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HORIZONS

Biotechnology

What is biotechnology and why is it important?

Hiding in plain sight – where biotechnology is involved

Biotechnology in Germany and elsewhere

What needs to happen now?

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NATIONAL ACADEMY OF SCIENCE AND ENGINEERING

acatech HORIZONS support the public debate on how we can apply and shape new technologies. Each issue is dedicated to a technology field that is economically relevant, opens up new horizons and enables social change. acatech HORIZONS examine these technology fields in a sound and illustrative manner. On the basis of current research, they explain the facts, social, economic and political aspects, as well as options for the future.

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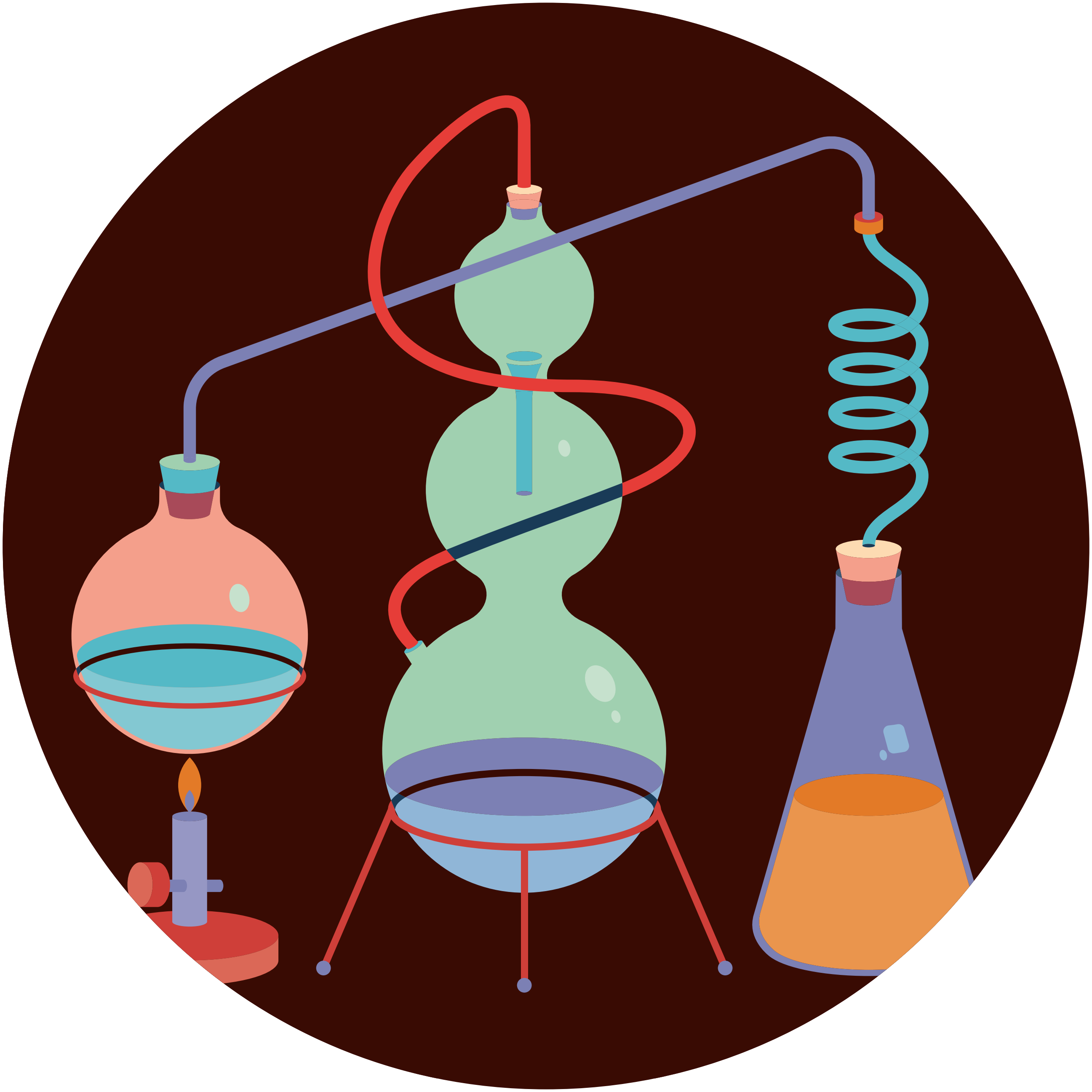


Contents

Nine key messages

1. Biotechnology means learning from nature and using these insights and methods to meet our daily needs today and tomorrow, enhance our well-being and promote good health.

2. While we are often unaware of it, biotechnological know-how is hidden away in countless everyday products, from bread, yoghurt, cheese, beer and wine to laundry detergents and personal care products.

3. Biotechnology has enabled many groundbreaking innovations, for instance antibiotics for combating serious bacterial infectious diseases, insulin for treating diabetes and coronavirus vaccines for bringing a global pandemic under control.

4. Genetic engineering, one of the most important tools in the biotechnological toolbox, is used as standard, for example to assist with the development of effective drugs in medicine and with plant research.

5. In the future, biotechnology will be the only way to deal with many of the substantial challenges which humanity is facing, especially in relation to health, nutrition, as well as environmental and climate protection.

6. Biotechnology plays an important role in transforming Europe's economic system towards a sustainable, circular economy.

7. Biotechnology is a cross-sectional science, involving a large number of disciplines. It is a key technology that opens up a wide variety of applications with novel solutions.

8. The development of biotechnology has been rapid, not least thanks to digitalisation and AI in data analysis, and also to the insights gained from genome sequencing.

9. In biotechnology, the path from research to application (in the form of products or processes) is often high-risk, protracted and capital-intensive. Biotechnological innovations, therefore, require greater research and growth funding to overcome these limiting factors and ultimately speed up progress.

1 What is biotechnology and why is it important?

Biology and technology – how do they fit together? We copy the way enzymes, cells and bacteria function from nature, and convert our observations into technological applications. Chapter 1 explains what biotechnology is and shows that it already is a substantial part of our lives.

Have you ever baked your own bread? Removed a stain from your trousers with gall soap or accidentally had milk go sour in the fridge? Congratulations! You have already, with variable success, put biotechnology to use. The above examples may sound mundane but are good illustrations of what the somewhat strange term biotechnology means; that is above all, manufacturing a product using **microorganisms such as bacteria, fungi or enzymes** and appropriate technology. Biotechnology is not limited to these simple examples – it has many applications and great potential, as the following chapters will show.

"Biotechnology is a way of turning nature's toolbox into technological solutions."*

Billions of years of evolution have allowed nature to optimise processes, for instance the production of specific molecules in plants or the conversion of substances by bacteria. In biotechnology, we **learn from nature** and use these discoveries to achieve progress in meeting our daily needs in regard to health and well-being. We observe how specific processes function in nature and transfer our insights to scientific methods and industrial production processes. In principle, we combine biological knowledge and industrial applications with one another to develop effective biotechnological tools. Biotechnology is a **broad field,** involving collaboration between specialists from numerous scientific disciplines, such as biology, chemistry, physics, process engineering, medicine, materials science, computer science and many others. This **interdisciplinary collaboration,** i.e., the involvement of many different specialities, offers enormous potential for new applications and products. The illustration on page 8 provides an overview of the history of biotechnology. The timeline shows how biotechnology came about somewhat by chance centuries ago and over the course of time has become a highly developed technology thanks to new scientific findings. For instance, it was put to good use recently in the speedy development of a coronavirus vaccine. The technical terms used in this publication can be looked up in the **glossary** on page 46.

"Biotechnology is an interdisciplinary science, which brings together various specialist fields and lives and breathes cooperation."

Biotechnology enables bioeconomy

The term bioeconomy describes an economic system which is based on renewable natural resources such as wood or plants, but also makes use of organic residues, bacteria, fungi or algae. With a bioeconomy the objective is to move completely away from fossil resources (oil, natural gas, coal), with a view to achieving climate targets. However, at the moment we are dependent on fossil resources, and not only for energy production. Oil is also used in many everyday products such as hair care products, shoes and construction materials. Through biological knowledge and innovation, biotechnology will enable the changeover to a sustainable, circular economy based on biogenic natural resources.

At the beginning of 2020, the German Federal government published its **National Bioeconomy Strategy.** This illustrates how we can simultaneously conserve limited resources, live sustainably and safeguard general prosperity. Achieving this will above all mean investing in **digitalisation, biotechnology and genetic engineering.**[1]

* Some selected key ideas expressed by interviewees are included in the text as anonymised quotes.

A brief history of biotechnology

Even in prehistoric times, humans used biotechnology, but without understanding what exactly lays behind it. Over the course of time, biotechnology became increasingly sophisticated, and is now contributing more than ever to progress in medicine, agriculture and food production. Biotechnology is wide ranging, but all applications have one thing in common: humans copy processes perfected by nature and then use them in technological applications to ensure that basic needs are met, especially in the areas of nutrition and health.

In ancient Egypt, wine and beer are already being produced, as well as **fermented foodstuffs** such as cheese and yoghurt.

In South America, in what is now Peru, humans are optimising potato varieties by selection and cultivation and so laying the foundations for **plant breeding.**

3rd millennium BCE

A patent is filed for the use of enzymes in laundry detergents, to break up the fat, protein and starch molecules in laundry stains.

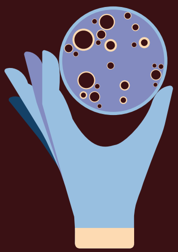
1915

Karl Ereky uses the **term biotechnology** for the first time in his book „Biotechnologie der Fleisch-, Fett- und Milcherzeugung im landwirtschaftlichen Großbetriebe" (eng. Biotechnology of Meat, Fat and Milk Production on Large Farms). The aim of his publication is to use biotechnology to improve food production in the "hungry years" following World War I.

1919

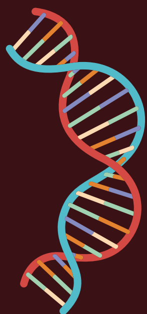
By chance, Alexander Fleming discovers **penicillin,** by inadvertently leaving a bacterial culture standing around. The world's first **antibiotic!** Biotechnological mass production of penicillin begins in 1942 and saves countless human lives over the remaining war years and beyond.

1928



James Watson and Francis Crick decode the **structure of DNA** – so firing the starting shot for genetic engineering.

1953



Stanley N. Cohen's and Herbert W. Boyer's work on restriction enzymes, that can be used to cut DNA into fragments, forms the basis of **genetic engineering.**

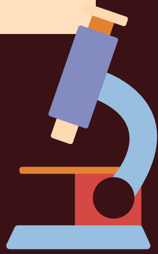
1973

Kary Mullis develops a method for **amplifying (multiplying) DNA.** The method is called PCR.

1983

Technical terms and their abbreviations can be found in the Glossary on page 46.

Antoni van Leeuwenhoek and Robert Hooke invent and perfect the **microscope.** Using it, they gain initial insights into **bacteria** and **cells.**



17th century

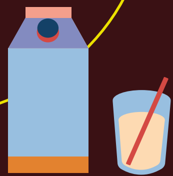
The physician Edward Jenner administers the **first vaccination.** He observes the smallpox epidemic and notes a connection between the variant of the virus that affects humans and the harmless cowpox. The name vaccine, therefore, comes from the Latin word for cow (vacca).

1796

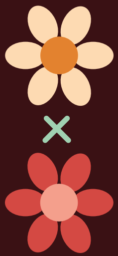
Charles Darwin develops his **theory of evolution,** which is based on mutations and natural selection.

1859

Louis Pasteur invents **pasteurisation,** in which foodstuffs such as milk are heated for a short time in order to kill off any microbes they contain and ensure a longer storage life.



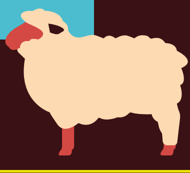
1864



Gregor Mendel is the first to formulate the rules for inheritance of genetic traits. **Mendel's Laws** still play a role in plant and animal breeding.

1865

Dolly the sheep is **cloned** from the mammary gland cells of a living ewe. Dolly is a "copy" of the other sheep.

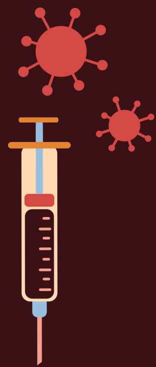


1996

Jennifer A. Doudna and Emmanuelle Charpentier develop the **CRISPR/Cas genome editing** method. This allows precisely targeted addition or removal of a gene from DNA.

2012

The COVID pandemic has seen the development of various **coronavirus vaccines** around the world, some of which are novel mRNA vaccines.

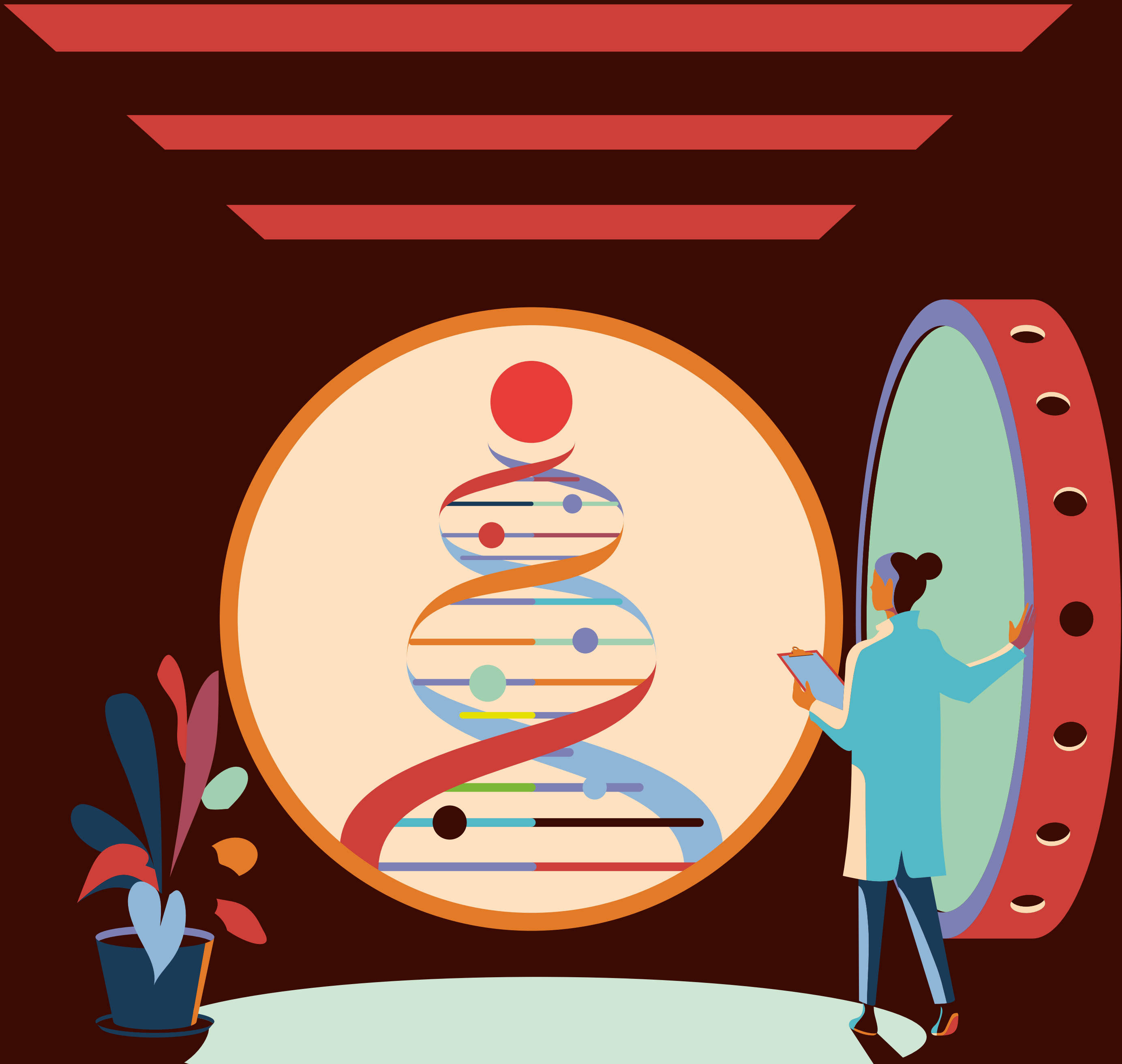


2021

Source: own presentation after Fonds der Chemischen Industrie (2009)[2] and BIO Deutschland (2019)[3]

2 Hiding in plain sight – where biotechnology is involved

Biotechnology is everywhere – often without us realising. It ensures our survival and safeguards our wellbeing in many fields of life. The following chapter is an overview of where biotechnology can be found, from everyday products through foodstuffs to medicines.

