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"Strengthening Food and Feed Security and Energy Sustainability to Enhance Competitiveness"

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“Strengthening Food and Feed Security and Energy Sustainability to Enhance Competitiveness”

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PREFACE

Alhamdulillahirabbil'alamin, I would like to express how grateful we are to finished "Proceeding of ISAE International Seminar 2017, Bandar Lampung, August 10-12, 2017 with theme "Strengthening Food and Feed Security and Energy Sustainability to Enhance Competitiveness". We are here to communicate and gather dissemination of information and research results in the field of agriculture as part of planning the development of agriculture in the future towards food and biomass-based energy self-sufficiency. Through this proceeding, we shared the problem, ideas, knowledge and technology to arrange solutions that communicated and discussed at ISAE International Seminar, Bandar Lampung, August 10-12, 2017. This proceeding contains 118 papers that divided by 8 categories namely Agricutural Engineering, Agribussiness, Agricutural Technology, Agricutural Science, Energy, Food, Natural Resources, and Sistem and Agricultural Management from many universities and many institutes in Indonesia.

I would like to extend gratitude for all authors of the proceeding who communicated and shared their research results, editorial team who work together to executed this proceeding, Agricultural Engineering Departement of University of Lampung, Faculty of Agriculture of University of Lampung, University of Lampung, PERTETA and committee members. Salutations to Dr. Ir. Sam Herodian, M.S. as Profressional Staff of The Minister of Agriculture of Republic of Indonesia; Ir. Sutono, MM as Regional Secretary of Lampung Province; Prof. Dr. Ir. Hasriadi Mat Akin, M.P. as Rector University of Lampung; Prof Dr. Ir. Irwan Sukri Banuwa, M.Si. as Dean of Agricultural Faculty of University of Lampung; Prof. Mikio Umeda from Kyoto University, Japan; Prof. Dr. Ir. Irwandi Jaswir, M.Sc. from International Islamic University, Malaysia; Dr. S. D. Filip To, PHD. PE from Mississippi State University, USA; Dr. Rosanna Marie C. Amongo from University of the Philippines Los Baños, The Philippines; Prof. Dr. Ir. Lilik Sutiarso, M.Eng. from Universitas Gadjah Mada, Indonesia; and Prof. Raden Achmad Bustomi Rosadi, M.S. from University of Lampung.

Last, we hope that you will have a great memories about the experience in Bandar Lampung and the relationship that have managed at Seminar can become better in the future.

Best Regard,

Dr. Ir. Sandi Asmara, M.Si
Chairman of ISAE IS 2017

TABLE OF CONTENTS

B : Agribusiness

C : Agricultural Technology

F : Food

G : Natural Resources

H : System and Agricultural Management

E.5

FEASIBILITY STUDY OF PLANT MICROBIAL FUEL CELL TECHNOLOGY IN INDONESIA'S RURAL AREA

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ABSTRACT

Seven points two million families are having no access to electricity services now in Indonesia's rural area. Mostly, people are using traditional kerosene lantern to obtained light. Apparently, the light output of kerosene lamp is minuscule, also harmful to the environment and human health. Hence, we would like to propose a possible green energy, plant microbial fuel cell (P-MFC), to generate electricity in the isolated district. P-MFC is a sustainable and renewable energy which take advantages of photosynthesis process of a plant and bacteria to transform the sunlight into electricity. Moreover, P-MFC is non-destructive, non-food compete, and applicable in the wetlands area and rice paddy field. The study focuses on the current development of P-MFC and reviews three main paradigms. Firstly, the effect of rhizodeposition and photosynthesis processes to plants in producing electricity. Secondly, the current development of P-MFC design and its power generation. And lastly, the potential to implement P-MFC in Indonesia's rural area.

Keywords : plant microbial fuel cell, bioenergy, light, rural area, Indonesia.

