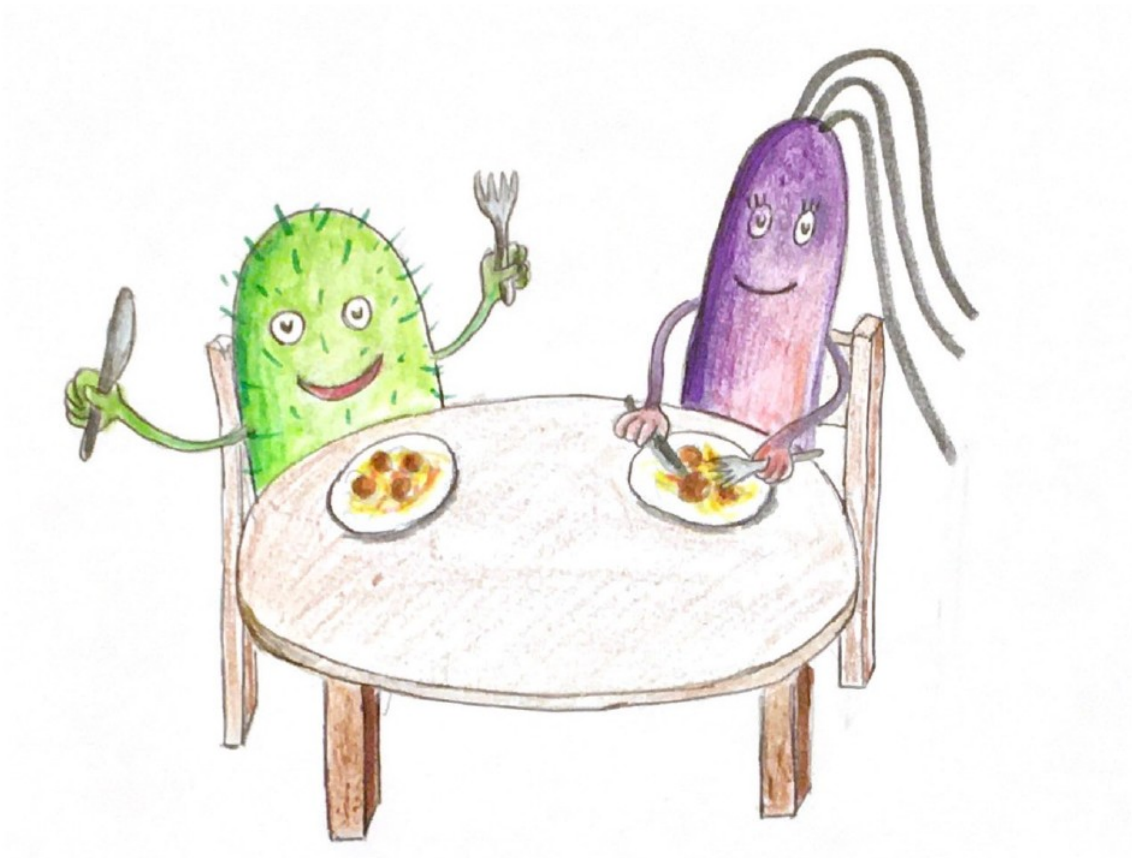
What do microbes eat and what happens to the food?

Mum: do microbes have set meals like us?



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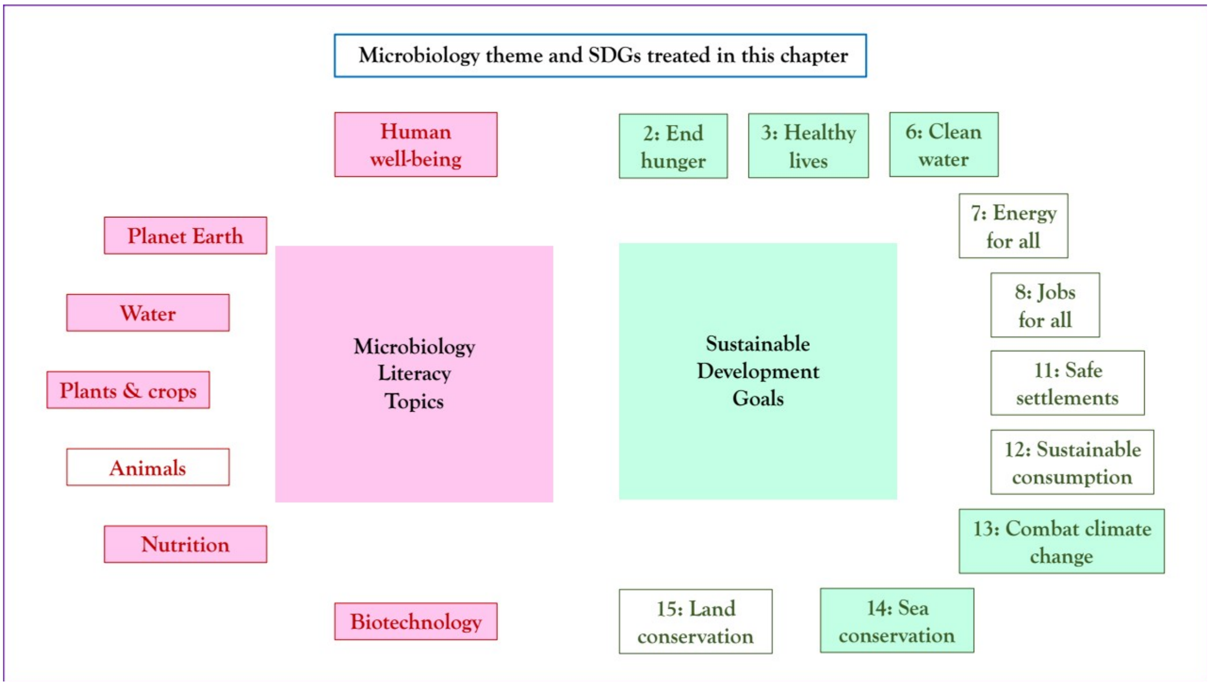
What do microbes eat?

