# Biogas

***Mum: Today, granny and I took a bright green bus around the city. It said "biogas bus" on it. What does it mean?***


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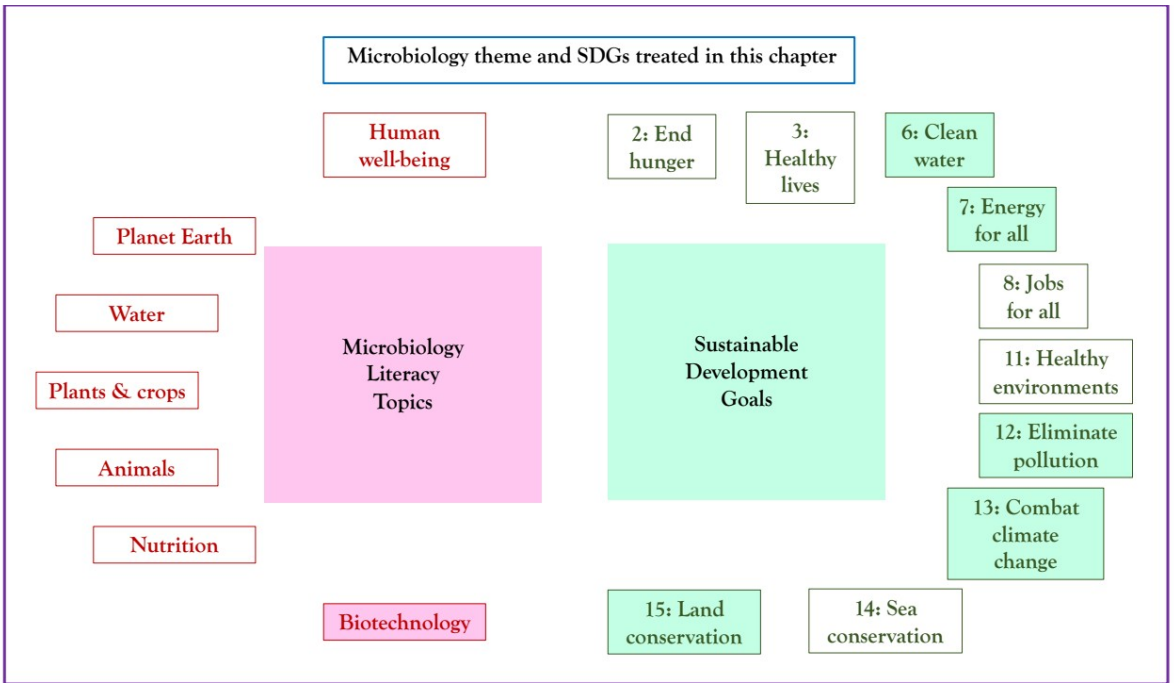
# Biogas

## Storyline

Biogas refers to the mixture of methane and carbon dioxide, which are produced by microorganisms through the decomposition of organic compounds such as sewage sludge, industrial wastewaters, food waste and animal manure. Biogas can be used as a fuel for vehicles or to generate electricity or heat instead of fossil fuels. In our daily lives it can replace natural gas for cooking and heating because methane is the biggest component of the natural gas. Turning waste into biogas is also beneficial for reducing waste and greenhouse gas emissions to the atmosphere. However, this task is challenging. This is because biogas production from organic compounds is carried out in environments with no oxygen, which requires strict operational control. Also, microorganisms that carry out this anaerobic process require different physical and chemical conditions to grow. Therefore, it is important to provide the growth conditions of all microorganisms involved. Another important point is that the carbon dioxide needs to be removed from the biogas to increase the efficiency of the process, which requires careful operation. Lastly, biogas requires to be transported in the same way as other fossil fuels, which increases its carbon footprint. However, the advantages of using biogas compensate for these disadvantages as it helps meet many of Sustainable Development Goals (SDGs).

## The Microbiology and Societal Context

*The microbiology:* Microbial biogas production; greenhouse gas reduction. *Sustainability issues:* Reduced fossil fuel consumption; waste recycling; nutrient recycling; climate change.




Biogas: the Microbiology

1. ***Biogas is a sustainable and renewable energy source.*** Biogas is produced via a natural process called anaerobic digestion, which is carried out by specific groups of microorganisms. These microorganisms are fed sewage sludge, industrial wastewater, agricultural or food waste. They break these wastes down into smaller organic materials and eventually into biogas (methane and carbon dioxide). Traditionally, non-renewable resources (fossil fuels such as coal, petroleum and natural gas) are used to generate useable energy: motion, heat and electricity. These fossil fuels were formed millions of years ago and are now found in the subsurface of the Earth. Therefore, they cannot be replenished and are difficult to extract. Biogas, however, is produced from recycling waste materials via anaerobic digestion, which provide us with a renewable energy source.

