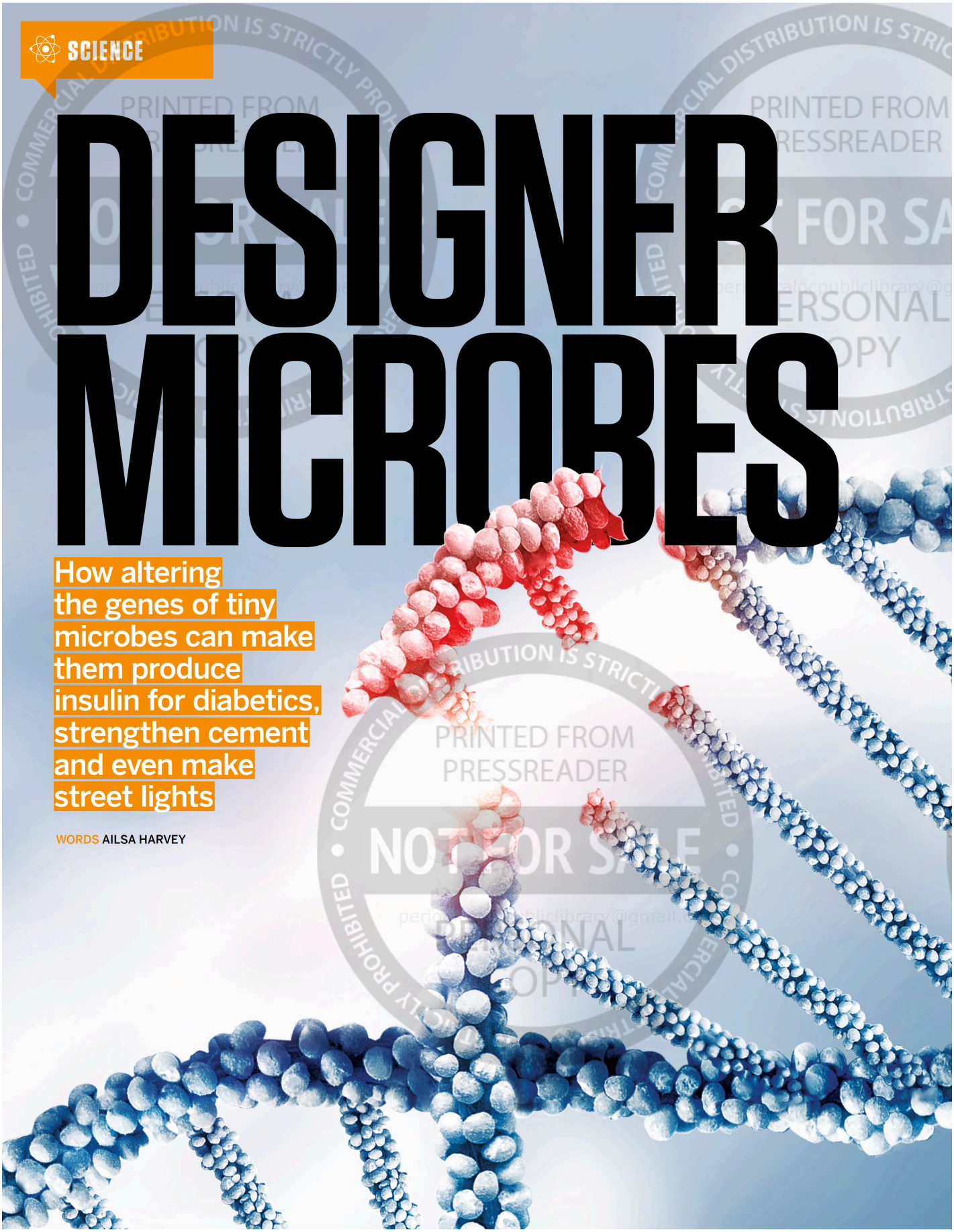
- Genetics / Diabetes

SCIENCE

DESIGNER MICROBES

How altering the genes of tiny microbes can make them produce insulin for diabetics, strengthen cement and even make street lights