I. INTRODUCTION

The great Thomas Edison narrative that "we will make electricity so cheap that only the rich will burn candles" is nearly right, especially to a current significant development of industrialisation. But, he didn't anticipate the perplexity of millions of people who still have lack access to electricity. However, IEA projected that today hundreds of billions of people worldwide are still left behind without proper energy service where mostly located in developing countries (IEA 2016). In more detail, four out of five people with no access to electricity are live in South Asia and sub-Saharan Africa (Mahapatra, Chanakya, and Dasappa 2009).

Nowadays, most of the inhabitants in non-electrified rural area are using candles, car batteries, diesel generator and kerosene lamp for lighting. Seven million of household or equal to 12% of Indonesian are still using kerosene for cooking and lighting which equal to 1.9 Mt of kerosene liquid (Permadi, Sofyan, and Kim Oanh 2017). Moreover, this high energy needs of fuel source are predicted to keep increase by 30% at 2040 where hundreds of people are projected to be still left behind without proper energy service (IEA 2016). However, excessive use of fossil fuel to generate light is regarded to bring a devastating consequence on the environment. Many believe that this nonrenewable energy fuel is the leading source of world's global warming pollution, such as climate change, resource depletion, pollution, toxicity, and diversity loss. The worst influence is a direct bearing on human health (Gates, Trauger, and Czech 2014). Hence, high production of energy derived from renewable and sustainable energy is needed to develop.

Renewable energy needs are projected to increase in the future and will replace the position of fossil fuel. Moreover, some environmental and economic advantages of renewable energy transition were measured. But, Pimentel (2014) in his book stated that several issues are rising due to the prerequisite of a large scale power generation from biofuels technology, such as competition for food and feed, also land opposition for agricultural, forestry, urbanisation and wildlife activities. With this intention, we considered Plant-Microbial Fuel Cell (P-MFC) as one of possible solution since this technology is non-destructive, renewable, and non-land/food compete (Strik et al. 2008).

II. DEVELOPMENT OF P-MFC

On 1910, a botanist named Potter implanted the idea of the possibility of electricity generation by microbes (Potter 1911). Unfortunately, his idea didn't reach a lot of attention. After two decades, the technology recognised and welcomed by the researchers because its state of arts of converting wastage into energy without any damaging effect on the environment (zero footprints). In the long run, many improvement and advancement were made within the Microbial Fuel Cell (MFC) technology. And one of the current innovation is by applying MFC onto plants which are known as Plant Microbial Fuel Cell (P-MFC). The idea of P-MFC was to incorporate a plant at an anode section as the source of food uptake for the bacteria (substrate).

This technology is a collaboration between many discipline areas differing from the study of microbes, bio-electrochemical, plants, environment, biosystem and other engineering areas., The focal point of plant science is to understand the adaptation of the rhizodeposition due to the choice of suitable plants upon their morphology and physiology point of view. The microbial study is required due to the factor of microbial strain chosen in the rhizosphere-soil consortium to study better electrically active microbes. Next, the environmental engineering is necessary to familiarise with the wastewater treatment approach of heavy metals removal and organics degradations. Chemical engineering is favourable for its possible fabrications of electrodes which are cost effective, and less toxic. Electrical engineering is necessary to know the possible stacking to maximise the power output. Then, biosystem engineering is comprised in the interconnection of living and non-living components to reach an understanding of P-MFC as a biosystem for the production of biomass and bioenergy (Nitisoravut and Regmi 2017).

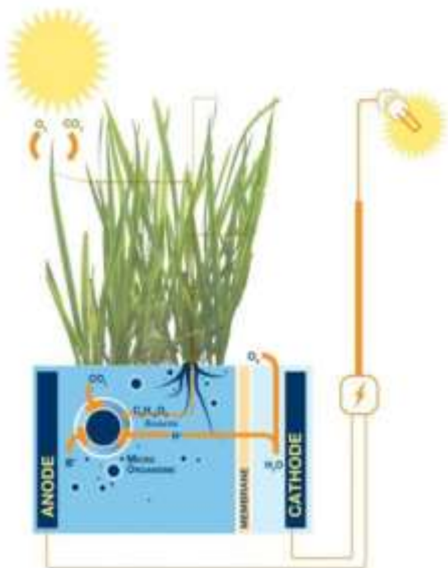

Fig. 1. Overview of Plant-Microbial Fuel Cell (Strik et al. 2008)