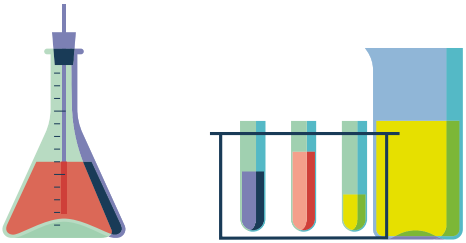


2.1 Biotechnology in daily life

Did you realise that in almost every room of your home there will be at least one product that has been produced using biotechnological methods? Biotechnology is our constant companion and our daily life is now unthinkable without it. It makes our wastewater clean, lends sweet foods their delicate flavour and helps in the production of medicines. Humans have been using biotechnological processes for thousands of years. It is therefore unsurprising that many products currently in daily use are based on biotechnological methods. However, a large part of the general public is unaware of this.[a] The following examples of **biotechnological products used in daily life** are just a small fraction of the plethora of biotechnological applications

The colours of biotechnology

In Germany, the various applications of biotechnology are distinguished by colour: red denotes biotechnology in medicine, white industrial biotechnology (e.g. due to the production of enzymes for white laundry detergents), green for biotechnology concerning plants, blue for maritime biotechnology and yellow for insect or food technology. Since the assignment of colours is not a generally applicable definition and moreover is completely different in some neighbouring EU states, this publication focuses on fields of application. The illustration on page 14 shows where we encounter biotechnology in daily life.



a According to a representative study, 11 per cent of Germans have never heard the term "biotechnology". 51 per cent are aware of the term but have never looked into it any more closely.[4]

Bacteria for digesting plastics or extracting gold

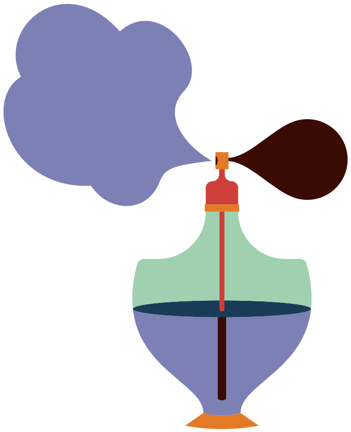
Plastic waste in the world's oceans and mountains of electrical waste are endangering humans and nature – so what can we do about it? Novel biotechnological recycling strategies are being applied in various ways to reduce waste and thus protect our environment. On the one hand, biotechnology offers sustainable alternatives to plastic packaging made from renewable raw materials. For instance, research is being carried out into packaging which can be completely broken down by naturally occurring bacteria. On the other hand, biotechnology is constantly discovering new biological processes for recycling existing waste such as electrical waste.

One method that can be mentioned here uses bacteria from mines to extract valuable metals such as gold or rare earth metals from waste and residue streams. The microorganisms from mines extract the desired substances in various ways: some leach out the desired metals to create solutions which are then recovered, while others have "capture molecules" on their surface which accumulate certain metals, like in a template into which only certain molecular shapes will fit. This also enables recovery of metals from waste incineration, in order to tackle the ever-growing mountains of electrical waste. More details can be found in the illustrations in **acatech HORIZONS Urban Mining:** "Bio-recycling: bacteria breaking down plastics" and "A look inside an old smartphone: turning waste into gold."[5]

Biotechnology contributes directly or indirectly to several of the United Nations' Sustainable Development Goals.

Perfume from a bioreactor

Biotechnology has also long had a place in our cosmetics cabinets. The fragrances found in cosmetics and personal care products are these days often produced chemically, as isolating them from natural sources is no longer environmentally acceptable or affordable. Sandalwood scent, for example, is traditionally extracted from trees that are at least 15 years old and that have to be felled for the substance to be isolated. In the past, sandalwood forests in India and on Hawaii were cleared almost to the point of eradication. To prevent such overexploitation, the biotechnological industry mimics the metabolic processes of plants using enzymes and bacteria in order to produce a nature-identical sandalwood scent. This sustainable mode of production thus allows the production of a chemically equivalent sandalwood scent while simultaneously conserving nature. Many other perfumes and fragrances can now likewise be produced biotechnologically.[2, 6]

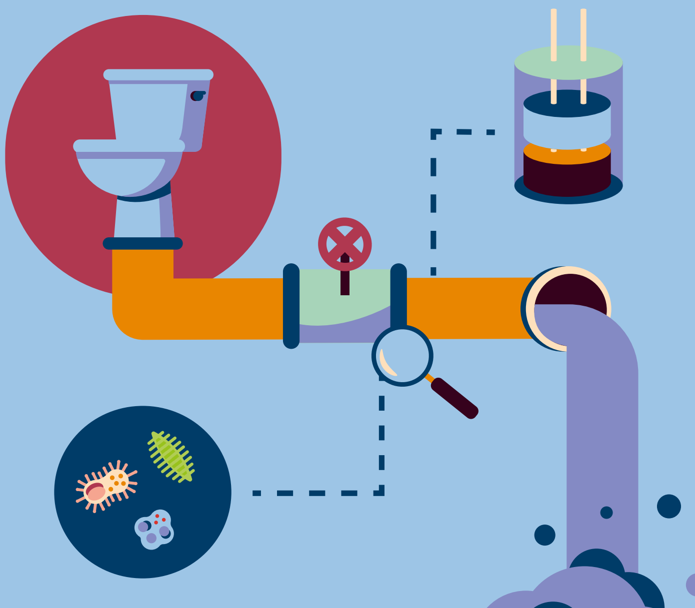


Biotechnology in daily life

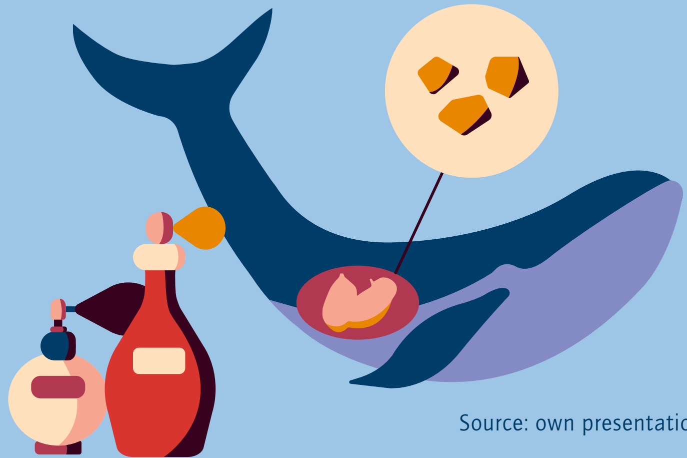
Biotechnology is playing an ever greater role and our daily life is now unthinkable without it. In addition, it contributes to environmental protection, health and greater sustainability.

Cosmetics
Anti-ageing creams and skin care products would be inconceivable without biotechnology. Many creams contain the coenzyme ubiquinol, also known as coenzyme Q10. This coenzyme acts as an antioxidant, keeping our cells healthy. It previously had to be recovered from ox hearts, a troublesome and costly procedure. Today it is produced in a laboratory from yeast ubiquinol. The end result is a Q10 which is identical to that present in animal organs.

Sewage treatment plants
Our wastewater from kitchens, bathrooms and toilets is cleaned using microorganisms such as bacteria or fungi in the biological phase, during which they break down the organic compounds in clarifier sludge.

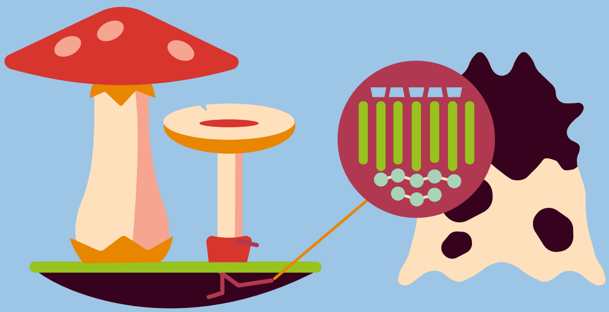


Perfume ingredient
Perfume also involves biotechnological know-how. The perfume ingredient ambergris is developed from ambrein, a metabolic product from the digestive residues of the sperm whale. The fragrance is very sought-after and costs many thousands of euro per kilogram! Researchers have succeeded in producing the ambergris fragrance synthetically using genetically modified yeast cells. This reaction, which in nature takes place as a result of seawater, air and sun, thus also works in the laboratory.

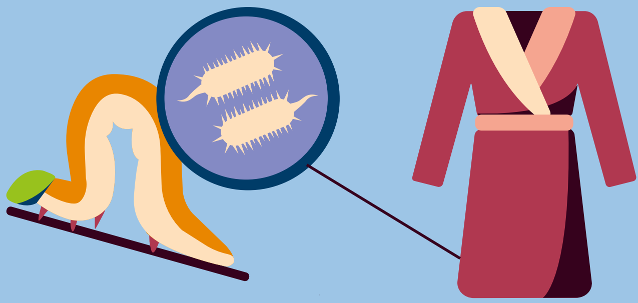


Source: own presentation

Leather
Leather is generally produced from animal skin or synthetic plastics. These production methods are resource-intensive and often not very sustainable. Fungi can provide a solution here: mycelium (thread-like fungal cells) can be readily cultivated on a large scale in bioreactors and further processed into a "fungal leather" to rival conventional leather.

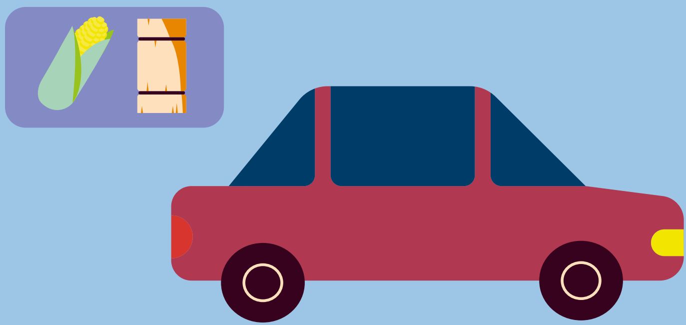


Silk from bacteria
Traditional silk is produced by silkworms and is therefore labour-intensive and costly to manufacture. Today, however, it is possible to produce spider silk on a large scale using genetically modified *E. coli* bacteria. These silk threads are even stronger than traditional spider silk and are used for textiles. Bacterial silk is also used in medicine for implants.



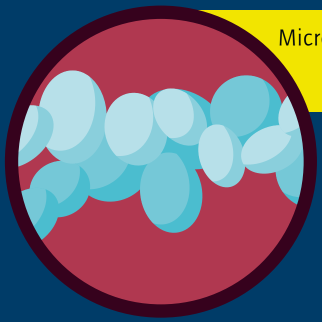
Laundry detergents
In the 1970s, biotechnology revolutionised laundry washing. Laundry detergents contain enzymes, which are substances that speed up chemical reactions. For instance, lipases break up fat molecules from oil stains, while proteases remove blood stains. As a result, less water and laundry detergent is needed and washing can be carried out at lower temperatures, making energy savings of up to fifty per cent per washing cycle!

Biofuels
The latest generation of biofuels is manufactured from straw rather than maize or sugar cane. Straw is a harvest residue and therefore does not compete with food production. Sugar building blocks from the straw are fermented by genetically modified yeast cells to yield bioethanol. This biotechnological production method is still being investigated, but it is thought to be a possible alternative to fossil fuels.



Biotechnology in the bioreactor

Biotechnological production takes place in "bioreactors" (also known as "fermenters"). These are tanks in which perfect conditions prevail for microorganisms such as bacteria, yeasts and fungi, which go on to produce the desired substances. In a research laboratory, these bioreactors are small, with volumes ranging from a few millilitres to a couple of litres; in large industrial plants, on the other hand, the tanks are huge, with capacities of up to one million litres. The foodstuffs sector as well as pharmaceuticals and cosmetics industries use bioreactors.



