The key role of microbes in the energy grid as the master chemist of Earth

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The current issues in food and fuel prices have sounded an alarm to the world. Global energy supply and minimizing of climate changes are the two greatest challenges facing the 21st century society. The unseen populations of the microbial world, that include bacteria, yeasts, fungi, and archaea, can be helpful to address these challenges. Over the bygone diverse mutations, recombination events, and lateral gene transfer processes have transformed the microbes to access most of the theoretically possible oxidation-reduction reactions, as well as capture solar and other energy resources, and inhabit in a wide range of impossible and diverse environments. Some microbes are extrememophile, and exist beyond the current limits of the living environment. There are about 10^{30} microbes estimated to be living in the Earth. Most of them are still unknown. These unknown microbes live on and in the human body. People encounter some microbes regularly in food, water and air. Others live in inhospitable places. Most of the microbes are beneficial, and their combined effort acts positively affecting numerous activities on Earth. The microbes offer efficient ways to convert plants or other biomass, into liquid fuels, hydrogen, methane, electricity, or chemical feedstocks which are currently derived from fossil fuels.

Microbes in biofuel production

For the purpose of energy production microbes can be sustainably utilized. For example, microbial fermentation of sugars and starch from food crops produces ethanol through the action of microbes such *Saccharromyces cerevisiae* (yeast). This ethanol can be blended with liquid transportation fuels. In Brazil, United States, and other European countries, ethanol-blended fuel is widely used (Figure 01). It is mainly a biofuel additive for gasoline. Ethanol is an alcohol used as a blending agent with gasoline, which increases octane and cuts down carbon monoxide and other smog causing emissions. Hence, biofuel protects the environment. However, it is expensive to convert edible plant materials into ethanol. Some ethical issues are also involved with this process. It has been argued that people should not grow food stuff for fuel production purposes when people in some developing countries are craving for foods. There is global concern about countries like Brazil which may remove large sections of their rainforest to produce sugar cane in order to obtain ethanol. Deforestation of rainforests is a critical issue because these rainforests purify the atmosphere by removing a huge amount of carbon dioxide during photosynthesis. Because of this reason, production of biofuels from food stuffs such as sugar cane are unlikely, as long term solution to replace fossil fuels.

However, there is a large underutilized resource like cellulosic biomass from trees, grasses, and the nonedible parts of crops that could also serve as a feedstock. Scientists are investigating methods that can convert cellulose into ethanol. The ethanol produced from cellulose is the same as the ethanol created from edible plant parts. Usually, cellulose ethanol is generated from lignocellulose, which is a mixture of lignin, hemicelluloses and cellulose. These three materials are the main

