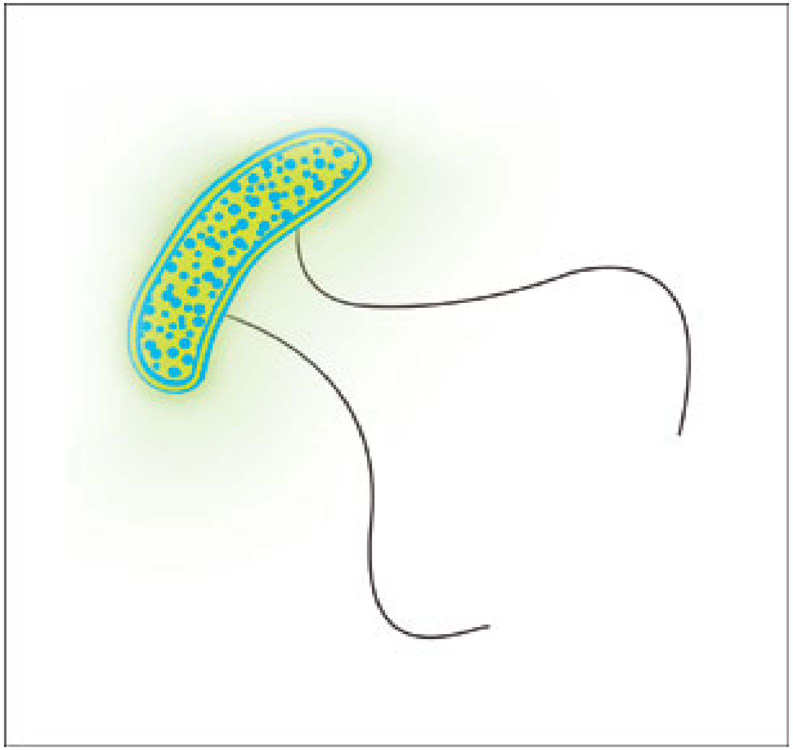
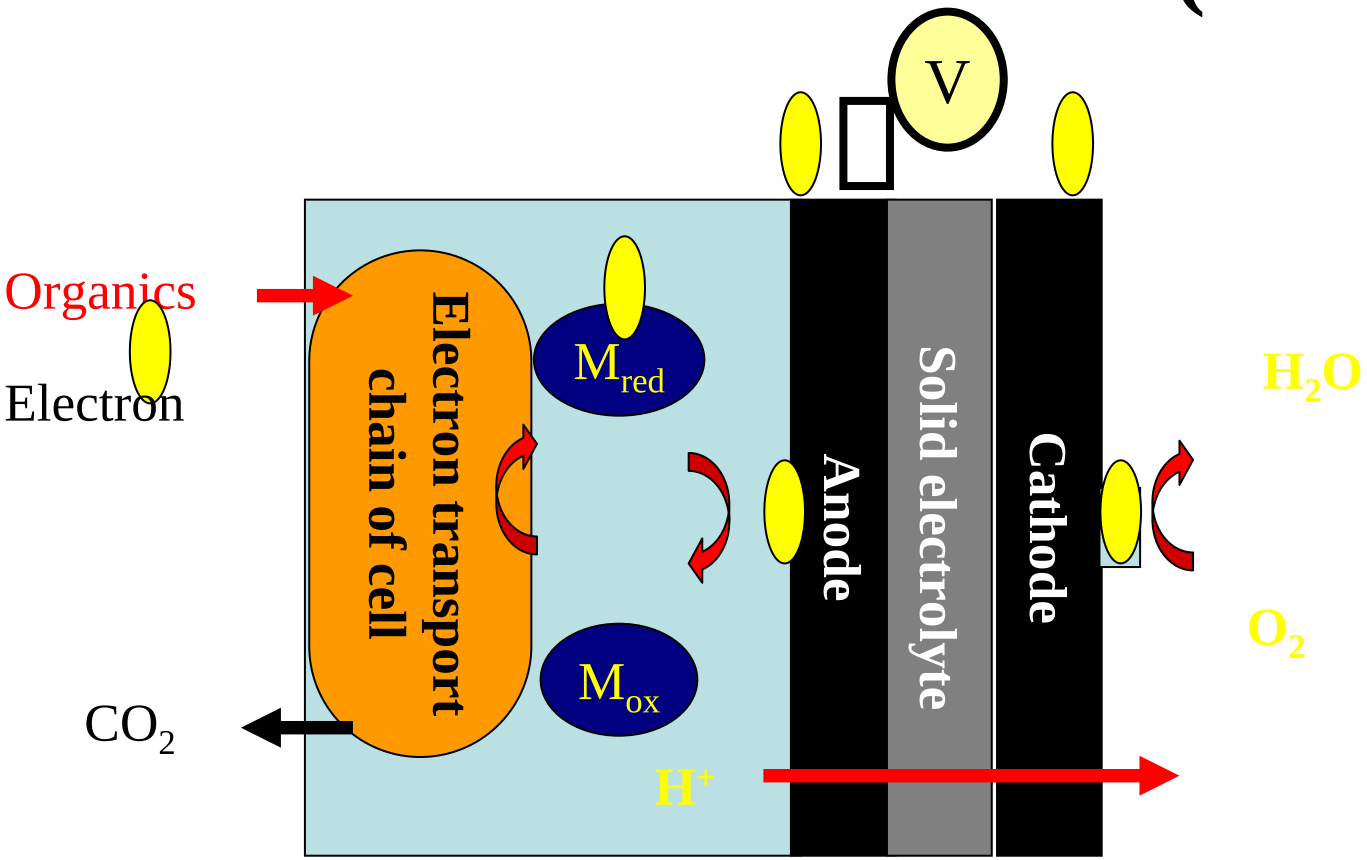
Microbial Fuel Cells for Spec



