HOW ENZYMES TURN BIOLOGY INTO TECHNOLOGY

Scientists are using enzymes from bacteria to power greener, cleaner and more sustainable technology.

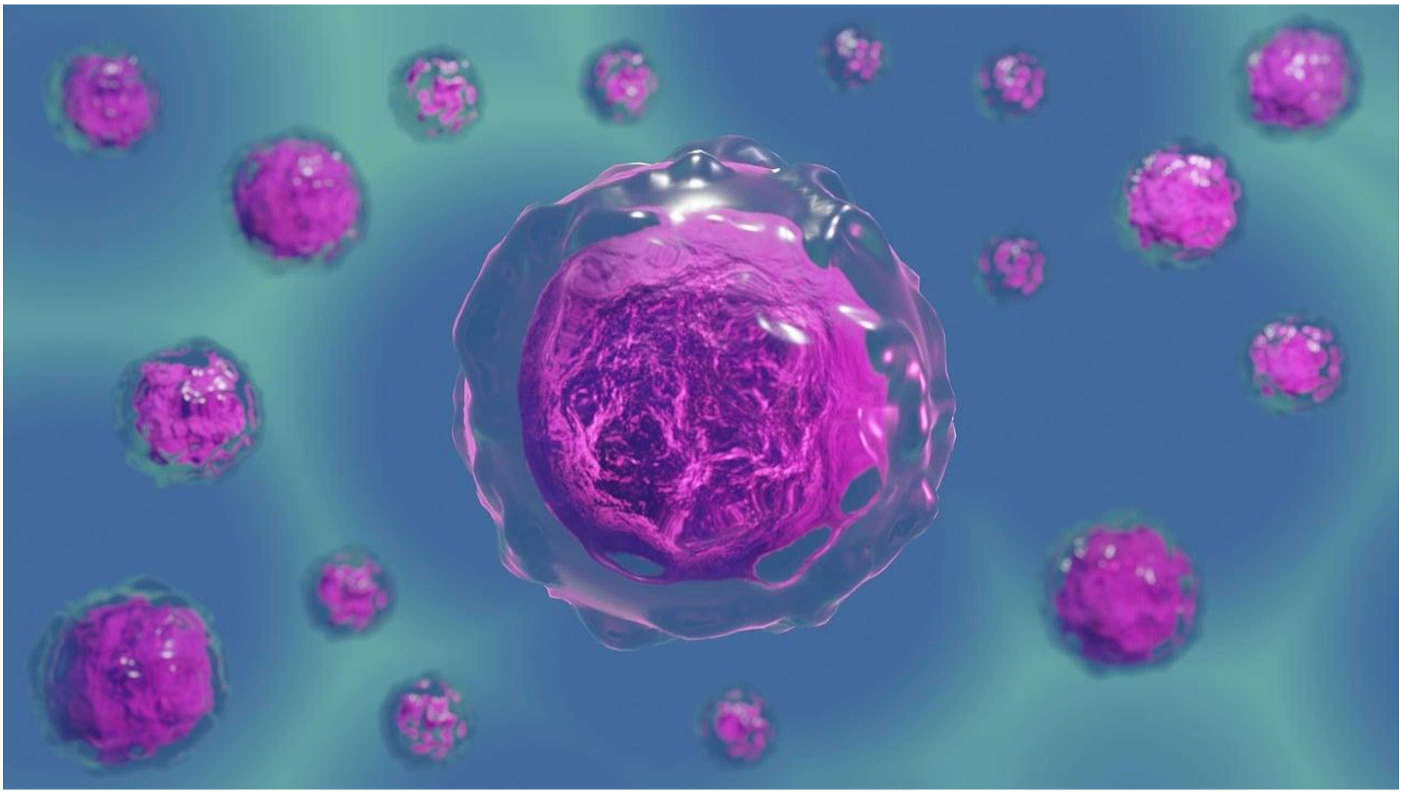
Biotechnology is the combination of biology and technology. Biotechnology takes advantage of the reactions and processes that occur in cells to develop new technologies and products that help improve our health, our daily lives and the impact that we have on the planet. In this article, we will look at how biotechnology can help us recycle waste, remove pollution and produce essential nutrients.

Scientists often take biology from microorganisms, such as bacteria, to develop biotechnology. Humans have used the biological processes of microorganisms for a long time. Food such as bread and cheese is made using microorganisms and has been produced for more than 6,000 years.

Today's biotechnology often, but not always, uses recombinant DNA technology. This form of genetic engineering involves transferring fragments of DNA from one organism into another organism. The resulting genetically engineered organism will then contain recombinant DNA and will be a genetically modified organism (GMO).