2. ***Biogas reduces greenhouse gas production.*** Generating usable energy (e.g. electricity) from non-renewable sources contributes to greenhouse gas emissions significantly. This is because when fossil fuels are burned, greenhouse gases (mainly composed of carbon dioxide and methane) are produced and emitted to the atmosphere. In addition, these gases, which have been locked up underground for a long time, leak during the extraction of fossil fuels from the subsurface. Recycling organic waste to generate motion, electricity or heat, therefore, provides us with a renewable and sustainable source of energy whilst reducing greenhouse gas emissions substantially. For instance, when agricultural waste is used to produce biogas, the carbon comes from the plants and crops that used carbon dioxide in the air to grow. This reduces the amount of carbon dioxide levels in air. Also, methane in biogas is used as an energy source, so methane emissions are reduced substantially.

3. ***Biogas reduces the amount of waste to be disposed in landfills***. Municipal solid waste, food waste and non-recyclable waste are disposed in landfills, where they slowly decompose. Once buried on landfills, oxygen is quickly used up by aerobic bacteria, the environment then turns anaerobic and anaerobic microorganisms start to decompose the waste. As a result, methane and carbon dioxide are produced. Methane is a flammable gas, so it can be dangerous

when it accumulates underground in an uncontrolled manner. Therefore, landfills should be monitored and managed carefully. Using industrial and food wastes to produce biogas reduces the amount of waste to be disposed in landfills. This not only helps to mitigate the greenhouse gas emissions and reduce uncontrolled methane generation, but also allows to return the landfill sites to beneficial use.

4. ***Biogas production process provides us with organic fertilizers***. The anaerobic digestion process generates biogas and a leftover solid fraction. This fraction contains nutrients (nitrogen, phosphorus, potassium and others) and other organic matter required in modern farming and so is used as biofertilizer. This allows recycling of nutrients, which is particularly important for protecting diminishing sources of nutrients such as phosphorus.

5. ***Production of biogas requires investment.*** Biogas is produced in anaerobic digesters, which require high investment and operational costs including construction, equipment, installation, technical staff and transportation of organic waste and biogas to and from the plant. Also, the optimum temperature for microorganisms to carry out the whole process (~35°C) is higher than the ambient temperature. So, the anaerobic reactors need to be heated up for successful operation, which increases the operational cost. However, this may be overcome by using biogas generated energy. Industries that use anaerobic digesters as part of their wastewater treatment plant can use the energy generated from their own waste. In fact, they sometimes sell excess energy they produce to the national grid and turn this costly investment into profit. Similarly, farmers can save energy by turning agricultural waste into biogas in small size anaerobic digesters and by using this biogas to fuel their equipment on site.

**6.** ***Improved biogas production efficiency and specialised knowledge required***. Biogas production via anaerobic digestion is a natural process where microorganisms are used at every step. Despite it being a natural process, specialised design and equipment are required for successful operation of anaerobic digesters. This is in part due to the sensitivity of microbial groups to some environmental factors such as temperature and pH. Since the microbial world is highly complex, we are far from fully understanding the optimum conditions for microorganisms and the interactions between them. This sets a barrier to further development of anaerobic digestion systems in short time frames. However, investment into research on the microbiology of anaerobic digesters is increasing every year. Likewise, training of technical staff is expanding.

## Relevance for Sustainable Development Goals and Grand Challenges

Biogas production through the activity of natural microbial populations relates to several SDGs, including:

- **Goal 6. Ensure availability and sustainable management of water and sanitation for all** *(assure safe drinking water, improve water quality, reduce pollution, protect water-related ecosystems, improve water and sanitation management).* Anaerobic digestion systems that are used to produce biogas also contribute to the efficiency of wastewater treatment by reducing the carbon load of treatment plants. They also provide decentralised, local waste treatment facilities, which reduce the spread of bacterial infections such as cholera and hepatitis (WHO, 2015).

