# BioGenerator – a Novel Bio-Technology for the Conversion of Hydrogen to Electricity

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## ABSTRACT

Here we are presenting a unique (bio)technology where the oxygen reduction in the electrochemical electricity generation process is performed by the respiration of living microbial cells. Therefore, every single electron in the electrical circuit ends up inside of a respiring microorganism. We named our technology "BioGenerator".

The unique features of the BioGenerator include:

- It is the first practical bio-technology for electrical power generation in megawatt scale;
- It is possibly the most efficient convertor of hydrogen to electricity;
- It is the only known power generation technology of any kind which consumes $CO_2$ from the atmosphere;
- It produces high-quality protein as a co-product;
- It is expected to be commercialized in less than 4 years, producing electricity at ~US$0.10/kWh.

***Keywords***: Hydrogen to electricity conversion, BioGenerator, $CO_2$ sequestration, power storage, power smoothing.

## 1 CONVERSION OF HYDROGEN TO ELECTRICITY

This work relates to a novel technology named BioGenerator. The BioGenerator is a convertor of the energy of hydrogen oxidation to electrical energy, using living organisms as an electro-bio-catalyst. The conversion of hydrogen to electricity is expected to play an important role in the future power generation complex. Currently, there are no well developed converters of $H_2$ to electricity. Table 1 below shows the advantages and the disadvantages of the most promising technologies for the conversion of hydrogen to electricity.

## 2 POWER STORAGE AND SMOOTHING

The conversion of hydrogen to electricity is expected

*Table 1.*

| Technology | Advantages | Disadvantages | Max. efficiency (HHV) |
|---|---|---|---|
| Internal combustion engine | Well established technology | $NO_x$ emissions;<br>Low efficiency | 25% |
| Simple turbine | Well established technology | $NO_x$ emissions;<br>Relatively low efficiency | 35% |
| Combined cycle turbine | Relatively high efficiency | $NO_x$ emissions | 50% |
| Fuel cell | Relatively high efficiency;<br>No toxic emissions;<br>Can be used for transportation | In development stage;<br>Expensive;<br>Some stability problems | 50% |
| BioGenerator (this work) | Very high efficiency;<br>Low cost;<br>No toxic emissions | Can be used only for stationary power generation | 70% |

to play an important role in many power generation technologies such as:

- Coal gasification;
- Conversion of renewable fuels, such as biogas or agro-waste gasification products into electricity;
- Production of electrical power from excess or waste industrial hydrogen;
- *Smoothing and storage of variable renewable power sources such as wind and solar*.

As stationary power plants account for a major share of primary energy consumption and the greenhouse gas emissions, it is of great importance to develop novel, environmentally-friendly power generation technologies. Renewable energy technologies hold the greatest promise for solving the above problems. Among them, the wind and solar power generation are considered the most important. Among the main advantages of these renewable energy sources are the environmental friendliness and their unlimited quantity. Unfortunately, there is one significant drawback – the time variation, which is often unpredictable. It has been well recognized that as soon as wind and/or solar power penetrates an electrical grid by more than 15%, their variability will destabilize the grid [1]. Currently, that problem is usually being solved by adding gas turbines as a backup for the raw wind power [1]. However, that solution reduces to a great degree the environmental advantages of wind power and is also technically and economically unfeasible. Germany, the world leader in renewable power generation, is recently losing its momentum in the grid-integrated wind power. It is suggested that one of the main reasons is that its power system is not fully equipped to integrate the highly intermittent wind power [2]. Unfortunately, currently there is no mature power storage and smoothing technology that can be used universally. The most promising power storage and smoothing technologies and their main features are shown in Table 2.

According to the Fraunhofer Institute, only approximately130 GW storage capacity is currently installed world-wide. Over 99% of it is based on pumped hydro, while 0.4% is compressed air storage and 0.3% - different types of batteries. While the pumped hydro and compressed air technologies have significant advantages, their main problem is the requirement for very specific geographical locations. The rest of the technologies listed in Table 2 are mostly on experimental stage of development.