Microscopic helpers: yeast cells

Sugar

↓

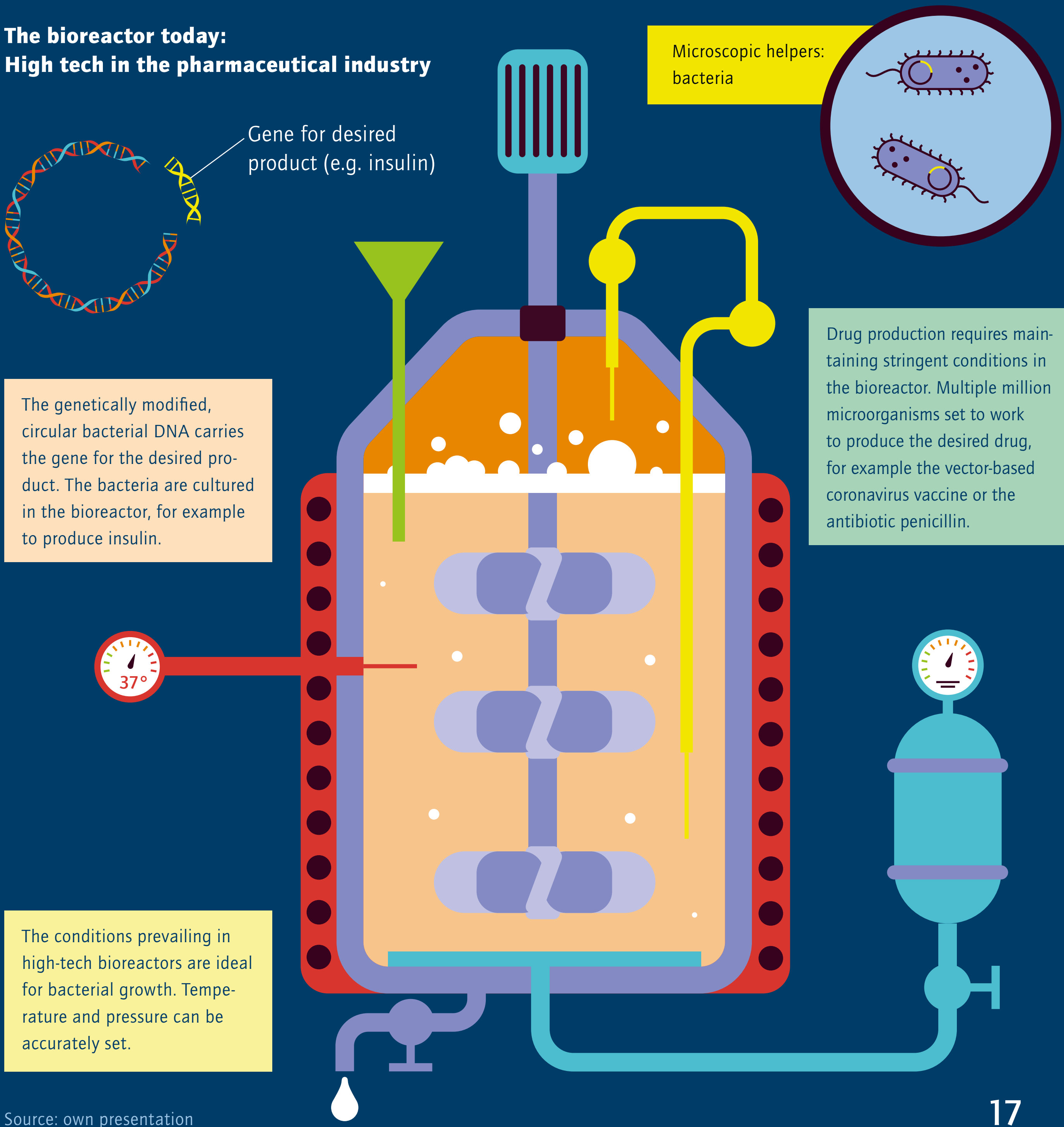
Alcohol
+
CO_2

The oldest bioreactor in the world: the brew kettle

Biotechnology has been used in beer brewing kettles or coppers for several millennia. During alcoholic fermentation, yeasts convert the sugar from the mash (crushed grain and water) into alcohol and carbon dioxide.

The bioreactor today:
High tech in the pharmaceutical industry

The genetically modified, circular bacterial DNA carries the gene for the desired product. The bacteria are cultured in the bioreactor, for example to produce insulin.



Drug production requires maintaining stringent conditions in the bioreactor. Multiple million microorganisms set to work to produce the desired drug, for example the vector-based coronavirus vaccine or the antibiotic penicillin.

The conditions prevailing in high-tech bioreactors are ideal for bacterial growth. Temperature and pressure can be accurately set.

Source: own presentation

How biotechnology can contribute to a healthy diet

Up to 35 cubes of sugar – that's how much sugar some drinks contain. This could come to an end in the next three years, as researchers have developed a protein sweetener which is ideally suitable as a sugar substitute because of its intense taste and good water solubility. **"Brazzein"** was originally derived from a berry in western Africa, but can now be produced resource-efficiently using biotechnology. Production and processing in large quantities and standardised quality using biotechnological methods is much simpler and more efficient than isolating the protein from the plant. These biotechnological methods involve microorganisms converting sugar into the sweet protein. Brazzein could thus revolutionise the beverage industry, which supplies around seventy per cent of the sugar consumed worldwide, and have a decisive impact on public health, given that excessive sugar consumption raises the risk of developing type 2 diabetes. Biotechnological production of the protein sweetener could therefore help to arrest sharply rising diabetes case numbers worldwide.[7]

2.2 Tradition and innovation: biotechnology for eating and drinking

Biotechnology is modelled on nature, which over the course of evolution has optimised processes such as the production of sugars, amino acids, proteins and fats. Over time, nature's systems have become ever more efficient overall, consuming ever less energy and only generating waste and residues which can be reused, so creating a closed circuit. Human beings recognised this early on and for thousands of years have been using biotechnological methods to produce, mature and preserve foodstuffs like bread, sauerkraut and wine. Biotechnology developed from observing natural processes: milk "turns" and goes sour, and fruit juice becomes vinegar or wine, depending on whether it is vinegar bacteria or yeasts that get the upper hand first. Humans have put these observations to good use and applied them in order to optimise production methods. In this way, biotechnology has conquered our kitchens.

"Biotechnology is not a new idea, we've already been using it for several thousands of years in food production."

Of course, knowledge about biotechnology has evolved with human beings. In **modern flavour production**, for example, industry uses biotechnological methods as these are often particularly efficient and conserve natural resources. Our next illustrations show which products in our refrigerator involve biotechnological know-how and what all the fuss is about with artificial and natural vanilla flavours (pages 20 and 22).

Reducing meat consumption

When it comes to nutrition, biotechnology offers innovative, sustainable possibilities for creating new products and at the same time countering **climate change.** The high and ever-growing consumption of meat makes a significant contribution to global warming: **industrial meat production and intensive animal farming** are responsible for **14 per cent of the world's greenhouse gas emissions.**[8] These include indirect CO_2 emissions from feed production and energy consumption, as well as methane gas released directly from cattle stomachs. The amount of water and land used in animal husbandry is also enormous. You can read more about this in **acatech HORIZONS "Sustainable Agriculture"**[9]**.** Nevertheless, many people do not want to go without meat, while others are trying to reduce their meat consumption and are looking for alternatives.

Here too, biotechnology offers some alternatives: one future possibility is laboratory-grown meat, known as **cultured meat**. Current studies suggest that cultured meat uses less water and land than meat produced conventionally by farming. However, growing meat in a laboratory requires more energy, as it is currently only produced for research purposes.[10] Processes are not yet optimized for industrial production, which is why so far no reliable final life cycle assessment is available. Cultured meat could also reduce the use of antibiotics in animal husbandry, which could in turn prevent the development of resistant strains of bacteria. In the final illustration of this chapter, on page 24, you will see how meat can be grown in a Petri dish and a bioreactor.

There are also many other meat substitutes which serve as a source of protein and are made from plant-based substances. These include traditional meat substitutes such as tofu or tempeh, which are made from soy beans and have long been used in Asian cuisine. Modern biotechnology is also constantly creating new, innovative meat substitutes. In the USA, a vegan burger made from purely plant-based ingredients has been a great success. In addition to wheat, potato and soy proteins and coconut oil, the meaty taste is provided by a "magic ingredient": leghaemoglobin, the plant-based counterpart of haemoglobin, which binds oxygen in human and animal red blood cells. Plant-based leghaemoglobin, in contrast, is produced by bacteria in the root nodules of leguminous plants. Researchers have genetically modified bacteria in the laboratory in such a way that they can produce leghaemoglobin in biotechnological installations. This substance makes up just 1 per cent of the burger but gives it 100 per cent of its "meaty" flavour, in the words of the manufacturer.[11] In the United Kingdom, vegetarian "meat and sausage products" are made from mycelium.[12] The fine filaments (hyphae) of a sac fungus are fermented, producing a "mycoprotein", which is processed into the finished products. Research is also being carried out into the industrial production of insects as a source of protein. The process of extraction from insects is not yet economic and is being further investigated.[10] Forecasts suggest that by 2030 meat alternatives will account for 28 per cent of the global market for meat products. By 2040 it could even be as much as 60 per cent.[13]

"It might at some point be possible to produce large quantities of meat inexpensively in a reactor."

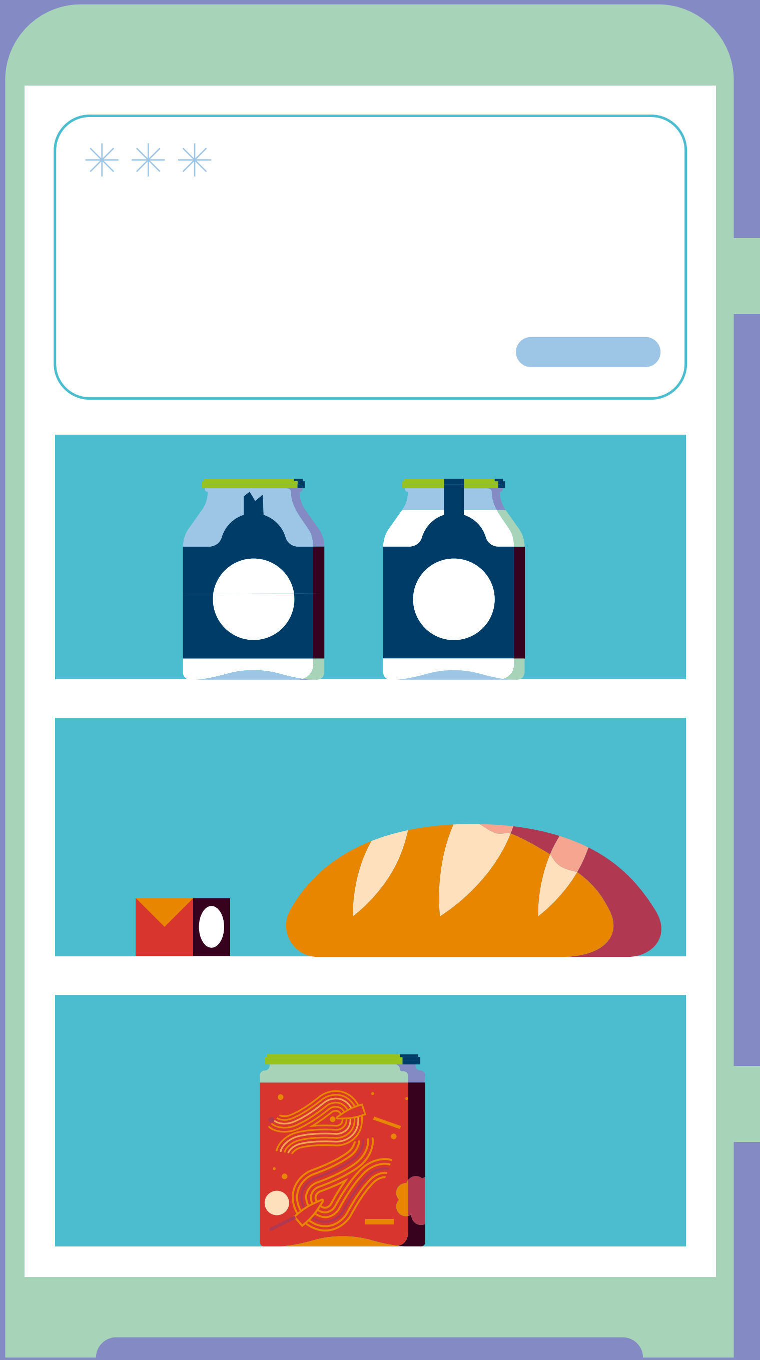
Palatable biotechnology

Biotechnology has played a part in our eating and drinking for millennia. Humans have made more or less deliberate use of the abilities of microorganisms and their enzymes to produce foodstuffs and make them safer, more digestible and tastier. It makes no difference whether we're talking wine, cheese, cake or steamed dumplings: without biotechnology these treats would not exist.

The word **yoghurt** comes from the Turkish (yoğurt) and means "fermented milk". Yoghurt has been around for thousands of years and is a classic product of biotechnology: bacterial cultures convert lactose into lactic acid. This gives yoghurt its thick consistency and a longer storage life. The flavourings used in yoghurt, for instance strawberry or vanilla, are today also predominantly produced using biotechnology.

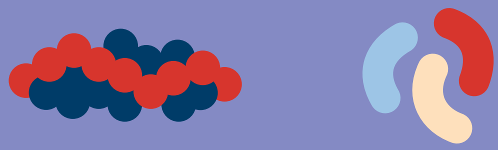
Over 4000 years ago, in ancient Egypt, yeast was used in **breadmaking.** We still bake our bread in the same way: yeast breaks down the sugar in the flour, producing the gas carbon dioxide, which causes the dough to "rise". Yeast also plays an important role in other areas of modern biotechnology , for example in the production of medicines or enzymes.

Kimchi is also obtained by fermentation processes, in particular by lactic acid bacteria. In Korean cuisine, Kimchi is widely based on Chinese cabbage; but the dish can also be based on other types of vegetable. The German counterpart is sauerkraut, which is likewise given a longer storage life and made more digestible by fermentation.

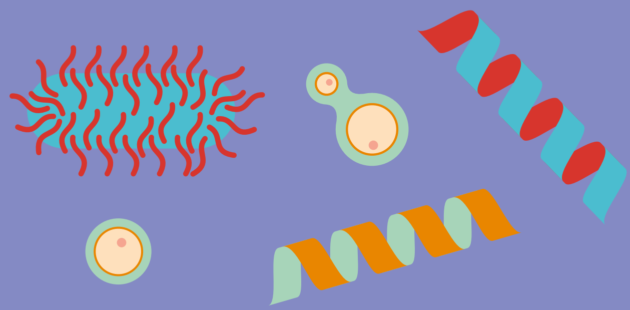


Source: own presentation

For centuries **soy sauce** has been obtained from soy beans and wheat with the aid of a fungus using a biotechnological process. The production process, which in Japan in particular took place in lots of small craft factories, didn't begin to be modernised until 1950. Today, large-scale production is the norm.



Archaeological finds in Israel indicate that humans were making beer-like beverages as long as 13,000 years ago. In ancient Mesopotamia, roughly 4000 years BC, there was already a sophisticated beer culture with a range of varieties. **Beer** is brewed using malt, water, hops and yeasts. During alcoholic fermentation, yeast converts sugar into alcohol. This biochemical modification is nothing other than biotechnology.



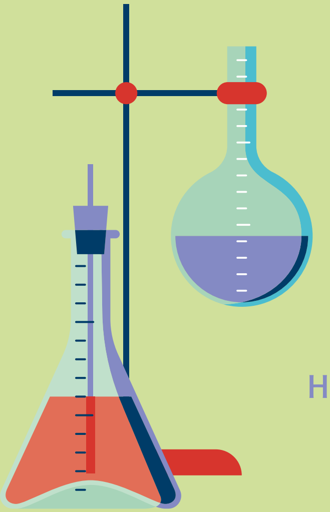
If **apple juice** is to be clear and not cloudy, biotechnology again has a part to play: xylanase and pectinase enzymes break down the plant fibres, so clarifying the juice.