Goryanin, Fedorovich Edinburgh, December 2008

Microbial fuel cell (MFC)



- **MFC – mimic of biological system in which bacteria do not directly transfer their produced electrons to their characteristic acceptors**
- **MFC could be mediatorless (e.g., external cytochromes like in *Shewanella putrefaciens* or *Geobacter sulfurreducens*)**

Simplified chemistry of MFC

- Glucose

Anode: $C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$

Cathode: $6O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$

Overall: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + electricity

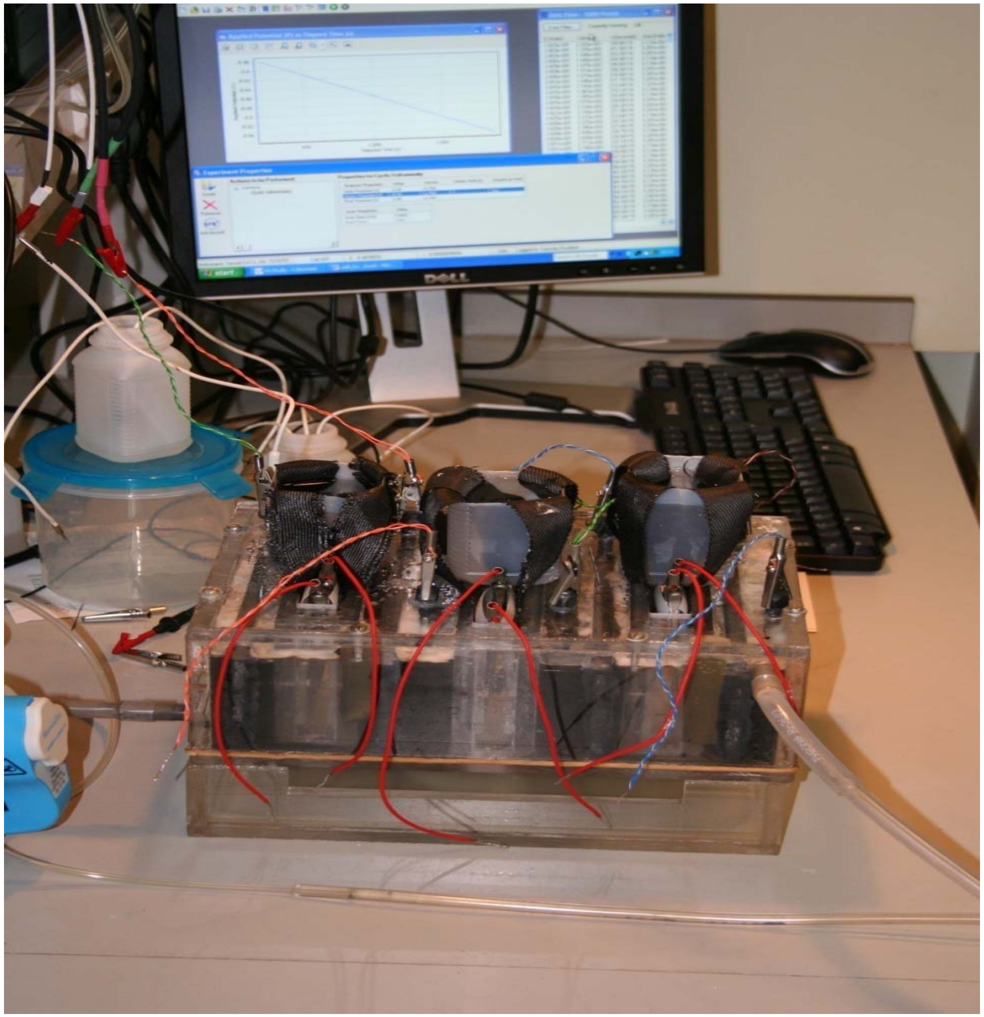
- Acetate (typical for wastewater)

Anode: $CH_3COOH + 2H_2O \rightarrow 2CO_2 + 8H^+ + 8e^-$

Cathode: $2O_2 + 8H^+ + 8e^- \rightarrow 4H_2O$

Overall: $CH_3COOH + 2O_2 \rightarrow 2CO_2 + 2H_2O$ + electricity

MFC configuration



Our MFC. Advantages

- Horizontal location of multi compartmental zones having an enlarged pathway of substrate from inlet to outlet and thus enhanced mass transfer.
- Close location of anodic and cathodic electrodes minimizes a distance between them and hence reduces an internal resistance of MFC.
- New flexible cathodes
- No metals involved
- Diverse substrates. Novel electrogenics bacteria
- Continuously working MFC construction, long-term operation (more then one year)
- Clearly seen possibility for enhancing a specific power