WORDS AILSA HARVEY



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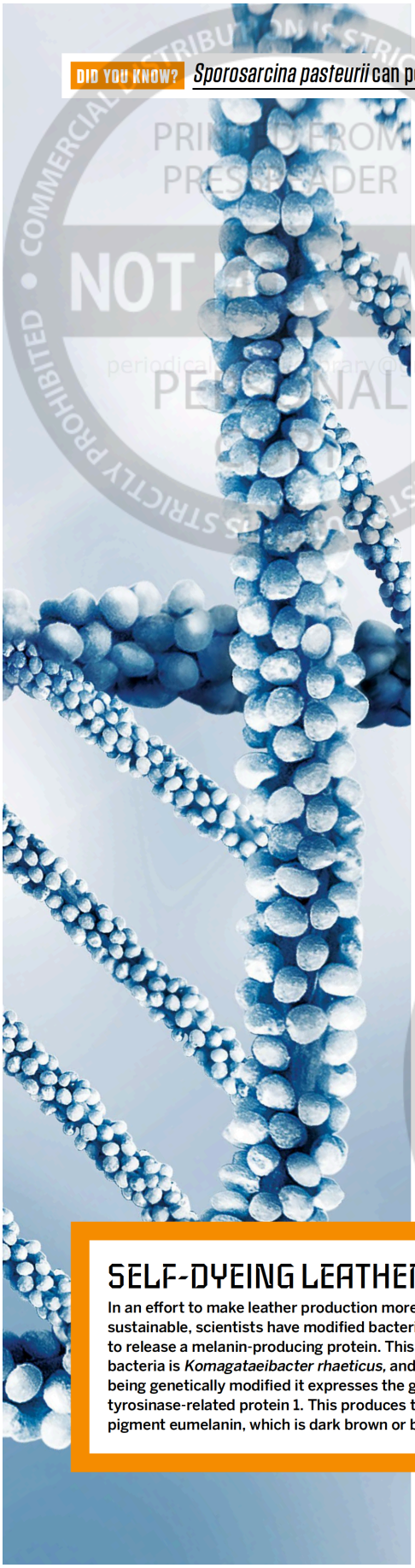


DID YOU KNOW? *Sporosarcina pasteurii* can potentially be used to solidify ground in earthquake-prone areas

Microbes are extremely versatile microscopic organisms that include bacteria and viruses. Unseen by the naked eye, they conduct chemical conversions on a tiny scale, keeping the planet alive by recycling nutrients, both causing and preventing disease, but generally playing a vital role in our living planet. Some thrive in extreme environments, while others are carried with us at all times. There are 39 trillion microbial cells covering your body, maintaining your immune system and daily processes like digestion.

As small organisms, microbes have simple genetic structures, making them easier for scientists to study. By gaining a more thorough understanding of what different sections of DNA control within a microbe, scientists can alter them to favour certain traits. These are genetically engineered microbes – dubbed 'designer microbes'. Microbes grow rapidly and multiply quickly. This enables desirable new genes to be mass produced. In many projects involving modified microbes, DNA from other organisms – including human DNA – can be incorporated into that of a microbe, like bacteria. When these bacteria reproduce, over time large volumes of human genetic material is generated. This can be used to produce medical treatments for people whose own cells don't naturally produce enough of a specific biological compound in the body.

Did you know?
Bacteria was the first genetically modified organism

The possibilities for designer microbes are expanding, and today research into their applications spans industries from medical and food to construction and textiles. Here are some of the most successful, inventive and futuristic applications of designer microbes.

BUILDER BACTERIA

Meet the bioengineered bacteria that have been called up for assistance in construction



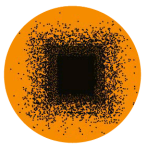
Escherichia coli
CEMENT STRENGTHENER
E. coli can be modified to make more of the enzymes responsible for converting calcium and carbonate ions into calcium carbonate. *E. coli* in concrete strengthens the mixture, as the calcium carbonate fills any gaps.



Bacillus subtilis
CONCRETE SELF-HEALER
This releases spores into concrete. If dry concrete cracks, moisture is able to seep through and reach dormant spores so they can germinate, producing calcium carbonate crystals that seal the cracks.



Sporosarcina pasteurii
BIOBRICK INSULATOR
S. pasteurii is genetically engineered to produce thermally insulating compounds. These fill gaps in concrete bricks, slowing heat loss from buildings.



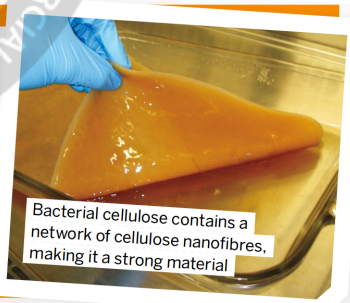
Synechococcus elongatus
BUILDING SITE DECOMPOSER
One application of this bacteria is for construction cleanup. It is engineered to improve its ability to degrade pollutants. For example, it can make proteins that bind to heavy metals at construction sites.