Storyline

All living organisms need to eat, and many higher life forms spend a large part of their days foraging for food. The same is true for unicellular organisms such as bacteria. But how do you eat without a mouth or a stomach, what kind of food do bacteria eat, and what can they do when they run out of food? Here we explain how bacteria are masters of metabolism which allows them to use a variety of food sources in different ways. This flexibility and adaptability make them incredibly successful in colonising even the harshest of environments and using many different types of resources as food. The fact that they have colonised all available environments on the planet in their endless search for food means that they now play a major role in the global cycling of key elements needed by all life. By learning more about how bacteria can "eat" diverse **substrates**, scientists are hoping to harness this ability to our advantage. For example, we want to use the ability of bacteria to eat a huge variety of different chemical compounds to help in bioremediation, by encouraging them to eat toxic compounds that have been spilled. Bacteria are already being used to produce some kinds of valuable molecules, like medicines, in industrial settings.

The Microbiology and Societal Context

The microbiology: bacterial metabolism; energy production; respiration; biosynthesis; degradation; microbial sensing of environmental signals; regulation of gene expression; bacterial population dynamics. *Sustainability issues*: human health, environmental pollution, bioremediation, resource utilisation, conservation, biotechnology, food production.



What do microbes eat? – the Microbiology

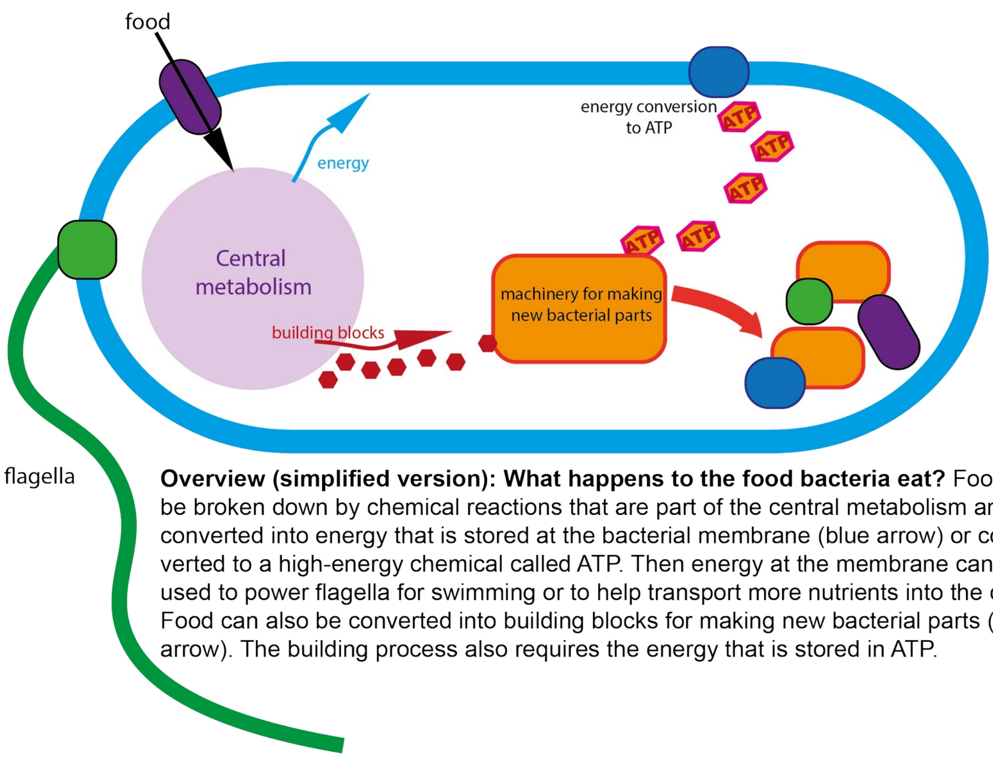
1. ***All living things need to eat***! Humans can go without food for only a few days before our bodies begin to break down, and malnutrition is a huge health problem around the world. Why do we so urgently and constantly need to eat? Food is converted in our bodies into two essential things: energy and building blocks.

a. **Energy** is required to power chemical reactions inside our body, including muscle movement, electrical signals in our brains, nerve signals connecting our brains to our muscles, growing bigger, and replacing cells in our body that wear out, such as skin cells that fall off over time.

Bacteria don't have muscles like we do, but many of them can still move using tiny propellers called flagella. They don't have brains like we do, but they can still sense food or danger or friends in their environments and carry out responses that depend on what they sense. Bacteria also make new copies of themselves – they multiply – any time they can find enough food to support this.

The energy from food is converted into different types of carrier molecules that can store it for later use. For example, **ATP** stores energy in the form of high-energy chemical bonds, that can later be broken to release the energy and power many types of chemical reactions in cells. NADH, NADPH, and $FADH_2$ are molecules that can carry energy in the form of electrons. Energy is released when the electrons are passed to a new molecule that holds them at a lower energy level. And the cell membrane itself can store energy as an electrochemical potential, a bit like a battery.

Some bacteria called **autotrophs** can capture energy from sunlight (these are **photoautotrophs**, or photosynthetic bacteria), or even from high energy inorganic chemicals (like the **chemolithotrophs** of deep-sea vents, see below). These bacteria don't have to find **organic chemicals** in their environment to convert into energy. However, many bacteria are like us, and need to consume organic material (food) as a source of energy; these are called **heterotrophs**.



Overview (simplified version): What happens to the food bacteria eat? Food can be broken down by chemical reactions that are part of the central metabolism and converted into energy that is stored at the bacterial membrane (blue arrow) or converted to a high-energy chemical called ATP. Then energy at the membrane can be used to power flagella for swimming or to help transport more nutrients into the cell. Food can also be converted into building blocks for making new bacterial parts (red arrow). The building process also requires the energy that is stored in ATP.

b. **Building blocks** on the other hand are required for building new parts or growing bigger. The key building blocks that bacteria need contain the elements carbon, nitrogen, phosphorous, and sulphur (plus other elements in much smaller quantities).

