Purple non-sulfur bacteria and the circular economy

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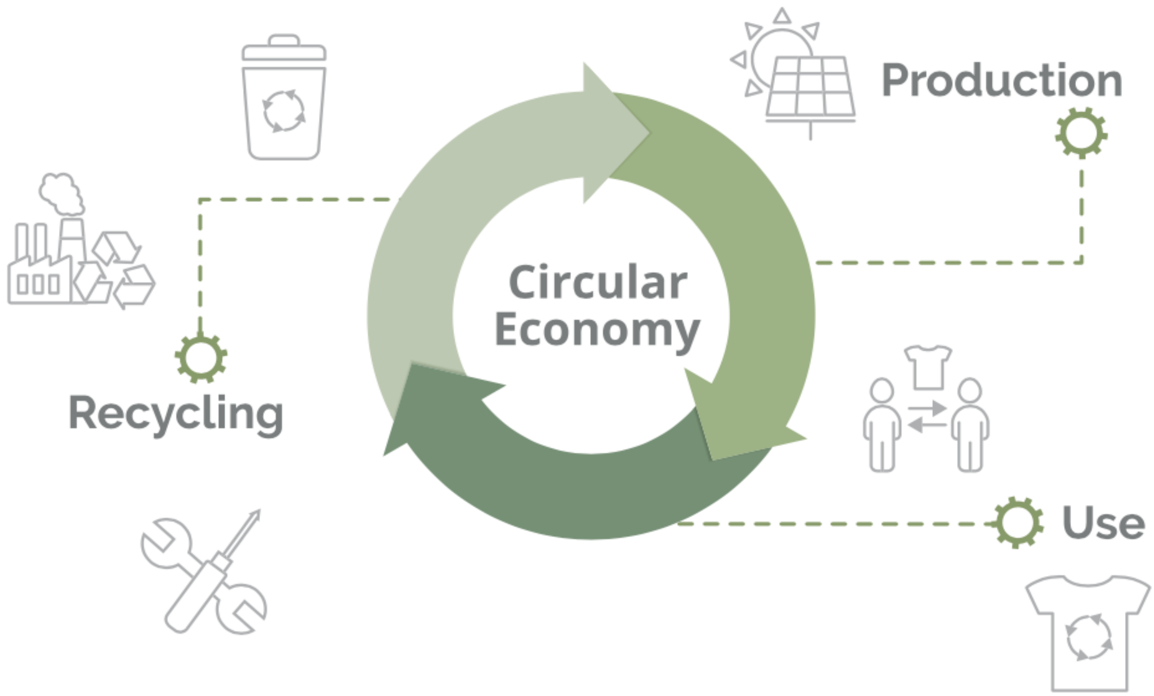

Arpita Bose, Associate Professor at Washington University in St. Louis, discusses the potential of microbial solutions in supporting sustainable and environmentally responsible alternatives to the traditional linear economy

Earth's climate is undergoing unprecedented changes due to human activities, primarily the emission of greenhouse gases. Widespread petroleum-based production of fuels and plastics releases large amounts of pollution, contributing to rising global temperatures, extreme weather events, and ecosystem disruptions.

Finding feasible solutions to the climate crisis is crucial to preserve essential resources and protect human and environmental health. Harnessing and strengthening the natural capabilities of microorganisms and microbial communities with synthetic biology will be the key to reducing and upcycling waste for a greener global economy.

Microbial communities and sustainability

Due to the many metabolic pathways within microbial communities, they can be utilized to recover biopolymers, metals, enzymes, and more, converting waste into value-added products. Recovery of essential resources allows wastewater treatment plants (WWTPs) to reach energy-neutral operation and reduce greenhouse gas emissions.

The microbial community in activated sludge is an integral part of WWTPs. During biological filtration, these microbes play a crucial role in nitrification, denitrification, and resource recovery, providing a cost-effective way to prevent eutrophication. Each microbe occupies a specialized role; some species oxidize ammonia to nitrite, and some oxidize nitrite to nitrate, preventing the buildup of ammonia and nitrite, which can be toxic to marine life.

