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Can microbes save the planet?

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Genetic engineering and accelerated evolution of microbes aim to help climate change.

In April, a new research initiative from Jennifer Doudna and Jill Banfield was announced called "Engineering the Microbiome with CRISPR to Improve our Climate and Health." This project is the largest scientific project funded through The Audacious Project, receiving $70 million in donor funding. The initiative will focus on using precision genome editing on microbial communities, and a large focus of the project seems to be on environmental applications, such as reducing methane emissions from livestock. We have covered the potential of microbial engineering to benefit human health, but what is the real potential for engineering bacteria to benefit the sustainability of the planet?

Microbes from livestock, soils and landfill wastes produce methane and nitrogen oxides, which contribute to greenhouse gas emissions. The initiative from Doudna and Banfield will start by trying to decrease livestock methane production through inhibition of methane-producing bacteria in the guts of these ruminants. They are not the first to try to reduce methane being produced by cattle. Others have fed cattle methane inhibitors or seaweed and have developed devices to deliver bioactives that could inhibit methane over time within the stomach. Doudna and Banfield's proposal is different in that it would use CRISPR–Cas gene editing to directly edit the microbes within the stomach of young livestock, engineering them to produce less methane. This builds on their previous work in soil using DART (DNA-editing all-in-one RNA-guided CRISPR–Cas transposase) and ET-seq, which are methods for microbe engineering without the need for isolation of the species. In theory, an early treatment along these lines that would be active within the ruminant gut would lead to cattle permanently low in methane production.

Engineered microbes could have an even wider scope if used for environmental applications. For example, a recent *Nature* publication showed that an engineered strain of bacteria could produce chemicals sustainably, at scale and without the need for toxic solvents or gases. This would also reduce carbon emissions. Startups are making an impact in this area, too. Industrial Microbes is engineering microbes to work with natural gas, not sugars, which further reduces the cost requirement for scaling up, as natural gas is a cheaper starting material.

Other applications would be relevant for bioremediation, such as using engineered microbes for removing elements like uranium from groundwater.

Microbes could aid crop growth by replacing the synthetic nitrogen used as fertilizers, a process that is not only inefficient — much of the fertilizer gets washed away — but also pollutes waterways. Pivot Bio raised $430 million in 2021 to engineer soil bacteria to be more efficient at nitrogen fixing. Their pilot program in 2022 replaced synthetic nitrogen on a total of 293,000 hectares of corn in the United States, avoiding more than 80,000 metric tons of CO_2 emissions. This is only about 20% of the synthetic nitrogen needed for the crop and only a small fraction of the land used for growing corn, but the product is easy to use and provides the same, or more, crop biomass while absorbing 14% more nitrogen from the soil microbes compared to traditionally farmed corn, according to their press release.

Engineering microbes to tackle specific challenges is not always easy, so researchers have also been searching for microbes that already have unique capabilities, such as ones that turn food waste into energy or break down plastics. The potential to use microbes to biodegrade plastics was clear in 2016 when a *Science* paper found a bacterium that was able to eat a particular kind of plastic. Since then, the MIX-UP consortium, which includes 14 institutions in Europe and China, has aimed to use microbes to depolymerize plastics into their constituent monomers, and new plastics built using protein engineering could make this breakdown even more efficient. Recent work has found a microbe that can break down plastic at low temperatures (where previously these microbes had to work at high temperatures — a limitation for large-scale use).

As scientists learn about how newly discovered microbes respond to pollutants or plastics, it becomes possible to harness these pathways and engineer microbial communities at scale. We can also synthetically promote microbial evolution towards a specific endpoint, such as improving the efficiency at degrading a specific compound or production of a certain chemical.

The main technical issue with bringing any of these to the world is scalability. Pivot Bio's nitrogen fixing product has been applied to over 3 million acres of corn in the United States, but there are 90 million acres of corn in the United States alone, not to mention the land planted with other crops such as wheat. Scientists have found microbes that can degrade plastic — but it hasn't been possible to deploy them because they work slowly; they only degrade a small subset of all plastics; and the plastics are degraded into polymers, which isn't ideal. Additionally, the cost of using these products must be low enough that they'll be adopted by developing countries. Combining the two approaches — genetic engineering and accelerated evolution — with artificial intelligence to speed the effort will likely be the most effective way forward.

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