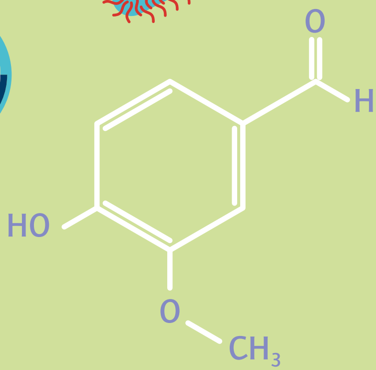
Vanillin – white gold

The Aztec ruler Moctezuma flavoured his chocolate drink with vanilla from vanilla orchids as long ago as the 16th century. To this day, we like to eat sweet foods and often flavour them with vanilla, while placing increasingly greater emphasis on natural, sustainable products. But what exactly does "natural" mean? What kinds of vanilla flavourings are there?

Vanilla flavour is made up of numerous flavouring substances, one of which is vanillin. Traditionally, vanillin can be produced by chemical or biotechnological processes. Ultimately, the result is always the same **vanillin molecule.**

Vanilla pods are highly sought after and are the second most expensive spice in the world after saffron and even more expensive than silver!





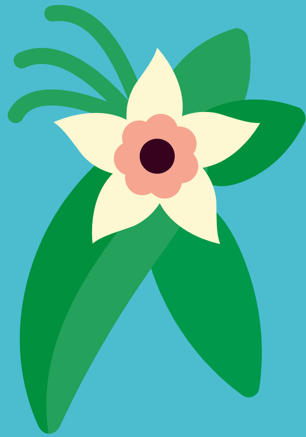
What is a natural flavouring?
The EU-regulation No. 1334/2008 specifies that, by law, only a flavouring which already occurs in nature and is produced from natural raw materials in a natural process can be described as natural. No other flavourings can be labelled as "natural". For example, vanillin produced biotechnologically from plant components with the assistance of bacteria counts as a natural flavouring substance.

Source: own presentation

Vanilla

From a vanilla pod

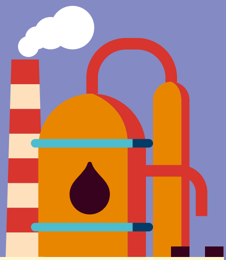
Vanilla pods are the fruit of the **vanilla orchid.** The majority of the vanilla orchids grown in the world come from Madagascar. Only vanilla from orchids from **Madagascar and Réunion Island** ("Île de Bourbon") can be called **Bourbon vanilla.** Cultivation on these two islands is very labour-intensive and cannot meet global demand.



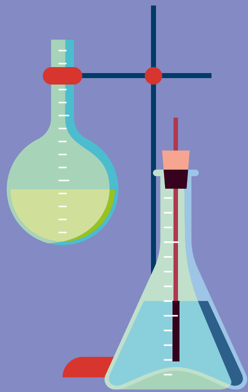
Vanilla sugar can only be described as such if it contains real vanilla extract from a vanilla pod.

Vanillin:

Chemical production



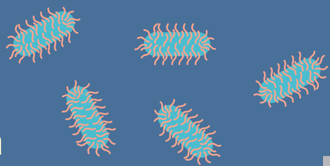
Traditionally, vanillin is sythesised from **petrochemicals.** It can also be produced industrially by oxidising eugenol, a component of clove oil.



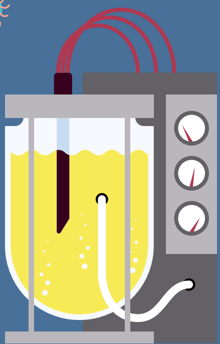
Vanillin sugar contains synthetic vanillin, or more precisely "vanillin flavouring" if it has been produced chemically.

Natural vanillin:

Biotechnological production



Vanillin can be produced biotechnologically in various ways: for example, naturally occurring bacteria can convert ferulic acid from rice waste into vanillin by fermentation. Another possibility is offered by genetically modified ***E. coli* bacteria,** which can produce vanillin from sugar (obtained from rice or maize) by fermentation.



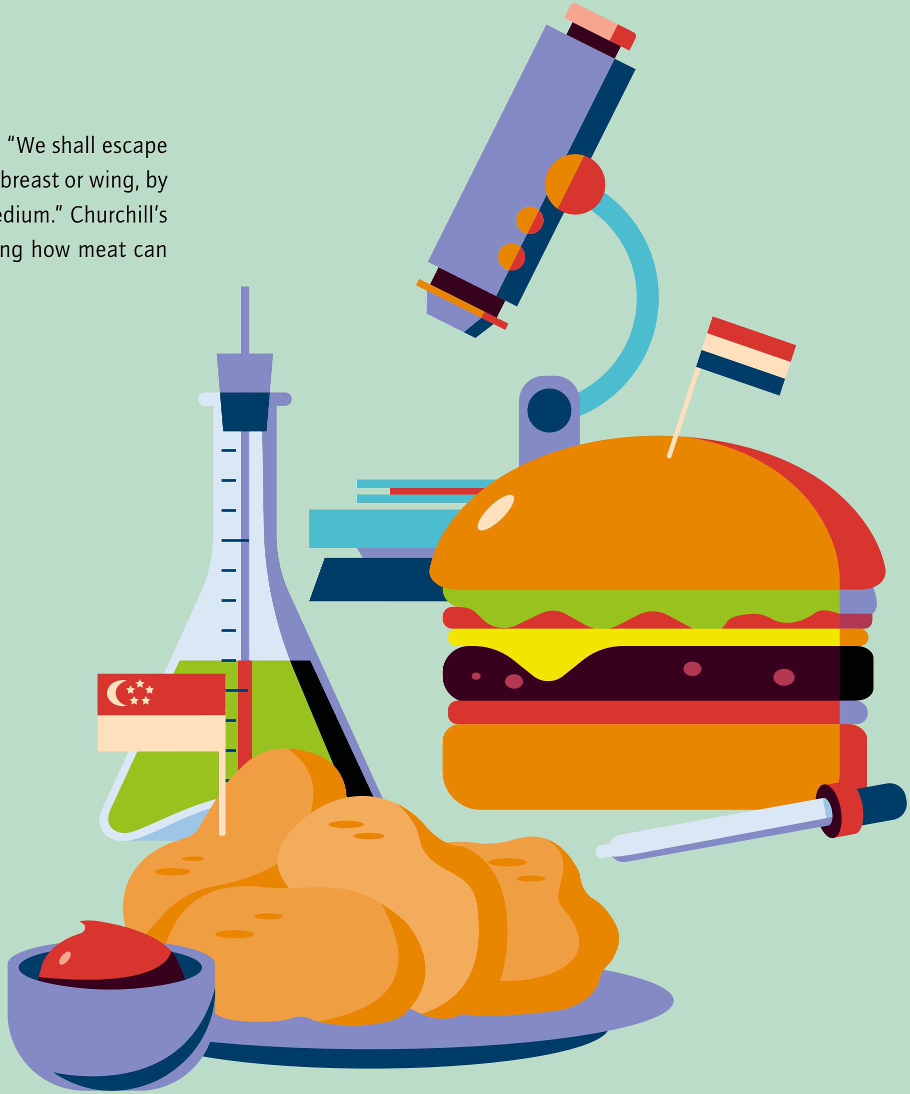
"**Natural** vanillin" in vanillin sugar can be described as such if it has been produced by biotechnological methods.

Meat from the laboratory

As long ago as 1932, Winston Churchill prophesied: "We shall escape the absurdity of growing a whole chicken to eat the breast or wing, by growing these parts separately under a suitable medium." Churchill's idea is now a reality: scientists are busily researching how meat can be grown in the laboratory.

In 2013, Mark Post from the Netherlands produced the first *in vitro* burger, i.e. a lab-grown burger, – it cost 300,000 euro! The Dutch government had previously invested 2 million euro in the research.

Singapore is so far the only country in the world to have officially approved lab-grown meat. In 2020, one restaurant served crispy sesame chicken from the lab for $23 - a world first!



In comparison with conventional meat production, *in vitro* meat uses less water and land, and emits fewer pollutants. Further process optimisation is required to cut energy costs as well.

Cultured meat may be part of the solution to minimising the environmental and climate issues associated with today's factory farming.

At present, researchers are focusing on minimising manufacturing costs and reducing the purchase price. So it may still be some years before we find meat from the laboratory on our supermarket shelves.

Biotechnology is again behind the scenes: a researcher takes a small tissue sample from a living cow or pig. This does not hurt the animal.

↓

This sample is used to create a cell culture that multiplies in a bioreactor.

↓

The researcher assembles the multiplied cell clusters into a number of muscle strips. The meat is formed layer by layer in a Petri dish. Its flavour and consistency match that of conventionally produced meat.

↓

Saffron or beetroot give the cultured meat its typical reddish colour.

↓

Research into scaling up this production technology is currently under way. Lab-grown meat can already be cultured in relatively large quantities in bioreactors. As a result, production costs have been reduced by 99 per cent in comparison with the first prototype.

Source: own presentation after Zeit Online (2013)[14] and McKinsey & Company (2021)[15]

2.3 (Green) biotechnology in agriculture

Plant breeding and genetic engineering

Ever since they became settled, humans have bred plants to feed themselves, selecting the biggest and most vigorous wheat or the tastiest tomato plants and using only those seeds for the next generation. To speed up the process, breeders have been using physical or chemical **mutagenesis** for decades. This is achieved by exposing plants to ionising radiation (radioactivity) or chemicals to introduce random mutations in the genome which in turn can randomly change the size or flavour of the plant. It is only thanks to this selection and **breeding** that we have such high-yielding wheat and flavoursome tomatoes today. For a long time, we were not even aware of how this process worked. It was not until 1865 that Mendel postulated his theory about the inheritance of gene-based traits, while in 1953, Watson and Crick decoded the structure of DNA (see first illustration on page 8). Today, the genome of many plants and animals has been completely decoded, and scientists can modify genomes in a targeted manner in the laboratory. The **genetic engineering of plants** which are primarily intended for use in agriculture is one facet of **green biotechnology.**

"Ninety per cent of our food has already had some involvement with genetic engineering."

Population growth – how will everyone eat their fill?

Growing population figures worldwide mean that agriculture too must reflect on new ways of obtaining food. The United Nations anticipates that **by 2050** there will be 2.1 billion more people living on Earth, giving a total **population of about 9.7 billion**. Even today, some 11 per cent of the world's population, or more than 800 million people, above all in Africa and South Asia, are suffering from hunger. 2 billion people are also deficient in essential nutrients such as iron, iodine, zinc and vitamin A. However, only 11 per cent of the planet's total land area is available for food production. Given an ever-growing world population and the additional threat of the climate crisis, agriculture faces the challenge to continue feeding all of humanity.[16, 17]

"Without biotechnology, it's questionable whether we can feed ten billion people."

This is where green biotechnology could help. Experts believe that **genetically engineering crop plants** such as rice, maize or cereals can make them more nutritious, robust and resistant. In this way, biotechnological progress can help to ensure sufficient global food supplies, despite ever more land being taken from agriculture due to climate change and despite ongoing growth in the world's population. The following illustrations on pages 28 and 30 explain how researchers can genetically modify a plant in the laboratory and why this might make good sense.

Germany's Genetic Engineering Act defines the legal framework for the use of genetic engineering methods. The purpose of the act is not only to promote this technology but also to ensure that it is used safely and responsibly. It regulates work with genetically modified organisms (GMOs), their deliberate release into the environment, and their placement on the market. ZKBS, Germany's Central Committee on Biological Safety, examines safety issues and advises federal and state governments by issuing position papers. In addition, various bodies from science and society, such as the German Ethics Council, the German Research Foundation, the National Academy of Sciences Leopoldina and churches monitor the ethical and social impact of biotechnological applications such as genetic engineering.

CRISPR/Cas – precise genetic scissors

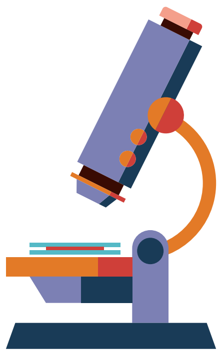
Emmanuelle Charpentier and Jennifer A. Doudna won the 2020 Nobel Prize in Chemistry for their discovery of the CRISPR/Cas genetic scissors. This new genetic engineering method allows researchers to cut and modify genetic material with pinpoint accuracy (genome editing) - and to do so even more efficiently, quickly and cost-effectively than with older methods. CRISPR/Cas was originally described as the "immune system" of bacteria which recognises and removes integrated viral DNA. Researchers are exploiting this observation by producing small mRNA strands or "guide RNAs", which define precisely where the genome is cut (see illustrations on pages 30 and 32 and Glossary). The Cas enzyme then docks onto these guide RNAs and cuts the DNA double strand, allowing genes to be removed, inserted or modified. CRISPR/Cas is not the first genome editing method, but it is among the most precise and efficient. Adaptation to cutting different genes is more complex and time-consuming in older methods.

CRISPR/Cas – complicated legislation frustrates plant research

The European Court of Justice has ruled that plants modified with CRISPR/Cas are covered by genetic engineering law, while plants created by physical mutagenesis, for example, are exempt. During research and development, the CRISPR/Cas method is therefore often used only in the initial stages to improve plant characteristics and to reveal which gene fragments researchers need to pay particular attention to. Since the use of these plants is prohibited, the attempt is then made to obtain these characteristics by permitted methods, for instance mutagenesis of the plants using ionising radiation (radioactivity). This latter method is applied until, by chance, exactly the desired characteristics are obtained as were initially achieved by CRISPR/Cas. Geneticists criticise this approach because mutagenesis leads to unwanted mutations throughout the genome, whereas CRISPR/Cas allows targeted changes. In May 2021, the EU Commission announced that Europe's controversial genetic engineering law will be reviewed.[18]

How healthy soils ensure our survival

One of the ways to combat the climate crisis is through bioeconomy, an economic system based on renewable raw materials (see page 7). This transformation is thus based on plants which need healthy soil to thrive. Soil, the earth in our fields and meadows, plays a central role in food security, biomass production and carbon storage. In a nutshell, it's crucial to the survival of humanity and the planet! We need healthy soil to grow food and regulate the climate by binding CO_2 in the soil and so removing it from the atmosphere. However, more and more land around the world is becoming infertile due to over-intensive use, suffering erosion, drying out and becoming no longer usable for agriculture. Experts are calling for soil health to be maintained by regenerative agriculture, for instance by avoiding the use of pesticides and artificial fertilisers, as well as monocultures. Innovative biotechnological strategies can also offer potential solutions here (see next illustration, "Small helpers in the soil"). Soil health is the foundation of a healthy climate, securing the food supply for the world's growing population.



