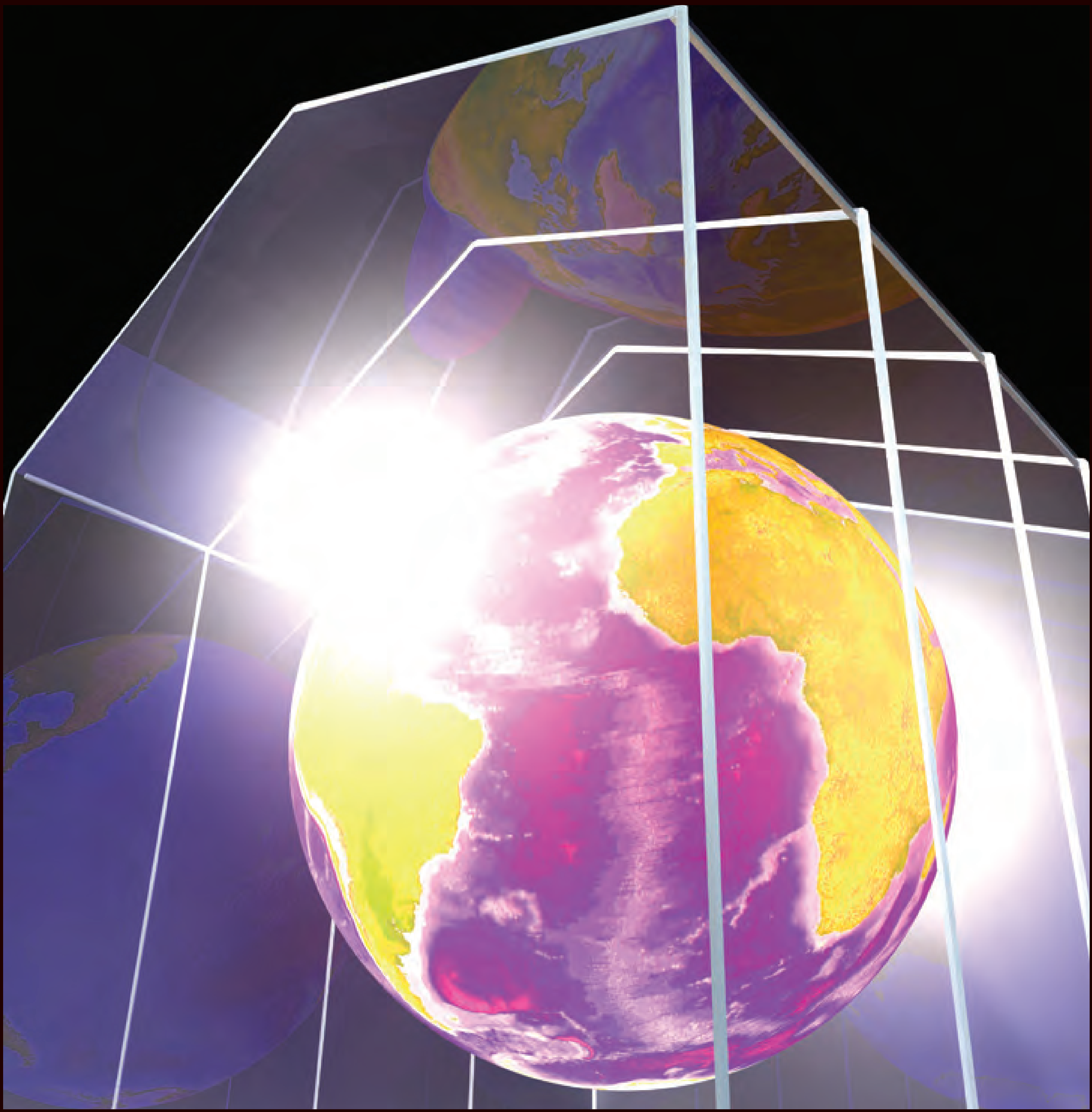
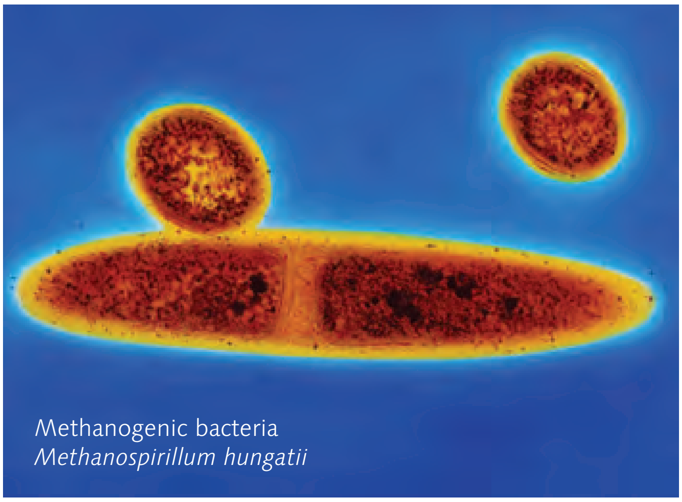
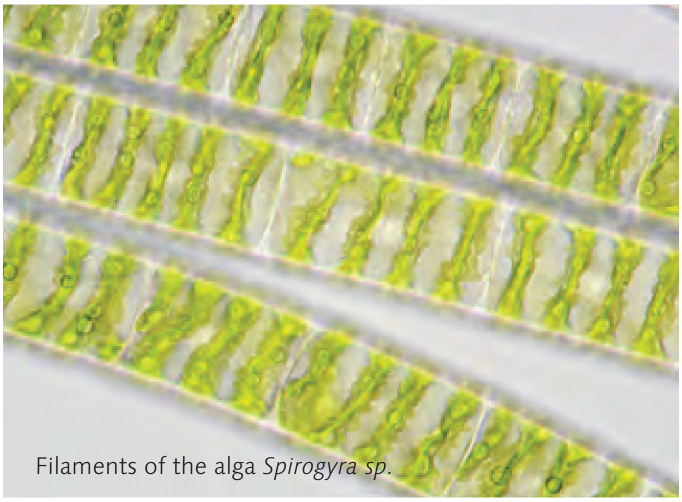