One of the promising technologies for power storage on intermediate and large scales is based on the use of hydrogen as a storage medium. While the conversion of electricity to hydrogen (by electrolysis) and the storage of $H_2$ are both efficient and relatively well established processes, there is no well-developed technology for the conversion of hydrogen back to electricity. There are two main possibilities: by using a thermal cycle in turbines and by electrochemical conversion of hydrogen to electricity in fuel cells. The main problems of turbines are two: 1) there are no turbines developed yet to work with pure hydrogen; and 2) the efficiency of the conversion of hydrogen to electricity is limited by the Carnot cycle.

*Table 2.*

| Technology | Advantages | Disadvantages | Round-trip efficiency |
|---|---|---|---|
| Pumped hydro | Mature technology;<br>Low cost;<br>High efficiency;<br>Large storage capacity | Very limited geographical locations | 80% |
| Compressed air energy storage | Low cost;<br>Large storage capacity | Very limited geographical locations | 30-70% |
| Rechargeable batteries | High efficiency | High cost;<br>Limited availability of some components;<br>Lower storage capacity | 60-90% |
| Redox flow batteries | Relatively high efficiency | Bulky;<br>Toxicity issues;<br>Expensive | 60-75% |
| Flywheels | High efficiency | Low storage capacity | 80-85% |
| Hydrogen/Fuel cells | Large storage capacity | Expensive;<br>Some stability problems;<br>Low efficiency | 20-30% |
| Hydrogen/Bio-Generator (this proposal) | Low cost;<br>Good stability;<br>Large storage capacity | Needs further development (this proposal) | 45-50% |

The main problems of conventional fuel cells, as seen in Table 1, are: 1) stack stability and 2) the relatively low efficiency, between 30% and 50%HHV, in addition to the high cost. As a result, the overall round-trip (electricity to electricity) efficiency of the hydrogen/fuel cell energy storage is below 30%, which is too low for practical applications.

Therefore, in order to make the hydrogen-based smoothing and storage of electricity viable, it is necessary to develop new convertors of hydrogen to electricity, which would have high efficiency and stability, combined with low cost. The BioGenerator, reported in this work, is expected to solve these problems to a great degree.

## 3 DESCRIPTION OF THE BIOGENERATOR

It is well known that electricity is a flow of electrons from point A to point B via conductor and load (Fig. 1a). In the electrochemical electricity generation methods, the electrons at point A are supplied by an electron-donor chemical reaction, while electrons are removed at point B by an electron-acceptor reaction (Fig. 1b).

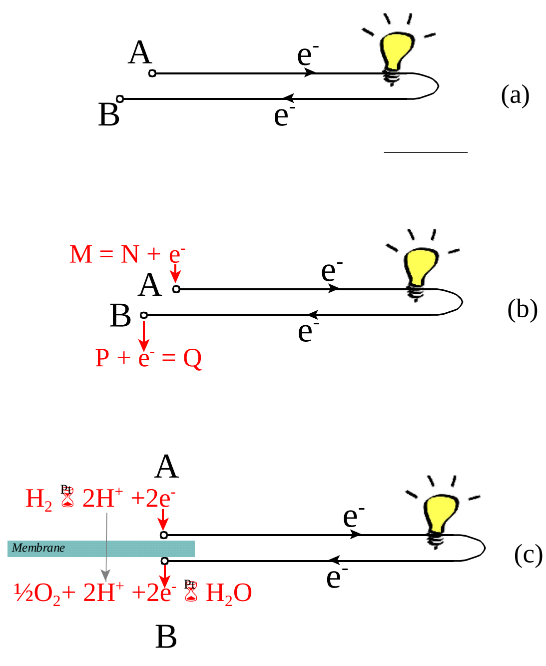


Figure 1.