Comparison with the best world record

absence ☐ —— Costs and energy expenses ——→ ■ high

	Existence of patent	Type of reactor	Anode	Cathode	Oxygen supply for cathode
Ghent group, Belgium*	**-**	**Several modules**	**Free granules of activated carbon + graphite collector**	**Free granules of activated carbon + graphite collector**	**Pumping of electrolyte with** hexacyanoferrate + external aeration of **electrolyte**
Our MFC**	**+**	**Entire vessel**	**granules of activated carbon attached to the graphite collector**	**Graphite + Metalloorganic catalyst**	* * **Air bubbling of electrolyte**

* Eviron. Sci. Technol. 2006, 40, 3388-3394

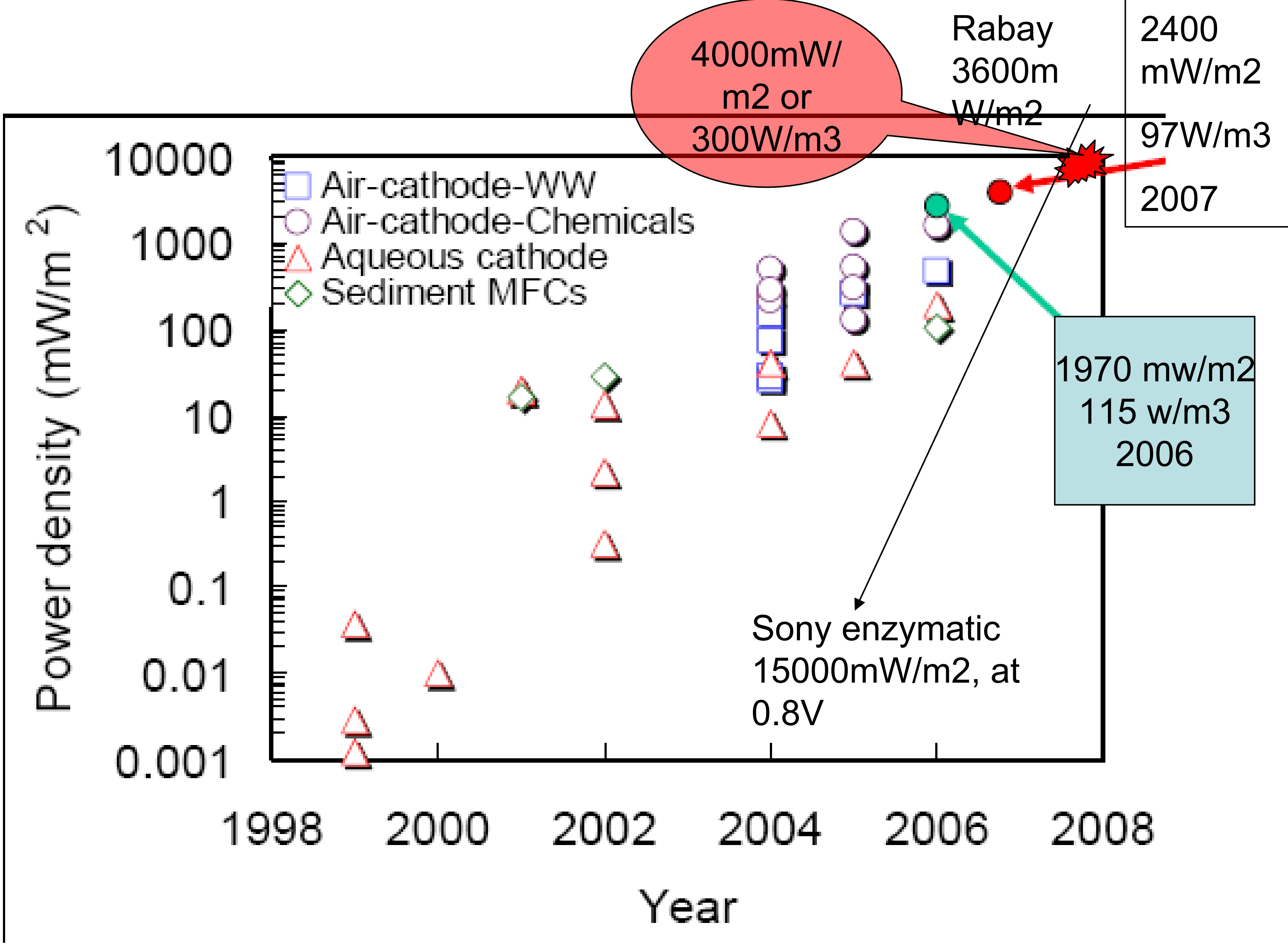
* * we have developed an effective and low cost “on air” cathode

Comparison with the best world record

	Fuel	Scaling up for commercial applications	maximal power (W/m^3)	Operation Duration	Possibilities for power enhancing
Ghent group	Glucose	Difficult	258	Weeks?	?
Our MFC	Sugar industry wastewater	+	45* 320**	years	+