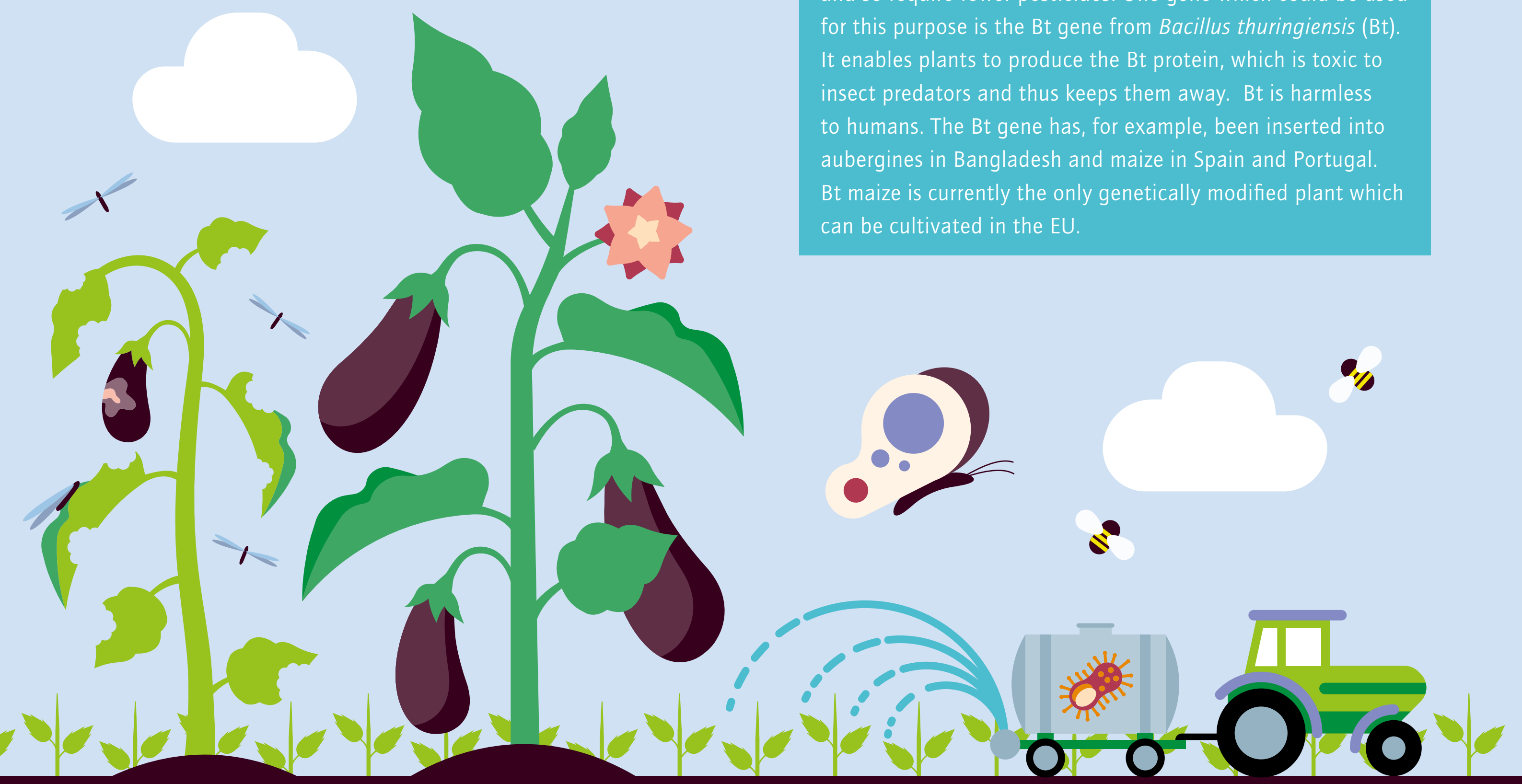
Biotechnology in agriculture

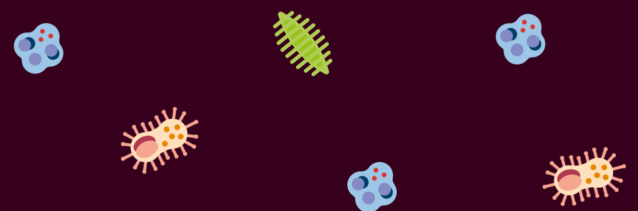
The world's population is growing steadily and estimates suggest that around ten billion people will be living on the planet by 2050, all of whom will need food. At the same time, resources are finite. How could biotechnology and genetic engineering help solve this problem?

Fewer pesticides thanks to resistant plants?

Farmers often use pesticides to protect their crops from plant pests. However, these are harmful to humans and the environment, killing beneficial insects such as bees, polluting the soil and water and sometimes causing diseases such as cancer.

Plants could be genetically engineered to be resistant to pests and so require fewer pesticides. One gene which could be used for this purpose is the Bt gene from *Bacillus thuringiensis* (Bt). It enables plants to produce the Bt protein, which is toxic to insect predators and thus keeps them away. Bt is harmless to humans. The Bt gene has, for example, been inserted into aubergines in Bangladesh and maize in Spain and Portugal. Bt maize is currently the only genetically modified plant which can be cultivated in the EU.





Small helpers in the soil

In agriculture, nitrate which plants need to survive, is supplied via liquid manure or fertiliser. Excessive nitrate, however, is bad for the climate, soil and groundwater. A US biotech company has developed a fertiliser which, instead of nitrate, contains soil bacteria which naturally convert nitrogen from the air into nitrate, hence preventing nitrate overfertilisation.

Plants which cope better with heat

Global warming means that plants in many parts of the world have to cope with higher temperatures and less water. Researchers are therefore breeding more resistant food crops which grow well despite heat and drought. Conventional breeding takes a very long time (often over a decade), which is too slow as a response to climate change. The method of choice would be genome editing, as it allows faster and more targeted change to genes which are relevant to heat resistance (see box on page 27 “CRISPR/Cas – complicated legislation frustrates plant research”).

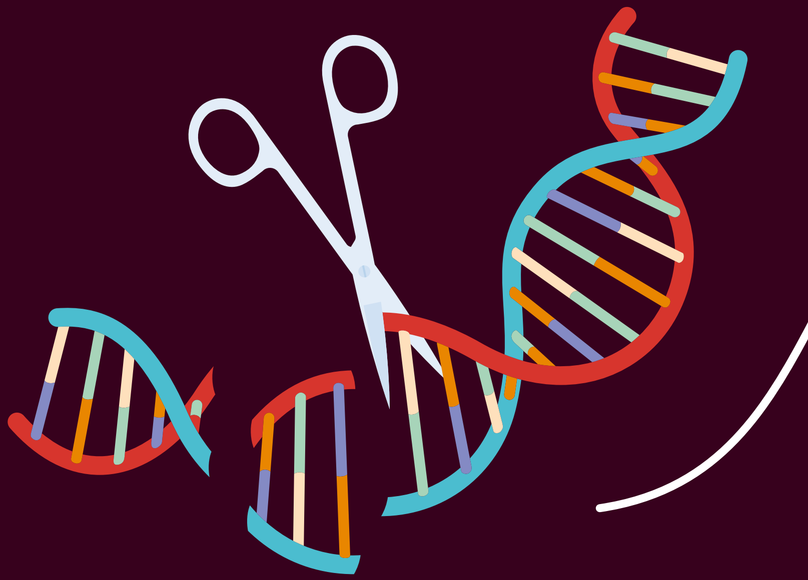
How can everyone eat their fill?

Especially in developing and emerging countries, people often have too little to eat or are deficient in vital nutrients. Researchers are using biotechnology and genetic engineering to try and find solutions.
For instance, rice (Golden Rice) or maize with an additional vitamin A gene could combat malnutrition in affected countries. Golden Rice is already approved in the USA and parts of Asia.

Source: own presentation

How do you make a genetically modified plant in the lab?

Other than random mutagenesis, there are various modern techniques for genetically modifying a plant in a targeted manner. Genes can be swapped, inserted or cut out using enzymes which act like scissors or glue. In this way, the vitamin A-gene can theoretically be inserted into a maize plant.



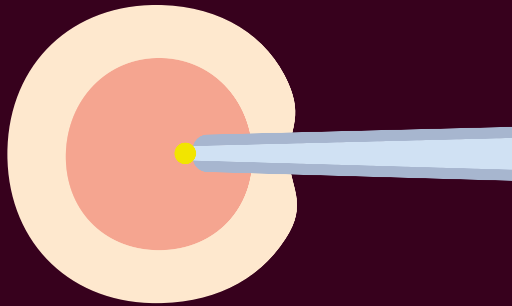
2. Using molecular scissors, so-called **restriction enzymes,** researchers can snip a portion out of the maize DNA.

1. A maize plant consists of numerous cells, each of which stores genetic information in the form of DNA in its nucleus.

Researchers are increasingly using the **CRISPR/Cas-method,** to modify genes in plants more precisely and efficiently (see page 26). The **restriction enzyme Cas9** cuts the DNA and short RNA fragments define precisely where this happens in the genome.

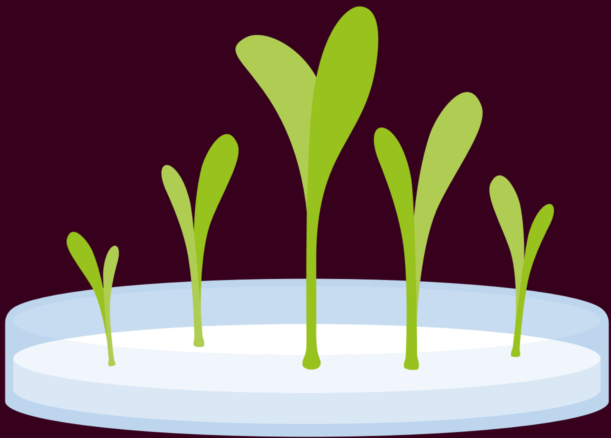
Source: own presentation

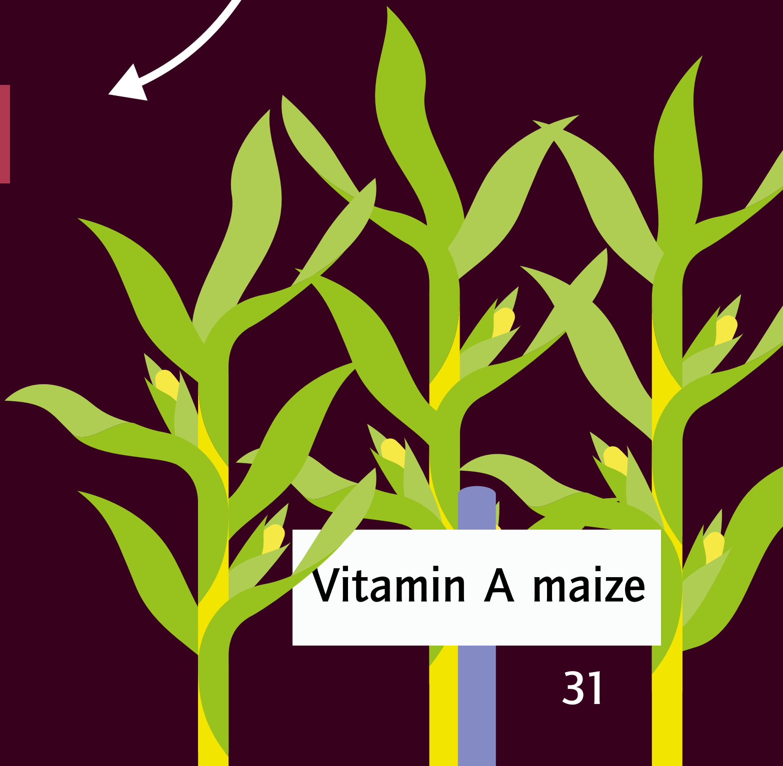
3. Glue enzymes, so-called **ligases,** enable the insertion of a foreign gene, for example the vitamin A gene (in yellow).



4. The modified DNA is introduced into plant cells in a tissue culture.

5. Small plantlets are then grown from these cells, and the vitamin A maize is ready.

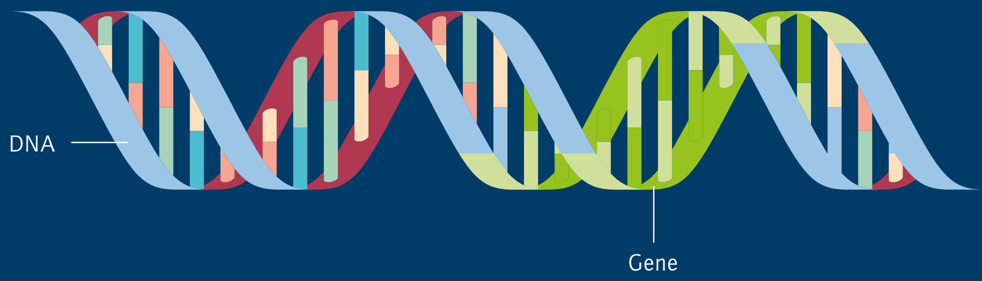




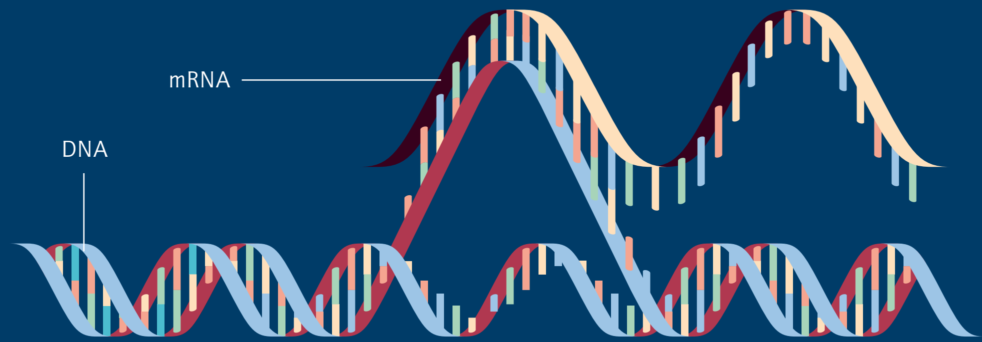
Protein biosynthesis: DNA, mRNA and proteins

DNA or mRNA are frequently being mentioned in the context not only of genetic engineering but also of the coronavirus vaccine. The following illustration explains what these terms mean.

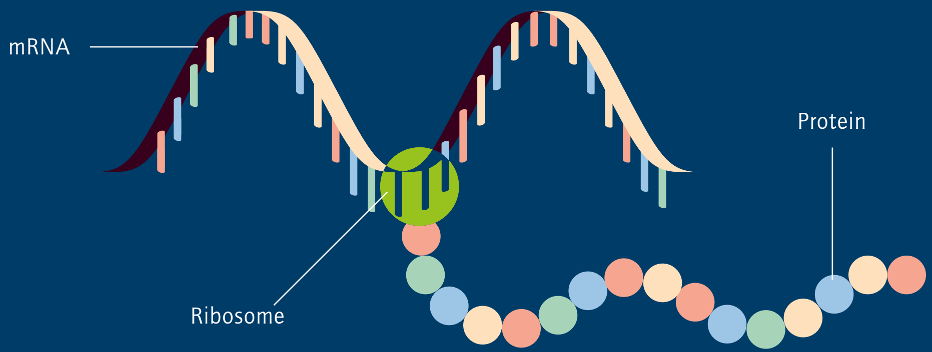
Plants, animals and humans consist of millions of **cells.** Each cell stores genetic information in the form of genes on its DNA.