MICROBES AND CLIMATE CHANGE


Soil bacteria


Methanogenic bacteria *Methanospirillum hungatii*


Filaments of the alga *Spirogyra sp.*


Nitrogen-fixing bacterium *Rhizobium leguminosarum*

Climate change is a hot topic – discover the role microbes play in this global challenge

What is climate change?

Most scientists now agree that climate change is taking place. This is being demonstrated globally by the melting of the polar ice sheets and locally by the milder winters we are having, coupled with more extreme weather such as heavy rain and flooding.

The Earth is surrounded by a thick layer of gases which keeps the planet warm and allows plants, animals and microbes to live. These gases work like a blanket. Without this blanket the Earth would be 20–30°C colder and much less suitable for life. Climate change is happening because there has been an increase in temperature across the world. This is causing the Earth to heat up, which is called global warming.

What causes global warming?

The blanket of gases that surrounds the Earth is getting much thicker. These gases are trapping more heat in the atmosphere causing the planet to warm up.

Where are these extra gases coming from?

These gases are called greenhouse gases. The three most important greenhouse gases are carbon dioxide, methane and nitrous oxide and these have increased dramatically in recent years due to human activity.

The Earth is known as a 'closed system' which means that it produces everything it needs to ensure the survival and growth of its residents. In nature there are chemical cycles such as the carbon cycle to control and balance these gases that surround the Earth. The carbon cycle is a complex series of processes through which all of the carbon atoms in existence rotate. This means that the carbon atoms in your body today have been used in many other molecules since time began e.g. as the carbon found in carbon dioxide in the air. Microbes play an important role as either generators or users of these gases in the environment as they are able to recycle and transform the essential elements such as carbon and nitrogen that make up cells.

Bacteria and archaea are involved in the 'cycles' of all the essential elements. For example:-

> In the carbon cycle methanogens convert carbon dioxide to methane in a process called methanogenesis

> In the nitrogen cycle nitrogen-fixing bacteria such as *Rhizobium* fix nitrogen, which means they convert nitrogen in the atmosphere into biological nitrogen that can be used by plants to build plant proteins.

Other microbes are also involved in these cycles. For example:-

> Photosynthetic algae and cyanobacteria form a major component of marine plankton. They play a key role in the carbon cycle as they carry out photosynthesis and form the basis of food chains in the oceans.