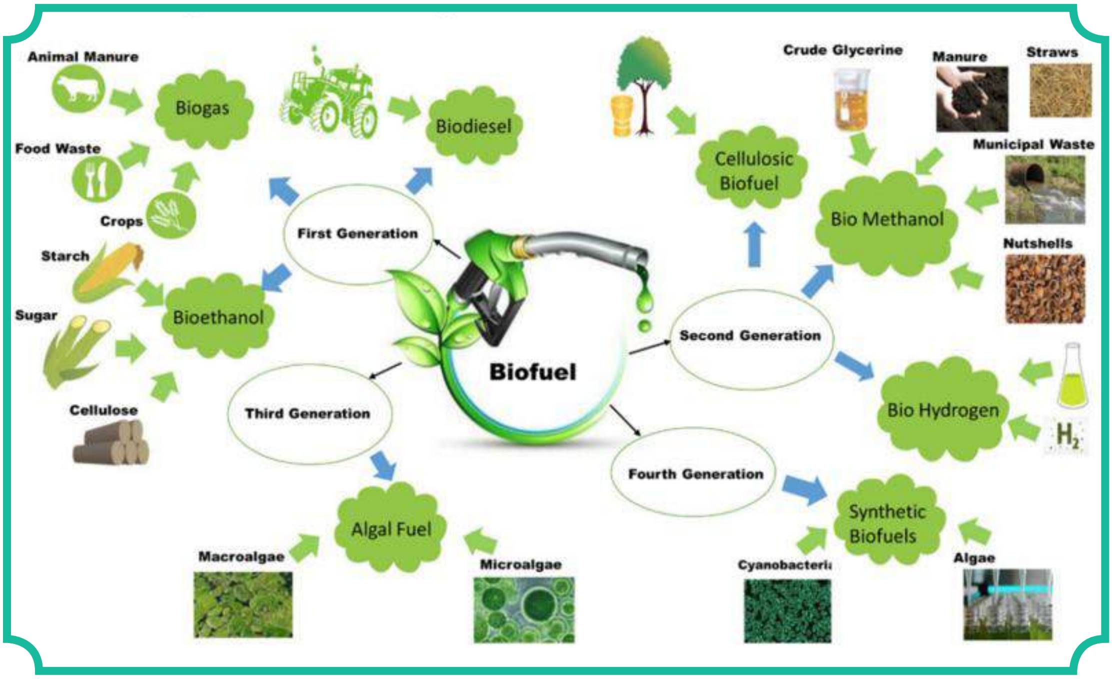

Figure 01: Biofuel production

components of the plant cell wall. The lignocellulose is the part that is undigested by human beings and most animals after consumption of plant based food sources.

Lignocellulose is also a part of non food stuff, such as stalks, saw dust and wood chip. There is therefore a huge amount of non edible plant waste that can be recycled. Through long term research scientists have already found some microbes that produce the group of enzymes called cellulase that can convert cellulose to fermentable sugars. There are three main members in this cellulase family; endoglucanase, exoglucanase and β glucosidase, which convert lignocellulose into fermentable sugar. These fermentable sugars subsequently produce ethanol by the action of yeast. Archaeans such as *Sulfolobus solfataricus* that lives in volcanic pools near Mount Vesuvius in Italy, and wood digester fungus *Triderma reesei*, which is found in all soil types, are some of the well-known examples of microbes producing cellulase enzyme. With genetic modifications to these microbes, it is possible to improve the performance of these microbes to produce more cellulase enzyme. Furthermore, a company in Canada has already genetically modified a fungus that can convert straw into glucose. A staggering amount of straw fiber is converted into sugar through this fungus. The glucose is then fermented with yeast to produce biofuel ethanol.

Research programs are underway to use metagenomic, synthetic, and other approaches to identify microbes, enzymes, or microbial communities that release sugars from cellulose. These ultimately convert sugars into ethanol or other fuels. Therefore, the microbial-plant ecofriendly relationships can improve the sustainability of biofuel production in the world.

The sustainability of biofuel production can be improved by the microbial plant relationship in different ways. Typically, microbes live inside root nodules of plants (*Rhizobium bacteria*). They also inhabit stems, root surfaces and leaf surfaces. The individual microbial activities provide plants with nitrogen which decreases the need for fertilizers. Their individual activities also help plants to access phosphorus, recycle nutrients, improve soil structure and protect plants from various diseases. These microbial plant associations can improve crop production on marginal lands. Ultimately, these benefit both food and biofuel production. In addition to that, successful microbial plant associations may also help to abate current food versus fuel debate, and thereby lessen the environmental foot print of agriculture.

