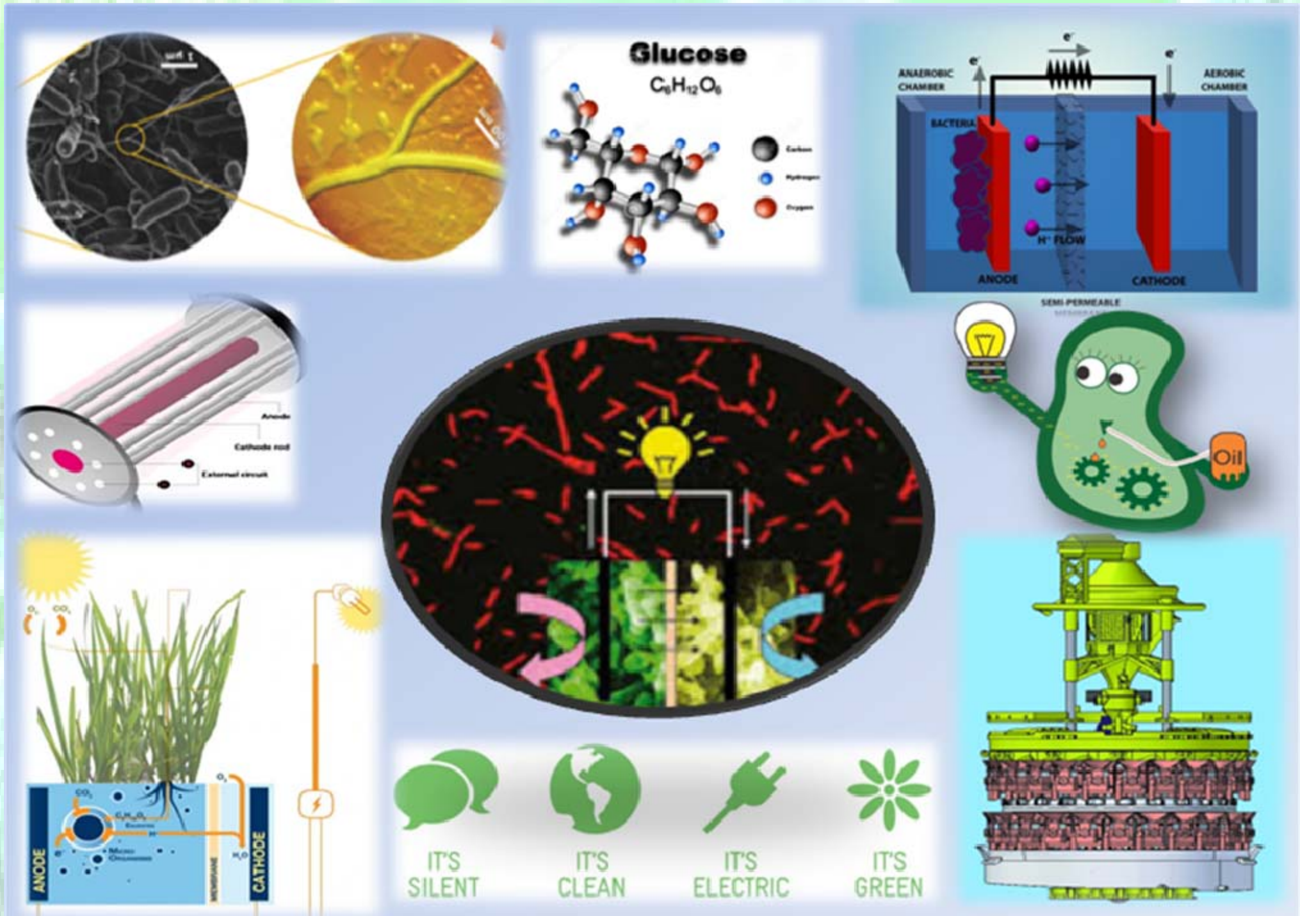
ENVIS CENTRE ON ENVIRONMENTAL BIOTECHNOLOGY

SUPPORTED BY:
MINISTRY OF ENVIRONMENT, FORESTS & CLIMATE CHANGE
GOVERNMENT OF INDIA, NEW DELHI

VOLUME-25 ISSN : 0974 2476 DECEMBER, 2014

Microbial Fuel Cells



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Figures and typed table should be in separate pages and provided with title and serial numbers. The exact position for the placement of the figures and tables should be marked in the manuscript.

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EDITORIAL

Microbial fuel cells (MFC) use the power of bacteria and convert energy released in metabolic reactions into electrical energy. This environmentally-friendly process produces electricity without the combustion of fossil fuels. Using microbes to generate electricity implies that the processes in an MFC are self-sustaining; the bacteria replicate and continue to produce power indefinitely as long as there is a food source to nourish the bacteria. Moreover, MFCs are very efficient, do not rely on fossil fuels, and can run effectively on sources like food waste and sewage. Due to the promise of sustainable energy production from organic wastes, research has intensified in this field in the last few years. To further improve MFC technology an understanding of the microbial processes and limitations of these systems is required.

In this newsletter (Vol. no. 25), we have attempted to discuss the **Microbial Fuel Cell (MFCs)** related issues and case studies.

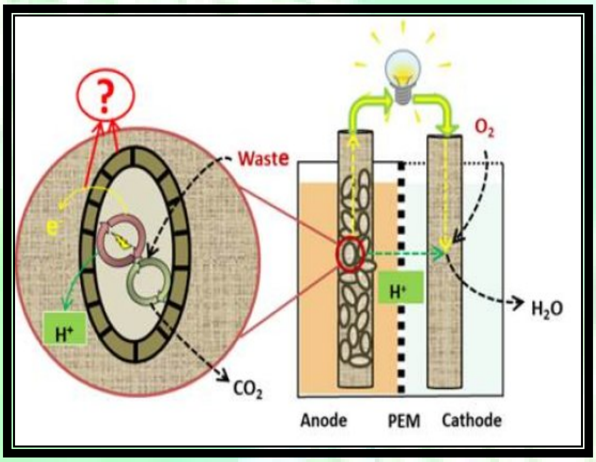
(S. C. Santra)

IN THIS ISSUE:

Microbial Fuel Cells

1. Introduction

Microbial fuel cell (MFC) is one choice that has received attention as alternative energy in directly generating electricity from organic matters. A microbial fuel cell is a bioreactor that converts chemical energy in the chemical bonds in organic compounds to electrical energy through catalytic reactions of micro-organisms under anaerobic conditions (Fig.1).

