Generating Current From Plants Plant-e Technology

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Abstract: The Plant Power concept is based on the cooperation of plants and microorganisms to produce in-situ electricity. Plants take up carbon dioxide and water and capture light energy. This energy is stored in the chemical bonds of sugars produced, using carbon dioxide and water. Part of this chemically stored energy is transferred to the roots of the plants. This energy present in the root zone can then be captured by the so-called electro-chemical active bacteria. These organisms are capable to oxidize the organic matter present in the root zone and transfer the energy rich electrons to an electrode. The energy carried by the electrons can be used as electrical energy, after which the electrons react at another electrode with oxygen to form water. The primary advantage of the Plant Power concept is that renewable, clean electricity can be produced while the facility can be well integrated in the landscape. The aim of the EU project is to enhance the productivity of the Plant Power concept such that it becomes competitive with other bioenergy systems

Keywords: renewable energy, weak energy source, atomic absorption spectroscopy, living plants

I. INTRODUCTION :

Plant Power is electricity based on cooperation of living plants and microorganisms in a fuel cell. Plants capture light energy during photosynthesis. In this process carbon dioxide and water is taken up and converted into chemical bonds of sugars. Part of this chemically stored energy is transferred via the roots and littered into the soil.

This energy transported into the soil can be captured by the so-called electro-chemical active bacteria. These micro-organisms are capable to oxidize the organic matter and transfer energy rich electrons to an electrode. The energy carried by the electrons can be used as electrical energy, after which the electrons react at another electrode with oxygen to form water. This technology is called the Plan-Microbial Fuel Cell (PlantMFC) (Figure I).

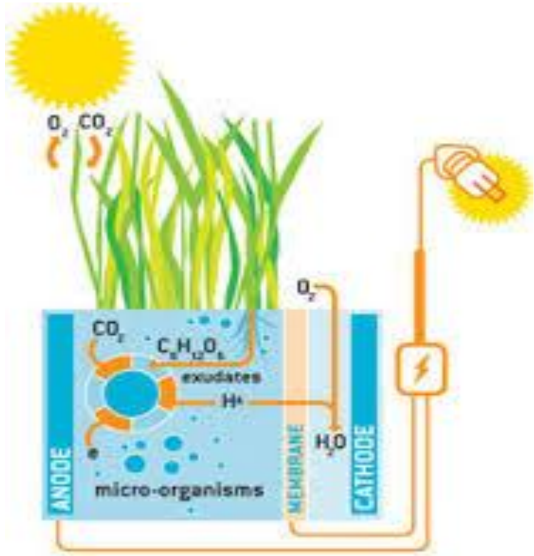


Figure I: schematic of the power plant concept

II. APPROACH:

The PlantPower consortium developed high-tech and sediment Plant-MFC systems. The maximum electricity output improved 16 times up to 1.1 W/m2 projected growth area. This was possible due to research steered on pre-defined prerequisites and standardised set-ups.

The Plant Power principle:

The principle of the Plant Power project is outlined here. Carbon dioxide is fixed by plant leaves using solar energy. Part of the fixed carbon is transported to the roots and released as small molecular weight components. These so called exudates are partly utilized by electrochemically active micro–organisms yielding carbon dioxide, protons and electrons. Carbon dioxide is returned to the atmosphere. Electrons are transferred by electrochemically active micro-organisms to the anode for gaining metabolic energy. The anode is coupled to a cathode. Thanks to a potential difference between anode and cathode, the electrons flow from the anode through an electrical circuit with a load to the cathode. To retain electro-neutrality a proton is transported through the membrane from the anode to the cathode. In the cathode oxygen is reduced, with protons and electrons, to water.

The Plant-MFC concept has been enabled by the discovery of electrochemically active micro-organisms in 1911. Since the beginning of this century microbial fuel cells gain renewed attention possibly due to the need for sustainable technologies. The proof-of-principle of the Plant-MFC, which uses plants to provide substrate for the micro-organisms, was independently described in 2008 by two consortium members. This showed for the first time that rhizodeposits from plant-roots can be used as a new electricity source.