The BioGenerator is based on the use of the respiration system of chemolithoautotrophic microorganisms as a catalyst for the indirect oxygen reduction reaction on the cathode of a fuel cell. More specifically, the microbial oxidation of ferrous ions for regeneration of the oxidant (ferric ions) in a redox flow system is used. The microbial iron oxidation by microorganisms such as *Acidithiobacillus* and *Leptospirillum* is based on the following overall reaction:

$$4Fe^{2+} + 4H^{+} + O_2 = 4Fe^{3+} + 2H_2O \quad (1)$$

It has been shown that the rate of microbial oxidation of ferrous ions is four orders of magnitude faster than that of the corresponding purely chemical reaction with oxygen at pH below 2.5. The electron transport chain of iron oxidation (3) by this microorganism contains two half-reactions:

$$Fe^{2+} = Fe^{3+} + e^{-} \quad (2)$$

which takes place outside of the cell membrane, and:

$$O_2 + 4H^{+} + 4e^{-} = 2H_2O \quad (3)$$

(respiration reaction) inside of the membrane.

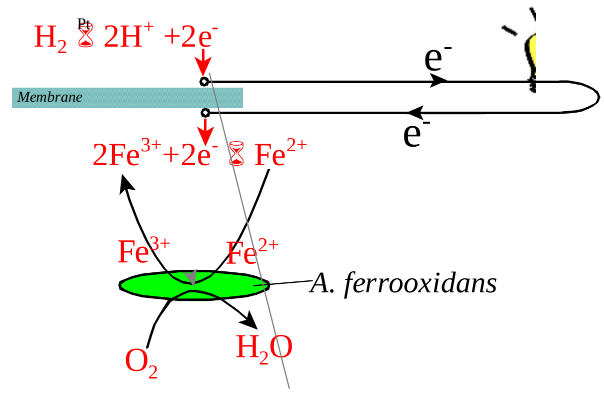


Figure 2.

The electron transport routes in the Biogenerator are shown in Fig. 2. The typical working voltage of the BioGenerator is over 800mV (55% HHV corresponding to 65% LHV efficiency) at a current density of up to 100mV/cm$^2$. While this value of current density is too low for a practical application in PEM fuel cells because of the high cost of the anode, cathode and the membrane, the BioGenerator can operate cost-effectively at such current density because both the cathode and the membrane are between 2 and 3 orders of magnitude less expensive than these in PEMFC.

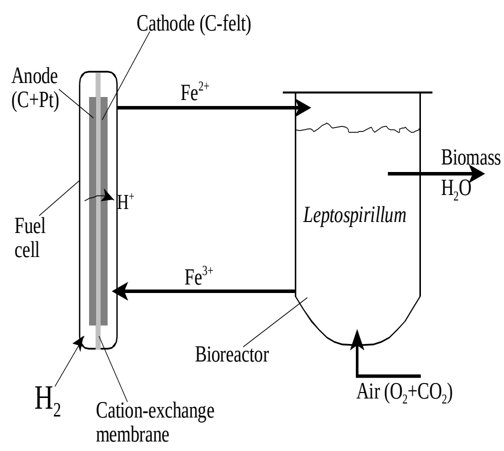


Figure 3.

The BioGenerator is shown schematically in Fig. 3. It contains two main units: the bioreactor and the electrochemical stack.

The material balance of the BioGenerator shows that a 100MW plant will:

- Produce 1,000 kg protein-based biomass per hour;
- Consume 4,000 kg $H_2$ per hour;
- Require a 10,000 $m^3$ bioreactor (similar in shape, size and cost to a typical activated sludge wastewater treatment basin);
- Remove from atmosphere 9,000 tonnes of $CO_2$ per year (in addition to the $CO_2$ reduction due to the higher efficiency).

Since *Leptospirillum* and *At. ferrooxidans* are autotrophs, i.e. they use $CO_2$ as a carbon source for biomass formation, the BioGenerator shown in Fig. 4 has a unique property - it transforms atmospheric $CO_2$ into cellular biomass. The latter is a high-protein feed source.

Since its discovery in 2003, the BioGenerator has been scaled up from an initial size of 0.1 W to 300 W (1 kW peak). Currently we are in the process of designing a 10 kW pilot-scale unit. It is expected that the BioGenerator will be used for power generation in multimegawatt unit size.

## REFERENCES


[1] B. Lee and D. Gushee, Chem. Eng. Progress, 105, 22, 2009.

[2] J. Levison, J. Policy Engagement, 2, 17, 2010.