P-MFC is a novel technology for energy generation which takes advantages from living plants to generate electricity (Fig. 1). It was proven to produce electricity in 2007 (Strik et al. 2008) by a demonstration using Reed mannagrass. Then it was being introduced in 2008. Moreover, P-MFC harvested the energy in situ without affecting any harm to the environment. To point out, the only side product of P-MFC is pure water that resulted from a simultaneous electron flows through the external circuit within the system.

P-MFC holds a naturally occurred process which leads it to be fully sustainable and renewable. Sunlight and carbon dioxide are two important matters to support the photosynthesis of the plant. Plants utilise solar energy to produce biomass with the help of chlorophyll pigments within the green parts of it leaves. However, only 40% of the energy used by the plants for its biological growth. The remaining half of it then exudates to the rhizosphere which resulted in the form of organic carbon; such as carbohydrate and glucose. Next, the organic matter is exploited by the microbe state which presents in the soil around the root to break it down become electrons, proton, and carbon dioxide. Lastly, this process could trigger the production of electricity after the electron flows from the anode to the cathode through a load, then the electricity produced is so called "bioelectricity."

In general, P-MFC needs a submerged anaerobic area to proceed the ions exchange from the anode to the cathode. Hence, this technology is projected to implement in a natural wetland area and to couple it with a rice paddy field. We could obtain two benefits by this implementation; additional values of wetlands function, and electricity production.

III. PHOTOSYNTHESIS PATHWAY AND RHIZODEPOTISION OF PLANTS USED IN P-MFC

The choices plant of PMFC gives a significant power output difference. Two factors contributed to this effect is probably rhizodeposition and photosynthesis. Plants are classified into three categories based on their photosynthetic pathways, namely; C3, C4 and CAM (crassulacean acid-metabolism). Plants didn't store all of the solar energy within their biomass due to energy losses through the photosynthesis process. A significant loss occurs mostly to outside photosynthetically active spectrum, reflection, and other limitation (Fig. 2). Hence, C4 plants efficacy is higher than other plants because of its ability to restrict photorespiration.

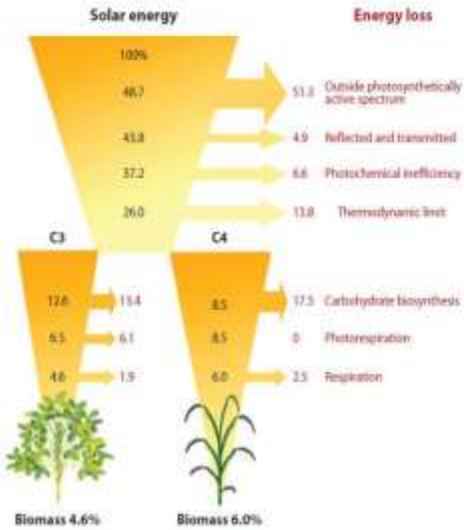

Fig. 2. Solar energy convertion to C3 and C4 plants (Zhu, Long, and Ort 2010)

Understanding the photosynthetic pathways of a plant is necessary for choosing the plants for PMFC. The conversion efficiency of C3 plants is estimated around 4.6%, while C4 is estimated to be 6%. This efficiency matter means that C4 plants are projected to produce more bioelectricity in the application of PMFC. Some advantages of choosing C4 over C3 in PMFC technology are:

1. C4 plants can grow well in hot and dry ambient.
2. Theoretically more efficient to absorb solar energy (6 % over 4.6 %).
3. Higher photosynthesis efficiency leads to a higher rhizodeposition. Hence, more rhizodeposition in C4 plants is available for microbes and fuel production.