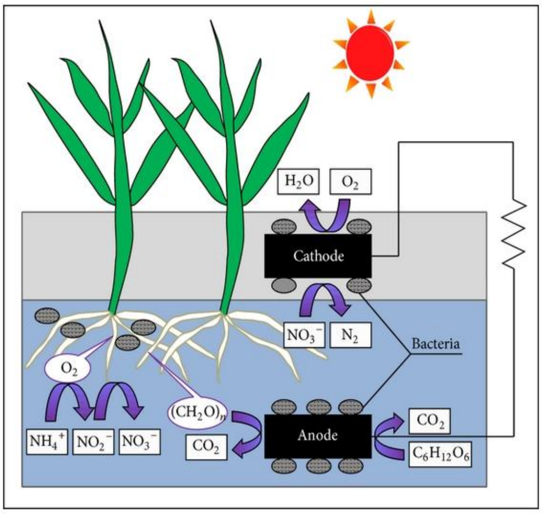
Electricity production by a Plant-MFC depends on several processes; photosynthesis, allocation of fixed carbon to the roots, rhizodeposition of carbon-sources to the rhizosphere, electron generation by the microorganisms in the rhizosphere and electricity production by the fuel cell. To achieve a high power density in the Plant-MFC all these elements must be aligned. Using a conservative estimation it was calculated that an average power density of 0.23 W/m2 can be achieved while with enhanced rhizodeposition a maximum up to 3.2 W/m2 can be achieved. Conventional bio-electricity systems under West-European climate conditions achieve 0.3 W/m2 year-round average when producing electricity. It should be noted that in case plant growth is not impaired by the rhizodeposition i.e. exudation, the Plant-MFC power is an additional benefit. Given the potential impact of the technology (a new clean electricity source), the novelty of the concept the following objective has been set for the project:

To explore new areas of science & technology needed to realize the novel, clean, renewable, sustainable, efficient Plant Microbial Fuel Cell as a future bioenergy source in Europe.

To guide our research towards the use of Plant-MFC as a future bioenergy source in Europe we first visualized two visionary lines for application. From these visionary lines we defined 6 plant MFC prerequisites. These prerequisites are the basis for structuring the project and steering the research toward our aim of the Plant-MFC as a future bioenergy source in Europe

III. TECHNOLOGY:

Plant-e develops products in which living plants generate electricity. These products are based on technology that was developed at WageningenUniversity, which was patented in 2007. The patent is now held by Plant-e. The technology enables us to produce electricity from living plants at practically every site where plants can grow. The technology is based on natural processes and is safe for both the plant, and its environment.



Via photosynthesis a plant produces organic matter. Part of this organic matter is used for plant-growth, but a large part can’t be used by the plant and is excreted into the soil via the roots. Around the roots naturally occurring micro-organisms break down the organic compounds to gain energy from. In this process, electrons are released as a waste product. By providing an electrode for the micro-organisms to donate their electrons to, the electrons can be harvested as electricity. Research has shown that plant-growth isn’t compromised by harvesting electricity, so plants keep on growing while electricity is concurrently produced.

Project Context and Objectives:

The possibilities of PlantPower

The plant microbial fuel cell (Plant-MFC) has the potential to become a large-scale electricity generating technology. Such a system can produce in-situ electricity without harvesting the plants, 24 hours per day. In the Plant-MFC living plants and micro-organisms form an electrochemical system that can produce sustainable electricity from solar energy, so called PlantPower.

It is expected that Plant-MFC technology can cover 20% of European Union’s primary future electricity need. This PlantPower project aimed to improve the net power output of the Plant-MFC from 0.0067 W/m2, as achieved in 2007, to 3.2 W/m2 in 2012. Therefore Plant-MFCs’ new areas of science & technology were researched. The Plant-MFC concept has several attractive qualities which can transform the current electricity market. The technology can reinforce the competitiveness of Europe on the global energy market because PlantPower’s energy source is available everywhere where plants can grow. PlantPower therefore reduces dependency of Europe on external energy resources. Moreover, PlantPower could become a European electricity export product in the future since the Plant-MFC could be implemented world-wide

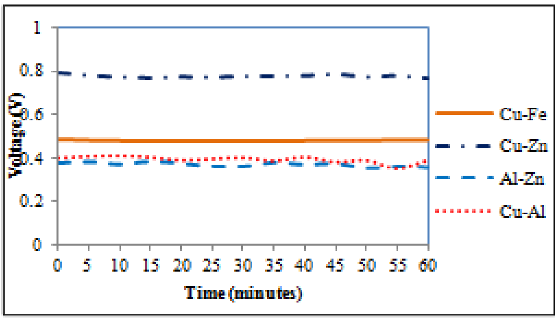


TABLE: The detailed calibration blank for standard solutions containing copper and zinc is shown in Table 2 from the range of 2.0 ppm-10.0 ppm. These data are used as the standards and validations for the analysis of samples

IV. MOTIVATION:

In 2008, it was discovered at our department that living plants and micro organism can generate green electricity in a biological fuel cell. Now, this is a future emerging technology with potential to provide 20% of Europe's electricity need. Therefore, the European PlantPower project explores new exiting areas of science & technology.