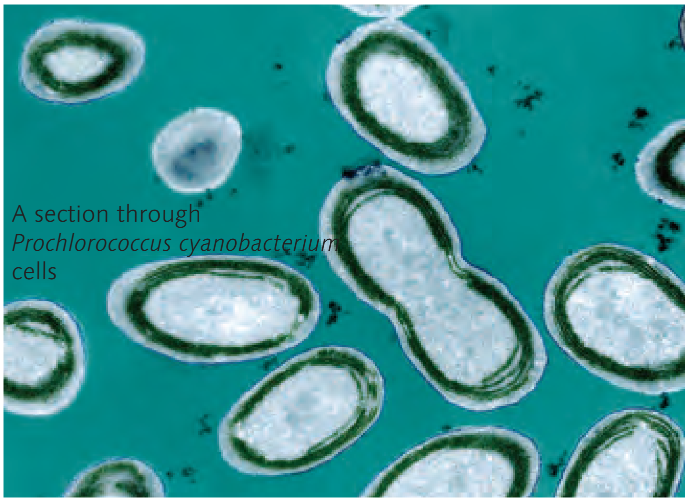
> Fungi and soil bacteria – the decomposers – play a major role in the carbon cycle as they break down organic matter and release carbon dioxide back into the atmosphere.

Can microbes help save the planet?

Prochlorococcus and *Synechococcus* are single celled cyanobacteria. They are the smallest yet most abundant photosynthetic microbes in the ocean. They are so small that a hundred of these organisms can fit end-to-end across the width of a human hair and there are around 100 million *Prochlorococcus* cells per litre of seawater. Researchers estimate that *Prochlorococcus* and *Synechococcus* remove about 10 billion tons of carbon from the air each year; this is about two-thirds of the total carbon fixation that occurs in the oceans. Scientists have deciphered the genomes of these two microbes.

> **What is a genome?**
> It is a map of the complete genetic make-up of an organism. The basic units of genetic information are called genes. The genome, which is made up of genes, contains all of the biological information needed to build and maintain a living example of that organism. The number of genes an organism has depends to some extent on the complexity of the organism.

With this knowledge scientists hope to understand why these two microbes carry out photosynthesis so successfully. Ultimately being able to harness such microbial power could slow down increases in levels of carbon dioxide and other greenhouse gases and eventually reduce global climate change.



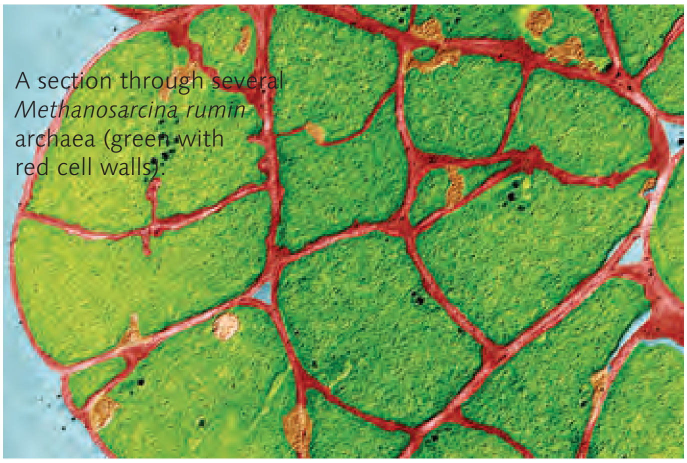
A section through *Prochlorococcus cyanobacterium* cells

How are microbes contributing to global warming?

A group of animals called the ruminants such as sheep, cattle, goats, camels and water buffalo have a special four chambered stomach. The largest compartment is called the rumen. This pouch is teeming with billions of bacteria, protozoa, moulds and yeasts. These microbes digest the cellulose found in the grass, hay and grain that the animal consumes, breaking it down into simpler substances that the animal is able to absorb. Cellulose is the tough insoluble fibre that makes up the cell walls of plants; it gives the plant structure. Animals can't break down cellulose directly as they don't produce the neccessary digestive enzymes.

The methanogens, a group of archaea that live in the rumen, specialise in breaking down the animal's food into the gas methane. The ruminant then belches this gas out at both ends of its digestive system. Methane is a very powerful greenhouse gas because it traps about 20 times as much heat as the same volume of carbon dioxide. As a result it warms the planet up to 20 times more than carbon dioxide. Around 20% of global methane production is from farm animals.

Highland cattle



A section through several *Methanosarcina rumin* archaea (green with red cell walls).

Scientists are looking at ways to reduce the amount of methane emissions from ruminants.

