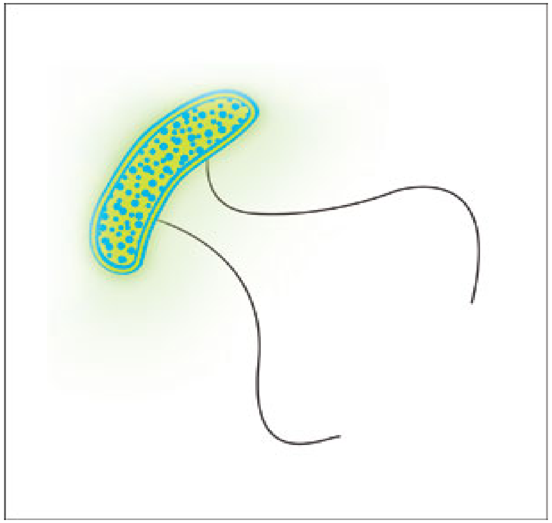
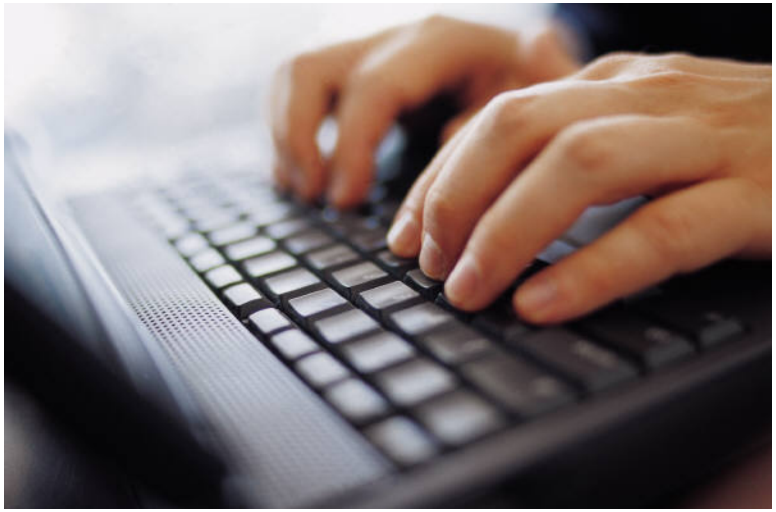
Microbial Sensors and Power Generators for Speckled Monitors in Natural Environment





Prof Igor Goryanin, School of Informatics, University of Edinburgh

Monitoring and managing of the Earth

1.Managing the environment. Energy and Waste. Emphasis of today's is on reuse and recovery of energy, which has led to new views on how these streams can be dealt with.