Myxococcus xanthus
BIOFILM LAYER
This forms complex biofilms over surfaces, but can be modified to improve its ability to cling to materials used in construction. The living layer makes materials more adhesive and helps prevent water damage by repelling water.

SELF-DYEING LEATHER

In an effort to make leather production more sustainable, scientists have modified bacteria to release a melanin-producing protein. This bacteria is *Komagataeibacter rhaeticus*, and after being genetically modified it expresses the gene tyrosinase-related protein 1. This produces the pigment eumelanin, which is dark brown or black in colour. This bacteria naturally produces cellulose, and along with its modified genes, this cellulose is leather-coloured, making it an ideal replacement for the animal skin material. This bacterial species produces the cellulose in strong, flexible and malleable sheets, ideal for textile purposes.



Bacterial cellulose contains a network of cellulose nanofibres, making it a strong material

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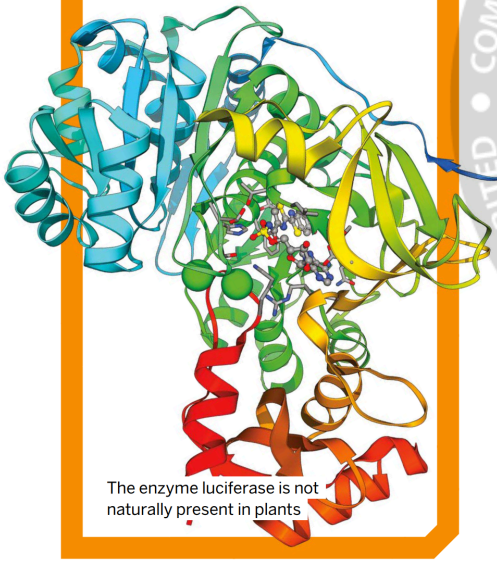
SCIENCE

PLANT STREET LIGHTS

£88,500 ($114,300) is spent per year per mile of street lighting used in the UK. These lights are expensive and use electricity throughout the night. However, new techniques are being explored to harness the natural bioluminescent qualities found in nature to produce a more natural variation of the common street light. Bacteria that contain an enzyme called luciferase naturally illuminate when a biochemical reaction takes place. Luciferase works to oxidise the substrate luciferin in the organism – a reaction that requires oxygen and causes the substrate to glow. Bacteria that glow do so to help themselves be dispersed: they can usually survive in the digestive tracts of animals, so attracting animals to them helps them be ingested and relocated.

Scientists have demonstrated that the genes responsible for producing luciferase and luciferin can be cut from bioluminescent bacteria and inserted into the genes of evergreen plants. The genes of the bacteria can be modified to alter their metabolic processes and sensory cues so that they produce more light and are consistently glowing when darkness falls. The plants that these genes are inserted into need to be strong to reduce the chance of damage, and also evergreen so that their leaves glow all year round. *Prunus lusitanica* is one such tree species being explored in research.