*with immersed cathods

** incorporation of "novel technology" cathodes



4000mW/
m2 or
300W/m3
Rabay
3600m
W/m2
2400
mW/m2
97W/m3
2007
Air-cathode-WW
Air-cathode-Chemicals
Aqueous cathode
Sediment MFCs
1970 mw/m2
115 w/m3
2006
Sony enzymatic
15000mW/m2, at
0.8V
Power density (mW/m 2)
10000
1000
100
10
1
0.1
0.01
0.001
1998
2000
2002
2004
2006
2008
Year

MFC powered robots

"Gastronome": Wilkinson (2000), University of South Florida

Robot EcoBot-II (Bristol, 2007), which is designed to power itself solely by converting unrefined insect biomass into useful energy using on-board microbial fuel cells with oxygen cathodes..
http://en.wikipedia.org/wiki/EcoBot

Gastrorobot

•Robot with a stomach (food powered machine)

• Goal – to create bioelectrochemical machine that derives all the operational power by tapping the energy of real food digestion, using microorganisms as biocatalysts

The challenges of gastrorobotics:

– Foraging (food location & identification)

– Harvesting (food gathering)

– Mastication (chewing)

– Ingestion (swallowing)

– Digestion (energy extraction) - **MFC**

– Defecation (waste removal)

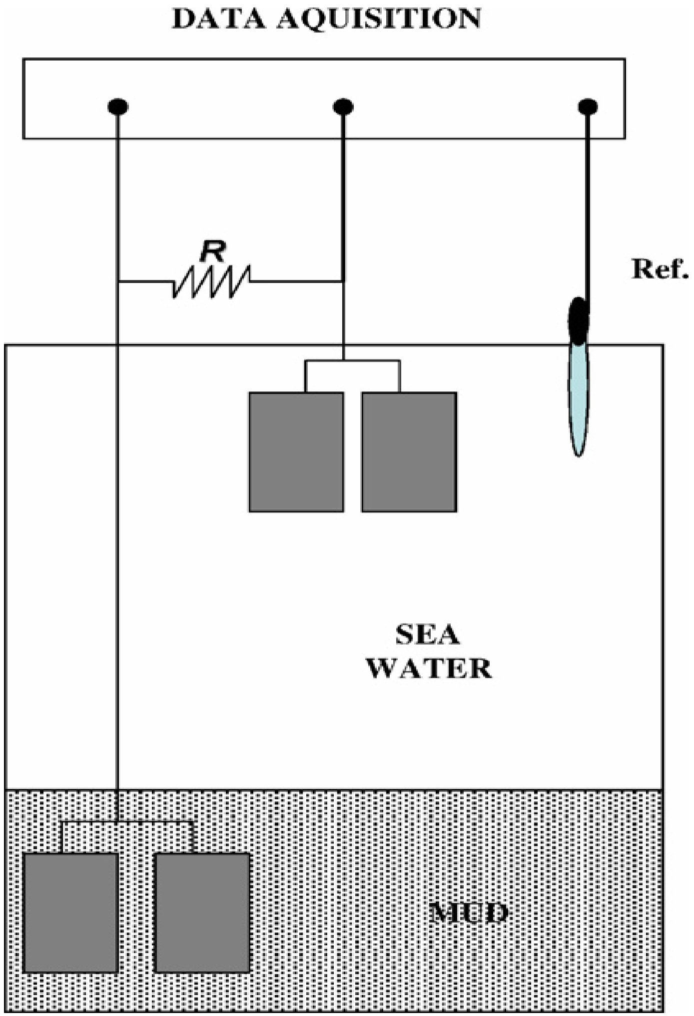
Benthic Unattended Generator (BUG)

Buoy data collected at: 19:57:00	
Air Temp:	73.2 F
Water Temp:	30 F
Humidity:	42.3%
Air PSIA:	14.822 psia
BUG Voltage:	320 mV
Anode Voltage:	16 mV
Capacitor Voltage:	5.643 V

Weather buoy, Potomac River, The Naval Research Laboratory's Center for Bio/Molecular Science and Engineering, Washington

Source: http://www.nrl.navy.mil/code6900/bug/

Marine microbial fuel cell



Rotated cathode (49mW/m2) compared to a nonrotating cathode system (29mW/m2).``

Which bacteria are the important exoelectrogens? DGGE

Wastewater (acetate)
(Lee et al. (2003) 24%=α-, 7%=β-, 21%=γ- , 21%= δ-*Proteobacteria; 27%=others*