Microbes in hydrogen and methane production

The microorganisms that produce methane as a metabolic by-product in low oxygen conditions are known as methanogens. They are prokaryotic organisms that belong to the domain of Archaea. Some of the well-known examples are *Methanosarcina barkeri, Methanobrevibacter smithii, Methanosarcina acetivorans, Methanococcus maripaludis, Methanocaldococcus jannaschii*, etc. They are very common in wetland areas in the world. These prokaryotic organisms are responsible for swamp gas (methane and other gases). These methanogens break down organic compounds to produce hydrogen (H_2), carbon dioxide (CO_2) and methane (CH_4). Normally, this breaking down process occurs in the digestive tract of domesticated and wild ruminants other than in the wetlands and rice patties. Methanogens are also responsible for the generated methane content of belching in ruminants, and flatulence in humans. Methane is a colourless, ordourless and inflammable gas (Figure 02). Methane is primarily used as a fuel to generate heat and light. Other than that methane is also used to manufacture organic chemicals. The reaction for reduction of carbon dioxide into methane in the presence of hydrogen is as follows;

$$CO_2+4H_2 \rightarrow CH_4+2H_2O$$

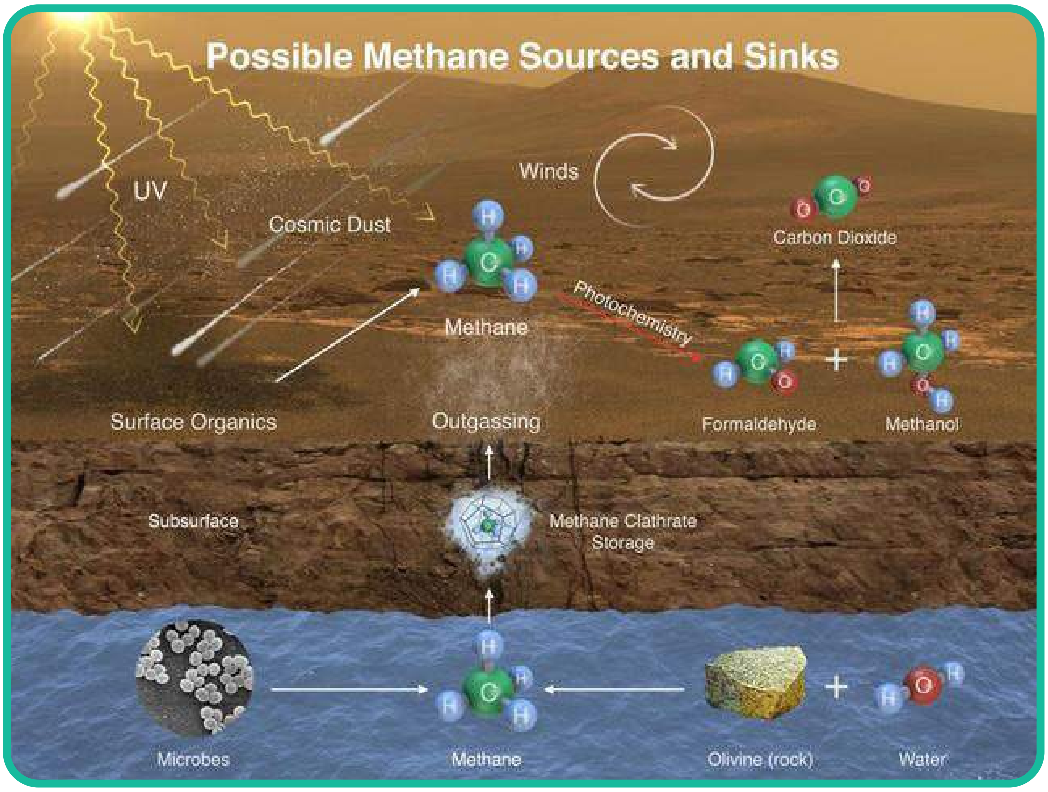

Figure 02: Methane production

The hydrogen that is produced while converting organic matter to methane, is also very useful. Hydrogen can be used to generate electricity, power and heat. Currently, hydrogen is commonly used for refining of petroleum and fertilizer production. Furthermore, methanogenic archaea play a vital role in anaerobic wastewater treatment.