The key parts of the bacteria that scientists use in biotechnology are enzymes. In biotechnology, enzymes are used to catalyse reactions that would be difficult or problematic to do using chemicals.

Enzymes are key workers



Enzymes are proteins that act as biological catalysts. Enzymes work by binding substrate molecules to the active site. The active site holds the substrate in place so that the chemical reactions can take place more easily. Enzymes are essential for almost all biochemical reactions in living organisms.

Enzymes are really useful in biotechnology for several reasons. First, there are lots of them, so there are thousands of different types of enzymes to choose from. Second, each enzyme is very picky about which substrate it acts on. One enzyme usually catalyses only one type of reaction due to the structure of the active site. This means that an enzyme produces only the desired product – such as a type of cheese. Enzymes are also super-efficient and work at ambient temperatures and pH values. This makes them very environmentally friendly.

Let's look at some examples of bacterial enzymes in action in biotechnology.

Bacterial enzymes as recyclers

The phones, laptops and other electronic devices that we rely on every day contain metallic elements that exist on Earth in tiny amounts. Examples of elements found in a mobile phone include gold, silver, copper, platinum and palladium. There's a lot of metal in electronic devices. It's estimated that there are 300 times as much gold in one tonne of iPhones than in one tonne of gold ore.

The processes needed to mine and refine these metals are bad for both the people who mine them and the environment. And one day we could run out of these metals if they are not recycled. I bet we all have an old unused phone or laptop sitting in a drawer or cupboard at home. Old unwanted electronic devices are called e-waste.

It's estimated that in 2021 all the countries in the world combined generated 52.2 million metric tonnes of e-waste. That's 5255 Eiffel towers. And the effect of COVID-19 lockdowns where we had to learn and work from home led to a boom in tech sales that added to the e-waste problem.

Recycling e-waste currently involves shipping it overseas to low-income countries, sorting the components by hand and then a process known as smelting. Smelting uses intense heat and chemical reactions to melt and extract metals. It is a really energy-intensive process that is not environmentally friendly.

We know that many enzymes found in bacteria need metals to work correctly. Bacteria use metals as part of a metabolic process to obtain nutrients or energy. To get the metals they need to survive, bacteria can take up metals from their surrounding environment.

A species of bacteria was discovered living in soil and sediments in Queensland, Australia. These bacteria take natural traces of gold found in the rocks and turn the gold into tiny nuggets to obtain metabolic energy.

So scientists wondered if they could exploit this bacterium that takes metal from its environment to help us recycle e-waste.

Scientists studied the bacterium in more detail in the lab using transmission electron microscopy and scanning electron microscopy. They investigated how gold gets into the bacterium, what structures it goes to once it is inside the bacterium, and how the bacterium responds genetically and biochemically to the gold. Such experiments showed that this bacteria had the right properties to be used to recycle the gold.

The next step was to test the bacteria on e-waste. To do this, the e-waste is first ground into a sand-like powder. Then chemicals are added to remove common and inexpensive metals for recycling, leaving behind gold and other precious metals. The remaining precious metals are dissolved, and bacteria are then added to the soup-like liquid. The bacteria find and ‘eat’ the gold. The bacteria get heavier as they take up the gold, so bacteria can be separated from the soup using a centrifuge. The gold contained within the bacteria is then extracted.

Using this method it is possible to extract about 150g of gold (about the weight of a hamster) from 1 tonne of e-waste (about the weight of a giraffe).

Scientists are also researching bacteria that can recycle other precious metals from e-waste. It’s hoped that one day there will be recycling plants for e-waste in every major city in the world so we can recycle our e-waste locally. This will avoid the environmental impact of shipping waste to other countries.

The above example relies on bacteria that are not genetically modified. The species of bacteria used are very good at recycling gold, and it’s easy to bring both the bacteria and the e-waste to the same geographical location. Let’s next look at an example of biotechnology that uses genetic engineering.

Bacterial enzymes as cleaners

An explosive called RDX, which stands for Royal Demolition Explosive, is used for training the military. It’s found on military training ranges, minefields and in places where military waste is dumped.

Explosives are serious environmental pollutants. RDX sits in the soil. It doesn't break down and is toxic to organisms that live in the soil. It can move easily from the soil into the underground water that forms part of the water cycle. RDX can contaminate drinking water supplies and it is toxic to humans. So techniques to clean up RDX are urgently needed.

Traditional methods, such as landfill or burning, cannot be used because large areas of land are contaminated with RDX. So scientists looked for bacteria that can grow on soil contaminated with RDX. A bacterium was found that degrades RDX because the bacterium uses RDX as a nitrogen source to enable it to grow.

