excellent indicators of air quality—their condition in a particular area can provide significant information about local air pollution levels.

The application potential of bioindicators becomes even more impressive when combined with technology. Imagine a system where lichens are integrated with electronic sensors and a microcontroller to monitor air quality. In such a setup:

- The lichen absorbs pollutants
- Sensors measure the lichen's health to infer air quality
- Data is transmitted in real-time to a central system
- Environmental conditions are continuously monitored

This fusion of biology and electronics opens a world of possibilities for environmental monitoring.



A lichen, Polycauliona polycarpa © Nemeton

Beyond lichens, other organisms serve as bioindicators:

Macroinvertebrates: Species like mayflies, stoneflies, and caddisflies are used to evaluate water quality. These creatures are sensitive to pollutants, and their presence or absence can indicate the health of a water body.

Birds as Early Warning Systems: The Kivi Kuaka scientific program investigates birds' behavioral responses to natural disasters like cyclones, earthquakes, and tsunamis. Certain bird species are sensitive to infrasound produced by cyclone vortices or submerged waves. By tracking migratory birds with GPS, researchers can detect potential behavioral changes that might indicate an approaching disaster. This project also identifies risks faced by these bird species due to climate change and coastal degradation, aiding conservation efforts.



Northern Plover (Pluvialis fulva) © MNHN - K. Kuaka

Biosensors for Pollution Detection: Biosensors provide fast, reliable, and cost-effective detection of pollutants. These devices leverage biotechnology to detect and screen pollutants in a selective, sensitive, accurate, and real-time manner. They are particularly effective in assessing ecological risks and can monitor soil, water, and air samples to detect pesticides, potentially toxic elements, pathogens, toxins, and endocrine-disrupting chemical compounds.

The integration of biology and technology in bioindicators and biosensors not only enhances our understanding of the natural world but also drives the development of innovative solutions for environmental protection and preservation.

Frugal Biotechnologies

Frugal biotechnologies represent an innovative approach to making biotechnological capabilities economical, accessible, and sustainable. The concept derives from the Latin word 'frugalis,'

meaning 'economical,' and embodies thriftiness in resource use. This approach is particularly vital in regions with scarce or costly resources.

Frugal biotechnologies are not just about affordability; they represent:

- **Empowerment:** Enabling communities to solve their own problems
- **Inclusivity:** Democratizing scientific fields and allowing more people to contribute
- **Innovation:** Finding creative solutions with limited resources

Practical Examples

A practical demonstration of frugal biotechnology is the creation of a homemade bacterial culture medium using readily available ingredients such as chicken broth, gelatin, and sugar. While not suitable for advanced scientific research, this homemade medium effectively demonstrates microbial growth and allows students and amateur scientists to conduct experiments without significant investment.

In scientific education and research, a remarkable example is the Foldscope - a paper microscope that costs less than one euro to produce. Developed by Manu Prakash's team at Stanford University, this origami-based microscope can be assembled in minutes yet provides magnification up to 140X with sub-micron resolution. Despite its simplicity, it enables scientific observation in resource-limited settings, from schools in remote villages to field researchers in challenging environments. The Foldscope perfectly embodies 'frugal innovation' by democratizing access to scientific tools while maintaining functionality comparable to conventional microscopes costing hundreds of times more.



© Foldscope

Community Engagement

Frugal biotechnologies often emerge from community-led initiatives, designed by the communities themselves. This involvement leads to solutions tailored to local needs, such as clay water filters for improving water quality. However, these innovations may face limited adoption due to lack of expertise or evidence validating their effectiveness. Collaboration with external partners can help improve these solutions, build confidence in their effectiveness, and support wider adoption.

Organizations can play a vital role by connecting communities and sharing know-how, thus expanding the reach and impact of these innovations. They can use their networks to link communities to each other and relevant ideas, overcoming the hyper-local limitations often associated with frugal innovations.

The Future of Biotechnologies

The future of biotechnologies holds immense promise in addressing environmental challenges and improving quality of life across various sectors. The rapid evolution of biotechnology, combined with interdisciplinary insights, presents exciting prospects for environmental sustainability, waste management, agriculture, water treatment, and healthcare.

Environmental Sustainability

Advancements in agricultural biotechnology have the potential to both mitigate and adapt to climate change:

- Development of crops resistant to environmental stressors like drought and increased temperatures
- Production of sustainable biofuels
- Carbon sequestration using trees and microbes

These developments contribute to reduced greenhouse gas emissions, improved global food security, and reduced environmental impacts from agriculture.

Waste Management

With increasing urban populations, biotechnology is expected to transform waste management through:

- Sanitary solutions
- Microbe surveillance systems
- Waste recycling technologies

These advancements could slow pathogen transmission and more effectively manage waste in populous urban centers.

Water Treatment

Biotechnology is introducing revolutionary water treatment methods, such as anaerobic bacteria-based systems. These processes offer advantages over current methods:

- More cost-effective and efficient
- Ability to digest pharmaceuticals and powerful herbicides

- Reduced energy use and costs
- Production of water pure enough for various uses, including irrigation and potentially drinking

Healthcare Innovations

Biotechnological advancements continue to transform healthcare, from personalized medicine to advanced diagnostics and treatments.

Conclusion and Next Steps

As we've explored throughout this document, biotechnologies permeate many aspects of our lives, offering solutions to challenges ranging from medicine to environmental conservation. These technologies are not limited to high-tech laboratories but can be adapted and leveraged in various contexts, even with limited resources.

Biotechnologies play a crucial role in sustainability efforts. For instance, MICP techniques are being explored to improve soil stability in areas previously considered unsuitable for construction, potentially transforming geotechnical engineering practices. Similarly, lichens have been successfully used in air quality biomonitoring systems, providing clear indications of air quality in different regions.

The concept of frugal biotechnologies emphasizes the power of creativity and resourcefulness in leveraging biotechnologies with everyday ingredients and minimal resources.

It's important to note that while biotechnologies offer incredible potential, assessing their environmental impacts remains complex. Considerations range from nonrenewable resource depletion to climate change and land transformation.

Preparing for Our Collaborative Prototyping

Drawing from these concepts, I invite you to consider how you might integrate principles of frugal biotechnology into your projects. How can you leverage biotechnological approaches with limited resources to create impactful and sustainable solutions?

The goal of our upcoming exercise is not just to create functional prototypes but also to consider the broader environmental and societal impacts of your work. As we embark on this journey

together, remember that innovation isn't just about sophistication or complexity—it's also about accessibility, sustainability, and responsible implementation.

I look forward to seeing your creative prototypes and the sustainable solutions you will design. Remember, the key is to think big, start small, and iterate rapidly. Together, we can explore new ways to apply biotechnology for positive environmental and social impact.

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