Moreover, crassulacean acid metabolism or CAM plants are dissents from C3 and C4 plants due to its characteristic of inhabiting a dry and arid area. The CAM names come from its plant family names, the Crassulaceae. CAM plants have an ability to uptake CO2 during the night, hence lead to water collection within their leaves. Furthermore, CAM plants grow slower than C3 and C4 which resulted in less biomass production. However, challenges are present to do further research on the prospect of CAM as a plant driver in PMFC.

Plants residues in the form of organic matter then exudate from the live roots. The secretion from the roots brings out the carbon based organic matter, such as glucose and organic acids. These organic compound can be easily used as a substrate in the rhizosphere by the microbes. From the total input of the organic compound, organic rhizodeposition could provide 30-40%. Hence, organic matter from plant roots holds a significant role in the rhizosphere.

Fig. 3 *Spartina anglica* plant (Sloth 2003).

Spartina anglica (Fig. 3) and *Glyceria maxima* are two most used kinds of grass in the current research of PMFC, and both of them belong to C4 class plant. Moreover, Oryza sativa is the most popular food crop being studied so far, and its belong to C3 plant. The power output of *S. anglica* reaches a better performance than the latter two in almost every study being carried (Helder et al. 2013, Helder et al. 2010, Timmers et al. 2010).

IV. DEVELOPMENT OF P-MFC DESIGN AND ITS POWER GENERATION

Three types of PMFC design recently studied are flat plat, tubular, and roof top (modular). Flat plat and tubular design are mostly used on the lab scale. On the other hand, the roof top system or commercially known as the modular design (plant-e.com) is initially aimed as a green roof garden to decrease the effect of dense population in the urban area. None of them is reportedly applied yet in the natural area. *Text Font of Entire Document*

Fig 4. Three types of P-MFC models; A. Tubular, B. Modular, and C. Flat plat (source: Wetser (2016) and plant-e.com)

Table 1. Overview of PMFC development

MFC Fabrication		Plant Types (Pathways)	Operating condition	Sub-strate	Max. power density (mW/m^2)	Reference
Anode	Cathode					
Graphite felt		O. *sativa* (C3)	Rice field	Soil/fertilizer	80	Ueoka et al. (2016)
Graphite granules		O. *sativa* (C3)	Greenhouse	Hoagland solution [a]	33	Schamphelaire et al. (2008)
Graphite granule	Graphite felt	G. *maxima* (C3)	Climate chamber	Hoagland solution	67	Strik et al. (2008)
Graphite felt		C. *involucratus* (C3)	Ambient condition	Lotus soil, wastewater	5.9	Klaisongkram and Holasut (2015)
Raphite rod	Graphite felt	A. *anomola* (C4)	Climate chamber	Hoagland solution	22	Helder et al. (2010)
Graphite plate		P. *setaceum*	Ambient condition	Red soil	163	Deng, Chen, and Zhao (2012)
Graphite felt		S. *anglica*	Climate chamber	Nitrate less ammonium rich medium	679 (PGA [b])	Wetser et al. (2015)

[a] Hoagland solution : rich nutrient solution for plant growth
[b] PGA : Plant Growth Area (total area of plants root within the reactor).

The system cost of PMFC reactor is consist of each anode and cathode 8.5%, reactor 68.5%, spacer (membrane) 11%, mediator 1.4%, and collector 2.7% (Deng, Chen, and Zhao 2012). The anode and cathode used in the experiment were mostly a carbon based material with electrical conductivity, for example; carbon felt, graphite felt, carbon fibre, graphite rod, etc. A spacer is needed to separate the anode and the cathode physically, preventing a short circuit. The spacer is preferably non-conductive and small (to reduce the ionic and transport losses). Moreover, the mediator is the section where the PMFC being put on, for example in modular type; it is set in a black plastic box, while in a flat plat design, thin glass is occupied. A current collector is needed to harvest the electricity generation, for example; titanium wire, gold wire and aluminium wire.