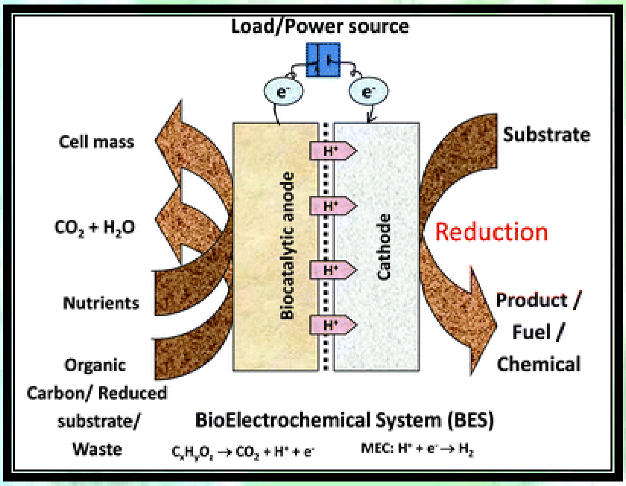


Source: http://www.rsc.org/

Fig. 1: MFCs produces energy

Energy has been the major aspects in the evolution of civilization, as fossil fuels have taken care of industrial revolution part. The energy needs cannot be sustained by fossil fuels only at the end of 21st century as they are not substantial enough because of their limited availability. So, the need for renewable alternative source of energy generation is need of the day.

Microbial fuel cells (MFCs) have emerged in recent years as a promising and challenging technology. In a MFC, microorganisms interact with electrodes using electrons, which are either removed or supplied through an electrical circuit. MFCs are the major type of bioelectrochemical systems (BESs), which convert biomass spontaneously into electricity through the metabolic activity of the microorganisms (Fig. 2).



Source: http://pubs.rsc.org/

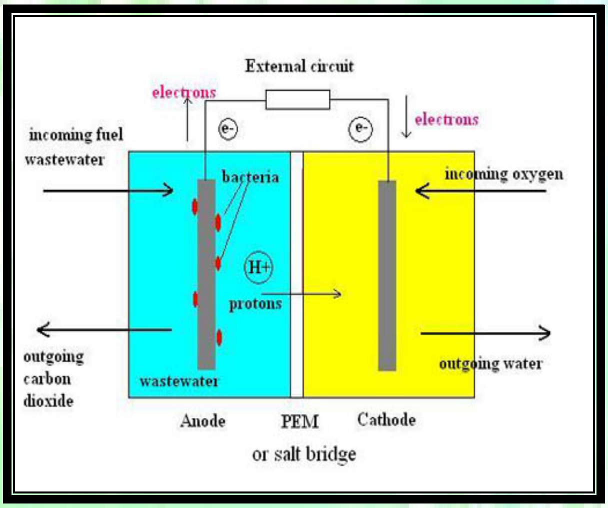
Fig. 2: Bioelectrochemical System

Types of BES	Cathode substrate	Product
MFC	Oxygen	Electricity
MEC	Protons	Biohydrogen
BES	Acetate	Ehtanol
BES	Oxygen	Hydrogen peroxide

Microbial fuel cells have become an interesting and promising area of research. There are many applications of MFCs will help to reduce the use of fossil fuels and allow for energy gain from wastes. MFC technology does not have the power to change the world single-handedly; microbial fuel cells will never be able to produce enough electricity to take the place of a coal-fired power plant. They will, however, help to bring the world to becoming a sustainable and more environmentally-friendly place.

It is now known that electricity can be produced directly from the degradation of organic matter in a microbial fuel cell. Like a normal fuel cell, an MFC has both an anode and cathode chamber. The anoxic anode chamber is connected internally to the cathode chamber via an ion exchange membrane with the circuit completed by an external wire (Fig. 3).

MFCs have various practical applications such as in breweries, domestic wastewater treatment, desalination plants, hydrogen production, remote sensing, and pollution remediation, and they can be used as a remote power source. Widespread use of MFCs in these areas can take our waste products and transform them into energy.



Source: www.sciencebuddies.org

Fig. 3: Simplified view of a two-chamber MFC with possible modes of electron transfer.

2. History of Microbial fuel cell

The idea of obtaining energy from bacteria began in 1911 with M. C. Potter, a professor of botany at the University of Durham. In his studies of how microorganisms degrade organic compounds, he discovered that electrical energy was also produced. Potter had the idea of trying to harvest this new found source of energy for human use. He was able to construct a primitive microbial fuel cell, but not enough was known about the metabolism of bacteria for the design to be improved upon.

In recent, researchers are working to optimize electrode materials, types and combinations of bacteria, and electron transfer in microbial fuel cells. Even though the idea of harnessing the energy produced by bacteria has been around for almost 100 years, researchers have just begun to fully understand the MFC and how to bring out its true potential.

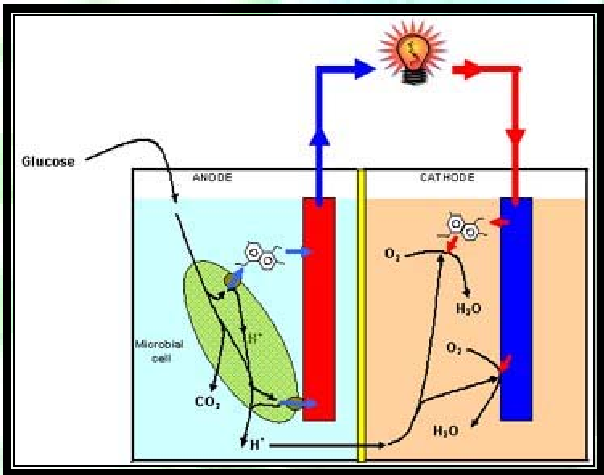
3. Types of Microbial fuel cell

A microbial fuel cell is a device that converts chemical energy to electrical energy by the catalytic reaction of microorganisms. A typical microbial fuel cell consists of anode and cathode compartments separated by a cation (positively charged ion) specific membrane. In the anode compartment, fuel is oxidized by microorganisms, generating CO_2, electrons and protons. Electrons are transferred to the cathode compartment through an external electric circuit, while protons are transferred to the cathode compartment through the membrane. Electrons and protons are consumed in the cathode compartment, combining with oxygen to form water.

Broadly, there are two types of microbial fuel cell: **mediator** and **mediator-less** microbial fuel cells.

3.1. Mediator microbial fuel cell

Most of the microbial cells are electrochemically inactive. The electron transfer from microbial cells to the electrode is facilitated by mediators such as thionine, methyl viologen, methyl blue, humic acid, neutral red and so on. Most of the mediators available are expensive and toxic (Fig.4).