These elements are joined together in compounds like sugars, fatty acids, **amino acids**, and **nucleotides**, which are molecules that can be used to build larger cellular structures and machines. Nucleotides are joined into DNA and RNA molecules, which carry the genetic information that defines the bacterium. Amino acids are linked together in long strings to make proteins, which then fold and fit together to form the tiny machines that carry out the cell's activities. Fatty acids are used to make the cell membrane and cell wall, which contain and protect the cell. All bacteria need to acquire these essential elements from their environment to build new cellular components.

2. ***What do bacteria eat, and how?*** Some heterotrophic bacteria eat the same things we do – that is why we find them growing on and spoiling our food if we give them a chance. Since bacteria don't have mouths or stomachs like we do, they need to break food down into small pieces – individual molecules and parts of molecules – in order to be able to bring the food into the cell.

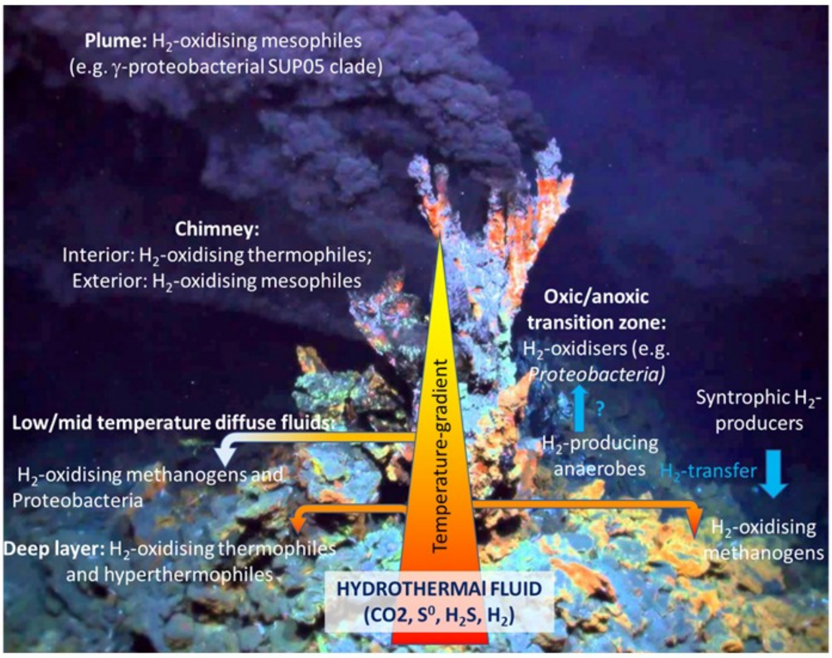
For this, some bacteria can secrete (release from the cells into the immediate environment) **enzymes** (tiny protein-based machines) to dissolve food sources, very much like the enzymes we humans secrete into our intestine (note that the bacteria living in our gut sometimes let our enzymes do the job for them, and sometimes their secreted enzymes can help us to digest our food!).

The food molecules then either diffuse into the cell passively or are actively imported by transporters in the cell membrane that are often specific for one type of molecule. Bacteria are in general much more flexible about what they can eat than humans and can extract useful molecules from all kinds of materials: hydrothermal fluid (see below), oil spills, dead and rotting organic material, pesticides, some kinds of plastics, or even the air!

3. ***What happens to the molecules that bacteria eat?*** As mentioned above, food is used to create energy and building blocks.

Central metabolism refers to complex sets of chemical reactions that can process nutrient sources that bacteria find in their environments and channel them towards providing either energy or building blocks as needed. Breaking food down all the way to **inorganic chemicals** like carbon dioxide and water to extract energy from it is a branch of central metabolism referred to as **catabolism**. Using food as a source of building blocks to make bigger molecules is a branch referred to as **anabolism**.

In this section, we will go into some detail about how these two branches of metabolism feed into the main activities of bacteria: extracting energy from food to power all their activities and building new things (including additional bacteria). Depending on the target audience, some of these details could/should be omitted. However, an important point is that learning more about the details is what will allow scientists to gain more control over how bacteria use nutrients to grow or make certain products. Sometimes, the goal of scientists is actually to prevent bacterial growth (such as with antiseptics, food preservatives, or antibiotics). Other times, bacteria are encouraged to produce certain medicines or foods for us, or to grow near plants to nourish and protect them.



BOX1: A deep-sea hydrothermal vent. Hydrothermal vents are like hot springs on the ocean floor, where seawater becomes super-heated (between 250 and 400°C) by hot magma and begins to dissolve minerals from the earth's crust. The hot, mineral-rich waters then exit the oceanic crust and mix with the cool seawater above. As the vent minerals cool and solidify into mineral deposits, they form different types of hydrothermal vent structures. The most famous ones are the Black smokers which release hot, dark plumes high in sulfur content, and form chimneys made of deposits of iron sulfide which can reach up to 180 feet high.

Despite the extreme temperatures and pressures, toxic minerals, and lack of sunlight that characterized the deep-sea vent ecosystem, the species living there were thriving. Scientists later realized that bacteria were converting the toxic vent minerals into usable forms of energy through a process called chemosynthesis, providing food for other vent organisms such as giant tube worms.

Hyperthermophile (i.e. able to live in extremely hot environments) bacteria harvest chemical energy from the minerals and chemical compounds such as hydrogen sulfide (H_2S) or hydrogen gas (H_2) that spew from the vents. The microbes release new compounds after chemosynthesis, some of which are toxic, but others can be taken in nutritionally by other organisms. Examples of bacterial species are *Methanopyrus kandleri*, a methanogen that harvests energy from hydrogen gas (H_2-oxidisers) and releases methane gas, *Pyrolobus fumarii* that gets its energy from hydrogen gas and produces hydrogen sulfide from sulfur compounds from the vents, or even green sulfur bacteria that contain chlorosomes, organelles that capture energy from the weak radioactive glow emitted from geothermally heated rock.