The enzyme luciferase is not naturally present in plants



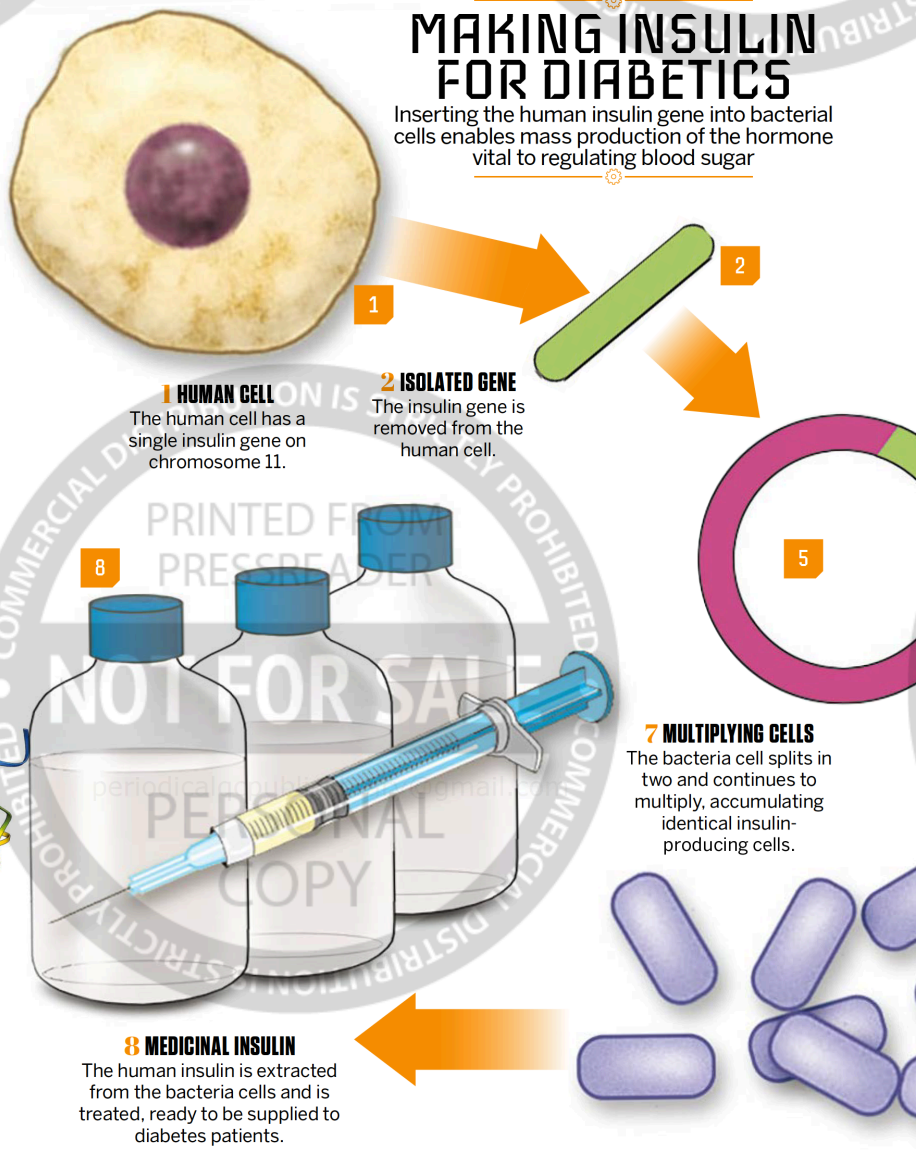
In US waters, there are over 150 oil spills a year

Did you know

200 million pe rely on insu therapy

MAKING INSULIN FOR DIABETICS

Inserting the human insulin gene into bacterial cells enables mass production of the hormone vital to regulating blood sugar



1 HUMAN CELL
The human cell has a single insulin gene on chromosome 11.

2 ISOLATED GENE
The insulin gene is removed from the human cell.

7 MULTIPLYING CELLS
The bacteria cell splits in two and continues to multiply, accumulating identical insulin-producing cells.

