ENZYMATIC BIOFUEL CELLS: BIOTECHNOLOGY FOR ENERGY PRODUCTION WITH BIOMEDICAL AND BIOTECHNOLOGICAL APPLICATIONS

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Bachelor's Thesis, Biochemistry degree

INTRODUCTION

Nowadays, due to the high-energy demands from the rapid growth of the worlds population, there is a vast search for alternative and sustainable energy sources. In this scenario, one of the most promising technologies is the biofuel cells system. Different from the classical noble metals catalyst of fuel cell, these new devices can use catalyst extracts from cells or even whole microorganism to oxide organic molecules and produce electrical work.

The aim of this work is to make a bibliographic review focused specifically on the enzymatic biofuel cell, showing how these biofuel cells are developed, their operating mechanisms and mainly their future applications in medical and biotechnological fields

1.ENZYMATIC BIOFUEL CELLS (BFC)

These devices are composted by the biological catalyst, the enzymes, that performance the oxidation reaction into the anode and the reduction into the cathode. It is the electron transport between the two points, according to their potential difference, that leads to the production of electric power[1].

This EBC offers great advantages, but still need to overcome critical barriers:

ADVANTAGES	DISADVANTAGES
Cheap and plentiful	**Electric current from enzymes much tougher than metal catalyst**
Produced as much as they are needed	**Necessity of immobilisation process of the enzyme onto electrode surfaces.**
Fuel selectivity	**Short enzymatic half-life not longer than couple of day**
Work under moderate temperature and pH conditions	**Incomplete fuel oxidation**

2. CONSTRUCTION OF AN ENZYMATIC BIOFUEL CELL

IMMOBILIZATION OF THE ENZYME

- **Chemical technics:** covalent linkage and cross-linking procedures involving modifications or functionalization of the surfaces to bind the enzymes
- **Physical technics** : capturing the enzyme in redox hydrogels

ENZYME ELECTRON TRASNFER

- **Direct electron transfer (DET):** enzymes possess tightly cofactors in the active site so electrons can be transferred directly to the electrode.
- **Mediated electron transfer (MET):** enzymes can shuttle electron between the active site and the electrode through mediators (weakly bound cofactor).

DET		MET	
✓ High selectivity and mass transport rate ✓ Facilitates bioelectrodes construction	✓ Avoid loss of performance from difference enzyme-mediator potentials ✓ Favours miniaturization of the device	✓ Higher output power ✓ Possibility of using commercially available enzymes	✓ Linked electrode and catalytic side buried into the protein structure
✧ Few enzymes can transfer by DET mechanism		✧ Low stability ✧ Low diffusion	✧ Possible toxicity of the mediators species