- **Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all** *(ensure access to clean, renewable and sustainable energy, and increase energy use efficiency).* Biogas production contributes to SDGs significantly by providing sustainable energy (electricity, heating, fuel) derived from waste. This reduces reliance on fossil fuels and natural gas. Anaerobic digestion systems also provide means for rural areas that currently do not have access to electricity or gas grids. The public can produce energy using their own agricultural, food or household waste.
- **Goal 12. Ensure sustainable consumption and production patterns** *(sustainable and efficient use natural resources, reduce waste generation, reduce fossil-fuel use).* Biogas production is carried out by microbial communities and serves as a natural, renewable and sustainable energy source by recycling and reusing waste products to generate energy that replace fossil fuels. This reduces our reliance on natural resources and increase the efficiency of their use. Furthermore, the organic fraction that is produced as by-product of anaerobic digestion is rich in nutrients (nitrogen, phosphorus and others), hence is used as fertilizer in farmlands. This is particularly valuable when food waste, which contains a high amount of nutrients, is used in anaerobic digesters. The nutrients in food waste are returned to agricultural land rather than buried in landfill.
- **Goal 13. Take urgent action to combat climate change and its impacts** *(reduce greenhouse gas emissions, mitigate consequences of global warming, develop early warning systems for global warming consequences, improve education about greenhouse gas production and global warming).* Global energy production is met mainly by fossil fuels (coal, natural gas and petroleum), which contributes to the emission of greenhouse gases, methane, carbon dioxide and nitrous oxide, to the atmosphere. This is via the leaks during fossil fuel extraction and burning the fossil fuels. However, biogas generation from organic waste reduces the extraction and consumption of fossil fuels, hence helping combat climate change. Methane in biogas is used as an energy source, reducing the methane emissions. Also, biogas from agricultural waste consists carbon from plant material and crops which use carbon dioxide already emitted to the atmosphere.
- **Goal 15. Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss** *(ensure the conservation, restoration and sustainable use of land, restore degraded land and soil, reduce the degradation of natural habitat).* Biogas production via food, agricultural and other organic waste decreases the amount of waste that would go into landfills. This helps reduce the area dedicated for landfills, which, if not managed properly, risk the quality of soil and groundwater.

## Potential Implications for Decisions

1. ***Individual***
   a. Setting up an anaerobic digestion system in the garden to turn food waste into methane, which I can use instead of natural gas. Cost vs. carbon footprint.
   b. Separation of the organic fraction from household waste.

2. ***Community policies***
   a. Use of local waste to produce energy by local management (i.e. councils). This reduces the burden on landfills and the cost of energy.
   b. Old landfill area can be designed as gardens for public use.

3. ***National policies***
   a. Limiting greenhouse gas emissions by industries, regardless of company scale.
   b. Setting up anaerobic digesters in rural areas.
   c. Strict management of landfills.
   d. Limiting the amount of waste that can go into landfills.

## Pupil participation

1. ***Class discussion of the issues associated with biogas production and energy sources***

2. ***Pupil stakeholder awareness***
   a. Can you think of anything you can personally do to reduce your energy consumption?
   b. Which of the SDG are most important for you and your family?
   c. Can you think of any ways we can do to reduce waste and sort waste for anaerobic digestion?

3. ***Exercises***
   a. Separate collection of food waste is available in only a few locations. How can we increase the awareness of this issue and facilitate food waste recycling?
   b. On what do we spend the most energy in cities? How can we reduce this?
   c. How would you design a small-scale anaerobic digestion system for your house? What would go into the digester? How would you use the energy and the left-over organic compound?

4. ***Class experiments***
   a. Visiting wastewater treatment plants (particularly the ones with anaerobic digesters) to understand the role of microorganisms in decomposing waste.
   b. Visiting waste composting companies and associated testing for greenhouse gas emissions.
   c. Visiting fossil fuel (petroleum, gas and coal) industries and companies providing services to them.
   d. Visiting farms and horticulture facilities to understand the role of biofertilizers.
   e. Visiting landfill sites and understand how they are managed.

## The Evidence Base, Further Reading and Teaching Aids

1. https://www.worldbiogasassociation.org/why-biogas/
2. https://www.europeanbiogas.eu/wp-content/uploads/2019/09/Biogas-Basics-EBA.pdf
3. https://www.parliament.uk/documents/post/postpn387_anaerobic-digestion.pdf
4. Xu, F., Li, Y., Ge, X., Yang, L. and Li Y. 2018. *Anaerobic digestion of food waste -Challenges and opportunities*. Bioresource Technology, 247:1047-1058.
5. Ziganshin, A.M., Liebetrau, J., Proter, J. and Kleinsteuber, S. 2013. *Microbial community structure and dynamics during anaerobic digestion of various agricultural waste materials*. Applied Microbiology and Biotechnology, 97:5161-5174.

## Glossary

**Sewage sludge**: Residual product of the treatment of municipal or industrial waste.
**Natural gas**: Mixture of naturally-produced gas mainly made up of methane.
**Anaerobic digestion**: Natural process by which microorganisms break down organic compounds into smaller organic compounds in the absence of oxygen.
**Fossil fuel**: Fuel produced by natural processes such as anaerobic digestion of dead plants and animals. Natural gas, coal, crude oil are all fossil fuels.
**Landfill**: Sites designed and dedicated for burying waste material.
**Aerobic bacteria**: Microorganisms that can survive and grow in the presence of oxygen. These microorganisms breathe oxygen.
**Biofertilizer:** Fertilizers that contain several microorganisms that are useful for the growth of plants by increasing the nutrient supply.