DNA
DNA (deoxyribonucleic acid) stores the genetic information in our cells like a blueprint. Specific sections of DNA are called genes. The entirety of the genes is known as the genome.



mRNA
Using the DNA as the blueprint, mRNA, a working copy, is produced. The mRNA acts as a messenger molecule on the way to the finished protein.



Protein
The mRNA is finally read to produce a protein, the target product. Proteins perform numerous tasks in our body, for example moving cells, pumping ions or accelerating chemical reactions. What are known as structural proteins form the skin, hair and nails.

Source: own presentation

2.4. Biotechnology driving medical progress

In medicine, biotechnology now plays a key role in the **diagnosis and treatment of disease.** For instance, biotechnological methods are involved in the development of virtually all drugs that come onto the market today. This applies to every stage of drug development, from researching the cause of diseases and underlying genes to the production of drugs using enzymes or bacteria. Genetic engineering is also one of the biotechnological methods used in medicine, being vital in the production of coronavirus vaccines or in cancer therapy (see box on page 35).

One of the earliest examples of medical biotechnology is the **production of the antibiotic** penicillin by a mould. This achievement can be traced back to an accidental scientific discovery in 1928: Alexander Fleming, a Scottish physician and microbiologist, left a bacterial culture uncovered in his laboratory and later noticed that mould had formed on it. The mould *Penicillium notatum* produced the antibiotic penicillin, which killed the bacteria on the plate where it grew. During World War II, the antibiotic saved millions of lives. Today, penicillin mould is cultured industrially in huge bioreactors in order to isolate the antibiotic in large quantities for medical applications. **Insulin,** the hormone which lowers blood sugar levels and is necessary for the treatment of diabetes, is also now produced biotechnologically. Animal insulin was formerly obtained from the pancreas of pigs and cattle. Today, human insulin is produced biotechnologically with the help of *E. coli* bacteria in bioreactors (see illustration on page 16), which means that animal products no longer need to be used.[19]

The example of the extremely rapid **development of coronavirus vaccines** using cutting-edge methods demonstrates the advantages of medical biotechnology. Vaccine development usually takes from several years to decades. This is where the interdisciplinary nature of biotechnology comes into play: mRNA technology was initially developed by Uğur Şahin and Özlem Türeci with the aim of preventing cancer cells from uncontrolled division. They then changed the site of action, with the target molecule becoming the coronavirus. Various technologies worked together, while fast approval procedures and appropriate funding further accelerated the process. It was only thanks to biotechnology and genetic engineering that the vaccines could be developed at this speed. The next illustration on page 36 shows how biotechnology helps make coronavirus vaccines.

"Without biotechnology and genetic engineering, there would be no coronavirus vaccines today."

In medicine, a broad distinction is drawn between two areas of application of genetic engineering: firstly, there is genetic modification of **somatic cells** which involves individual genetic modification of specific body cells of a patient. One example of this is gene therapy, which is used to treat cancer patients (see box on page 35). Secondly, there is the possibility of genetically modifying **"germline" cells** (egg or sperm cells) in germline therapy. This involves specialist medical staff repairing a defective gene in the germ cells before they fuse and produce a fertilised zygote. This prevents hereditary diseases caused by a genetic defect from being passed on to the next generation. Since the modification can be inherited, this form of genetic engineering on humans is prohibited in Germany, as it is in most other countries.[20]

"Gene therapy means a large proportion of previously incurable types of cancer will be treatable."

Genetically modified immune cells to fight cancer

In CAR T-cell therapy, T-cells (immune cells) are taken from the blood of cancer patients and genetically modified in such a way that they can recognise and destroy cancer cells. Using the CRISPR/Cas method, the T-cells are provided with a gene for the artificial receptor CAR (Chimeric Antigen Receptor) (see chapter 2.3). The cells form this receptor and bear it on their outer envelope, allowing them to recognise cancer cells. The immune cells with a CAR receptor are called CAR T-cells. Millions of copies of these genetically modified CAR T-cells are cultured in the laboratory and then returned to the patient's bloodstream via an infusion. The CAR T-cells then seek out and destroy cancer cells in the body.[21]

The forgotten female pioneers of biotechnology

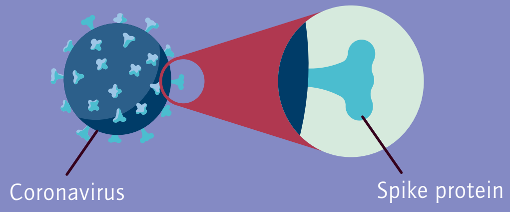
Women have been true pioneers in all areas of biotechnology.[22] For example, the coronavirus was discovered and visualised back in the 1960s by the Scottish virologist **June Almeida.**[23] Historically, however, the scientific achievements of women have often not been appreciated to the same extent as those of their male colleagues. For instance, the discovery of the double helix structure of DNA in 1953 is still predominantly attributed to James Watson and Francis Crick, despite the work of the British scientist **Rosalind Franklin** having contributed significantly to the two men's findings. Unlike Crick and Watson, her achievements did not win her a Nobel prize, and biology textbooks frequently also fail to mention her.[24]

Despite biology and biotechnology being the natural sciences in which women are most strongly represented, each with a share of around sixty per cent in Germany,[25] women are still under-represented in leading scientific positions and hold only 27% of biology professorships in German universities.[26] The same pattern can be seen in business, for example in biotech start-ups in Germany. The "Female Founders Report", which looked at the founding teams for 150,000 start-ups, found that women accounted for 14.8 per cent of founders in "biotechnology and medicine" in 2020.[39] So there is still a lot to be done to ensure that the achievements of female scientists and their innovative spirit conquer the biotech industry, especially in the executive ranks.

With biotechnology to the coronavirus vaccine

What happens in the lab? – the way to the coronavirus vaccine

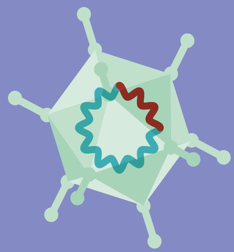
The concept
The coronavirus vaccination trains our immune system to recognise and combat the coronavirus. The spike protein, a protein in the envelope of the virus, is the recognition feature here.



Did you know?
In addition to the mRNA and vector vaccines, there is now also a protein-based vaccine which contains the spike protein packaged in nanoparticles.

The vaccines
The most widely used types of coronavirus vaccines – **vector and mRNA vaccines** – introduce the genetic information of the spike protein into our bodies in different packaging.

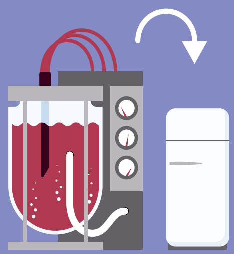
A **vector vaccine** contains **DNA** which encodes the information for the spike protein. This DNA is packaged in a harmless **vector virus.**



An **mRNA vaccine** contains **mRNA** which encodes the information for the spike protein. **Lipid nanoparticles** "package" the mRNA and ensure that the mRNA can pass through the cell membrane.

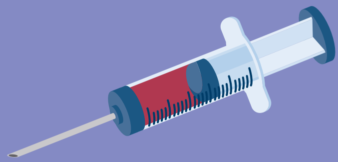
The production
mRNA and vector vaccines are produced differently, but **biotechnology and genetic engineering** play a central role in both processes.

Vector vaccine is grown in large volumes of cell cultures in a bioreactor. The vaccine is stable and can therefore be stored in normal refrigerators for an extended period.



mRNA vaccine can be straightforwardly produced in any laboratory using a quick, inexpensive and flexible process which means the vaccine can be more easily adapted to mutations. The required refrigeration at -80 °C, on the other hand, is problematic.

What happens in our body after vaccination? – Training for our immune system

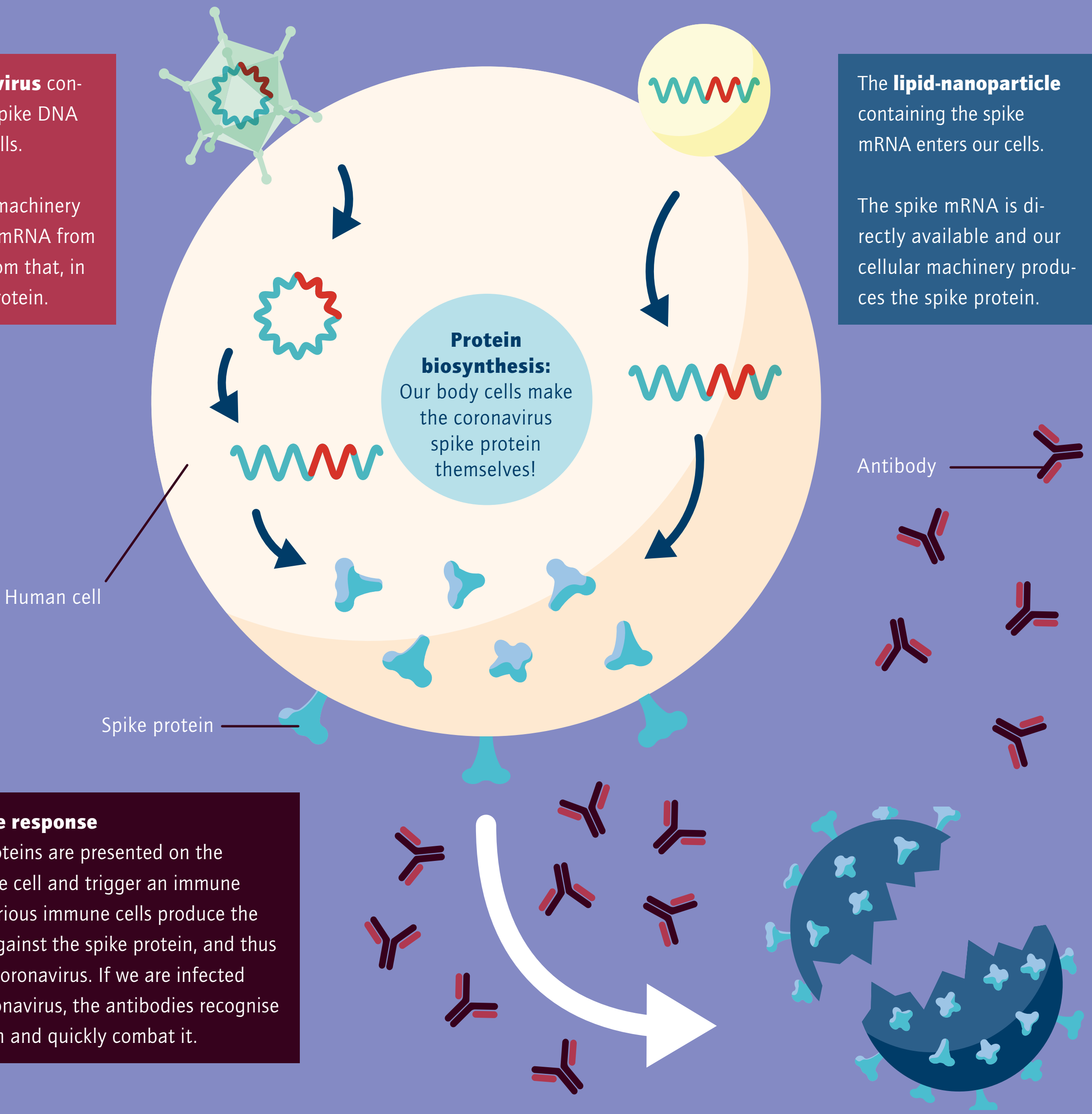


The **vector virus** containing the spike DNA enters our cells.

Our cellular machinery makes spike mRNA from DNA, and from that, in turn, spike protein.

The **lipid-nanoparticle** containing the spike mRNA enters our cells.

The spike mRNA is directly available and our cellular machinery produces the spike protein.



The immune response

The spike proteins are presented on the outside of the cell and trigger an immune response. Various immune cells produce the antibodies against the spike protein, and thus against the coronavirus. If we are infected with the coronavirus, the antibodies recognise the pathogen and quickly combat it.

Source: own presentation after ZDFheute[27]

3 Biotechnology in Germany and elsewhere

Experts believe that biotechnology will allow us to make ever greater progress in tackling global challenges such as health, nutrition and environmental and climate protection. How does Germany's biotech sector measure up internationally? And how are other countries dealing with biotechnological innovations? The following chapter compares the German biotechnology landscape internationally and presents interesting biotech projects from abroad.

Biotechnology often enables more energy-efficient modes of production, helps in some cases to save land and water, and offers alternatives to conventional industries with high CO_2 emissions. In terms of bioeconomy, it contributes to achieving climate targets through **sustainable economic management.** In addition, biotechnology has the potential to revolutionise our foodstuffs and their production, ensuring the well-being of animals, humans and the planet. The rapid development of coronavirus vaccines was also only possible thanks to the preceding decades of biotechnological research and the advanced technologies being available at the time when they were truly needed. Climate crises, food supplies and the COVID pandemic are global challenges which we will only overcome by working hand-in-hand with other societies due to the intertwined nature of our global relationships. At the same time, each country has different legal and economic frameworks, which influence the development and implementation of biotechnological solutions.

"Alongside artificial intelligence, biotechnology is the key technology of the 21st century."

Germany's biotechnology sector in an international comparison

The COVID pandemic has revealed just how Germany's biotechnology sector fares in an international comparison. Experts agree that Germany is a pioneer in most fields of research, including biotechnology.[28] Within the shortest possible time, German companies, using the knowledge gained from years of excellent research, were able to develop coronavirus vaccines and bring them to market. Germany's problem has more to do with corporate financing, in particular for the jump from start-up to company with production scaled for large output volumes. Although the COVID pandemic has led to record sums being invested in biotech within Germany, the amounts involved are still low when compared with other countries. In addition, the German foreign trade regulations complicate foreign investment.[29] Due to deficiencies in Germany's venture capital ecosystem, it is difficult for its biotechnology sector to reach its full potential. In general, start-ups with risky new ideas receive less funding in Germany than large established companies. By comparison, in the USA more money flows into innovative start-ups.

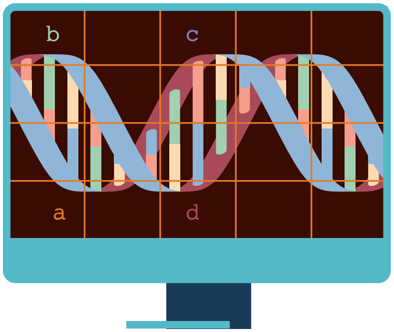
Additionally, experts criticize the legal framework in Germany and Europe, which often leaves biotechnological research and companies far behind what is possible. Businesses which, for example, apply genetic engineering methods such as CRISPR/Cas to plants, are faced with legal obstacles that make implementation excessively time-consuming and costly. Cultivating food plants which have been genetically modified using the CRISPR/Cas method requires EU approval which can take up to 6 years to obtain and entails costs of up to 16 million euro.[30] This regulatory framework indirectly complicates and impedes commercial scaling, although CRISPR /Cas applications are not prohibited per se.