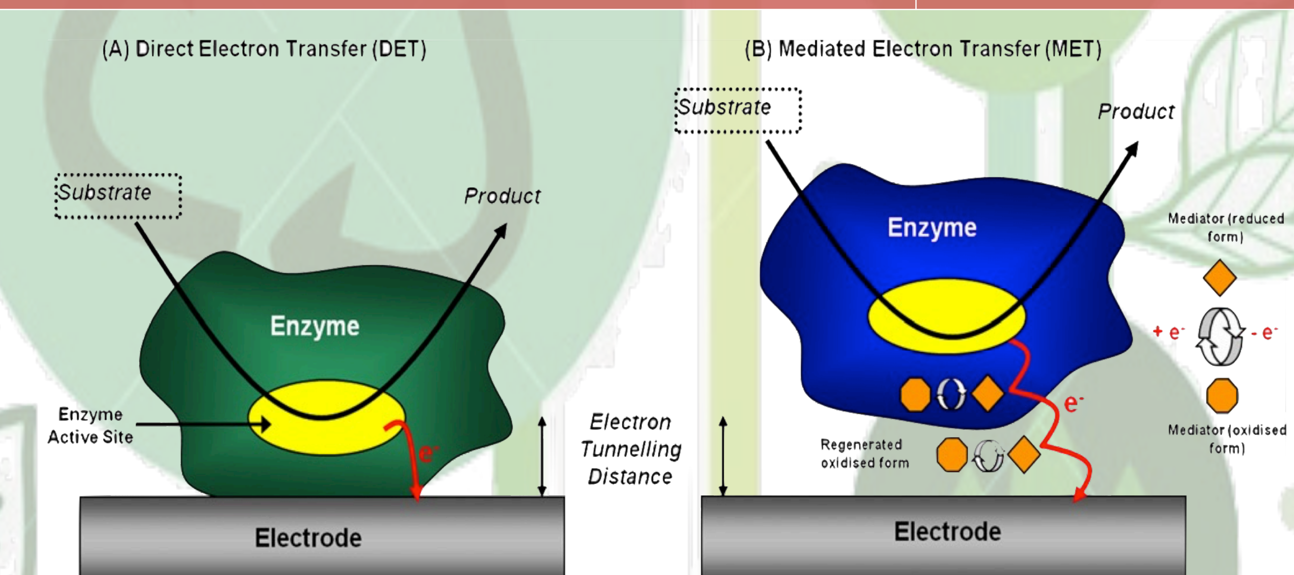

Figure 2. Schematic depiction of electron transport in an enzymatic biofuel cell. Reprinted from reference [1].

3. APPLICATIONS OF EFC

3.1 Supply pacemaker

The research team of Philippe Cinquin and Serge Cosnier, at Joseph Fourier University (France), have been working in the development of a micro-device able to generate electricity from the oxidation of sugar molecule[2].

How does this EFC work?

- The production of electricity is done via a series of electrochemical reactions catalysed using enzymes that react with the glucose stored in the blood.
- Electrons are transported through a circuit from the anode to the cathode, giving useful electrical work.

Cathode: glucose + ½ O2 → gluconate + H^+

Anode: $CO(NH_2)_2 + H_2O \rightarrow CO_2 + 2\,NH_3$

$2NH_3 + 2NH_4 \rightarrow 2NH_4^+ + 2OH^-$

Structure: composite graphite discs containing
- **Anode: glucose oxidase + ubiquinone**
- **Cathode: polyphenol oxidase (PPO) + quinone**

Results

This GBFC produced a specific peak power of **24.4 µW mL^{-1}**, which is better than the pacemaker requirements. Now it is only a matter of time before this new kind of pacemaker running on biofuel cell will be implanted into the first people