Source: http://www.vcharkarn.com/

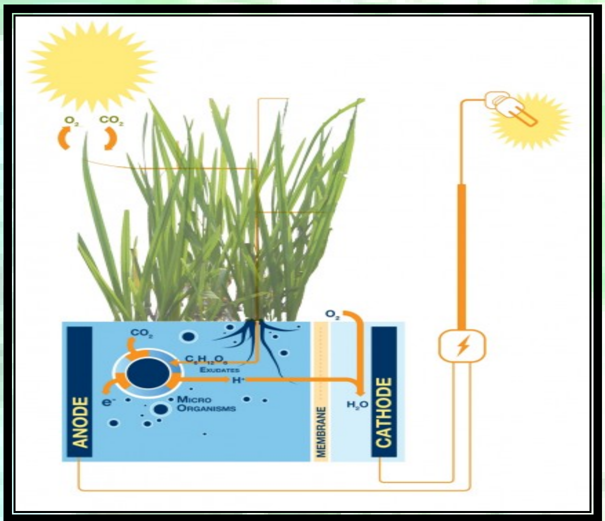
Fig. 4: Electrons can flow to the anode via chemical mediators.

3.2 Mediator-free microbial fuel cell

Mediator-free microbial fuel cells do not require a mediator but use electrochemically active bacteria to transfer electrons to the electrode (electrons are carried directly from the bacterial respiratory enzyme to the electrode). Among the electrochemically active bacteria are, *Shewanella putrefaciens*, *Aeromonas hydrophila*, and others. Some bacteria, which have pili on their external membrane, are able to transfer their electron production via these pili. Mediator-less MFCs are a more recent area of research and, due to this, factors that affect optimum efficiency, such as the strain of bacteria used in the system, type of ion-exchange membrane, and system conditions (temperature, pH, etc.) are not particularly well understood.

Mediator-less microbial fuel cells can, besides running on wastewater, also derive energy directly from certain plants. This configuration is known as a plant microbial fuel cell. Possible plants include reed sweet grass, cord grass, rice, tomatoes, lupines and algae (Fig. 5). The mediator free microbial fuel cells are of designed in various types, like-

- Microbial electrolysis cell
- Soil-based microbial fuel cell
- Phototrophic biofilm microbial fuel cell

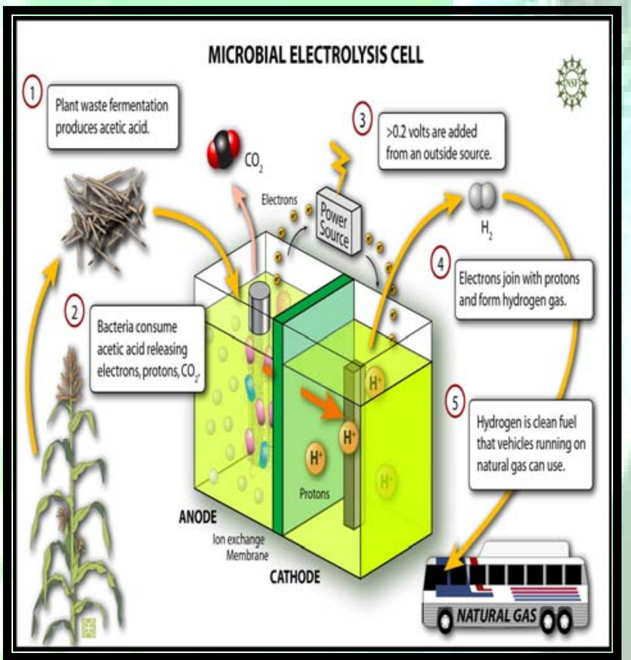


(designed by NIOO-KNAW)

Fig. 5: A plant microbial fuel cell (PMFC)

3.2.1. Microbial electrolysis cell

A variation of the mediator-less MFC is the microbial electrolysis cells (MEC). Whilst MFC's produce electric current by the bacterial decomposition of organic compounds in water, MECs partially reverse the process to generate hydrogen or methane by applying a voltage to bacteria to supplement the voltage generated by the microbial decomposition of organics sufficiently lead to the electrolysis of water or the production of methane. A complete reversal of the MFC principle is found in microbial electrosynthesis, in which CO_2 is reduced by bacteria using an external electric current to form multi-carbon organic compounds (Fig. 6).



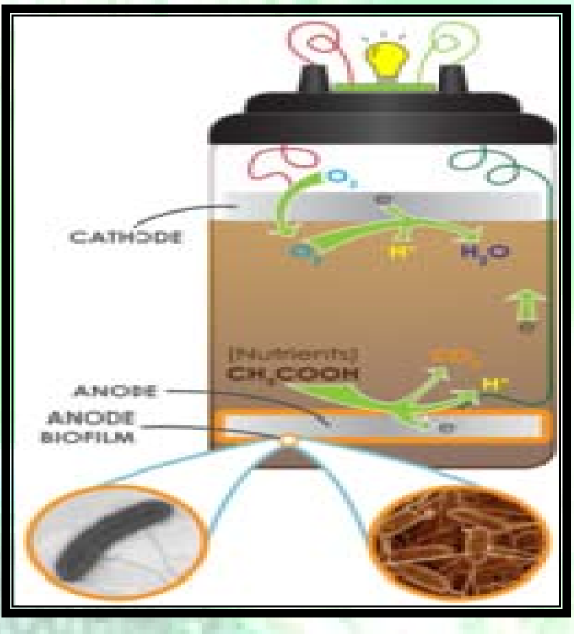
Source: http://peswiki.com

Fig. 6: Microbial electrolysis cell

3.2.2 Soil-based microbial fuel cell

Soil-based microbial fuel cells adhere to the same basic MFC principles. Soil acts as the nutrient-rich anodic media, the inoculum, and the proton-exchange membrane (PEM). The anode is placed at a certain depth within the soil, while the cathode rests on top the soil and is exposed to the oxygen in the air above it.

Soils are naturally teeming with a diverse consortium of microbes, including the electrogenic microbes needed for MFCs, and are full of complex sugars and other nutrients that have accumulated over millions of years of plant and animal material decay. Moreover, the aerobic (oxygen consuming) microbes present in the soil act as an oxygen filter, much like the expensive PEM materials used in laboratory MFC systems, which cause the redox potential of the soil to decrease with greater depth (Fig. 7).