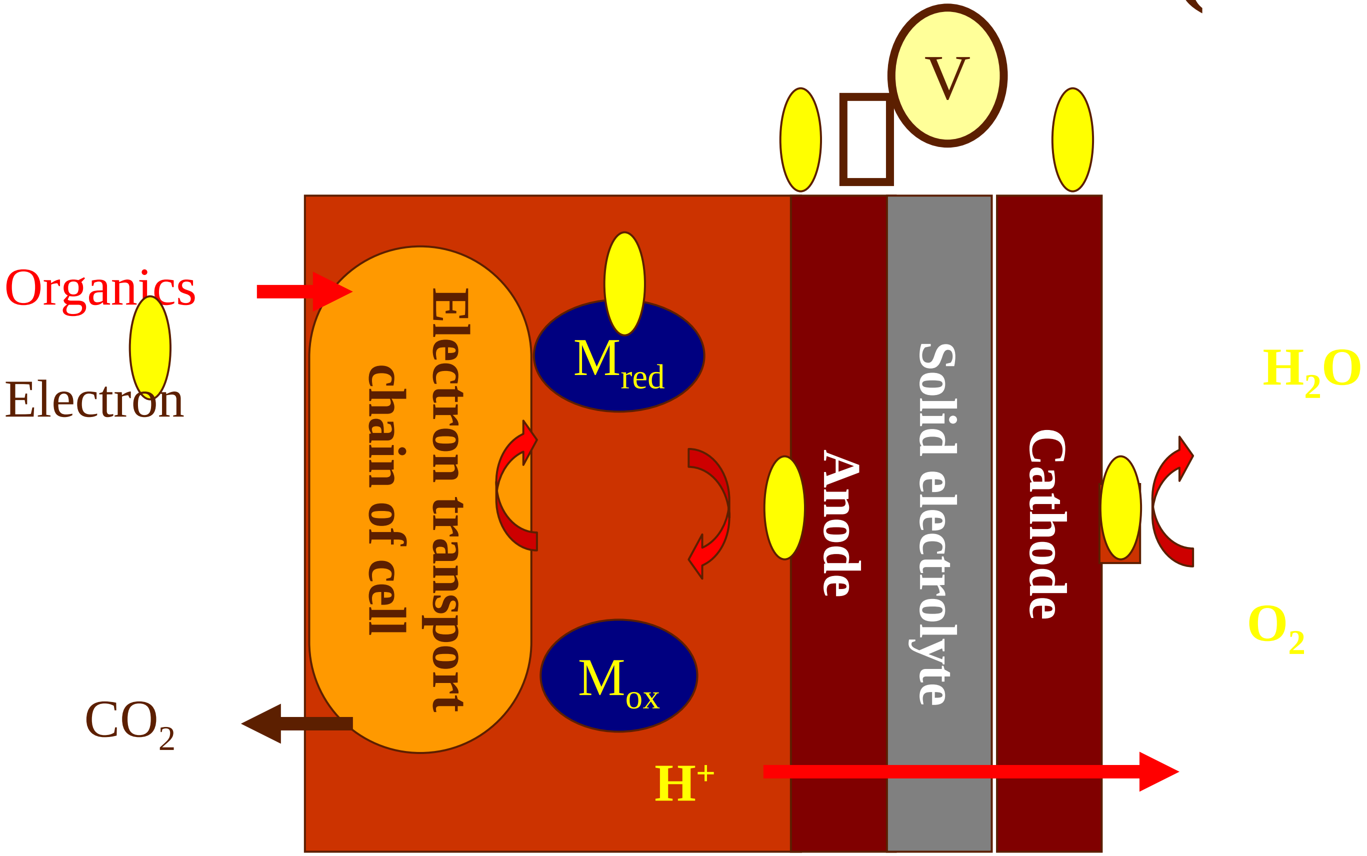
- Sustainable use of natural resources to provide oxygen in water treatment in USA is equivalent to almost 2% of the total US electricity consumption genesis.

2. Monitoring of environment. Pollution and Human Health

•According to a recent World Health organization report (WHO, 2006), an estimated 24% of the global disease burden and 23% of all deaths can be attributed to environmental factors.

Natural Hazards
Temperature,
Ocean acidification
CO_2,
Methane,
Xenobiotics,
Dyes