But it is not possible to take the polluted land to the bugs – there is way too much of it. As an example, it's estimated that in the USA, an area the size of Iceland is contaminated with RDX. And it is not possible to grow the bacteria on the polluted sites as the growth conditions are not optimal.

Scientists identified the genes that encode the enzymes that break down RDX. They then used genetic engineering involving plasmids to put the genes into something that grows easily in soil – plants!

The plant they used is called Arabidopsis and is used a lot in research. Although genetically modified Arabidopsis degraded RDX, there was one big problem. Arabidopsis is a type of cress – like the cress we eat in salads – that would be turned to mush by military equipment such as tanks before it could do its job.

So they had to try a plant that was stronger and more robust. Switchgrass turned out to be ideal. They expressed the genes in this plant and tested its ability to degrade RDX in plants grown in greenhouses.

Next, scientists tested the genetically modified switchgrass in field trials. The field trial showed that genetically modified switchgrass detoxifies RDX on a real-life military range. So the next step is for its more widespread use. It's hoped that this will be a cost-effective and sustainable method for preventing RDX from contaminating the water cycle.

Let's next look at an example of how a genetically modified organism can be used to make an essential nutrient.

Bacteria and their enzymes as factories

Vitamin B12 is a nutrient that is needed by every single cell in our body to function properly. Our nervous system needs vitamin B12 to make myelin and to replicate and repair our DNA. A lack of B12 in the diet causes a disease called macrocytic anaemia. People with this condition have larger but fewer red blood cells, and their red blood cells have low levels of haemoglobin. People with macrocytic anaemia get very tired and their immune system doesn't function properly.

We must obtain vitamin B12 through our diet. Good sources of B12 are red and white meat, fish, and seafood. Eggs and milk contain some B12. You might have noticed that these B12 sources are animal products.

B12 is the only nutrient in the human diet that must come from animal products. People who eat a vegetarian diet often have low levels of B12. People who follow a vegan diet must supplement their diet with B12. But if they don't eat animal products, where does this B12 come from?

The B12 found in animal products is actually made by bacteria that live in the animals. So the good news is that it is possible to grow these bacteria outside the animals using fermentation. The B12 that is made in this way is then sold in shops as a supplement, or added to vegan products such as soya milk.

The bad news is that making B12 this way takes a long time, and the process is complicated, expensive and doesn't produce much B12. Yet the demand for B12 is increasing due to the rise of vegetarian and vegan diets. This makes B12 expensive, which is a problem for people in low-income countries such as India who traditionally follow a vegetarian diet.

So we need to find a way of making B12 more efficiently and cheaper. Scientists aim to use genetic engineering to take the B12 production process from types of bacteria that can make B12, albeit not very well, and put the genes into a different type of bacterium that is well-understood, and cheap and easy to grow.

But moving the B12 production pathway is tricky because vitamin B12 is very big and has the most complicated chemical structure of all vitamins. It is made from about 30 molecular components and involves over 10 chemical reactions. This means that lots of genes need to be genetically engineered.

First, scientists took genes from a Salmonella bacterium. In this organism, most of the B12 genes form a string with one gene after the other on the DNA. This feature enabled scientists to take most of the genes from the B12 pathway from Salmonella and put them in Escherichia coli. E. coli was then able to produce vitamin B12 at a higher level than Salmonella. But the amount of B12 produced was still too low to make enough for everyone who needs this vitamin.

So an alternative bacterium was used to obtain the B12 genes. The chosen bacterium produces B12 aerobically. This feature means it is easier to grow in large quantities. At first, all the B12 genes were cloned individually, the signals for enzyme synthesis were optimised and then the genes were cloned together using plasmids. But these plasmids proved unstable, meaning that the B12 genes were not properly expressed in E. coli. So instead of using plasmids, scientists used new DNA technologies that directly manipulate the chromosome — such as CRISPR — to carry the B12 genes to E. coli.

Using new DNA technologies, all the genetic information for B12 synthesis has been transferred to E. coli. Getting E. coli to make B12 has taken over 20 years! But the process is not optimal. Scientists still need to identify all the bottlenecks in the synthesis and fix them. But this research is underway, and it's hoped that soon E. coli can be used as a miniature B12 factory.

These are just three examples of many ways that bacterial enzymes are used in biotechnology to help make the world around us a better place.

Terms explained:

Gold ore – gold contained in natural rocks
Switchgrass – a type of grass that is tough and stands up to a variety of harsh conditions
Field trial – a test of something under the conditions in which it will be used in real life
CRISPR (pronounced "crisper") – a technique that enables researchers to easily alter DNA sequences; it uses an enzyme that acts like a pair of molecular scissors to precisely cut DNA
The terms in blue in the text relate to the A-level school syllabus for 16–18-year-olds

Charlotte Harrison