One group in Australia has developed a vaccine which can be given to the animal. The vaccine works by preventing the microbes that live in the animals' rumen from producing methane. The vaccine was tested on sheep which belched 8% less methane in a 13 hour test. At present the vaccine is only effective against 20% of the microbial species that produce methane. To reduce methane production further scientists need to produce a vaccine that is active against more of the archaea that produce methane.

The scientists were concerned that stopping the methanogens from working might affect the digestion of the ruminants and result in the animal being smaller. However what they did find is that cutting down the amount of methane an animal produces actually boosts its growth. This is because the process of methanogenesis uses energy which can result in a small but significant loss of energy available to an animal.

Another group of researchers is looking to see if adding certain food additives to the diet of cattle will reduce the amount of methane they emit.

The role of soil microbes in climate change

Soil is not a sterile substance. It is home to a vast array of life ranging from moles to microbes which makes it a very active substance.

As the climate heats up it is predicted that the activity of microbes responsible for the breakdown of carbon-based materials in the soil will speed up. If this happens then even more carbon dioxide will be released into the environment. This is because increased microbial activity results in an increase in respiration, which produces more carbon dioxide as a waste product.

Experiments in the laboratory have shown that soil respiration and carbon dioxide release can double with every 5-10°C increase in temperature. A vicious cycle is set up. As more carbon dioxide is released it causes global warming, which in turn speeds up the activity of the soil microbes again. Researchers are carrying out investigations to see if this theory is correct and if microbes in their natural habitat will speed up their activity as it gets warmer and increase global warming.


Growing maize for biofuels.

Microbes and biofuels

Biofuels are made from living things or the waste that they produce. One of the most common biofuels, ethanol, is produced from plants. The plant material used is the edible part of the plant such as sugar cane (Brazil) and sugar beet (France) or corn kernels (USA) because it can be easily be broken down to sugar (glucose). The sugar can then be fermented (broken down) to ethanol by microbes such as the yeast *Saccharomyces cerevisiae.* Not only is it expensive to convert edible plant material


Unicellular yeast cells *Saccharomyces cerevisiae.*

What is a carbon neutral fuel?

If biofuels can be made without using huge amounts of energy then they would be carbon neutral. This means that when they are burned the amount of carbon dioxide released into the atmosphere is similar to the amount absorbed by the growing plant when it carries out photosynthesis. At present a large amount of energy, provided by fossil fuels, is required to grow the biofuel crops, transport them and process them into ethanol. When fossil fuels are burned they release huge amounts of stored carbon that have been trapped for thousands of years: releasing the stored carbon upsets the carbon cycle. At present biofuels are not carbon neutral.

into ethanol, ethical issues are also involved. It has been argued that we shouldn't grow food stuffs for fuel when people in some developing countries don't have enough to eat. There is a worry that Brazil will remove huge sections of their rainforest to produce sugar cane. This is an issue because the trees in the rainforest use up huge amounts of carbon dioxide while carrying out photosynthesis. As a result biofuels from food stuffs such as sugar cane are not likely to provide a long term solution as a replacement to fossil fuels.

New ways of producing biofuels

Scientists are investigating the use of cellulose to produce ethanol. The ethanol produced from cellulose is exactly the same as the ethanol that is created from edible plant parts. Cellulose ethanol is produced from lignocellulose which is a mixture of lignin, hemicellulose and cellulose. These three materials make up the plant cell wall. The lignin is the glue that holds the cellulose fibres together and gives the plant its rigidity. The lignocellulose is the part of the plant that remains undigested by us and most animals i.e. it is a non-foodstuff e.g. stalks, sawdust and wood chip. Nearly 430 million tons of plant waste are produced from just farmland every year, not including the waste from forestry operations. There is a huge amount of non-edible plant waste to recycle.

Cellulose is made up of long chains of repeated units of glucose. Hemicellulose is made up of various monosaccharide sugars. It is extremely difficult to breakdown cellulose and convert it into sugars which can then be fermented to produce ethanol because the cellulose is tightly wrapped in lignin.

Scientists have turned to their attention to microbes to see if they can find any that are capable of converting the cellulose and even hemicellulose in lignocellulose into ethanol. The remaining lignin by-product can be burned to produce energy. They have looked in the strangest of places from termites' stomachs to the soil surrounding volcanoes. What they have found is a range of very different microbes that all have one thing in common - they produce a group of enzymes called cellulase.