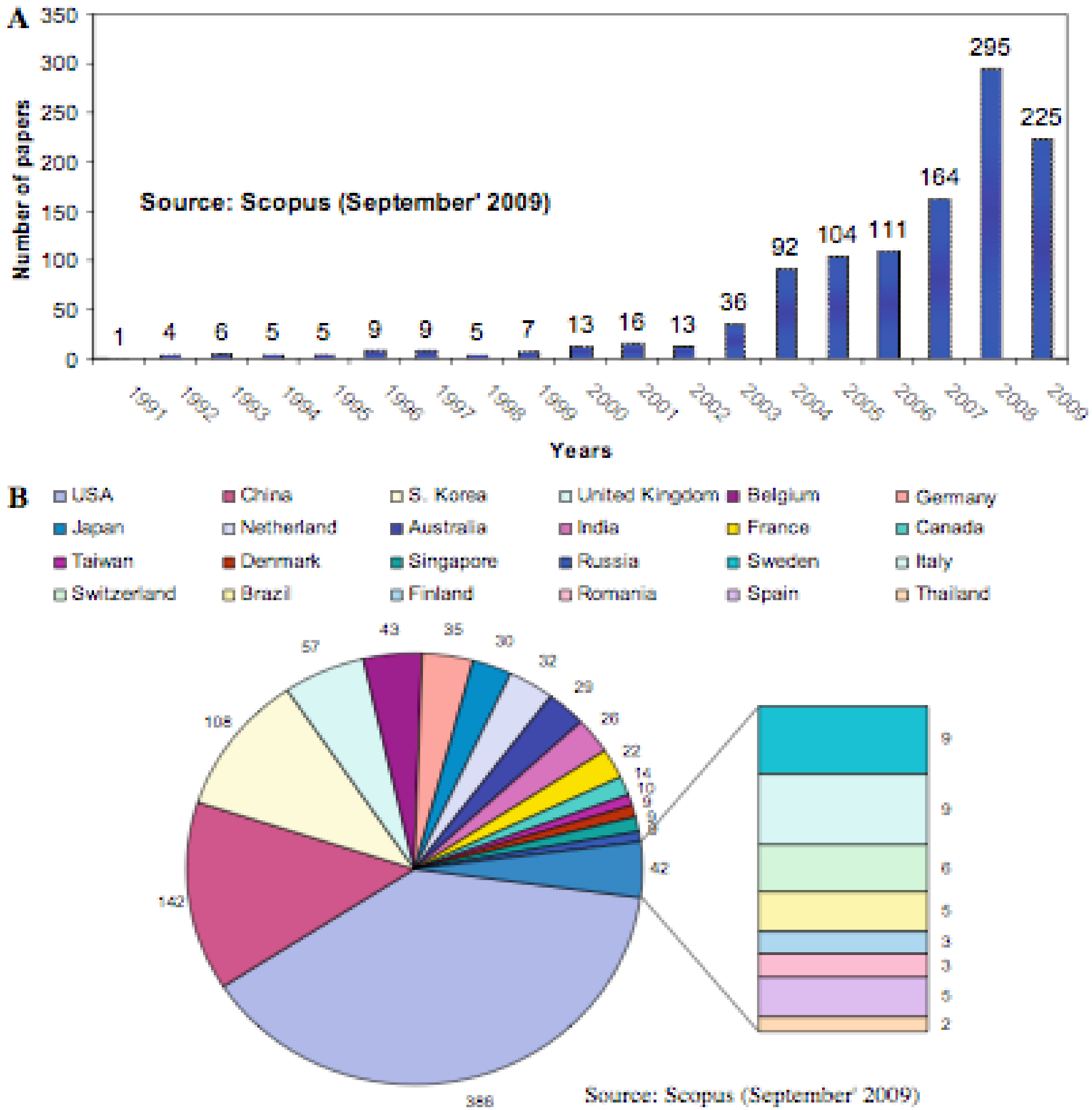
Microbial fuel cell (MFC)



• **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*)**

•Kim, J.R., Jung, S.H., Regan, J.M., Logan, B.E., 2007. Electricity generation and Potter, M.C., 1911. Electrical effects accompanying the decomposition of organic compounds. Proc. R. Soc. Lond. B Biol. Sci. 84, 160–276.