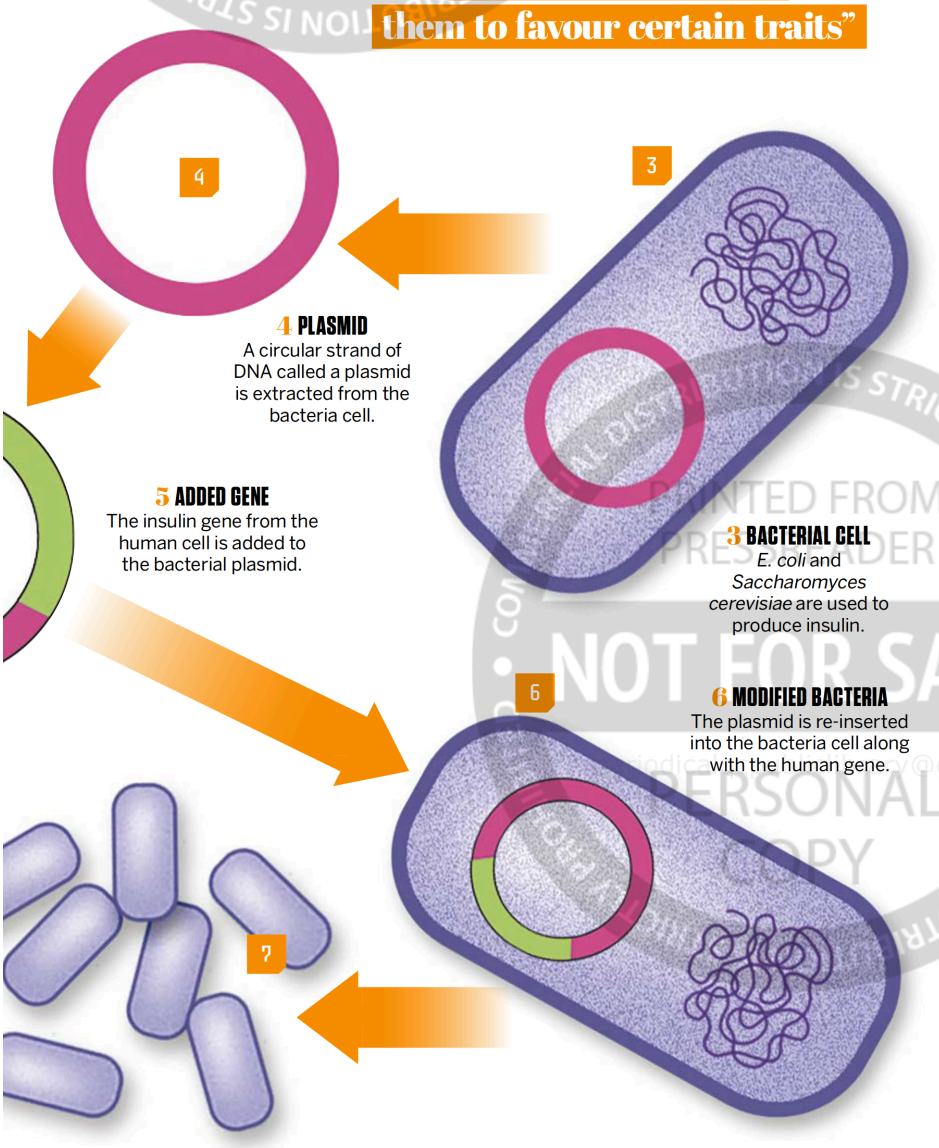
8 MEDICINAL INSULIN
The human insulin is extracted from the bacteria cells and is treated, ready to be supplied to diabetes patients.

DID YOU KNOW? Under optimal temperatures, *E. coli* can reproduce in as little as 20 minutes

OIL-SPILL EATERS

Around 9 million tonnes of oil enters the world's oceans each year, polluting marine environments. Many of the spills come from drilling rigs, tankers, storage facilities and pipelines. The main pollutants in these spills are hydrocarbons – compounds that contain hydrogen and carbon. Hydrocarbons remain in the water for many years, killing wildlife with their toxic chemicals and sinking to the seafloor to contaminate sediment. In addition, they are poisonous to humans. The minute microbe facing the mighty cleanup task in polluted seas is called *Pseudomonas putida*. The bacteria's plasmids are genetically modified to alter their metabolism, allowing them to break down and feed on the masses of complex hydrocarbons tainting the seas.

"Scientists can alter them to favour certain traits"



4 PLASMID
A circular strand of DNA called a plasmid is extracted from the bacteria cell.

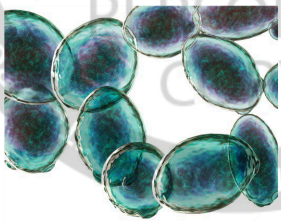
5 ADDED GENE
The insulin gene from the human cell is added to the bacterial plasmid.

3 BACTERIAL CELL
E. coli and *Saccharomyces cerevisiae* are used to produce insulin.

6 MODIFIED BACTERIA
The plasmid is re-inserted into the bacteria cell along with the human gene.

BOOSTING BIOFUEL

How editing yeast produces ethanol for an eco-friendly alternative at the fuel pump



1 ENGINEERING YEAST
During fermentation, yeast converts the sugar from food waste into ethanol. This yeast is genetically modified to increase its tolerance to the ethanol it produces.



2 FERMENTING FUEL
The enzymes in the yeast convert glucose into ethanol, carbon dioxide and water. This process requires controlled conditions, with no oxygen present and warm temperatures of 25 to 35 degrees Celsius.



3 ETHANOL EXTRACTION
The ethanol is extracted from the bioreactor to be added to gasoline fuels. Because the yeast was modified, higher concentrations of ethanol can be produced before the yeast stops working.

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SCIENCE

MAKING MILK WITHOUT COWS

How microbes could take over the dairy production line





Cow-free dairy company Opalia is already able to produce milk without input from any animal



1 COW DNA EXTRACTION

The genes responsible for producing dairy proteins and other milk components are isolated from a dairy cow's DNA.

2 MODIFYING MICROBES

The milk-producing genes are inserted precisely into microbial DNA so that the host can read the new instructions.