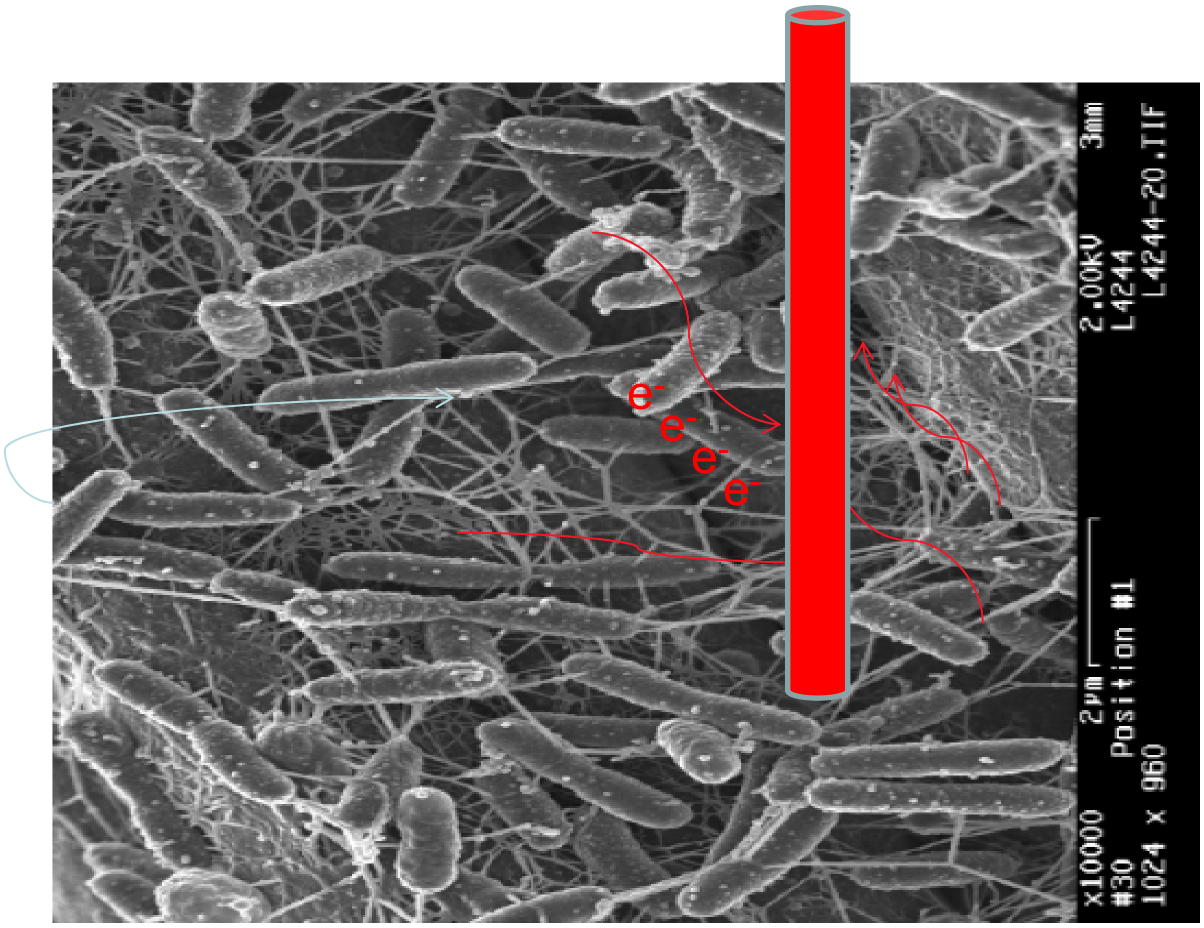
Wastewater (starch)
Kim et al. (2004) 36%=unidentified, 25%=β- and 20%=α-
Proteobacteria, and 19%=Cytophaga+Flexibacter+Bacterioide

Marine sediment (cysteine)
Logan et al. (2005) γ-*Proteobacteria, 40% Shewanellaaffinis KMM, then Vibrio spp.*
And Pseudoalteromonas sp.

River sediment (river water)
Phung et al. (2004) β-*Proteobacteria (related to Leptothrix* spp.)

River sediment (glucose+glutamic acid)
Phung et al. (2004) α-*Proteobacteria (mainly Actinobacteria)*
Wastewater (acetate).
Xing, et al (2008) *Rhodopseudomonas palustris* DX-1
Fedorovich (2008) submitted γ-*Proteobacterium,*

Gorby et al. PNAS (2006)



Different ways of electron transfer.

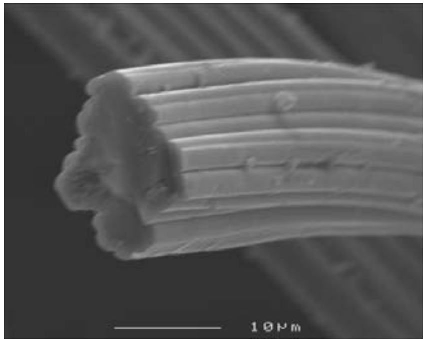
✓ Exocellular electron transfer. Dissimilatory metalreducing or DMR bacteria. Electron transfer that do not require exogenous mediators

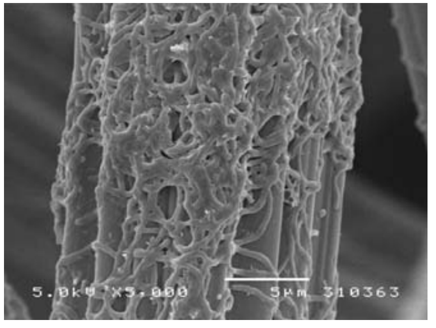
✓self-produced mediators (*Newman, Nature 2000, Rabaey, Appl. Environ. Microbiol. 2004)*