Microbes in electricity production

It is possible to generate electricity from microorganisms. This is an alternative approach to the usual electric power from water, wind, solar and steam. Scientists have been studying the ability of microorganisms such as bacteria to generate electricity. For this particular purpose scientists are using a special system called bioelectrochemical system. One of the examples for bioelectrochemical system is the microbial fuel cell (MFC) (Figure 03). The microbial fuel cell has one anode chamber (negative electrode) and one cathode chamber (positive electrode). A microbial fuel cell functions very similar to a normal battery. In microbial fuel cells, microbes decompose organic and inorganic matter in an anode chamber which results in electrons. Later, these electrons flow from anode chamber to cathode chamber through an external circuit made up of conductive material. The conductive material used is usually copper based wires. Ultimately, this biochemical reaction produces electricity. Many companies in the world are already involved in MFC technology. Companies that are applying MFC technology in a commercial scale include EcoVolt by Cambrian Innovation, and VIVA MFC by MICROrganic Technologies in United States, Prongineer in Canada and Plant-e in Netherlands. These companies integrate plant microbial fuel cells (PMFCs) in their MFC technology. The most researched electrochemically active bacteria (EAB) in microbial fuel cell technology are *Geobacter sulfurreducens* str.PCA and *Schewanella oneidensis* str.MR-1.

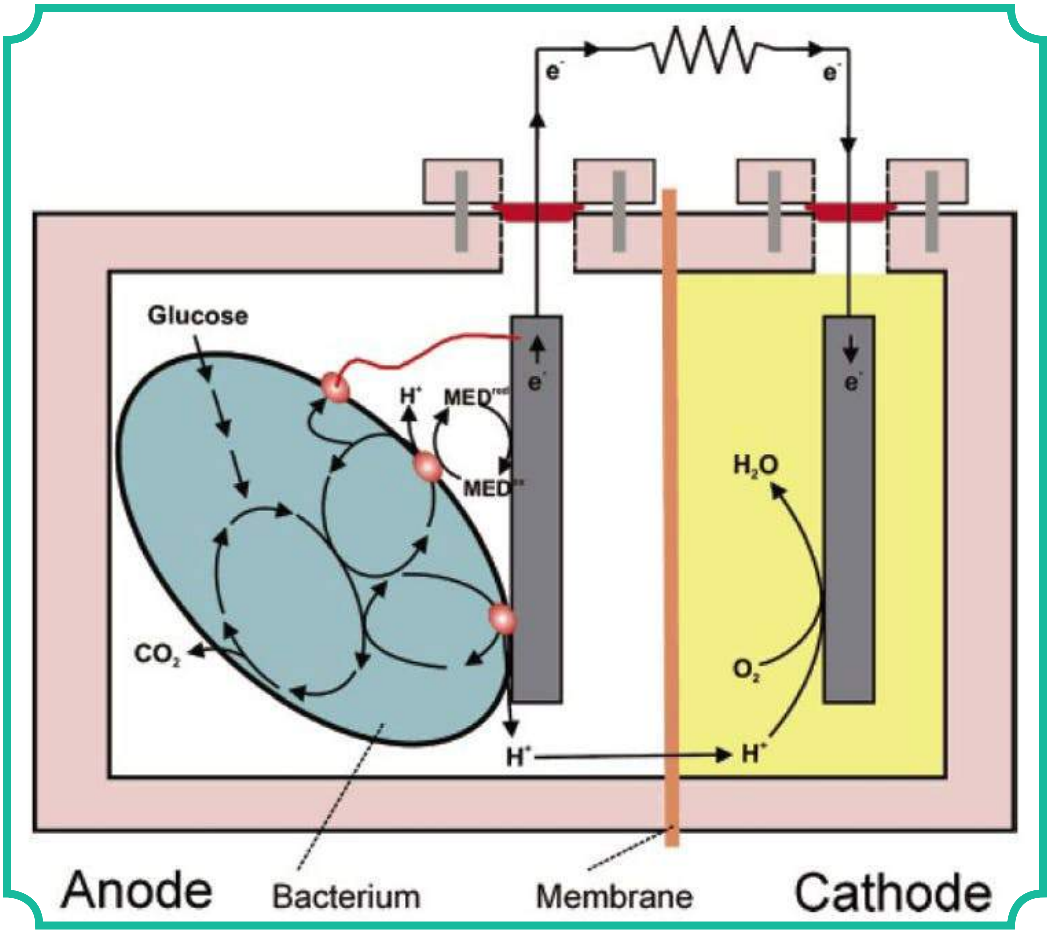

Figure 03: Microbial fuel cell- (MFC)