The future of medical biotechnology: digital databases

In medicine, for instance in research into COVID-19, cancer or other life-threatening diseases, biotechnology is an important driver of progress. Researchers are currently working on digitalised databases in which they collect patients' medical data. Experts see this as the basis of tomorrow's medicine, in which diseases are detected before they break out and personalised treatments are used as standard.

Some examples of best practice include biomedical databases from other European countries.[31-34] Independent digital databases from the United Kingdom and Finland store medical data of approx. 500,000 people each and make this data available for research purposes.[31, 32] The data includes general medical facts such as height, weight and blood pressure, as well as individuals' genetic sequences. To ensure data protection, data donation to these databases is voluntary and pseudonymised. The databases are growing constantly and make this data available to research into life-threatening diseases such as cancer. The volume of biomedical data available offers researchers new opportunities to identify correlations and so improve human health in the long term. This has already led to numerous scientific discoveries, which in turn form the basis for medical applications in biotechnological drug production. Digitalisation, Big Data,[b] research and biotechnology thus go hand in hand when it comes to ensuring good health for people all around the world.

If personalised medicine is to be possible for individuals in the future, it is precisely this "medicine of the many" which is required, i.e. digitalised databases combining medical data donations from large numbers of participants. Only in this way will it be possible to detect and treat diseases early on, instead of taking action against them only at an advanced stage. The Federal Ministry of Health's plan **genomDE** is pursuing the objective of using genome sequencing data in Germany and making it available for research on a large scale.[37] This should lead to better, more targeted healthcare, always with patient consent, of course. Analysis of large bodies of data will pave the way for new, advanced diagnostics and therapies worldwide. International, interdisciplinary collaboration is crucial to success.



The algorithm in the white coat

Multiple factors are contributing to the dynamic development of medical biotechnology. Ever-improving methods for analysing biological processes and systems are providing the basis, after which the resultant data must be digitalised and filed. Computer science is playing a crucial role in the subsequent evaluation and linking of the huge volumes of data generated ("Big Data"). More and more **AI (Artificial Intelligence) algorithms** are being used to identify patterns and relationships that are beyond the capabilities of human comprehension. For example, researchers are working on AI algorithms which can detect tumours in mammograms more reliably than the eyes of an experienced doctor. In general, the analysis of genetic sequences of thousands of people would not even be possible without the assistance of computer science.

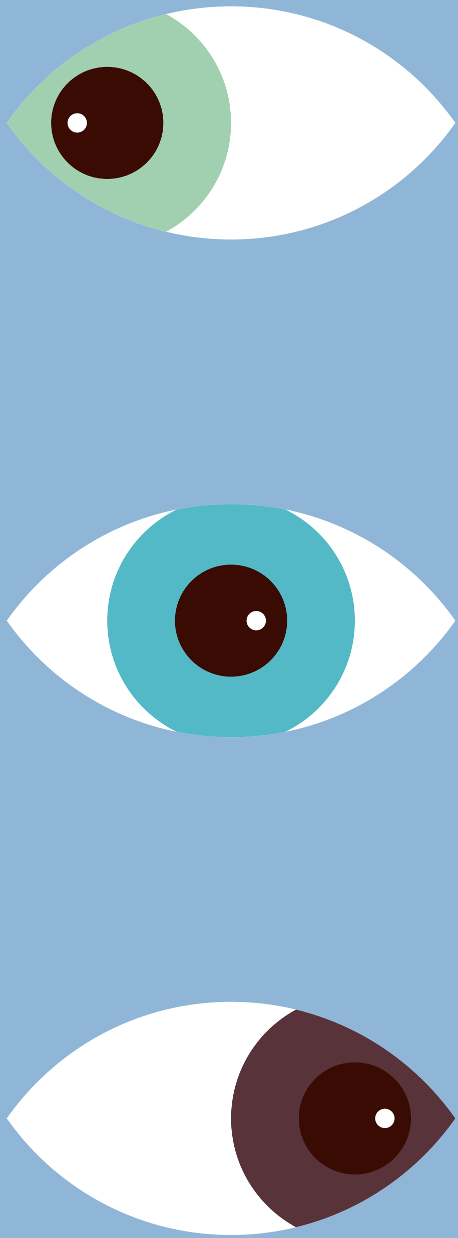
In addition, ever-increasing volumes of medical data are being analysed in **computer models.** This way, the biological processes of a disease can be computer-simulated in order to better assess, for example, the course of the disease or the response to treatment in patients with that disease. A "digital twin", i.e. a virtual image of the person on the computer, is created, on which individual treatment methods can be tested. The advantage of simulation is that new insights are quickly gained through virtual experiments, enabling better therapeutic approaches.

b "Big Data" refers to data volumes that are too large or complex to analyse using conventional methods.

Example: United against glaucoma

Nearly eighty million people worldwide have glaucoma, an eye disease that can lead to loss of sight. Increased pressure inside the eye triggers glaucoma, causing damage to the optic nerve resulting in impaired vision. Although some genes which play a role in altering intraocular pressure and causing glaucoma have already been identified, no clinical results have as yet been obtained leading to any new forms of treatment.

A recent study used genetic data from over 500,000 patients from Finnish and British databases to further explore the genetic basis of this eye disease. From this abundance of data, the researchers discovered a previously unknown, rare variant of a gene. Individuals carrying this gene variant had lower intraocular pressure and a reduced risk of developing glaucoma. Pharmaceutical companies are now using this knowledge to develop drugs that target this newly discovered gene using biotechnological methods. The results of this study could only be achieved thanks to the democratisation of large amounts of medical data through these databases. This example shows how research, digitalisation and biotechnological know-how are working hand-in-hand to ensure people's well-being across national borders.[35, 36]



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What needs to happen now?

So, what's next? What needs to happen now to ensure that the potential of biotechnology is fully exploited and of equal benefit to society, the economy and the environment? What do we have to do so that biotechnology helps us get a grip on humanity's problems such as nutrition and climate change? And what role can government, business, research and society play in this?

Policy makers can help to shape the framework in which biotechnology works through funding and legislation. A greater willingness to take risks and increased support for young, agile stakeholders would be welcome, especially when it comes to supporting start-ups and medium-sized companies. A look at the regulation governing genetic engineering shows that lengthy, costly approval processes hamper innovation. Science and research are the prime mover and foundation of biotechnological progress. Students of science, technology, engineering and mathematics (STEM) should learn the principles of entrepreneurship while still in college so that they can apply research findings to real-world applications.

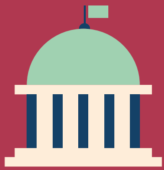
Transparent science communication is playing an increasingly important role in the cycle of science, politics, business and society. Abstract scientific concepts must be presented understandably and communicated at every level: to laypeople, in order to enable dialogue in society, and to policy makers so that they can set the right course. While scientific information is important, it does not necessarily lead to social acceptance of new biotechnological applications. Rather, there is a need for an open dialogue between science and the public which can take account of the opinions, expectations and fears of the general public.[38] Even if it is important not to enter into such a dialogue with a preconceived outcome in mind, it is desirable for society to be aware of the advantages these technologies bring for the reality of day-to-day life. This is necessary so that consumers use their market power and help steer the economy through their purchasing decisions.

From politics to business and research through to society, all together they form a circle. If all stakeholders pull together, biotechnology offers huge opportunities to shape our future in a sustainable, healthy and modern way.

"Another task facing scientists is to communicate better to create understanding among policy makers and in society."

The stakeholder cycle

Policy makers creating the framework



Making the **regulatory and legislative framework** more flexible and agile to keep pace with technological progress.

Business

Recognising and exploiting the **potential of biotechnology** for the economy.

Heterogeneous teams: Nature's complex systems can only be understood through an interdisciplinary lens.

Promoting **investment and partnerships** between small and medium-sized companies and start-ups.

Better involve stakeholders outside the corporate world as investors. Promoting openness to new **funding models** such as crowd funding and cooperative approaches.

The foundation: science and research

Integrating **entrepreneurship** into STEM degree programs. Boosting interdisciplinarity.

Dovetailing with business: Putting research into practice.

Not just focusing on top dogs but having a punt on **start-ups** too.

Strengthening **dialogue** with science. Talking about reservations regarding bio-technology and educating the community.

EU Green Deal Investment Plan: Promoting sustainable investment.

Society

Recognising opportunities: Biotechnology as a contri-bution to sustainability, health, environment and animal welfare.

Willingness to engage in dialogue: Dialogue with science and policy makers is the way for a well-informed society to freely form an opinion on biotechnological issues.

Market power as consumers: The younger generation in particular is highly aware of the relevance of sustaina-bility and can make a positive contribution through their consumption behaviour.

Proactively addressing **ethical aspects** and shaping the dialo-gue with other stakeholders.

Transparent science communi-cation: Explaining scientific con-cepts to society with new formats, social media and podcasts.

Source: own presentation

Glossary

Amino acids: Amino acids are the building blocks of proteins. There are 21 amino acids in total, nine of which humans must obtain from food as our bodies cannot produce them.

Antibiotics: Antibiotics, which are natural metabolic products of specific bacteria or fungi (e.g. penicillin), are capable of killing bacteria or inhibiting their growth. As a result, they are nowadays used to treat bacterial diseases and are often produced synthetically or by genetic engineering.

Antibodies: Antibodies are proteins which the body uses to combat pathogens. They are produced by white blood cells and secreted when an antigen is encountered.

Antigens: Antigens are substances which the human body recognises as foreign and which trigger an acquired immune response in defence of the body. Antigens may be proteins, carbohydrates or other substances. The word antigen is derived from the term antibody generator.

Bacteria: Bacteria are the smallest life forms on our planet and belong to the group of microorganisms. They are single-celled organisms and have only few cell organelles. They also have no cell nucleus, for which reason they are classed as prokaryotes. While bacteria do clump together physically, they are nevertheless usually completely independent organisms.

Cell: The cell is the smallest living unit of all organisms. A distinction is drawn between those living organisms consisting of a single cell (unicellular organisms), and those consisting of multiple cells (multicellular organisms). Cells can be categorised into prokaryotes and eukaryotes. Prokaryotic cells have no nucleus; the DNA floats freely in the cytoplasm. Eukaryotes, on the other hand, do have a nucleus containing the DNA and have a much more complex structure than prokaryotes.

Deoxyribonucleic acid (DNA): DNA is the carrier of genetic information in every living organism. It consists of two strands, each composed of phosphate and a specific sugar (deoxyribose), which are wrapped around one another. Nucleobases, which are linked together by molecular interactions, are located between the strands. DNA acts as a blueprint for the formation of corresponding RNA, which is in turn used for protein synthesis.

Enzymes: Enzymes are proteins which act as biocatalysts. They accelerate biochemical reactions by lowering the energy barrier for initiating a reaction. Many important metabolic processes would be inconceivable without enzymes. Enzymes act highly specifically: one enzyme catalyses just one reaction (lock-and-key principle).

Escherichia coli (E. coli): The bacterium *E. coli* occurs naturally in the intestines of birds, mammals and humans, where it breaks down nutrients or fends off pathogens. *E. coli* includes many different strains of bacteria, some of which can also cause disease and infection. Long a subject of study, this bacterium is frequently used in genetic engineering and in biotechnology for research and production.

Fats: Fats are organic molecules which have glycerol as their backbone, to which various fatty acids are attached. Depending on their properties, fats are solid or liquid (oil) at room temperature. Naturally occurring fats are known as lipids. Due to their high calorific value, they are the human body's most important energy store.

Fermentation: Fermentation is the name for any process in which microorganisms or individual enzymes modify the chemical composition of an organic starting material. Whether in food manufacturing, drug production, or wastewater treatment plants, fermentation is the process underlying nearly all applications of biotechnology and is performed on a large industrial scale in bioreactors or fermenters.

Fungi: Fungi form their own diverse kingdom in biology. There are some 100,000 species of fungi which range in size from microscopically small moulds to the edible mushrooms on our plates. Unlike plants, they cannot synthesise organic substances from light, but instead feed on living or dead organisms.

Gene: A gene is a section of DNA containing the information for producing an mRNA strand, which is then converted into a protein. Genes thus determine all the characteristics of a living organism, each specific trait usually being defined by a combination of a number of genes.

Genome: The genome refers to the entirety of a cell's genetic information.

Ligases: Ligases are enzymes which accelerate the process of linking two molecules with a chemical bond. Doing this requires external energy which ligases obtain, for example, by cleaving (splitting) energy-rich molecules.

Messenger RNA (mRNA): In contrast to DNA, mRNA is a single strand with a backbone made up of the sugar ribose (deoxyribose in DNA). mRNA acts as the blueprint for the synthesis of a specific protein. First of all, the DNA double strand is separated by an enzyme, such that a corresponding mRNA strand can be synthesised. The mRNA is then transported out of the nucleus to the ribosomes, where the information for forming the protein is read and in the next step the protein is formed.

Molecule: A molecule consists of at least two atoms which are joined together by chemical bonds. There are very simple molecules consisting of just two identical atoms (oxygen molecule O_2) and much more complex macromolecules such as DNA.

Mutagenesis: Mutagenesis describes the deliberate induction of mutations in living organisms via chemicals or ionising substances. Mutagenesis is usually undirected, which means that it is not a specific gene that is changed, but instead primarily the rate of mutation in a living organism's genetic material that is increased. Modern genetic engineering, however, also enables targeted mutagenesis or "genome editing".

Mutation: A mutation describes a spontaneous, irreversible change in a living organism's genetic information. Mutations can be classified into different categories depending on which cells are affected by the mutation, why it occurred, or what its impact is.

Nitrates: Nitrates are nitrogen compounds which naturally occur in soil. They are important plant nutrients and therefore used in farming as a component of fertilisers. Excessive amounts of nitrate can be harmful to humans, especially to infants.

Organisms: Organisms are complex living beings in which various organs constitute a functional unit. There are also microscopically small organisms consisting of individual cells or cell aggregates. These are microorganisms, which include bacteria, viruses, fungi and single-celled organisms.

PCR: The polymerase chain reaction is a molecular biology method for amplifying or multiplying DNA. Polymerase is the name of the enzyme which copies the DNA.

Pesticides: The term pesticides covers not only plant protection products used in agriculture, forestry and gardening but also biocides used to control pests and disease vectors in our households. The substances involved are produced chemically and are toxic to the relevant unwanted organisms.

Proteins: Proteins are the most important biochemical functional units; they make up 15 to 17 per cent of human body mass. In chemical terms, proteins are macromolecules which consist of amino acids linked together by what are known as peptide bonds. The blueprint of all proteins is stored in DNA.