direct electron transfer via

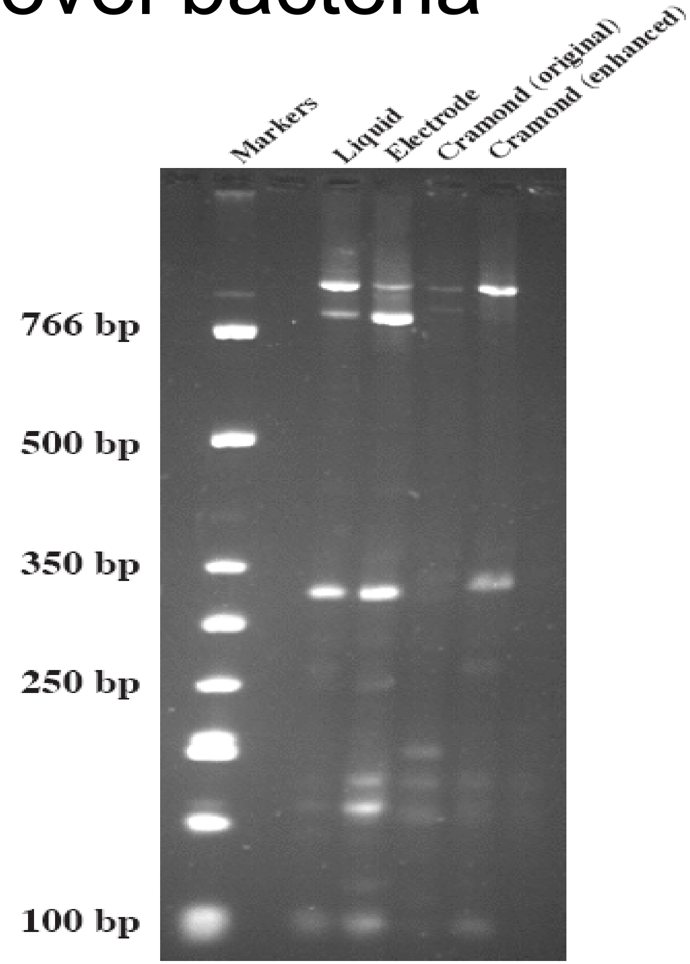
✓membrane-bound cytochromes (*Shewanella putrefaciens , Myers, J. Bacteriol. 1992),*

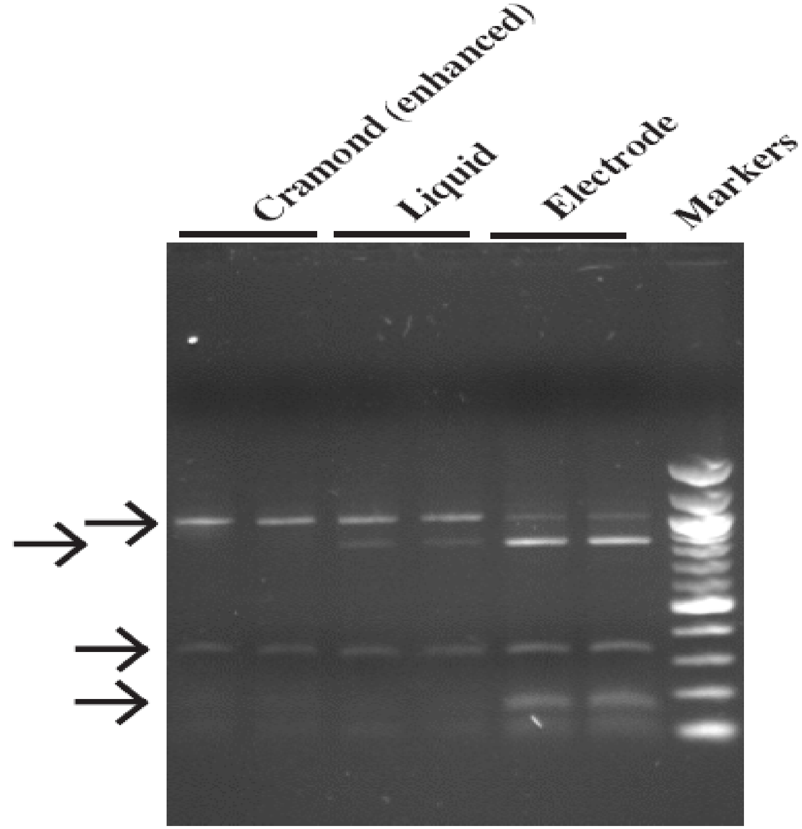
✓*nanowires (Shewanella oneidensis, Gorby, Y. A PNAS 2006, Reguera, Nature 2005)*