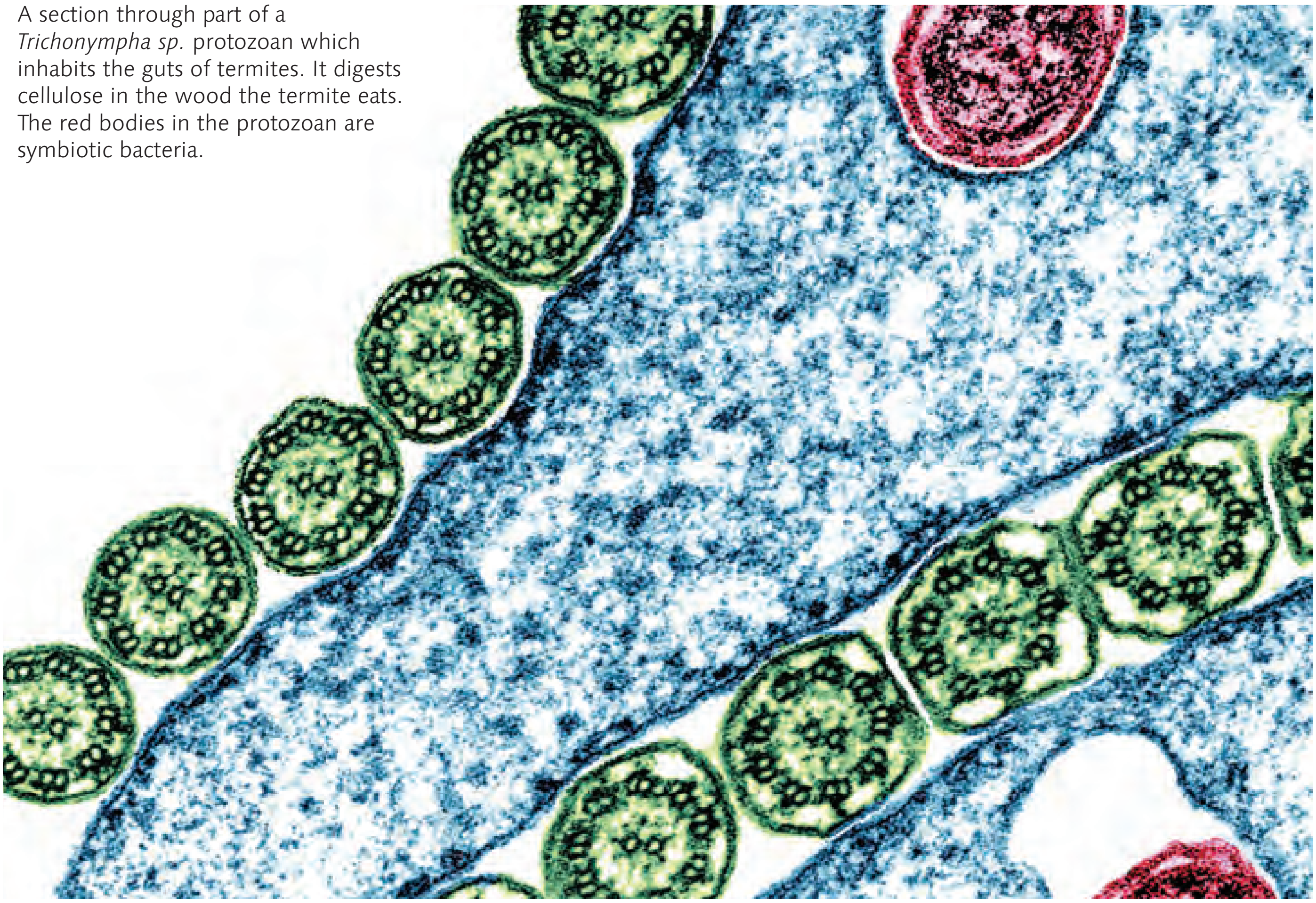
What is an enzyme?
An enzyme is a protein that starts or speeds up a chemical reaction. Every chemical reaction in living organisms is helped by an enzyme. Cellulase speeds up the breakdown of cellulose into sugars.

An archaeon *Sulfolobus solfataricus* lives in volcanic pools near Mount Vesuvius in Italy. It produces cellulase. Researchers are looking at ways of genetically modifying this microbe to see if they can get it to improve its performance and produce more cellulase. In the future *S. solfataricus* may be used to produce biofuel.


Sulfolobus sp.