Microbes in chemical feedstock production

In chemistry a chemical feed stock is a substance that is used to support a large scale chemical reaction. For example, petroleum is the chemical feedstock for gasoline and other chemicals including methane, propylene and butane. But petroleum based industries are criticized due to environmental pollution and their high cost of production.

Domestic biofuels are really good alternatives for petroleum based transportation. Biofuels are typically produced from plant materials like oils, sugars and biomass. The plant matter is derived from photosynthesis. Photosynthesis is the process of converting solar energy into chemical energy in plants. Photosynthesis however is not an efficient way to transfer energy from the sun to a plant and then to biofuel. So, incorporating electrofuel that bypasses the photosynthesis process by using microbes, can directly use energy from electricity and chemical compounds to produce liquid fuels.

Recently, Massachusetts Institute of Technology (MIT) in United States developed a new technique that uses carbon dioxide (CO_2) and hydrogen (H_2) generated from electricity to produce natural oils which can later be improved to hydrocarbon fuels. For this purpose MIT has developed a 2-stage biofuel production system. In the first stage CO_2 and H_2 are fed to a microorganism that is capable of converting these feedstocks to a 2-carbon compound called acetate. Then in the second stage the acetate is delivered to another microorganism that can use acetate to produce natural oils. Later, the oil can be removed from reactor tank and chemically converted to various hydrocarbons. The electricity for this process can be supplied from the combustion of municipal waste. Combustion of municipal waste would also produce the required CO_2 and hence enhance the efficiency of biofuel production system. For the above purpose acetogenic and methanogenic bacteria can be used (Figure 04). Further, chemical feedstocks such as 1,4-butanediol and malic acids are produced by using microorganisms such as *Escherichia coli*, *Aspergillus* and *Ustilago trichophora*. 1,4-butanediol is produced through *Escherichia coli* bacteria which is used to make floor stripper, paint thinner and other solvent products industrially. While, malic acid is produced by using fungi such as *Aspergillus* and *Ustilago trichophora*, Malic acid is used in medicine, in food industry as a flavoring agent, and to resolve 1-phenyethylamine.

Microbes in mitigating climate changes

Plants and autotrophic microbes

can also be helpful in mitigating climate change, because they sequester atmospheric carbon dioxide at a higher rate. This depends on the subsequent oxidation of soil and plant carbon by microbes. The potential way to mitigate climate change is through reduction of green house gases. The green house gases are increasing due to human activities and natural factors. For example, green house gases increase through combustion of coal, oil, fossil fuels, decay of plant matter and burning of biomass. At the moment climate change and the global warming are the major