Novel bacteria



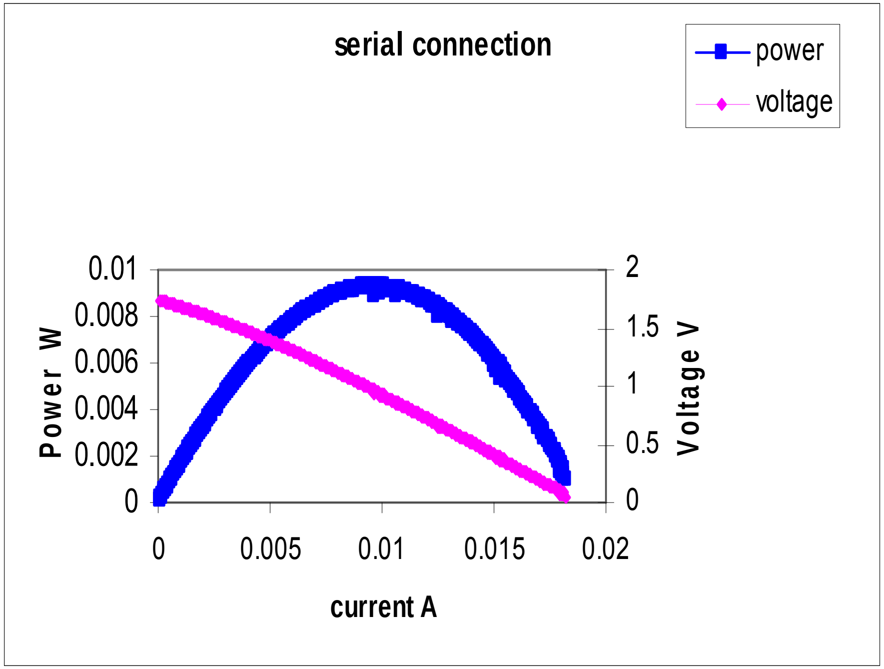


The novel superelectrogenic ϒ protobacteria (no mediators) has been identified. by 16s RNA analysis. Reconstitution experiments has been performed on rich medium. Metagenomics analysis (RIKEN) has started. (UK Patent application in preparation)

Data and model availability. Geobacter

Whole genome microarray
Knockout of OmcF, a monoheme outer membrane c-type cytochrome, substantially decreased current production. OmcF is required for the appropriate transcription of other genes either directly or indirectly involved in electricity production.
(Kim, 2008)
Metabolic model
Characterization of metabolism in the Fe(III)-reducing organism *Geobacter sulfurreducens* by constraint-based modeling. Mahadevan**,** 2006

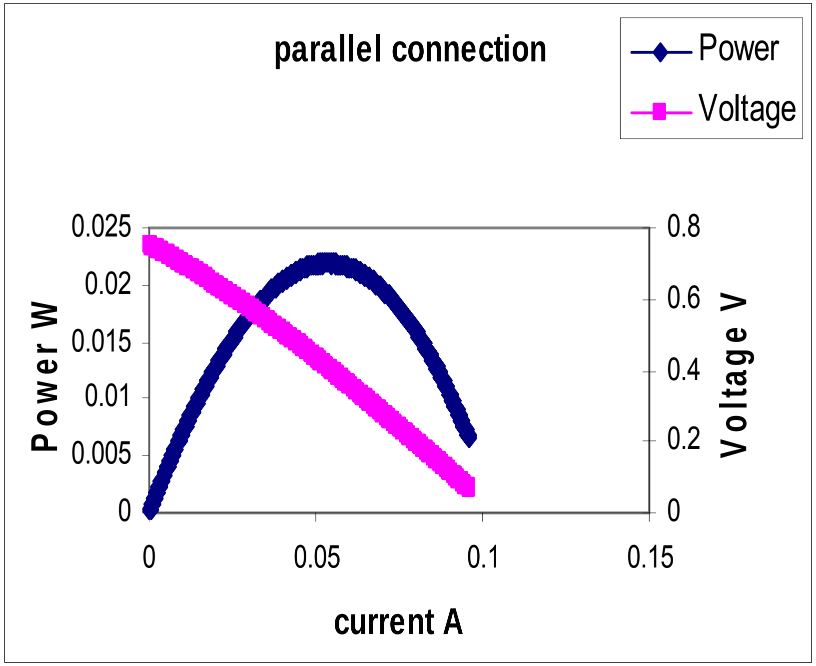
Sustainable power generated in MFC with serial and parallel connections of electrodes