The concept of this renewable energy production is that living plants transform solar energy into organic compounds of which 40% or more can be released into the soil. The released organic compounds can be oxidized by electrochemically active micro organisms that use the anode of a fuel cell as electron acceptor. The electrons are reduced at the cathode with oxygen to water. In this way, day and night electricity can sustainably be produced from biomass without harvesting the plant.

Technological challenge

The challenge is to increase the power output of this system with several European research groups. Our research group is focused on maximizing the power output by increasing efficiency and adapting the reactor design and operation.

Plant Microbial Fuel Cell

- no combustion gasses thus clean
- solar energy thus renewable
- living biomass & nutrients reuse thus sustainable
- 5 times more then conventional thus efficient
- 24 hours per day electricity in-situ
- bioenergy without competition to food

High-tech Plant-MFCs reach long term power density of 0.22 W/m2

The power output of the Plant-MFC depends on the photosynthetic efficiency of the plant, the rhizodeposition, and energy efficiency of the MFC which is a combination of coulombic efficiency and the internal resistances (=voltage efficiency). This WP investigated and developed the high tech Plant-MFC towards the output of 3.2W/m2. A Plant-MFC with low internal resistance has been realised (0.101 Ω.m2). The plant-growth medium has been adapted such that alternative electron acceptors were removed and both plant-growth and electrochemically active micro-organisms were able to thrive in the Plant-MFC. This has led to an average power density of 0.22 W/m2 and an average current density of 0.47 A/m2.

Coulombic efficiency depends on rhizodeposits and is estimated at 20%

Coulombic efficiency (CE) is the percentage of electrons present in the rhizodeposits which end up as electrons in the electrical circuit to obtain electricity. CE is affected by alternative electron acceptors (e.g. oxygen), micro-organisms and other parameters in the Plant-MFCs. Lowering the anode potential can lead to a higher power output. Coulombic efficiency of 60-70% was obtained with citrate oxidation. The effect of oxygen on the coulombic efficiency was positive, maybe due to methanogenesis inhibition. However, oxygen can also reduce the Coulombic efficiency since it's energetically a more effective electron acceptor. Experiments with different rhizopdeposits revealed that the CE in the Plant-MFC is likely 20%.

Anode: $2C_6H_{12}O_6 \rightarrow 2C_6H_{10}O_6 + 4H^+ + 4e^-$

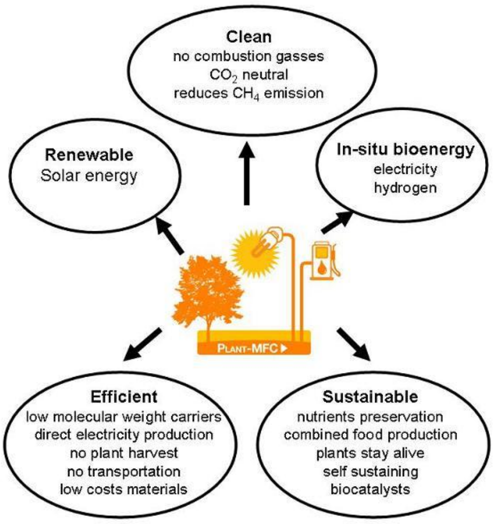
Cathode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Resulting in the net reaction:

$2C_6H_{12}O_6 + O_2 \rightarrow 2C_6H_{10}O_6 + 2H_2O$

Benefits:

By its nature, the Plant-MFC can become 10 times as efficient as conventional bio-electricity systems (like biogas and bio-ethanol production), because no energy has to be invested to generate electricity. Furthermore, the systems' concept is principally clean, renewable and sustainable. The technology might be implemented in several ways, ranging from local small scale electricity providers to large scale electricity wetlands & islands, high-tech electricity & food supplying greenhouses and novel bio-refineries.



This way, affordable electricity can be produced everywhere where plants can grow. This is not limited to Europe. It offers opportunities for developing countries and remote regions as well. Plant-MFCs can be integrated in landscapes invisibly which makes this technology socially highly acceptable

V. CONCLUSION:

Extensive progress has been made in understanding the Plant-MFC. The Plant-MFC has now a performance that matches the net performance of current crop based electricity systems. The knowledge of this project is disseminated world-wide and an spin-off company is building follow-up projects to exploit our developments. Still, further fundamental research, technological integration, wetlands selection and demonstration in real wetlands is needed to show the full PlantPower electricity potential. After a first full scale implementation a complete environmental and economic performance analyses can be made to prove the potential impact of PlantPower.

REFERENCE:

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