Restriction enzymes: Restriction enzymes are enzymes which recognise and "cut" specific locations on the DNA double helix. They originate from specific bacteria where they serve as a defence against viruses. Since the 1970s, they have also been used in the laboratory for certain genetic engineering processes.

Sugars: In chemical terms, sugars are carbohydrates (saccharides) and consist of hydrogen, carbon and oxygen atoms. Some types of sugar such as glucose (dextrose) consist of only one molecule and are known as monosaccharides. Sugars which consist of several molecules linked together are known as polysaccharides. The best known example is sucrose, ordinary table sugar.

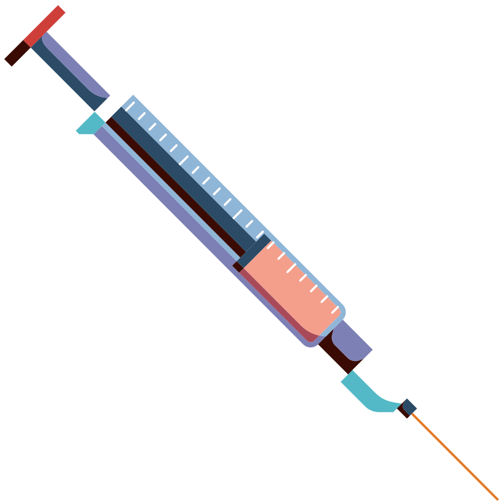
Spike proteins: Spike proteins are proteins which protrude from the surface of the viral envelope like little spines. They perform an important function when the virus docks with a host cell. Only by binding its spike proteins to host cell receptors can the virus inject its genetic information into the cell's interior.

Viral vectors: Viral vectors are used in medicine and genetic engineering to introduce genetic information into a cell. The vectors used for this purpose are usually inactivated viruses that are no longer capable of reproducing. The transport process is known as transduction.

Viruses: Viruses are infectious particles which have no metabolism of their own and can only reproduce by means of a suitable cell (host) by causing the host to produce new viruses. By biological definition they are therefore not considered living organisms. They are much smaller than bacteria and only visible under an electron microscope. Some viruses can also store their genetic information as RNA.

Yeasts: Yeasts are unicellular fungi; they are microorganisms and multiply by budding or division. Yeasts have been used in biotechnological processes, especially in food production, for thousands of years. In biological research, they play an important role as model organisms since they are among the smallest eukaryotic organisms and therefore easy to culture and study.

Zygote: A zygote is the cell formed when two gametes (germ/sexual reproductive cells) fuse. When the cells fuse, the nuclei of the two gametes fuse, resulting in a complete set of chromosomes.



Bibliography

1. Bundesministerium für Bildung und Forschung (BMBF) (2020): Nationale Bioökonomiestrategie. https://www.bmel.de/DE/themen/landwirtschaft/bioeokonomie-nachwachsende-rohstoffe/nationale-biooekonomiestrategie.html

2. Fonds der Chemischen Industrie im Verband der Chemischen Industrie (2009): BIOTECHNOLOGIE – kleinste Helfer – große Chancen. https://www.vci.de/vci/downloads-vci/biotech- brosch-2aufl-02.pdf

3. BIO Deutschland (2019): 100 Jahre Biotechnologie – Meilensteine der Biotechnologie. https://www.102jahre-biotech.de/

4. Amgen Deutschland (2019): Der Begriff Biotechnologie ist in der Bevölkerung positiv besetzt, Gentechnik weniger. https://www.amgen.de/medien/news/436/fortschritt-biotechnologie-und-gentechnik/

5. Deutsche Akademie der Technikwissenschaften (acatech) (2021): Urban Mining (acatech HORIZONTE). https://www.acatech.de/publikation/acatech-horizonte-urban-mining/

6. DECHEMA-Forschungsinstitut (2019): Natürliche Aromen und Düfte dank Biotechnologie. https://dechema-dfi.de/nat%C3%BCrliche_Aromen.html

7. Wissenschaftsjahr 2020/21 Bioökonomie, an initiative of the Federal Ministry of Education and Research (2021): Natürlich süßen mit einem Protein - Biotechnologie machts möglich. https://www.wissenschaftsjahr.de/2020-21/aktuelles-aus-der-biooekonomie/koepfe-des-wandels/natuerlich-suessen-mit-einem-protein-biotechnologie-machts-moeglich

8. Food and Agriculture Organization of the United Nations (FAO) (2013): Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. https://www.fao.org/3/i3437e/i3437e.pdf

9. Deutsche Akademie der Technikwissenschaften (acatech) (2019): Nachhaltige Landwirtschaft (acatech HORIZONTE). https://www.acatech.de/publikation/acatech-horizonte-nachhaltige-landwirtschaft/

10. Umweltbundesamt (2020): Die Zukunft im Blick: Fleisch der Zukunft. https://www.umweltbundesamt.de/publikationen/die-zukunft-im-blick-fleisch-der-zukunft

11. Mittler, H. (2016): Burger Impossible Foods – Ist das Fleisch? https://lebensmittelpraxis.de/fleisch/15917-burger-impossible-foods-ist-das-fleisch.html?web=1&wdLOR=cDA0A3AC2-C737-44DE-B9CF-D8F0104A891A

12. Quorn (2021): Quorn's mycoprotein. https://www.quorn.co.uk/mycoprotein

13. Chemnitz, C., Wenz, K. (2021): Fleischatlas. Daten und Fakten über Tiere als Nahrungsmittel / 1st edition. Heinrich-Böll-Stiftung, Bund für Umwelt und Naturschutz Deutschland. https://www.boell.de/de/de/fleischatlas-2021-jugend-klima-ernaehrung

14. Schadwinkel, A. (Zeit Online) (2013): Einmal Kunstfleisch-Burger für 300.000 Euro, bitte! https://www.zeit.de/wissen/2013-08/kuenstliches-rindfleisch-in-vitro-burger/komplettansicht

15. Brennan, T., Katz, J., Quint, Y., Spencer, B. (McKinsey & Company) (2021): Cultivated meat: Out of the lab, into the frying pan. https://www.mckinsey.com/industries/agriculture/our-insights/cultivated-meat-out-of-the-lab-into-the-frying-pan?cid=eml-web

16. Bundesministerium für Ernährung und Landwirtschaft (BMEL) (2018): Welternährung verstehen – Fakten und Hintergründe. https://www.bmel.de/SharedDocs/Downloads/DE/Broschueren/Welternaehrung-verstehen.html

17. Welthungerhilfe (2021): Hunger: Verbreitung, Ursachen & Folgen. https://www.welthungerhilfe.de/hunger/

18. Europäisches Informations-Zentrum Niedersachsen (EIZ) (2021): Studie der EU-Kommission zu Gentechnik: Für neue Verfahren braucht es neue Regeln. https://www.eiz-niedersachsen.de/studie-der-eu-kommission-zu-gentechnik-fuer-neue-verfahren-braucht-es-neue-regeln/

19. Pieroth, I. (1992): Penicillinherstellung: Von den Anfängen bis zur Großproduktion. Wiss. Verl.-Ges, Stuttgart.

20. Heescher, W. (2019): Deutscher Ethikrat. Gentechnik: Alles machen, was man kann? https://www.zdf.de/nachrichten/heute/gentechnik-ethikrat-legt-stellungnahme-vor-100.html

21. Deutscher Ärzteverlag GmbH, Redaktion Deutsches Ärzteblatt (2018): CAR-T-Zell-Therapie: Aussichten und Risiken. https://www.aerzteblatt.de/archiv/196295/CAR-T-Zell-Therapie-Aussichten-und-Risiken

22. Good Day BIO (2021): Women's History Month: 28 pioneering women in science and biotechnology to know. https://www.bio.org/blogs/womens-history-month-28-pioneering-women-science-and-biotechnology-know

23. Fieber, T. (2020): June Almeida – die vergessene Coronavirus-Entdeckerin. https://www.br.de/nachrichten/wissen/june-almeida-die-vergessene-coronavirus-entdeckerin

24. Abrell, A. (2021): "Solange Frauen in Leitungsfunktionen fehlen, fehlen auch Rollenvorbilder". https://www.mpg.de/11968981/rosalind-franklin

25. GENESIS-Online, Statistisches Bundesamt (2021): Studierende: Deutschland, Semester, Nationalität, Geschlecht, Studienfach. https://www-genesis.destatis.de/genesis//online?operation=table&code=21311-0003&bypass=true&levelindex=0&levelid=1634537349481#abreadcrumb

26. Statistisches Bundesamt, Fachserie 11, Reihe 4.4 (2020): Personal an Hochschulen. https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bildung-Forschung-Kultur/Hochschulen/Publikationen/Downloads-Hochschulen/personal- hochschulen-2110440207004.html

27. ZDFheute (2021): mRNA- und Vektorimpfstoffe. https://zdfheute-stories-scroll.zdf.de/mRNA_Vektor_Impf stoffe_Mutation/index.html

28. Deutsche Akademie der Technikwissenschaften (acatech) (2018): Innovationspotenziale der Biotechnologie. https://www.acatech.de/publikation/innovationspotenziale- der-biotechnologie/

29. Ernst & Young GmbH (2021): Deutscher Biotechnologie-Report 2021. Biotech am Tipping Point. In welche Richtung entwickelt sich der Sektor nach der Pandemie? https://assets.ey.com/content/dam/ey-sites/ey-com/de_de/news/2021/04/ey-deutscher-biotechnologie-report-april-2021.pdf

30. Deutsche Akademie der Technikwissenschaften (acatech) (2020): Resiliente und nachhaltige Lebensmittelversorgung. Die Coronakrise und weitere Herausforderungen (acatech IMPULS). https://www.acatech.de/publikation/resiliente-und-nachhaltige-lebensmittelversorgung/

31. UK Biobank (2021): Enabling scientific discoveries that improve human health. https://www.ukbiobank.ac.uk/

32. FinnGen (2021): FinnGen research project is an expedition to the frontier of genomics and medicine. https://www.finngen.fi/en

33. deCODE genetics (2021). https://www.decode.com/

34. Estonian Biobank (2021). https://www.eithealth-scandinavia.eu/biobanks/the-estonian-biobank/

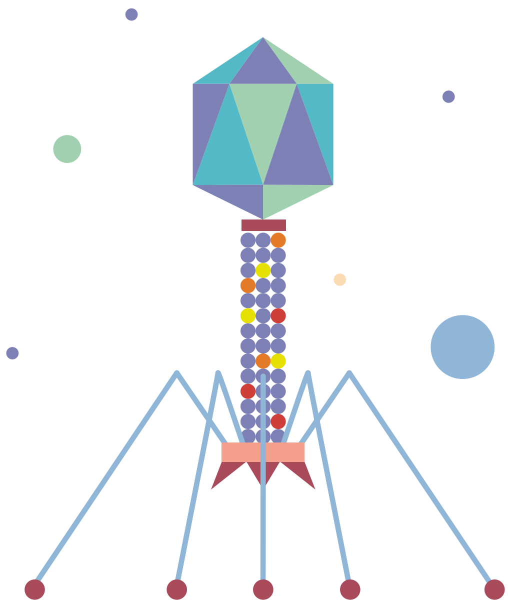
35. FinnGen (2020): Gene variants that protect against glaucoma identified, opening therapeutic possibilities. https://www.finngen.fi/en/news/gene-variants-protect-against-glaucoma-identified-opening-therapeutic-possibilities

36. Tanigawa, Y., Wainberg, M., Karjalainen, J., Kiiskinen, T., Venkataraman, G., Lemmelä, S., Turunen, J. A., Graham, R. R., Havulinna, A. S., Perola, M., Palotie, A., Daly, M. J., Rivas, M. A. (2020): Rare protein-altering variants in ANGPTL7 lower intraocular pressure and protect against glaucoma. PLOS Genetics, 16(5):e1008682.

37. Bundesgesundheitsministerium (2021): Die deutsche Genom-Initiative – genomDE. https://www.bundesgesundheitsministerium.de/themen/gesundheitswesen/personalisierte-medizin/genomde-de.html

38. Deutsche Akademie der Technikwissenschaften (acatech) (2012): Perspektiven der Biotechnologie-Kommunikation (acatech POSITION). https://www.acatech.de/publikation/perspektiven-der-biotechnologie-kommunikation-kontroversen-randbedingungen-formate/

39. Startbase Female Founders Report (2021): Frauen in der deutschen Start-up Szene: Antiquierte Rollenbilder oder neuer Schwung? https://www.startbase.de/downloads/female-founder-report/2021/female-founder-report.min.pdf



Interviewees

The project group presented on page 54 determined the content of this publication. acatech conducted interviews with experts from academia, business, policy makers and society. The interviews took place between February and September 2021. Some key ideas expressed by interviewees are included in the text as anonymised quotes.

The acatech Executive Board would like to thank all experts sincerely for their participation in the interviews. In detail these were:

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Biotechnology project group:
acatech's Executive Board appointed an independent project group from academia, business and society for this issue of HORIZONS. The content of this publication was determined by the project group and does not reflect the opinion of acatech's Executive Board. acatech would like to thank the project group sincerely for their cooperation and for the interviews conducted. Members of the group:

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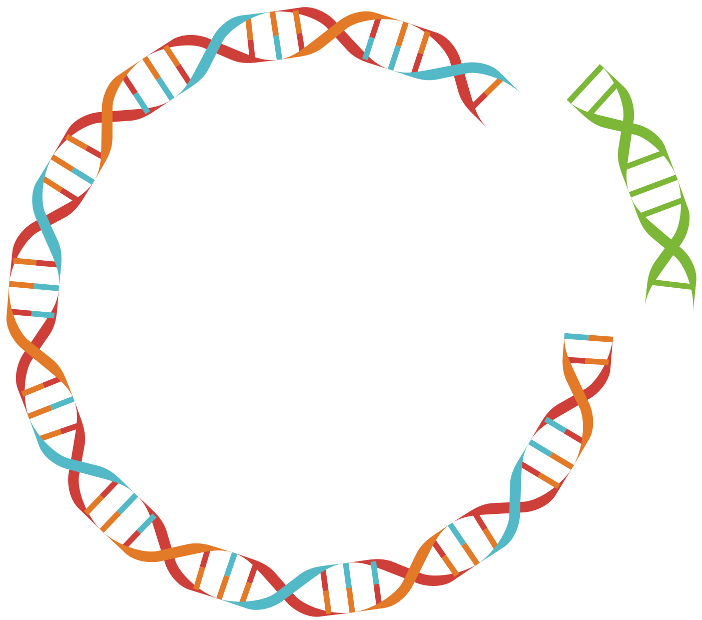

What do vanilla ice cream and a coronavirus vaccine have in common? Like many other everyday products such as bread, wine, apple juice, medicines, shampoo and even sneakers, they both involve biotechnology. But what exactly is biotechnology? It includes any industrial application using biological processes to manufacture a product. What changes has biotechnology seen over the centuries and where do we come across it today? And most importantly, how can it help us meet the challenges of the present and the future? acatech's new HORIZONS Biotechnology answers these and other vital questions.