3 MICROBE MULTIPLICATION

The microbes reproduce. Each one is copied to contain the DNA instructions for making dairy proteins.

4 CELL SHRINKING

Adding sugar to the microbes causes them to expel proteins by osmotic shock. This is when water leaves the cells to balance substrate concentrations, causing the microbe to shrink.



5 PROTEIN COLLECTION

As a stress response to shrinkage, the microbe releases its contents, including the dairy proteins.

6 ENTERING THE FACTORY

The proteins are purified and separated from other cell debris. They are processed and mixed with the rest of the milk ingredients.



7 FINISHED PRODUCTS

The resulting dairy products have the same taste, texture and nutrients as those in cow's milk.

Did you know?

Saccharomyces cerevisiae isn't affected by microgravity



There are billions of microbes in a rice plant's microbiome

PIONEERING ENGINEERING

For the first time, research published at the beginning of 2024 shows that scientists have engineered the microbiome of a plant. The microbiome of an organism is the community of microbes covering it. In a plant, this protects it from disease and influences the nutrients available to it. When modifying a rice plant's microbiome, scientists increased the population of beneficial bacteria by editing one gene. Plants with this healthy new microbiome are less reliant on pesticides that are damaging to the environment. Within a complex molecule of the plant's cell walls, called lignin, the team of scientists found one gene that directly influences the microbiome. When they overexpressed the gene, the result was an influx of these beneficial microbes.

© Adrian Mann

DID YOU KNOW? *E. coli* is the most widely used microbe for genetic engineering

REDUCING BEER BITTERNESS

One of the processes in which genetically modified microbes are used to influence a product's taste is beer fermentation. Yeast is used to ferment sugars and turn them into alcohol for beverages. But the extra roles of these microbes can be controlled through changing their genes. As well as providing the alcohol content, yeast can be modified to express different enzymes depending on their roles. Some of the enzymes made by yeast break down bitter compounds in beer. Overexpressing the genes responsible for this enzyme's production will increase the number released into the beer batch, making a milder tang and creating new flavour profiles.



Yeast content influences a beer's taste and aroma

3D-PRINTED MEALS

NASA is working on ways astronauts could make a range of nutritional foods in space from yeast

1 SYNTHETIC CHROMOSOME

A synthetic chromosome is built from natural components that can be inserted into a cell. In this case, the genes contain instructions to produce a specific food's traits.

2 SENSORY ATTRIBUTES

Some of the genes that need modifying include those responsible for carbon assimilation, nutrient production, colour and flavour. Carbon assimilation ensures that compounds with a single carbon atom can be used by the yeast for its growth so waste gases in space can be used up.

3 YEAST

The new traits then need to be genetically engineered into *Saccharomyces cerevisiae*. Yeast is already edible and can double its biomass in 90 minutes.



© Nicholas Forder

4 METABOLIC REPROGRAMMING

The yeast has to be reprogrammed so that it can express appropriate traits from its genes.

5 INTELLIGENT BIOREACTOR

The yeast is stored in a bioreactor, which tweaks how traits such as colour and nutrients are expressed in the yeast for each food.

6 FOOD VISION

Data about the desired food is communicated to the bioreactor.

7 3D-PRINTED PRODUCT

Food compounds produced by the yeast are pumped out of the bioreactor in a liquid-like 'food ink' to be precisely printed onto a tray in the shape of well-known foods. In layers of varied composition, more complex foods can be recreated.

5 FACTS ROLES OF DESIGNER PROBIOTICS

1 DIGESTIVE AID
The probiotic *Lactobacillus acidophilus* can be genetically modified to produce the enzyme lactase. The enzyme helps break down lactose into glucose and galactose in lactose-intolerant people.

2 ALLERGY TARGETING
When *Bifidobacterium bifidum* is edited, the probiotic makes anti-inflammatory proteins called cytokines that prevent allergic reactions.

3 IMMUNE SUPPORT
Lactobacillus rhamnosus can be genetically engineered to produce beta-defensin 2, a protective molecule that assists the body in fighting germs.

4 REDUCING INFLAMMATION
The gut microbe *Faecalibacterium prausnitzii* can be modified to increase the production of anti-inflammatory fatty acids in the gut.

5 VITAMIN PRODUCTION
When its genes are edited, *Lactobacillus reuteri* produces vitamin B12 in the gut, an essential vitamin for red blood cell production and nerve health.

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