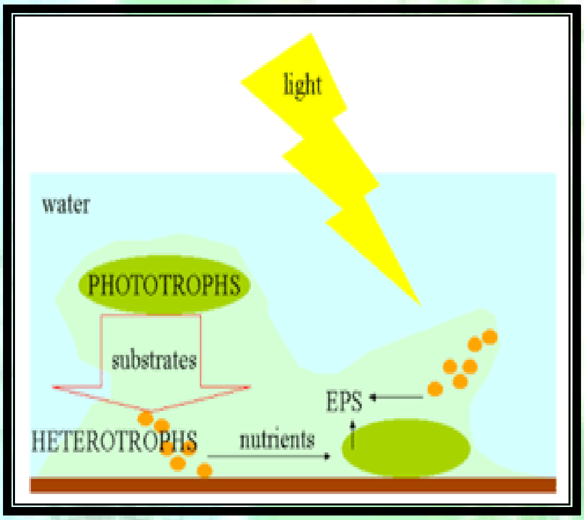
Source: http://ramank.info.cm/

Fig. 7: A soil-based MFC

3.2.3 Phototrophic biofilm microbial fuel cell

Phototrophic biofilm MFCs (PBMFCs) are the ones that make use of anode with a phototrophic biofilm containing hotosynthetic microorganism like chlorophyta, cyanophyta etc., since they could carry out photosynthesis and thus they act as both producers of organic metabolites and also as electron donors.

The sub-category of phototrophic microbial fuel cells that use purely oxygenic photosynthetic material at the anode are sometimes called biological photovoltaic systems (Fig.8).



Source: http://phobia.itqb.unl.pt/

Fig. 8: Phototrophic biofilms.

4. Basic components of microbial fuel cells

A typical MFC consists of an anodic chamber and a cathodic chamber separated by a proton-exchange membrane (PEM). A one-compartment MFC eliminates the need for the cathodic chamber by exposing the cathode directly to the air.

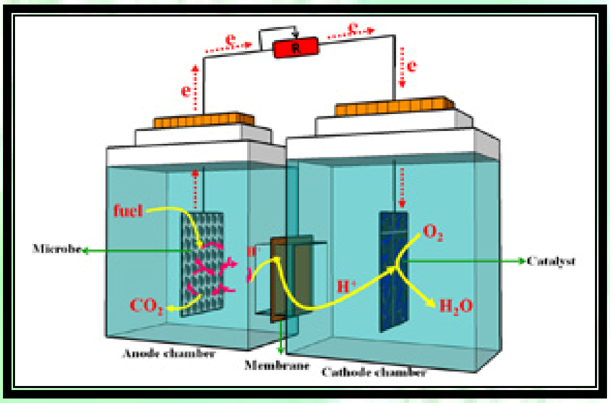
Items	Materials
Anode	Graphite, graphite felt, carbon paper,carbon-cloth, Pt, Pt black, RVC
Cathode	Graphite, graphite felt, carbon paper,carbon-cloth, Pt, Pt black, RVC
Anodic Chamber	Glass, polycarbonate, Plexiglas
Cathodic Chamber	Glass, polycarbonate, Plexiglas
Proton Exchange system	Proton exchange membrane: Nafion, Ultrex, polyethylene. poly, (styrene-co-divinylbenzene); salt bridge, porcelain septum, or solely electrolyte)
Electrode catalyst	Pt, Pt black, MnO_2, Fe^{3+}, polyaniline, electron mediator immobilized on anode

(Source: Du et. al., 2007)

5. Factors affecting the MFCs efficiency

5.1. Electrode Material

Type of material used in electrode preparation will show vital effect on MFCs efficiency. Better performing electrode materials usage will always improve the performance of MFC because different anode materials result in different activation polarization losses (Fig. 9).



Source: http://electrochem.xmu.edu.cn

Fig. 9: Electrode material for MFCs

5.2. pH Buffer and Electrolyte

If no buffer solution is used in a working MFC, there will be an obvious pH difference between the anodic and cathodic chambers, though theoretically there will be no pH shift when the reaction rate of protons, electrons and oxygen at the cathode equals the production rate of protons at the anode. The pH difference increases the driving force of the proton diffusion from the anode to the cathode chamber and finally a dynamic equilibrium forms.

5.3. Proton Exchange System

Proton exchange system can affect an MFC system's internal resistance and concentration polarization loss and they in turn influence the power output of the MFC. Nafion (DuPont, Wilmington, Delaware) is most popular because of its highly selective permeability of protons.

5.4. Operating conditions in the anodic chamber

Substrate type, concentration and feed rate are important factors that impact the performance of an MFC. Power density varies greatly with different substrates using same a given microbe or microbial consortium. Electricity generation is dependent on substrate concentration both in batch and continuous-flow mode MFCs.

5.5. Operating conditions in the cathodic chamber:

Oxygen is the most commonly used electron acceptor in MFCs for the cathodic reaction. Power output of an MFC strongly depends on the concentration level of electron acceptors.

6. Microbes use in MFCs

Many microorganisms possess the ability to transfer the electrons derived from the metabolism of organic matters to the anode. A list of microbes with substrate and application is shown in Table 1.

Table 1. Microbes use in MFCs

Microbes	Substrate	Applications
Actinobacillus succinogenes	Glucose	Neutral red or thionine as electron mediator
Aeromonas hydrophila	Acetate	Mediator-less MFC
Alcaligenes faecalis, Enterococcusgallinarum, Pseudomonas aeruginosa	Glucose	Self-mediate consortia isolated from MFC with a maximal level of 4.31 W m^{-2}
Clostridium beijerinckii, Clostridium butyricum	Starch, Glucose, Lactase, molasses	Fermentative bacterium
Desulfovibrio desulfuricans	Sucrose	Sulphate/sulphide as mediator
Erwinia dissolven	Glucose	Ferric chelate complex as mediators
Escherichia coli	Glucose, sucrose	Methylene blue mediators needed
Lactobacillus plantarum	Glucose	Ferric chelate complex-mediators

Gluconobacter oxydans	Glucose	Mediator (HNQ, resazurin or thionine) needed
Geobacter metallireducens, Geobacter sulfurreducens	Acetate	Mediator-less MFC
Klebsiella pneumoniae	Glucose	HNQ as mediator biomineralized manganese as electron acceptor
Proteus mirabilis	Glucose	Thionin as mediator
Pseudomonas aeruginosa	Glucose	Pyocyanin and phenazine-1-carboxamide as mediator
Rhodoferax ferrireducens	Glucose, xylose,	Mediator-less MFC
Shewanella oneidensis	Lactase	Anthraquinone-2,6-disulfonate (AQDS) as mediator
Shewanella putrefaciens	Lactase, pyruvate, acetate, glucose	Mediator-less MFC
Streptococcus lactis	Glucose	Ferric chelate complex as mediators

Source:Du et al., 2007

7. Application of Microbial fuel cell

Microbial fuels cells is an important application in wastewater treatment. The organic carbon waste can be removed, and electricity is produced. Industries that produce wastewaters high in easily degradable organic carbon are good candidates for this application. Examples are food industry, dairies, breweries, the bioproducts industry, and the biofuels industry, such as biorefineries.