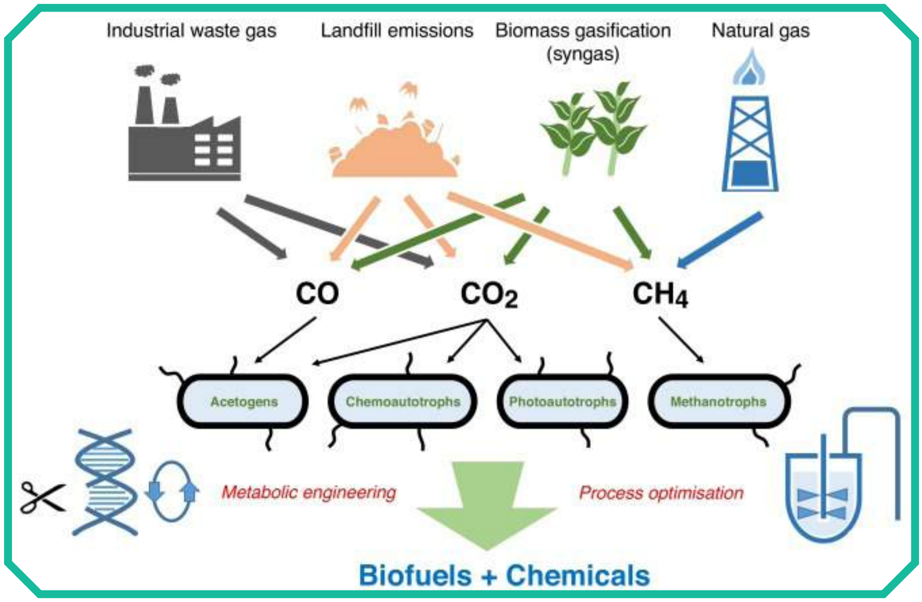

Figure 04: Chemical feedstocks

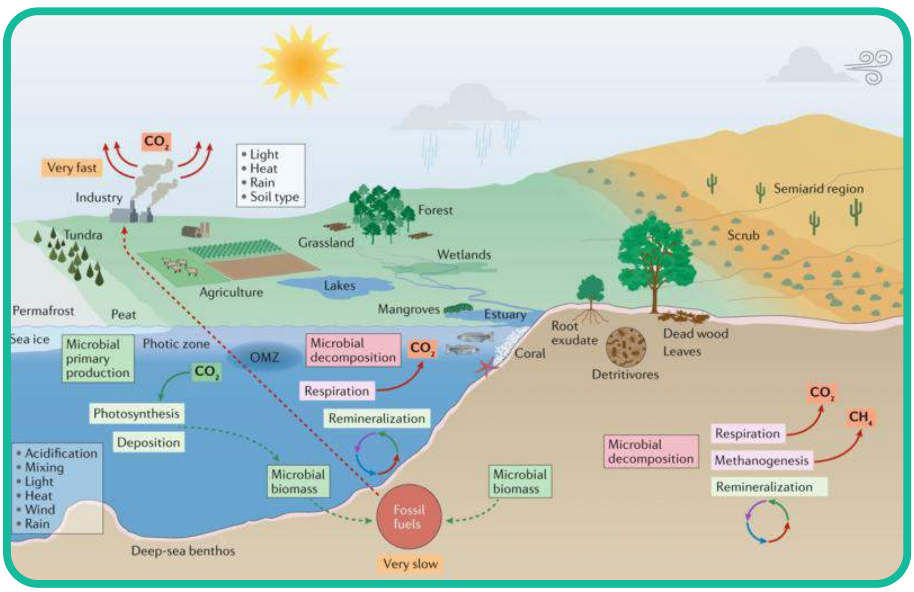

Figure 05: Microbes in mitigating climate changes

problems in the world. Climate change and the global warming can cause more frequent severe weather conditions, higher death rates, dirtier air, higher wildlife extinction, acidic ocean, higher sea level, etc. In order to compromise climate changes there are several methods. One of the methods is the use of microorganisms and other biological components that can mitigate climate changes. The autotrophic microbes reduce green house gas through nutrient recycling processes. The marine phytoplankton is a good example of an autotrophic microbe that is involved in global photosynthetic CO_2 fixation (Figure 05). Furthermore, bacteria belong to families such as *Comamonadaceae* and *Sphigomonadaceae,* which can also be used to reduce green house gas. A concerted effort in co-ordinated research would be crucial in order to get the maximum use of advantages referred to above microbes acting as master chemists can help the global population to face the challenges of energy, encounter pollution, and ensure adequacy of food. All in all, the rich genetic blueprints of microbes will provide new energy sources while improving the health of the biosphere.

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