Background Image credit: Oregon State University / CC BY-SA 2.0

a. **Breaking down food for energy (catabolism).** Some bacteria like to eat sugars (just like our cells) and extracting energy from this type of food requires many chemical reactions that store energy in multiple types of energy-carrying molecules.

Glucose (one kind of sugar made up of 6 carbon atoms) is first split into two three-carbon molecules called pyruvates in a ten-step process called **glycolysis**. The net products of this process are two molecules of ATP and two molecules of NADH (two different types of storage molecule for chemical energy). The two pyruvate molecules can then be converted into two two-carbon molecules called acetyl-CoA and two carbon dioxide molecules in a process called **pyruvate oxidation,** which does not create or use any ATP, but does release one molecule of NADH per pyruvate in the process. The next step in the process is the so-called **Krebs cycle**, also known as the citric acid cycle or the tricarboxylic acid (TCA) cycle. It is one of the most important reaction sequences in biochemistry. Fuel for the eight-step sequence of reactions of the Krebs cycle comes from acetyl coenzyme-A (acetyl-CoA) produced from glucose and other carbohydrates, or from the metabolism of lipids. The Krebs cycle produces four

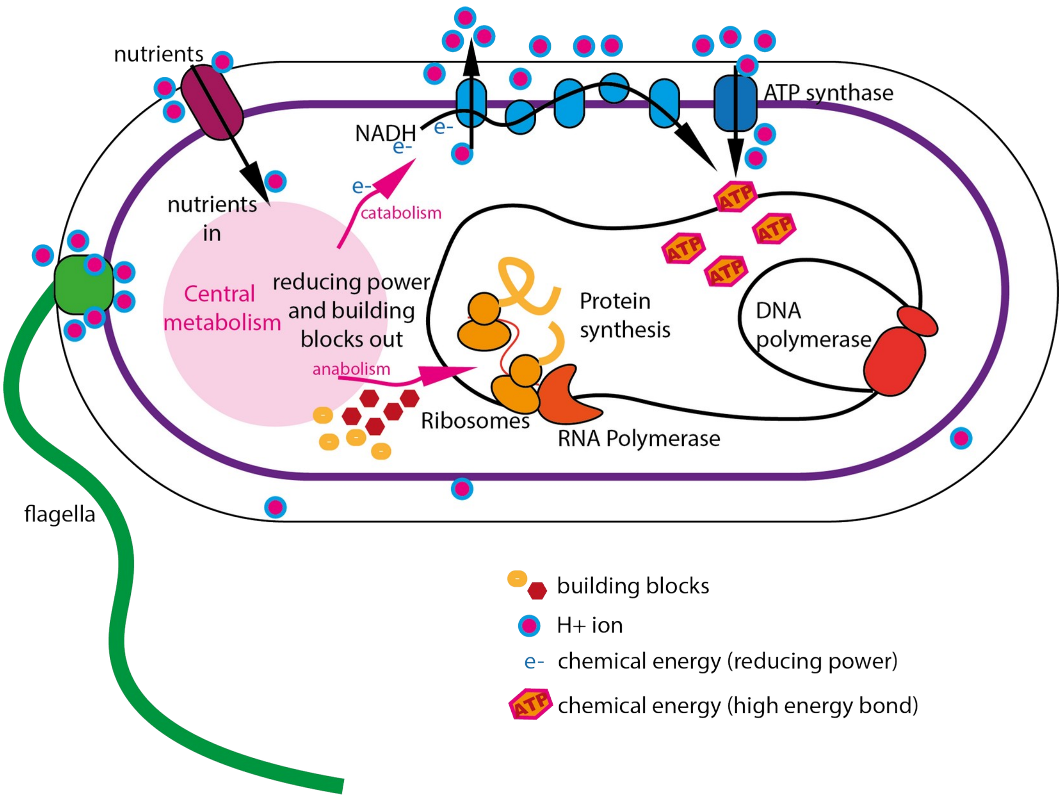
CO_2, six NADH, two $FADH_2$ and two ATPs per original glucose molecule. The NADH and $FADH_2$ molecules are very important, and carry electrons into the electron transport chain, which can ultimately generate a lot of ATP.

i. **Aerobic respiration** a.k.a. **oxidative phosphorylation** uses an electron transport chain to transfer electrons from NADH or FADH2 to oxygen. The chain sequentially releases energy stored in a food molecule in small energy packages rather than in one large single package which would be difficult to handle, like paying for a hamburger with a $ 100 bill.