7.1 Brewery Wastewater Treatment

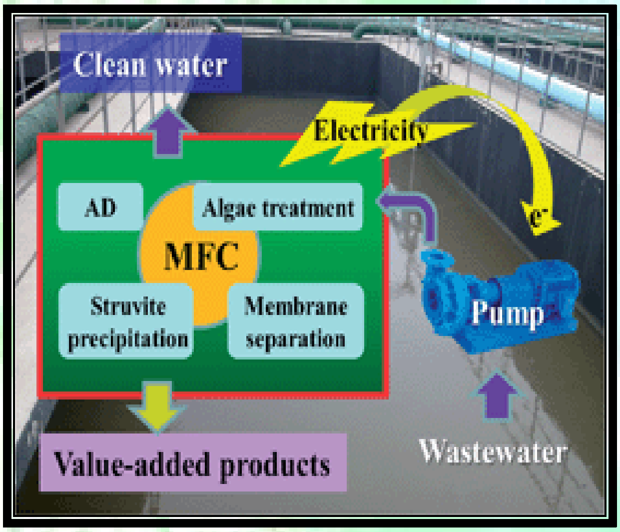
Brewery and food manufacturing wastewater can be treated by microbial fuel cells because their wastewater is rich in organic compounds that can serve as food for the microorganisms. Breweries are ideal for the implementation of microbial fuel cells, as their wastewater composition is always the same; these constant conditions allow bacteria to adapt and become more efficient. The power generated from cleaning the brewery wastewater is expected to pay for the initial cost of the MFC in ten years (Fig.9).

Source: http://illumin.usc.edu

Fig. 9: A microbial fuel cell in a brewery used for wastewater treatment.

7.2 Sewage Treatment

Sewage wastewater can also be converted via microbial fuel cells to decompose the waste organic material. Micro-organisms can perform the dual duty of degrading effluents and generating power. MFCs are presently under serious consideration as devices to produce electrical power in the course of treatment of industrial, agricultural, and municipal wastewater. When micro-organisms oxidize organic compounds present in waste water, electrons are released yielding a steady source of electrical current. If power generation in these systems can be increased, MFCs may provide a new method to offset operating costs of waste water treatment plants, making advanced waste water treatment more affordable in both developing and industrialized nations. In addition, MFCs are also known to generate less excess sludge as compared to the aerobic treatment process (Fig. 10).

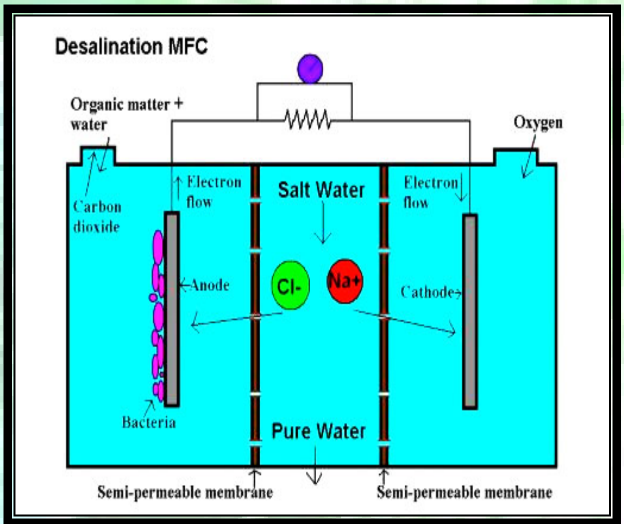


Source: http://pubs.rsc.org/

Fig. 10: Waste water treatment

7.3 Desalination

Desalination of sea water and brackish water for use as drinking water has always presented significant problems because of the amount of energy required to remove the dissolved salts from the water. By using an adapted microbial fuel cell, this process could proceed with no external electrical energy input. By adding a third chamber in between the two electrodes of a standard MFC and filling it with sea water, the cell's positive and negative electrodes attract the positive and negative salt ions in the water and, using semi-permeable membranes, filters out the salt from the sea water (Fig. 11).

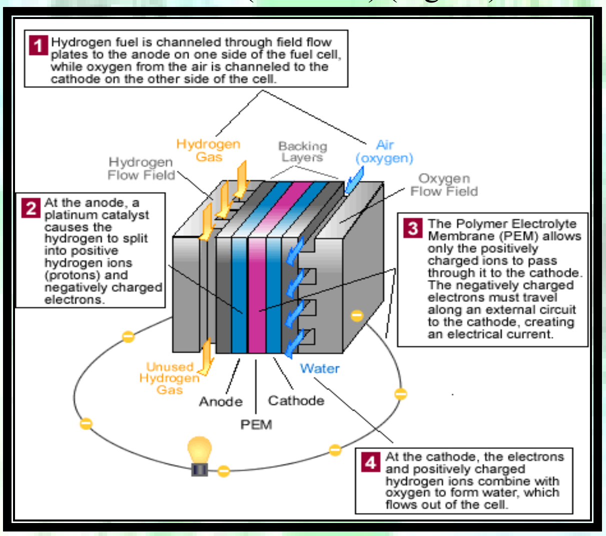


Source: http://illumin.usc.edu

Fig. 11: A desalination microbial fuel cell

7.4 Hydrogen Production

Hydrogen production by MFCs operating on organic waste may be an interesting alternative. In such devices, anaerobic conditions are maintained in the cathode chamber and additional voltage of around 0.25 V is applied to the cathode. Under such conditions, protons are reduced to hydrogen on the cathode. Such modified MFCs are termed bio-electrochemically assisted microbial reactors (BEAMR) (Fig. 12).

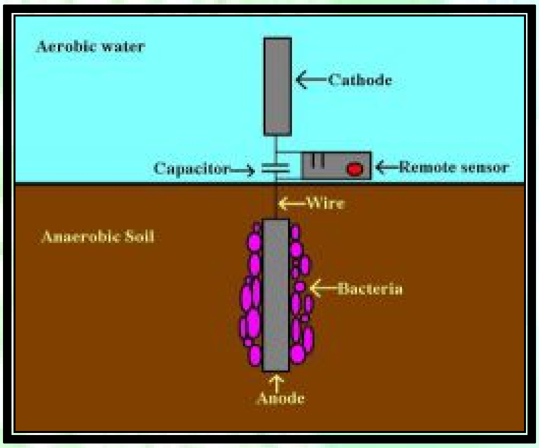


Siurce: http://polizeros.com/tag/fuel-cells/

Fig. 12: Fuel cells are powered by hydrogen

7.5 Remote Sensors

MFCs can run low-power sensors that collect data from remote areas. A simple microbial fuel cell consisting of a cathode attached to an anode by a metal wire. By placing the anode in the anaerobic sediment of a river or ocean and placing the cathode in the aerobic water right above the sediment, a current is generated. Anaerobic bacteria that naturally grow in the sediment produce the small current that can be used to charge a capacitor to store energy for whenever the sensor needs it. One major advantage of using a microbial fuel cell in remote sensing rather than a traditional battery is that the bacteria reproduce, giving the MFC a significantly longer lifetime than traditional batteries. The sensor can thus be left alone in a remote area for many years without maintenance (Fig. 13).