V. POWER POTENTIAL OF P-MFC IN INDONESIA'S RURAL AREA

P-MFC needs an anaerobic state which only possible in a submerged area. Two kinds of an immersed area which has a potential for PMFC application in Indonesia are rice paddy field and natural wetlands such as peatland or marsh. The total area of rice paddy field in Indonesia is 8.114.829 ha (BPS 2017), while the total of a natural wetland, especially peatland, is around 6 million ha (Sari 2012). Moreover, wetland methane emission could give an estimation to the national potential power generation of the PMFC. Therefore, particular data of each wetland type is required to get the ultimate potential power. In this estimation, we only consider rice paddy field and peatland area, while of course other wetland area such marshes and swamps also present.

The electricity potential calculation is based on the ability of electrochemically active bacteria to outcompete the methanogens as an electron donor. Consequently, the methane is not released to the atmosphere but used for electricity production. The power generation is calculated using equation 1 (Wetser, 2016).

$$P=JnFU/Mt \tag{1}$$

Where P is the estimated power (Tera Watts), J is methane production (Tg yr -1), n is the number of electrons in acetate redoks reaction (8)*, F is the Faraday constant (96485 A s mol -1), U is the PMFC voltage (assumed to be 0.6 V), M is methane molar mass (16 g/mol), and t is total of seconds in a year (s/year). *Acetate is assumed to be the organic materials degraded by the microbe in this calculation.

$$P\ total=P\ rice\ field+P\ wetland \tag{2}$$

According to Khalil et al. (2008), methane emission from rice paddy field is nearly 30 mg/m^2/hr which is equal to 21.3 Tg/year in national level. Furthermore, methane emission in natural wetland according to IPCC report is around 1260 kg/ha/yr or equal to 7.56 Tg/year. The power potential from each submerged area is calculated separately. Then, the total power potential is determined by summing the potential from rice paddy field and peatland (Equation 2) which equal to 26,512 Mega Watt/year (Table 2).

Table 2. Power production estimation from Rice paddy field and Peatland

Wetland type	Area (million ha)	Methane Emission (Tg/yr)	Estimated power production (MW/yr)
Rice Paddy Field	8.1	21.3	1,957.9
Peatland	6.0	7.56	6,938.9
Total power			26,512.9

Additionally, P-MFC needs a high ambient temperature for the plant to grow.. The fact that the location of Indonesia next to the equator line gives it a relatively high temperature and humidity. Data from Meteorological Station (BMKG) shows that the maximum temperature in 2015 reaches 39.5 ^{O}C and the lowest is 17.0^{O}C. Where the average normal temperature is around 27 ^{O}C (BPS 2017). However, the lab scale P-MFC's use an artificial temperature between 23 and 27 ^{O}C (mostly 25 ^{O}C) because the plant is assumed to grow under this condition (Strik et al. 2008, Timmers et al. 2012, 2013).

Solar irradiation value is another notable ambient condition to support the photosynthesis process of the plants in P-MFC. Kouzuma, Kaku, and Watanabe (2014) found out that PMFC electricity production was dependent to sunlight (due to photoshyntesis and root exudates). However, the average solar irradiation value in Indonesia is quite high which is around 170 - 200 W/m2 (solargis.com). As a comparison, in The Western Europe area (the location of the previous research), the average solar radiation is about 150 W/m2 (Strik et al. 2008). While the favoured condition for the plants (rice paddy and marsh species) is 170 W/m2 (Deng, Chen, and Zhao 2012). Hence, Indonesia's ambient condition is favourable for PMFC application.

VI. CONCLUSION

This preliminary study presents the potential of applying newly emerged technology, plant microbial fuel cell (PMFC), in Indonesia's rural areas. Some factors influencing the performance of the technology have been explained regarding plant types, and operational condition. The climate condition of Indonesia as a tropical country is favourable for PMFC application, concerning local temperature and solar irradiation value. The power output potential of this technology in rice paddy fields and natural wetlands is estimated to be around 26,512.9 MW/year. This energy production is projected to serve the needy people as a new electricity/light source around the isolated areas.

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