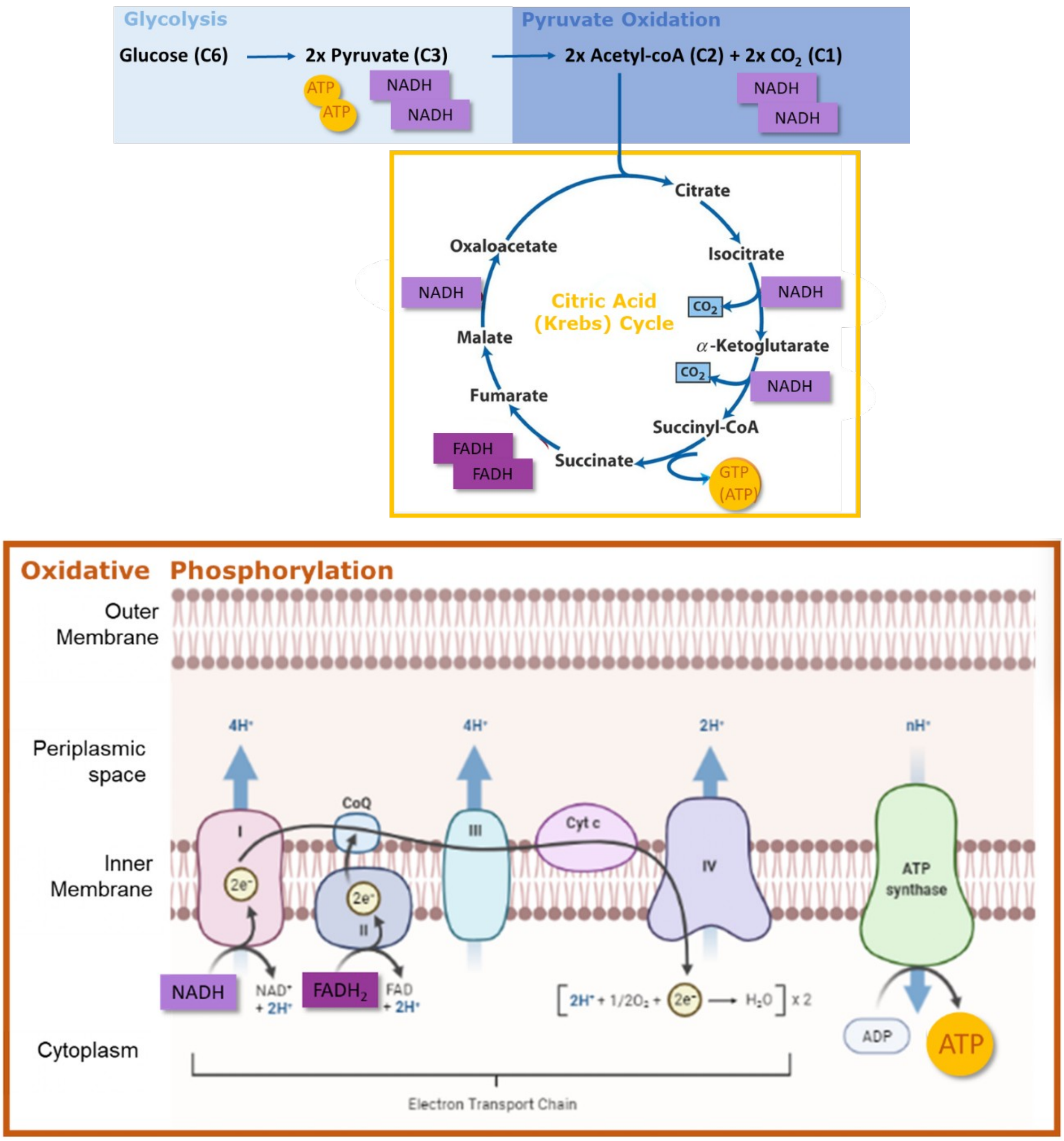
When cells use enzymes to transfer electrons from their food source to oxygen, they move the electrons from a higher energy level to a lower energy level, thereby releasing energy. When electrons are transferred to an oxygen molecule it splits into half and joins with H+ to form water.

Some of the energy released by this process is used to pump additional hydrogen ions (H+) across the cell membrane, so that there is a large imbalance in the amount just outside the cell compared to just inside the cell. This imbalance is referred to as an **electrochemical gradient**. The electrochemical gradient is another way the cell can harness and store energy.

Basically, the H+ ions will always flow across any opening in the membrane to try to balance the levels on both sides so that they are the same. An analogy is how water will flow through a siphon between two buckets until the water levels are the same. This flow of H+ ions can be harnessed by enzymes in the cell membrane.



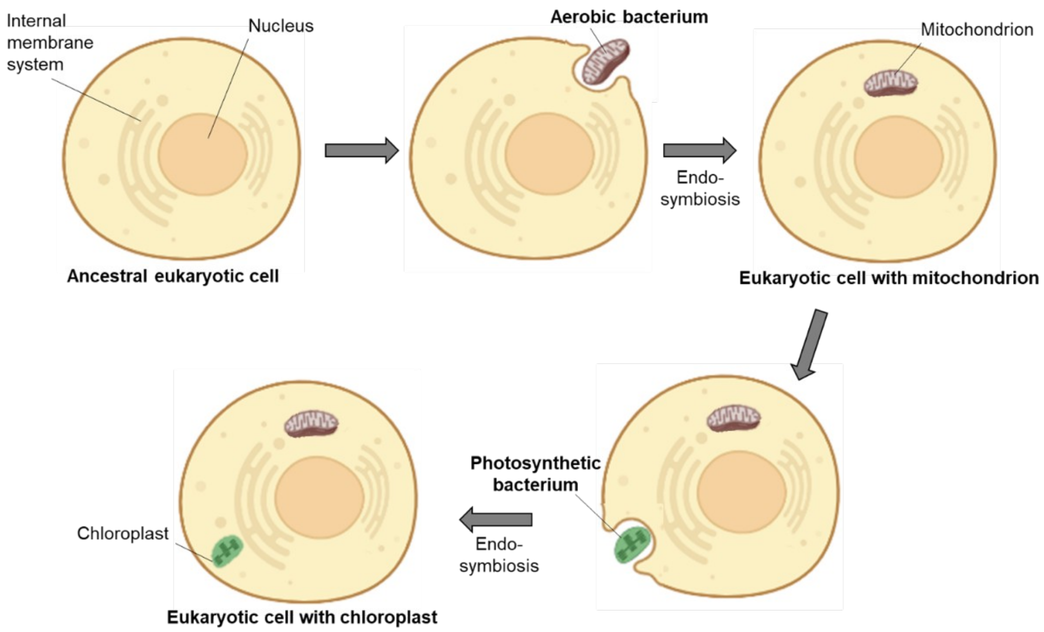
Overview (detailed version): What happens to the food bacteria eat? Food can be broken down by chemical reactions that are part of the central metabolism and converted into reducing power that is then fed into the electron transport chain. The electron transport chain pumps hydrogen ions across the bacterial membrane, creating an imbalance. This "electrochemical gradient" can be used to power the flagella for swimming, the import of additional nutrients, or the production of a high-energy chemical called ATP. into the cell. Food can also be converted into building blocks for making new proteins, mRNA, and DNA. These building processes are carried out by ribosomes, RNA polymerase, and DNA polymerase, and also require the energy that is stored in ATP.