Source: http://illumin.usc.edu/

Fig. 13: Microbial fuel cell integrated into riverbed.

7.6 Cleansing Polluted Lakes and Rivers

Microbial fuel cells can also be used in the bioremediation of water containing organic pollutants such as toluene and benzene, compounds found in gasoline. The MFC design is altered so that the fuel cell floats on top of polluted water. The anode is submerged in the water where organic pollutants feed the bacteria while the cathode floats on top of the water. The organic pollutants are decomposed to carbon dioxide and water, cleansing the polluted lake or stream. The MFC can be left alone in remote natural bodies of water, just like the remote sensor (Fig. 14).

Source:http://illumin.usc.edu/

Fig. 14: A robot powered by an integrated microbial fuel cell.

7.7 Remote Power Source

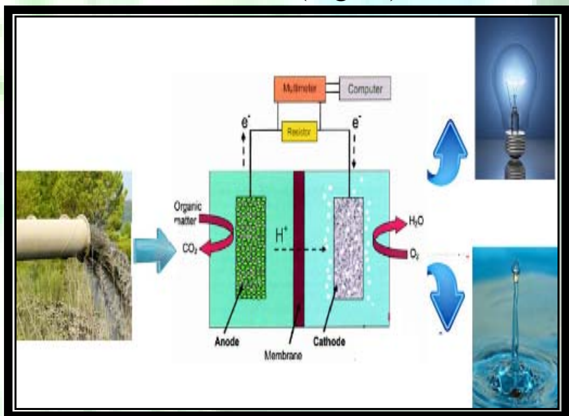
The advancement of microbial fuel cell technologies provides cheap, accessible power to remote regions of Africa, where 74% of the population lives without electricity. The electrical current produced by a simple homemade MFC is enough to recharge a cell phone battery, an important communication and lighting tool to rural African communities. The materials required to construct this simple MFC are soil, manure, copper wire, buckets, and graphite cloth (Fig. 15).

Source:http://illumin.usc.edu/

Fig. 15: A cheap microbial fuel cell made by the Lebone group.

7.8 Generation of Energy out of Bio-waste/ Organic Matter

Electricity is being generated in a direct way from biowastes and organic matter. This energy can be used for operation of the waste treatment plant, or sold to the energy market. Furthermore, the generated current can be used to produce hydrogen gas. Since waste flows are often variable, a temporary storage of the energy in the form of hydrogen, as a buffer, can be desirable (Fig.16).

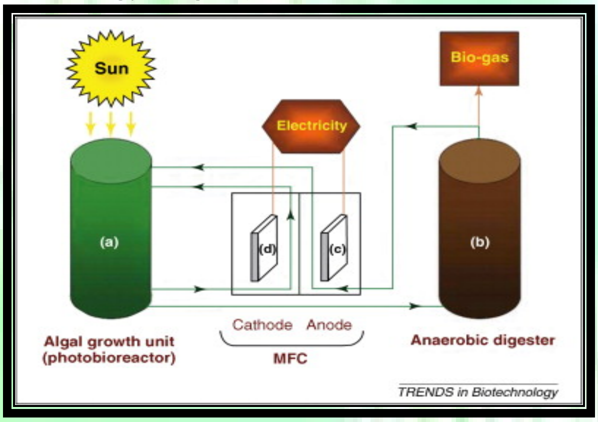


Source: http://itphot.shdongliang.net/

Fig. 16: Energy out put

7.9 Direct Conversion of Substrate Energy to Electricity

Application of microbial fuel cells (MFCs) to wastewater treatment for direct recovery of electric energy appears to provide a potentially attractive alternative to traditional treatment processes, in an optic of costs reduction, and tapping of sustainable energy sources that characterizes current trends in technology (Fig 17).



Source: http://www.cell.com

Fig. 17: Energy production

7.10 Sludge production

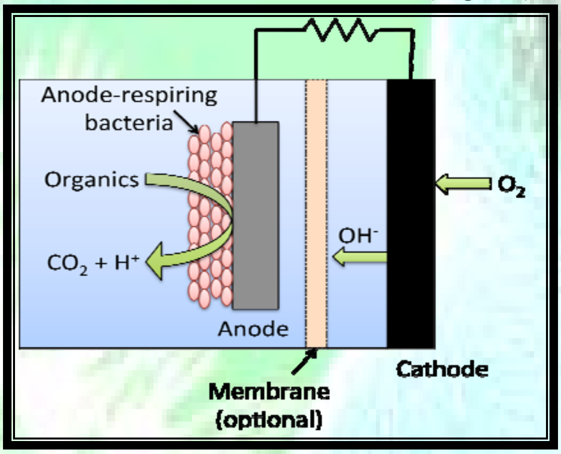
A two-chambered microbial fuel cell (MFC) with potassium ferricyanide as its electron acceptor was utilized to degrade excess sewage sludge and to generate electricity. This study demonstrates that this MFC can generate electricity from sewage sludge over a wide range of process parameters (Fig.18)

Source: http://www.innovationtoronto.com

Fig. 18: Fuel cell trats waste water

7.11 Omission of gas treatment

Generally, off-gases of anaerobic processes contain high concentrations of nitrogen gas, hydrogen sulphide and carbon dioxide next to the desired hydrogen or methane gas. The off gases of MFCs have generally no economic value, since the energy contained in the substrate was prior directed towards the anode. The separation has been done by the bacteria, draining off the energy of the compounds towards the anode in the form of electrons. The gas generated by the anode compartment can hence be discharged, provided that no large quantities of H_2S or other odorous compounds are present in the gas, and no aerosols with undesired bacteria are liberated into the environment (Fig. 19).



Source: asunews.asu.edu

Fig. 19: Gas Treatment

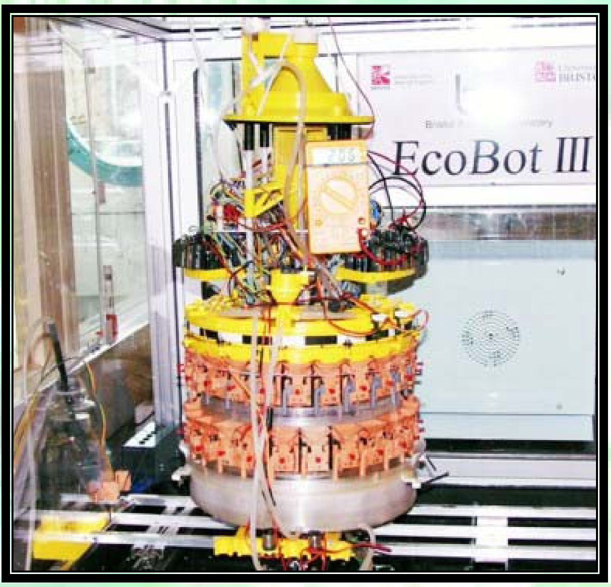
7.12 Microbial Fuel Cells for Robotics

For a robot to behave truly autonomously it will need not only to use its energy in an effective way but also extract this energy from its environment. This requires the robot to convert energy from natural raw materials and also deal with replenishing reserves and waste management.