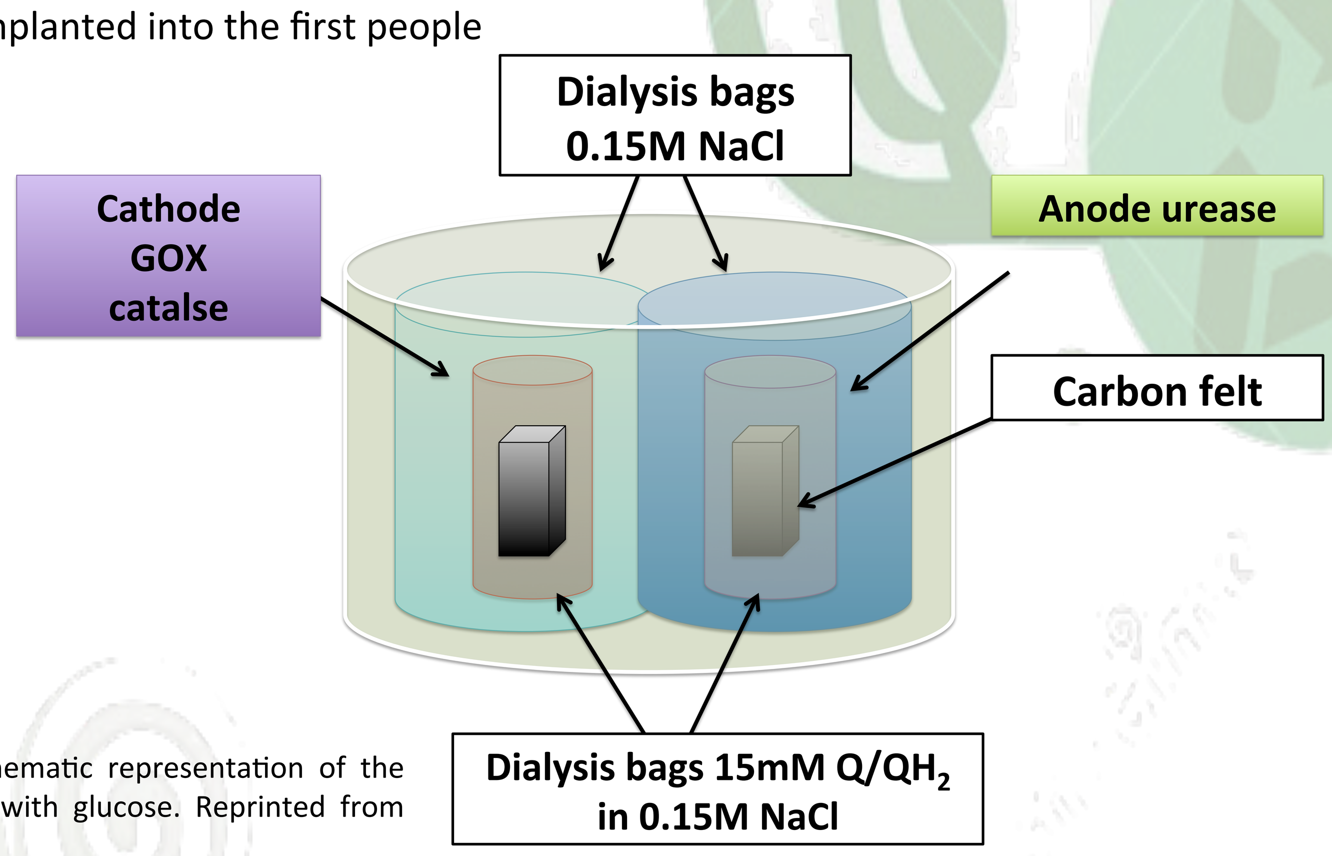

Figure 1. Schematic representation of the EFC running with glucose. Reprinted from reference [2]

3.2 Power integrated medical feedback systems for drug delivery

A novel integrated management system is in study for the treatment of diabetes . This device could monitor the intravenous glucose concentration continuously and deliver small doses of insulin when is necessary[4].

Challenge : **the battery**, which must have
- Low cost and a size miniaturized enough to be integrated
- High intrinsic energy density and being made with not toxic matter.

Solution: Apply a **miniature glucose O_2 biofuel cell** as a power source.

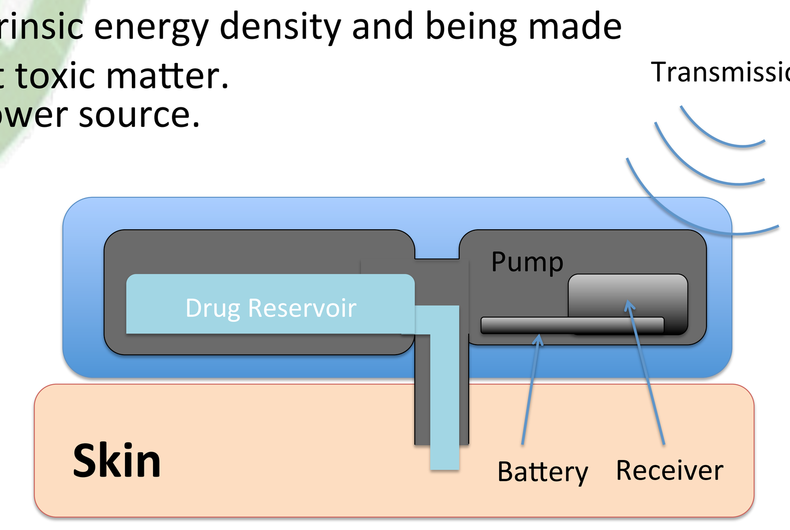

Figure 3.Elements of the drug delivering skin patch. Reprinted from reference [4].

Characteristics of the EFC

- Two printed carbon lines: one with a wired glucose anode, and the other with a wired bilirubin oxidase O2 cathode, both over-coated with a bioinert, crosslinked poly(ethylene glycol) film.
- Volume = **0.005mm³**, which represent 1/1000th of the volume of the smallest battery produced.
- Production = **1 Joule/week**, what is 100 times more electrical energy than obtained by the highest energy density battery.

3.3 Biobattery

In 2007 Sony company developed a bio battery able to produce energy from the breaking down of sugar molecule by enzymatic catalyst. The invention was classified as the world's highest power output and ecologically-friendly energy device of the future[5].

Structure
- **Anode:** sugar-digesting enzymes: glucose dehydrogenase + diaphorase, mediator: Vit.K3 + cofactor NADH attached by two polimers*.
- **Cathode:** contains appropriate water levels that ensures optimum conditions for the efficient enzymatic oxygen reduction.

Result : EFC of 39mm³ able to produce 50nW in a volume representing the world's highest power output

4. CONCLUSION

- Biofuel cell represents great **advantages** over conventional fuel cells as: reaction selectivity, non-toxic renewable components, biocompatibility, fuel flexibility and operation under physiological conditions.
- Still need to overcome some challenges: modest power output, low enzymatic stability, difficult electron mediator and in-vivo few applications due to their short lifetime.
- Necessary further studies to improve the biocatalysts and enzymatic stability, as well as environmental tests to obtain better rates of electron transporting and enzymatic activity

Reference

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