Box 2: Metabolic pathways in the presence of oxygen and carbohydrates as the main food source. Longer carbohydrate molecules are first broken down into individual sugar molecules and then converted into glucose, where possible. Glucose molecules are then broken down into two molecules of pyruvate, which are then converted into acetyl-CoA and carbon dioxide. The acetyl-CoA molecules feed into the Citric Acid cycle. All three steps mainly create NADH and FADH molecules, which then act as electron donors in the oxidative phosphorylation pathway in which electrons are transferred along membrane-bound enzymes, with an oxygen molecule acting as the final electron acceptor. The net equation for aerobic respiration is: glucose + oxygen → carbon dioxide + water (+ energy released). In aerobic respiration, one molecule of glucose yields 38 ATP molecules, either produced directly or indirectly through NADH: eight are produced during glycolysis, six from the link reaction and 24 from the Krebs cycle. The net gain is 36 ATP, as two of the ATP molecules produced from glycolysis are used up in the re-oxidation of the hydrogen carrier molecule NAD. The molecules that are produced in the Krebs cycle can be used as building blocks for a large number of important processes, including the synthesis of fatty acids, steroids, cholesterol, amino acids for building proteins, and the purines and pyrimidines used in the synthesis of DNA. Created with Biorender.com.

For example, the H+ ions pass through an enzyme called ATP synthase and the flow pushes a wheel around (like a water wheel, but on an extremely tiny scale) to form the high-energy chemical bonds of ATP. The H+ ions can also directly turn propeller-like appendages called flagella to allow some bacteria to swim. Finally, H+ ions can help nutrients to get into the cell through specialised channels, sometimes by flowing along with the nutrients. If bacteria run low on food, all these processes must slow down, but maintaining some imbalance of hydrogen ions across the cell membrane (some "charge") is perhaps the most important priority. If the cell fails to do this, it dies.

In human cells, which are much bigger than bacteria, these same processes also take place, but inside a specialised compartments of the cell called mitochondria. It is now widely accepted by scientists that mitochondria came from ancient bacteria that were engulfed by the ancient ancestors of human cells, and that they evolved a cooperative relationship over many millions of years! (see Box 3 for the origin of mitochondria as a product of endosymbiosis with a bacterial cell).



Box 3: Endosymbiosis theory of the origin of eukaryotic organelles. Eukaryotic (=nucleus-containing) organisms such as higher animals and plants are thought to have acquired their ATP-synthesis capacity (taking place in organelles called mitochondria) and photosynthetic capacity (taking place in organelles called chloroplasts), respectively, by engulfing different types of bacteria. In the first instance, an ancestral eukaryotic cell acquired a bacterial cell, which later form a symbiotic relationship with its host by providing energy through ATP-production by oxidative phosphorylation in exchange for nutrients. Mitochondria have retained their own circular DNA which is more closely related to the DNA of Alphaproteobacteria than that of any eukaryotic organisms. Later on, a mitochondrion-containing eukaryotic cell also acquired a photosynthetic bacterium, which also entered a symbiosis by performing photosynthesis for its hosts that developed into what is now known as the plant kingdom. Created with Biorender.com

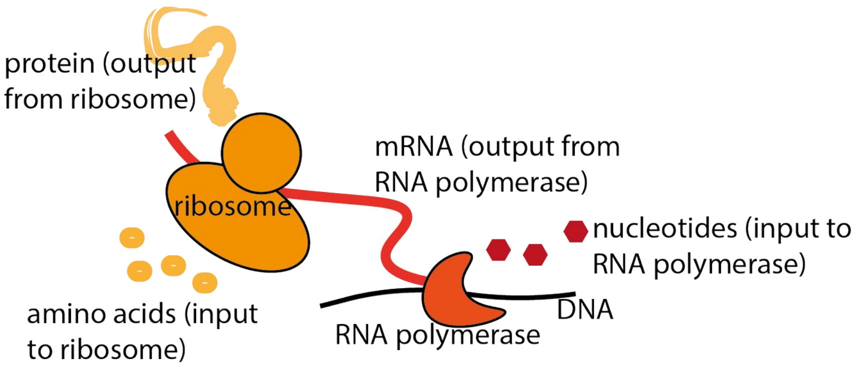
ii. **Anaerobic respiration.** Some bacteria, described as anaerobic, do not like to live where oxygen is present. One option for them is to perform many of the steps described above in a similar way, but instead of giving the electron that has travelled through their electron transport chains to oxygen, their enzymes can give it to a different terminal electron acceptor.

Examples of alternative terminal electron acceptors include other chemicals such as nitrate (NO_3), fumarate, dimethyl sulfoxide, or even metal ions like iron or manganese. These bacteria live in environments where such molecules are abundant.

Another option is to avoid an electron transport chain altogether. The bacteria that adopt this strategy can still perform metabolic steps that extract some energy from their food (such as glycolysis) but they do not donate electrons to an electron transport chain that pumps hydrogen ions across their membrane. They tend to have less total energy available to them, and they still must use some of their energy to maintain a gradient of H+ ions across their membrane. New ways of generating and maintaining an H+ gradient in anaerobic bacteria are still being discovered, as it is difficult to study bacteria that die in the presence of oxygen!

b. **Using food to build new things (anabolism)**. Bacteria must reproduce to perpetuate their species. Many bacteria reproduce by growing larger until they have doubled in size and then by dividing in half. This means that each bacterium must make new copies of all its parts to divide from one into two bacteria that each have approximately the same contents.