Max. sustain. power

9.2 mW at 10mA

Rint=19 Ohm

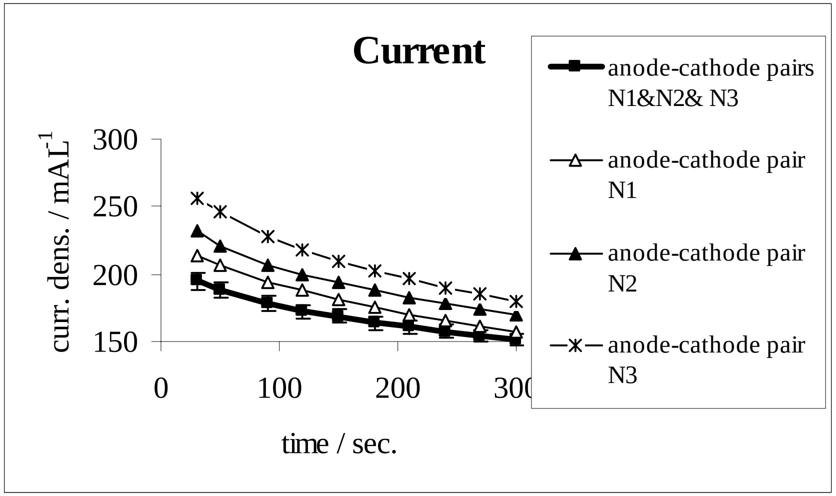


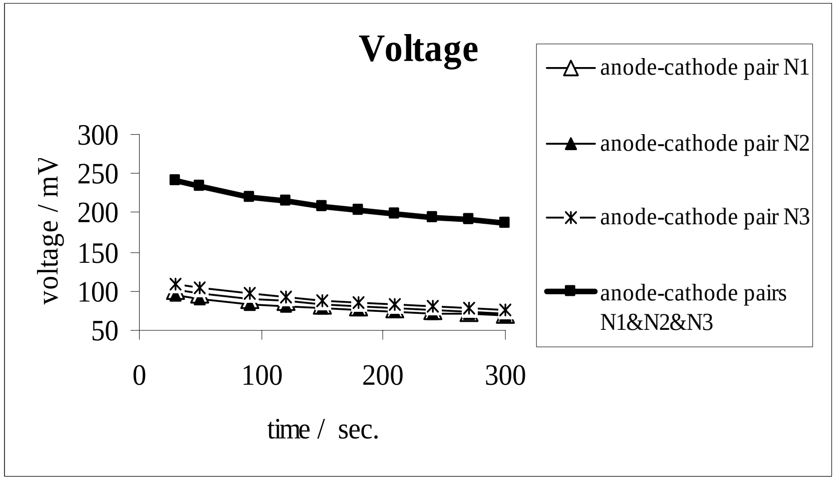
Max. sustain. power

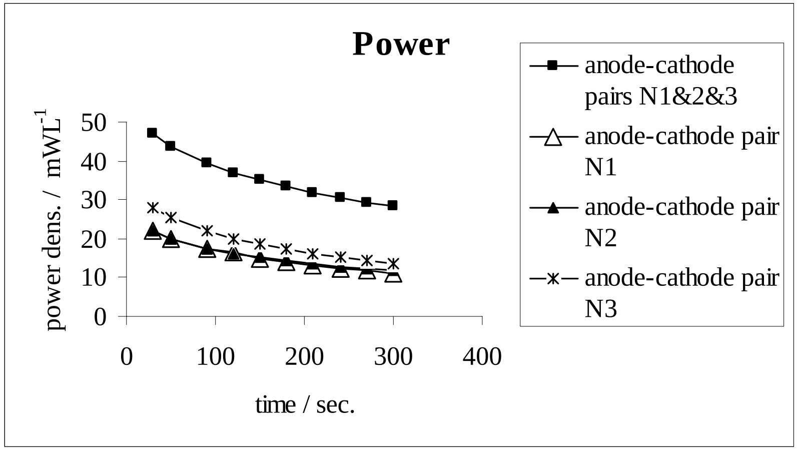
22 mW at 56 mA

Rint=7.5 Ohm

Dynamics of electrical parameters for individual anode cathode pairs and three in parallel in short circuit mode







Max. achieved power

296 mW/L

Computational models.

Ideal Models should include

- Chemical and electrochemical reactions in the bulk liquid, in the biofilm and at the electrode surface
- Biological networks of microbial community members

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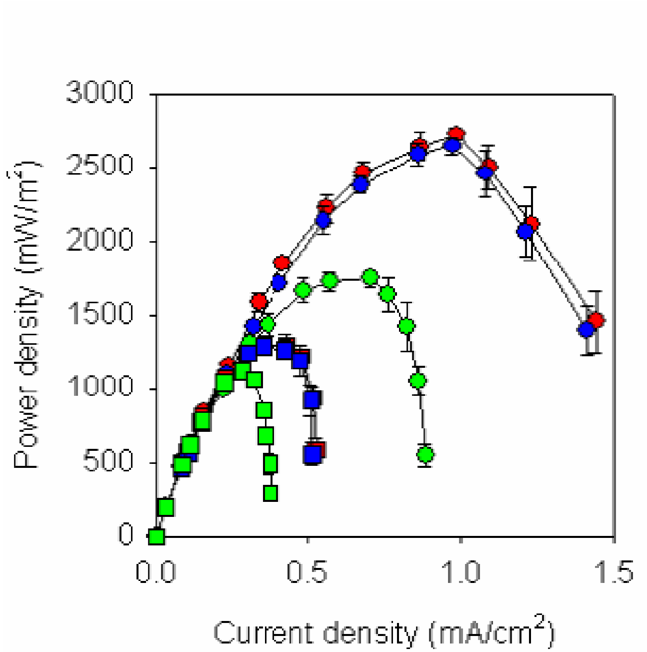
Ideal Models should predict



- The evolution in time of important MFC parameters
  - current,
  - charge,
  - Voltage
  - power production
  - internal load resistance
  - consumption rate of substrates, s
  - Suspended and attached biomass growth,
  - COD and BOD removal

A computational model for biofilm-based microbial fuel cells, Picioreanua (Water Research, 2007)

Detailed model of the processes in double layer using Nernst-Planck and Poisson equations, (Fedorovich, 2008,in preparation)

Challenges

MFC can be used as a platform technology for systems biology studies.

MFCs are capable (impact 3-5 years) to solve simultaneously two tasks: waste treatment and electricity generation.

•MEC architecture challenges:

– Improve power

– Reduce costs of materials

• Exoelectrogen challenge:

– Identify or construct the high current and high power producing strains

– Understand mechanisms for power production

• Scale up and down challenge: Pilot testing is needed

•Stability of parameters during long term operation

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