Termites, which are insects, in nature eat woody plants like trees. When they infest human homes they eat the wood in the house such as doors and also paper products like books. This is because in the termite's stomach there are more than a hundred different species of microbes, many of which are found nowhere else on earth. Scientists are interested in a group of bacteria that digest the termite foodstuffs such as wood and grass. These bacteria produce the enzyme cellulase which breaks down cellulose into sugars. Without these bacteria the termites would die as they couldn't digest their woody diet. The scientists are hoping to find the genes that control the cellulase enzymes and then put

A section through part of a *Trichonympha sp.* protozoan which inhabits the guts of termites. It digests cellulose in the wood the termite eats. The red bodies in the protozoan are symbiotic bacteria.



them into another bacterium that is much easier to grow in the laboratory. They are also hoping to add the microbial genes that are responsible for the breakdown of the sugar into ethanol. This genetically modified bacterium, with its new set of genes, will then, it is hoped, be able to do both steps in the production of biofuel.

Another common wood digester is the fungus *Trichoderma reesei*. It is found in nearly all soils and secretes huge quantities of cellulase. The fungus was originally discovered by the United States during the Second World War. It was responsible for breaking down the cellulose in the soldiers' canvas tents and uniforms which meant they became very holey. It was known as 'jungle rot'.

A company in Canada has harnessed the microbes' ability to convert straw into glucose. The company genetically modified the fungus so that it produces even larger quantities of cellulase. A staggering 75% of the straw fibre is converted into sugar. The left over woody matter, lignin, is dried and then pressed into burnable cakes. The glucose is then fermented with yeast to produce the biofuel ethanol.

So microbes could be the key to the future of powering cars in an environmentally sound way and in the not to distant future we could all be fuelling up at the pump with cellulose ethanol!

The soil fungus *Trichoderma sp.*

Microbiology — society for general

The Society for General Microbiology (SGM) is a professional body for scientists who work in all areas of microbiology. An important function of the Society is the promotion of the public understanding of microbiology. SGM produces and distributes a wide range of resources to support microbiology teaching in schools and colleges across all key stages and post -16. It also runs training courses in practical microbiology for teachers and technicians and occasional workshops. The Society also offers an information service to teachers and participates in schools competitions and other activities.

School Membership of the SGM offers many benefits including:

- *Microbiology Today*, the award-winning magazine
- Discounts on SGM INSET courses
- Priority mailings of SGM teaching resources

Contact
SGM, Marlborough House, Basingstoke Road, Spencers Wood, Reading, RG7 1AG, UK
T: 0118 988 1800
F: 0118 988 5656
E: education@sgm.ac.uk
W: www.microbiologyonline.org.uk

Microbes and Climate Change – A resource for secondary schools

Written and designed by **Dariel Burdass**
Edited by **Janet Hurst**

Acknowledgements
Thanks are due to **Professor Jo Verran (Manchester Metropolitan University)** and **Dr Colin Bielby (Manchester Metropolitan University)** for their helpful comments on the text. Every care has been taken to ensure that the information provided in this factfile is correct, but the author will be pleased to learn of any errors that have remained undetected.

Picture credits
Front cover, Pasieka/SPL*, *p.2 upper left,* David Scharf/SPL, *p.2 upper right,* Dr Kari Lounatmaa/SPL, *p.2 lower left,* Andrew Syred/SPL, *p.2 lower right,* Andrew Syred/SPL, *p.3,* Claire Ting/SPL, *p.4 middle left,* Barbara Strnadova/SPL, *p.4 lower left,* Eye of Science/SPL, *p.5 top half,* Chris Knapton/SPL, *p.5 lower right,* David Scharf/SPL, *p.6 middle right,* Eye of Science/SPL, *p.7 top half,* SPL, *p.7 lower right,* Claude Nuridsany & Marie Perennou/SPL.

**SPL, Science Photo Library*

Microbes and Climate Change is copyright. The Society for General Microbiology asserts its moral right to be identified as copyright holder under Section 77 of the Designs Patents and Copyright Act, UK (1988).

Educational use: Electronic or paper copies of the resource or individual pages from it may be made for classroom and bona fide educational uses, provided that the copies are distributed free of charge or at the cost of reproduction and the SGM is credited and identified as the copyright holder.

First published in 2008 by the Society for General Microbiology, Marlborough House, Basingstoke Road, Spencers Wood, Reading RG7 1AG

©2008 Society for General Microbiology