A lot of the ATP energy created and stored by the catabolic branch of metabolism is used to power the enzymes that build new cellular parts. These enzymes also require a supply of building blocks as input: other nucleotides, amino acids, and fatty acids, which come from metabolic conversions of food molecules. A lot of the new molecules being built are new protein–based enzymes, which can in turn contribute to the building activities. To make new proteins, the cell first copies instructions that are permanently stored as **DNA** into a temporary working copy known as **mRNA**. This is carried out by an enzyme called the **RNA polymerase**. The mRNA molecule is then translated into an ordered sequence of amino acids by a large and complicated enzyme called the **ribosome.** Finally, the chain of amino acids folds up into a three-dimensional structure that can carry out a specific task.



Box 4: Details of new protein production. The RNA polymerase copies instructions for building a new protein from the DNA sequence into an mRNA molecule, using nucleotides as building blocks. Next, a ribosome adds amino acids together to form a new protein in the order specified by the sequence of the mRNA. The new protein then folds up from a string of amino acids into a 3D structure that can carry out functions in the cell.

4. Do bacteria ever run out of food? Bacteria are very resourceful and can live in almost every environment. This is one way in which bacteria have evolved to deal with shortages of their preferred food – they have just acquired the ability to use new and different kinds of molecules as food! However, they do often need to search for food or wait for more to come along. For additional discussion of strategies that bacteria use to survive food shortages, see also Topic Framework “Food Deprivation Stress”.

Some environments do not have very much food available or have other kinds of stresses present (too hot, too cold, too salty, or too acidic for example). These environments tend to have relatively low total numbers of bacteria, and the bacteria there grow very slowly all the time. They have evolved over many millions of years to get by with the poor nutrient sources that are available, and even if you give them plenty of food, they still can’t grow quickly. Although they are always subsisting on a very limited amount of food and energy from their environment, they do not have to compete with as many other bacteria, so growing very slowly is not a problem.

In nutrient-rich environments, bacteria can grow very quickly – some species can make a new bacterium in under 10 minutes, and the common laboratory bacteria *E. coli* can divide every 20 minutes. However, they can’t keep this up for long. If you started with one *E. coli* cell and gave it enough food so that it and all its descendants could keep dividing every 20 minutes, they would become more massive than the known universe in less than 3 days. Obviously, this does not happen. The fast-growing bacteria in nutrient-rich environments quickly use up the existing food, and then they must stop growing and wait for more food to become available.

Nutrient-rich environments often have large numbers of bacteria present, so they are all competing to consume newly available foods as fast as possible. This can result in a “boom and bust” dynamic where the arrival of nutrients causes a burst of very fast growth, followed by a long period of waiting when nutrients are scarce. Examples of environments where this happens can include the soil, the oceans, lakes, and even plants and the bodies of animals. A burst of nutrients in soil or the ocean could come in the form of a plant or animal that has died and can then be recycled by microbes. It can also come from pollutants that humans spill into the environment.

In the case of bacteria that are stably associated with living plants or animals in a cooperative relationship, the host may be able to control when its bacterial partners have good access to food. In the case of infections, one strategy the immune system can use is to try to deprive the infecting bacteria of essential nutrients so that they cannot grow. Bacteria who live in these kinds of “sometimes nutrient-rich” environments must have strategies for navigating both situations – they must be able to respond quickly and grow rapidly when nutrients are available but stop growing and conserve resources when the nutrients are used up.

Relevance for Sustainable Development Goals

- **Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture.** Bacteria play roles in every step of food production and consumption, and their activities are driven by their own efforts to find food for themselves. They live in association with plants because plants can help them obtain carbon, and they can in turn help the plants obtain nitrogen and phosphorus. Better understanding of this cooperation could help us improve agricultural efficiency and decrease reliance on chemical fertilisers. Bacteria are also responsible for spoiling food sometimes, when they eat the food before we get to it. Understanding how to decrease their growth on our foods can help reduce food spoilage. Finally, bacteria play essential roles in helping us to digest and process our food once we have eaten it – we have huge numbers of them living in our guts.
- **Goal 3: Ensure well-being and promote healthy lives at all ages.** We have trillions of bacteria living on our skin, in our mouths, and in our guts, and we are just starting to understand the importance of keeping our bacterial friends happy and healthy if we ourselves

wish to be healthy. For example, if we do not feed the "good" bacteria in our guts the things that they want to eat (vegetables!), they may start to starve and begin eating things they are not supposed to, like the mucus layer that protects our gut cells. Human bodies are great sources of nutrients for bacteria, and they compete to be able to live on us. Sometimes, the health-promoting "good" bacteria can lose out to dangerous bacteria that can grow too much and damage our tissues – we call this situation a bacterial infection. Normally, we take antibiotics to kill off the dangerous bacteria, and if the antibiotics can kill most of the bacteria in an infection, the balance between our immune systems and the good bacteria can usually be restored. However, we now know that antibiotics can sometimes kill too many of the good bacteria, leaving an open source of food for dangerous bacteria to pursue. A better understanding of how bacteria compete for food in our bodies can help us design better antibiotics.