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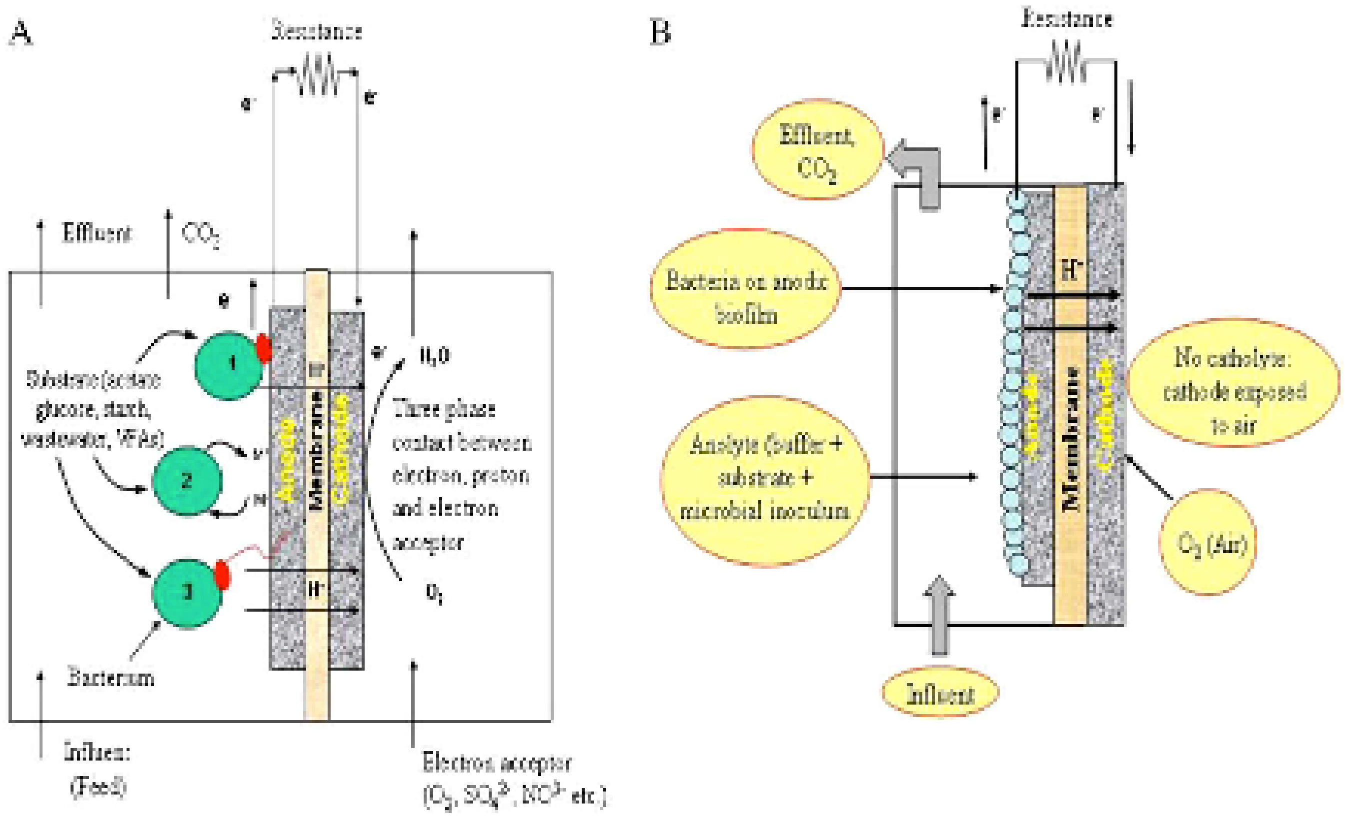
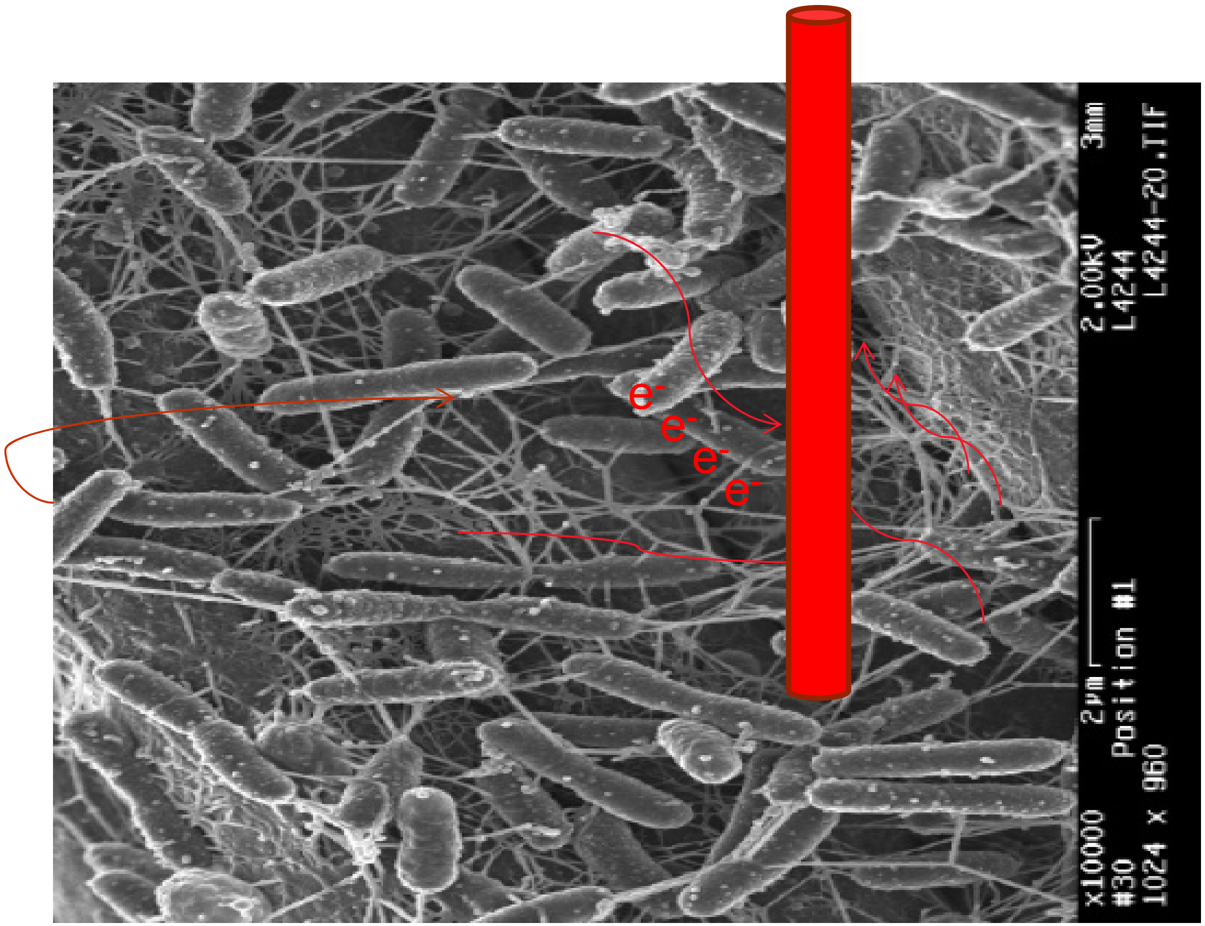