Based on this technology the EcoBot-I, EcoBot-II and EcoBot-III have been developed, which - to some extent - exhibit this type of behaviour.

EcoBot-I, which was developed in 2002, employed *E. coli* and was fed with sugar. **EcoBot-II**, which was developed in 2004 used sludge microbes and was fed (amongst other substrates) with dead insects and food waste.

EcoBot III developed in 2007 is a lightweight(6kg) self-sustaining robot designed to clean wastewater. Powered by MFCs, the robot runs off human waste, using it to produce electricity necessary for performing its cleaning task. The robot is consists of the ingestion, artificial digestion and solid waste excretion mechanism. The project was funded by Engineering and Physical Sciences Research Council (EPSRC) and developed in collaboration between Wessex Water and the Bristol Robotics Laboratory in England (Fig. 20).



Source: http://inhabitat.com/ecobot-iii-is-a-human-waste-powered-robot-that-cleans-wastewater

Fig. 20: EcoBot III

8. Case studies & Current research on MFCs

8.1 MFC for wastewater treatment: heavy metal removal, sewage sludge treatment, and its potential application in wastewater reuse in irrigation.

High power generation (3.6 W/m^2) and high Cd (90%) and Zn (97%) removal efficiencies were achieved in a single chamber air-cathode microbial fuel cell (MFC). The maximum tolerable concentrations (MTCs) that did not affect power output were 200 µM for Cd and 400 µM for Zn. MFC has been used to convert organic matter in sludge into electricity.

(http://ir.library.oregonstate.edu/xmlui/handle/1957/47329) (**20.03.2014).**

8.2 Microbial Fuel Cell generating electricity from wastewater

The Amrita Center of Biotechnology introduced a Microbial Fuel Cell, which utilizes energy from bacterial growth in wastewater to generate electricity while simultaneously bringing about purification of the wastewater–an important step in addressing the sanitation and energy problems that are very relevant in our country (http://www.amritapuri.org/, 27 Sep 2014).

8.3 New Microbial Fuel Cell can Produce Electricity from Waste Water

Engineers at Oregon State University have made a breakthrough in the performance of microbial fuel cells that can produce electricity directly from wastewater. The new technology can now produce 10 to 50 more times the electricity, by volume, more than most other approaches using microbial fuel cells, and 100 times more electricity than some.

The new microbial fuel cell technology cleans sewage by a very different approach than today's aerobic bacteria systems. Microbial fuel cell bacteria oxidize the organic matter and, in the process, produce electrons that run from the anode to the cathode within the fuel cell, creating an electrical current. Almost any type of organic waste material can be used to produce electricity – not only wastewater, but also grass straw, animal waste, and by-products from such operations as the wine, beer or dairy industries

(http://oilprice.com/BrianWestenhaus, August 2012).

8.4 Microbial fuel cell for production of bioelectricity from whey and biological waste treatment.

Electricity generation by MFC with paneer whey degradation with different microorganisms was investigated in a two compartment cell without mediators in the microbial fuel cell.

Microorganisms were able to utilize the carbohydrate (mainly lactose) existing in the whey for generation of bioelectricity. The open circuit potential was determined and the maximum voltage given by different organisms was estimated. The MFC was run using *Klebsiella pneumonae* and sewage sample. It was found that the maximum OCV of 453 mV was shown by *Klebsiella pneumonae* and proves to be the best organism for obtaining bioelectricity from whey. (Aishwarya et. al., 2011, International Journal of Advanced Biotechnology and Research).

8.5 Substrates used in microbial fuel cells (MFCs) for sustainable energy production.

MFCs offer the possibility of extracting electric current from a wide range of soluble or dissolved complex organic wastes and renewable biomass. A large number of substrates have been explored as feed. The major substrates that have been tried include various kinds of artificial and real wastewaters and lignocellulosic biomass. Though the current and power yields are relatively low at present, it is expected that with improvements in technology and knowledge about these unique systems, the amount of electric current (and electric power) which can be extracted from these systems will increase tremendously providing a sustainable way of directly converting lignocellulosic biomass or wastewaters to useful energy. (Deepak et. al., 2009, Bioresource Technology)

8.6 Bioelectricity Production from Soil Using Microbial Fuel Cell

As soil is an environment with the highest number of microorganisms and diversity, it should have the potential for energy generation. The soil used for the study was Mollic Gleysol collected from the surface layer (0–20 cm). Four combinations of soil MFC differing from each other in humidity (full water holding capacity [WHC] and flooding) and the carbon source (glucose and straw) were constructed. Voltage (mV) and current intensity (μA) produced by the MFCs were recorded every day or at 2-day intervals. (Wolińska, et. al., 2014 Appl Biochem Biotechnol).

8.7 Electricity generation and waste water treatment of Oil refinery in Microbial fuel cells using *Pseudomonas putida*

By Using *Pseudomonas putida* (BCRC 1059), a wild-type bacterium. The refinery waste water could be treated and also generate electic current in air-cathode chamber over four-batch cycles for 63 cumulative days. The oil refinery waste water containing chemical oxygen demand (COD) could be used as a sustrate for electicity generation in the reactor of the MFC. The removal efficiency of the COD reached 30% as a function of time. This study demonstrated that oil refinery waste water could used as a substrate for electricity generation (Majumdar et. al., 2014 International journal of Hydrogen Energy)

8.8 Microbial battery: Team uses 'wired microbes' to generate electricity from sewage

Stanford scientists have developed a "battery" that harnesses a special type of microbe to produce electricity by digesting the plant and animal waste dissolved in sewage. Engineers at Stanford University have devised a new way to generate electricity from sewage using naturally-occurring "wired microbes" as mini power plants, producing electricity as they digest plant and animal waste. (http://phys.org/news/2013-09-microbial-battery-team-wired-microbes.html#jCp) **Sep 16, 2013**.

8.9 Bacteria that turn waste to energy in microbial fuel cells studied

Anaerobic microorganisms which can consume waste while generating electricity in a type of microbial electrochemical cell known as a microbial fuel cell, are being studied by researchers at Arizona State University's Biodesign Institute. Joseph Miceli, a researcher at Arizona State University's (ASU). Biodesign Institute studies specialised microorganisms known as anode respiring bacteria (ARB). Rather than investigating their role in health and disease however, his research explores the ability of these microbes to clean up waste and produce useful energy in the form of electricity or hydrogen.