- **Goal 6: Ensure availability and sustainable management of water and sanitation for all.** Clean water is actually not a very good environment for most bacteria to live in – there is not enough food! Therefore, ensuring that people have clean water to drink is a very good way to decrease the chances of infection by dangerous bacteria. Interestingly, some other kinds of bacteria have been put to work in water treatment facilities to help with the water cleaning process. It turns out that these bacteria have evolved to be very good at extracting even tiny amounts of nutrients from water. When wastewater comes into the treatment plant, it is full of nutrients from fertilisers that people use in their gardens, from the dirty dishes they washed in their sinks, and from the wastes they flushed down the toilet. The bacteria in the wastewater treatment plant are not given any other nutrients so they are ready to eat up as many nutrients from the wastewater as possible. Once they have filled up on nutrients, they sink to the bottom of the pool they are in, and the water can be moved along to the next step in the process, leaving the bacteria and all the nutrients they consumed behind. Because these bacteria are so good at extracting nutrients from water, once they have finished it is much less likely that dangerous bacteria will find enough left-over nutrients to grow. Scientists are still learning more about how to get bacteria to do their most efficient work to help us clean our water.
- **Goal 13: Take urgent action to combat climate change and its impacts.** Bacteria play enormous roles in global cycling of carbon, and we are still learning about the ways in which they can impact levels of greenhouse gases in the atmosphere. Different bacteria can either consume and/or produce the main greenhouse gases, carbon dioxide and methane, at different rates depending on what other resources are available to them. For example, the bacteria in a healthy soil ecosystem can help the plants and trees in that ecosystem to remove carbon dioxide from the atmosphere and store it as organic carbon in the soil, where it does not cause warming. However, if the trees and plants are cut down, different bacteria will use them as nutrients, and in the process release carbon dioxide back into the air. Another example is in the ocean. Huge numbers of photosynthetic bacteria in the ocean can remove large amounts of carbon dioxide from the atmosphere, but only if they can find enough nitrogen, phosphorus, and iron to support their growth. Before industrial whaling killed a huge percentage of the whales in the world's oceans, the whales did an important job of distributing these key nutrients throughout the oceans. This helped to support the growth of the cyanobacteria in oceans far away from land. Understanding how bacterial nutrition and metabolism impacts carbon cycling on a global scale may help us learn which types of ecosystems are most important to preserve and how best to support them to encourage their plants and bacteria to remove carbon dioxide from the atmosphere rather than adding it.
- **Goal 14: Conserve and sustainably use the oceans, seas, and marine resources.** A major threat to coastal waterways is pollution running off from the land or from oil spills.

Many bacterial species view these pollutants as food sources. On one hand, this means that in addition to the problems directly posed by the pollutant itself, a secondary problem of increased bacterial growth is often caused by the pollution. The increased bacterial growth can cause enormous problems for fish and other marine wildlife, and sometimes also causes health problems for humans. Controlling pollution of marine environments to limit bacterial blooms near coasts should be an important priority. On the other hand, when spills of pollutants like oil happen, some types of bacteria could be usefully deployed to help clean up the spill by eating the oil for food. Scientists are beginning to learn more about the specific types of bacteria that are best at doing this.

Pupil participation

1. ***Class discussion of the issues associated with food sources and survival strategies of bacteria***

2. ***Pupil stakeholder awareness***

a. The ability of bacteria to “eat” unusual substrates is being used in many different industries. Can you name some examples?

b. Many types of bacteria like to eat the same foods that we eat, and when they start to eat our food they cause it to spoil. Other times, people can become ill if dangerous bacteria are growing in their food. What are some examples of things we do to try to prevent bacteria from eating our food? What other things might we try?

c. Can you think of any times when humans might add nutrients to the environment that cause a burst of bacterial growth? Are there ways to change our activities to avoid this?

d. Bacteria have evolved ways to reduce, re-use, and recycle resources, so they can make their food sources last longer when they are limiting. Do you think humans should be thinking of ways to do these things too, to conserve resources that are important for us? What are some examples of how we are already doing these things? How might we be able to do better to conserve our resources?

The Evidence Base, Further Reading and Teaching Aids

How Do Bacteria Feed? (sciencing.com)
Nutritional Types of Bacteria (sciencing.com)
The Microbes That Keep Hydrothermal Vents Pumping | Smithsonian Ocean (si.edu)
The hole that whaling left behind (The Atlantic)
Can soil microbes slow climate change? (Scientific American)
Biointeractive_Winogradsky.jpg (7200×5400)

Glossary

aerobic respiration/oxidative phosphorylation: A series of chemical reactions taking place at a membrane in which electrons are transferred from a carrier molecule, down an electron transport chain, to oxygen and hydrogen ions are pumped across the membrane. Later, the hydrogen ions flow back down the concentration gradient and ATP is produced.
amino acid: a chemical building block that is a constituent of proteins

anabolism: the branch of metabolism that is responsible for using nutrients as building blocks for new cellular components
ATP: adenosine triphosphate, a molecule that can store energy in the form of a high-energy chemical bond
autotroph: an organism that does not need to consume organic chemicals as a source of energy
catabolism: the branch of metabolism that is responsible breaking down nutrients to provide energy
central metabolism: the collection of chemical reactions that process food and partition nutrients toward energy or building blocks
chemolithotroph: an organism that does not require organic chemicals for energy but can instead use chemical reactions of inorganic chemicals as a source of energy. A type of autotroph.
DNA: The molecule that stores all the genetic information of an organism, in the form of deoxyribonucleotide sequences that are instructions for making proteins.
electrochemical gradient: An imbalance of electric charge and/or hydrogen ion concentration across a membrane.
enzyme: A protein-based machine that can help carry out a chemical reaction.
glycolysis: A series of chemical reactions that break down the sugar glucose into two molecules of pyruvate.
heterotroph: An organism that requires organic chemicals as a source of energy.
inorganic chemical: Any chemical that lacks either carbon or hydrogen atoms.
Krebs cycle/tricarboxylic acid cycle: A series of chemical reactions that remove electrons from acetyl-coA molecules, releasing carbon dioxide and delivering the electrons to the electron transport chain.
mRNA: The temporary "working copy" of instructions to make a protein. The instructions are copied from the DNA sequence of deoxyribonucleotides into the mRNA sequence of ribonucleotides.
nucleotide: The basic building block of DNA and mRNA molecules; includes ATP as well.
organic chemical: Any chemical containing carbon and hydrogen atoms.
photoautotroph: An organism that can obtain energy from light.
pyruvate oxidation: The conversion of a pyruvate molecule to a molecule of carbon dioxide and a molecule of acetyl-coA.
RNA polymerase: An enzyme made up of several individual proteins that copies instructions from DNA into mRNA molecules.
ribosome: An enzyme made up of many individual proteins that reads the instructions from an mRNA molecule to build a protein.
substrate: The starting material on which a chemical reaction (or series of chemical reactions) takes place. This term can be broadly used to refer to the food sources that bacteria transform into energy and building blocks by a series of chemical reactions.