Species such as Rhodopseudomonas palustris (TIE-1) have diverse metabolisms and can fix dinitrogen gas to ammonia while utilizing various carbon sources – even toxiccompounds from the chemical industry. Thus, purple non sulfur bacteria like TIE-1 can serve many roles in nature, contributing to numerous biogeochemical cycles and being ideal microbial chassis for the circular economy (reduce, reuse, and recycle).

Microbes can form consortia to produce critical industrial compounds. Researchers formed a triple microbe species to produce phenylpropene, aplant-based derivative with broad industrial applications such as fragrances and pharmaceuticals. The biosynthesis of phenylpropene presents a sustainable solution to the traditional harvesting of phenylpropane and can be an energy-neutral solution.

Microbial co-culture can also be used for low-cost production of biofuel. Lignocellulosic biomass (LCB) is an abundant and renewable plant resource and can be used as a starting material for biofuel production.

Traditionally, monocultures are implemented in biosynthesis. However, complex substrates such as LCB require multiple monocultures to convert LCB to biofuels fully. Thus, co-culture fermentation could be used to degrade LCB into biofuels all within one refinery, minimizing downstream purification and degradation costs. Microbes are optimal for LCB valorization as they can be scaled through genetic engineering advances. Microbes recycle waste biomass into value-added products, contributing to a more sustainable and circular approach to resource utilization.

Enhancing microbial metabolism with synthetic biology

The Bose lab employs a synthetic biology approach to investigate microorganisms capable of biofuel production, such as TIE-1. TIE-1 fixes CO2 to produce biofuels and bioplastics in a carbon-negative process using light. Previous work in the Bose lab has shown that deleting ancillary electron-consuming pathways increases product formation. Without electron-demanding biosynthetic pathways, electrons are free in greater numbers to fix CO2 to produce biofuels and bioplastics. A TIE-1 nitrogenase deletion mutant produced the biofuel n-butanol more efficiently than wild type.

TIE-1 also exhibits various routes of bioplastic synthesis. The Bose lab has studied polyhydroxybutyrate (PHB) synthesis under various photoautotrophic conditions. TIE-1 possesses putative PHB cycle genes that present promising candidates for bioengineering.

In addition to gene deletion to construct metabolically efficient mutants, current work in the Bose lab investigates the use of a phage integration system to incorporate genes capable of enhancing PHB production into the TIE-1 genome. Integration of RuBisCO into the TIE-1 genome and deletion of glycogen synthase improved PHB production under photoautotrophic growth with hydrogen and ammonia.

Whether by deletion or overexpression of relevant genes and pathways, genetic engineering of TIE-1 is a viable avenue for enhancing TIE-1's efficiency as a microbial chassis for sustainable bioproduction. In the context of the larger circular economy, efforts to optimize bioproduction in microbes represent progress towards scalable and feasible means of renewable production.

Progress towards a circular economy

Microbes play a central role in the development of a circular economy. Microbes have evolved powerful enzymatic and metabolic processes that can be used to make valuable commodities out of low-value starting materials like toxic waste from coal and oil production or environmental carbon dioxide. As described above, the purple non-sulfur bacterium, R. palustris TIE-1, will be a key organism for the future of carbon-negative production, leveraging renewable, low-cost inputs like carbon dioxide, light, electrons from electricity or iron as well as many other waste products to produce biofuels and bioplastics.

Recycling existing materials to minimize waste and negative production externalities is the foundation of striving towards a greener economy.

When microbes work together, they form microbial communities with immense potential for advancing environmental sustainability, whether through resource recovery, bioremediation, or the reduction of greenhouse gas emissions. Enhancing such native processes using genetic engineering approaches further amplifies the impact of microbial solutions and makes them possible on a global scale.

The circular economy is of extreme importance, especially in today's world, as it offers a sustainable and environmentally responsible alternative to the traditional linear economy. Rather than extracting, using, and ultimately discarding resources, the circular economy promotes longevity, conserving valuable resources and reducing the environmental impact of production and consumption. Building a circular economy can also serve as an economic opportunity.

Transitioning to a carbon-neutral sustainable system can create jobs, drive innovation, and reduce the long-term costs associated with climate-related damages. Developing microbial solutions to the climate crisis at their intersection with synthetic biology will reduce society's heavy reliance on fossil fuels while actively creating the groundwork for an economically resilient and green future.

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