(http://www.waste management-world. com/ articles/ 2013/04/ bacteria-turn-waste-to-energy-microbial-fuel-cell.html)

8.10 Geobacter Bacteria Breakthrough- Electricity Generated from Hydrogen

Researchers at the University of Massachusetts, Amherst, have engineered a breed of electricity producing bacteria- the Geobacter species- who grow simply by using hydrogen gas as their exclusive electron donor, while carbon dioxide suffices all its carbon requirements.

A strain of bacteria were specifically engineered in a microbial fuel cell so that they did not feel the requirement of organic carbon, and the conclusion observed was that when the hydrogen supplied to the microbial cell was intermittently stopped, electrical signals drooped substantially and cells attached to the electrodes did not produce any significant electricity.

(http://www.crazyengineers.com/threads/geobacter-bacteria-breakthrough-electricity-generated-from-hydrogen.68064/) **May 20, 2013**

8.11 Waste to Watts: Improving Microbial Fuel Cells.

According to César Torres and Sudeep Popat, researchers at Arizona State University's Biodesign Institute, certain kinds of bacteria are adept at converting waste into useful energy. These microorganisms are presently being applied to the task, through an innovative technology known as a microbial fuel cell or MFC. (Richard Harth, July 19th, 2012).

(http://researchmatters.asu.edu/stories/waste-watts-improving-microbial-fuel-cells-2317)

8.12 Electricity Generation from Biowaste Based Microbial Fuel Cells

Voltage generated in a microbial fuel cell decreases linearly with respect to time. In other words, the first order derivative of voltage generated with respect to time is a negative constant. Thus the rate of change of voltage generated with respect to time has been established to be independent of time. It has been found that a mixture of biowastes can actually result in higher extractable current than any single component although this is not always true in general. Further, it has been found that when a component results in higher voltage production, it ends up reducing the cell life.

(Barua and Deka, 2010 International Journal of Energy)

8.13 Recent developments in microbial fuel cell technologies for sustainable bioenergy

Microbial fuel cells (MFCs) are devices that exploit microbial catabolic activities to generate electricity from a variety of materials, including complex organic waste and renewable biomass. These sources provide MFCs with a great advantage over chemical fuel cells that can utilize only purified reactive fuels (e.g., hydrogen). A developing primary application of MFCs is its use in the production of sustainable bioenergy, e.g., organic waste treatment coupled with electricity generation, although further technical developments are necessary for its practical use (Watanabe K., 2008).

8.14 Electric Power Generation from municipal, Food, and Animal wastewaters Using Microbial Fuel Cells

The microbial fuel cell (MFC) technology can replace activated sludge processes for secondary wastewater treatment. When a complex wastewater is treated with a diverse and undefined community of microbes in large-scale systems. These challenges include low coulombic efficiencies, slow kinetic rates, and nonlinear power density increases during scaleup efforts. Finally, developed a prediction of the main economic gain from treating wastewater with microbial fuel cells. The lectricity generation will not justify MFC operation, but that BOD removal with this more sustainable technology is attractive (Jeffrey et al., 2010, Electroanalysis)

8.15 Electricity production from beer brewery wastewater using single chamber microbial fuel cell

The performance of electricity production from beer brewery wastewater in a single chamber membrane-free microbial fuel cell (MFC) was investigated. The MFCs could generate electricity from full-strength wastewater (2,239 mg-COD/L, 50mM PBS added) with the maximum power density of 483mW/m^2 (12W/m^3) at 308C and 435mW/m^2 (11W/m^3) at 208C, respectively. Temperature was found to have bigger impact on cathode potential than anode potential. Results suggested that it is feasible to generate electricity with the treatment of beer brewery wastewater. (Wang et al. 2008).

9. Advantages

- ✓ Fuel cells eliminate pollution caused by burning fossil fuels; the only by-product is water.
- ✓ If the hydrogen used comes from the electrolysis of water, then using fuel cells eliminates greenhouse gases.
- ✓ Since hydrogen can be produced anywhere where there is water and electricity, production of potential fuel can be distributed.
- ✓ Installation of smaller stationary fuel cells leads to a more stabilized and decentralized power grid.
- ✓ Fuel cells have a higher efficiency than diesel or gas engines.
- ✓ Most fuel cells operate silently, compared to internal combustion engines
- ✓ Fuel cells have no "memory effect" when they are getting refueled.
- ✓ The maintenance of fuel cells is simple since there are few moving parts in the system.
- ✓ Fuel cells provide high quality DC power.
- ✓ The absence of combustion and moving parts means that fuel cell technologies are expected to provide much improved reliability over traditional combustion engines.
- ✓ Use a variety of fuels, renewable energy and clean fossil fuels.
- ✓ The power densities are high values.
- ✓ Cogeneration Capability.
- ✓ Fuel cells can be responsive to changing electrical loads.

10. Disadvantages

- ✓ Fuelling fuel cells is still a major problem since the production, transportation, distribution and storage of hydrogen is difficult.
- ✓ Reforming hydrocarbons via reformer to produce hydrogen is technically challenging and not clearly environmentally friendly.
- ✓ The refueling and the starting time of fuel cell vehicles are longer and the driving range is shorter than in a "normal" car.
- ✓ Fuel cells are in general slightly bigger than comparable batteries or engines. However, the size of the units is decreasing.
- ✓ Fuel cells are currently very expensive to produce, since most units are hand-made.
- ✓ Some fuel cells use expensive materials.
- ✓ The technology is not yet fully developed and few products are available.

FORTHCOMING EVENTS		
Events	**Date**	**Place & Correspondence**
2015 International Conference on Environment and Bio-Engineering (ICEBE 2015)	10- 11th January, 2015	http://www.icebe.org/ Dubai, United Arab Emirates
2015 International Conference on Substantial Environmental Engineering and Renewable Energy (SEERE-15)	13-14th January, 2015	http://seere.org/ Abu Dhabi, United Arab Emirates
2015 5th International Conference on Future Environment and Energy (ICFEE 2015)	24-25th January, 2015	http://www.icfee.org/ Taipei, Taiwan
The Energy & Materials Research Conference - EMR2015	25- 27th February, 2015.	http://emr2015.org/ Madrid (Spain)
5th European Fuel Cell Forum, Switzerland	30 – 3rd July, 2015	http://www.efcf.com/ Kultur- und Kongresszentrum Luzern KKL Lucerne, Switzerland
Global Biotechnology Congress 2015	22-25th July, 2015	http://www.globalbiotechcongress.com Boston, MA, USA

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