(A) Simplified view of a two-chamber MFC with possible modes of electron transfer is shown. (1) Direct electron transfer (via outer membrane cytochromes); (2) electron transfer through mediators; and (3) electron transfer through nanowires. (B) Single-chamber MFC with open air cathode.

Deepak Pant (2009) Bioresource Technology

Gorby et al. PNAS (2006)



Simplified chemistry of MFC

- Glucose

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

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

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

Acetate is the end product of several metabolic pathways for higher order carbon sources (including the Entner–Doudoroff pathway for glucose metabolism) (Biffinger et al., 2008).

Applications

- Anaerobic digestion (AD) – high strength wastewater & moderate temperature.
- MFC – low strength wastewater & low temp. (complementary to AD)

Domestic wastewater treatment and monitoring

Sewage → Clarifier → Supernatant → Conventional WWTP → River

Clarifier → AD + Self powered **MFCSensor** → Conventional WWTP

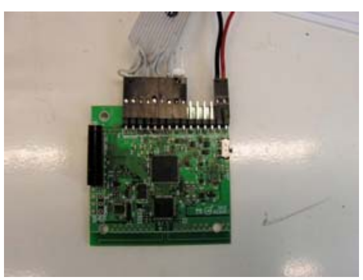
AD + Self powered **MFCSensor** → **Electricity water monitoring. Domestic**

Industrial wastewater treatment and monitoring

High strength WW → AD → Low strength WW → **Self powered MFCSensor**

Self powered MFCSensor → **Electricity and water monitoring Industry**

Self powered MFCSensor → Conventional WWTP → River



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/

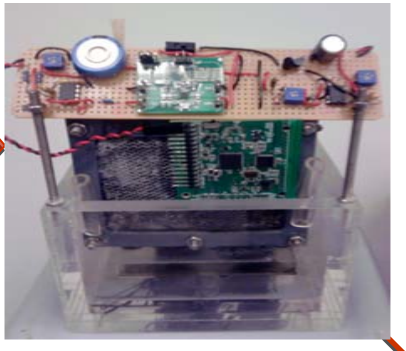
Which bacteria are electrogens? >10 and more coming

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)* **,** *Proteus vulgaris,*
Glucose
Proteus vulgaris, Rhodococcus, E. cloacae and Paracoccus
Lactate
S. oneidensis MR-1
Wastewater (acetate).
Xing, et al (2008) *Rhodopseudomonas palustris* DX-1
Fedorovich (2008) γ-*Proteobacterium, Arcobacter ED-1*
Carboxymethyl cellulose (CMC)
Co-culture of Clostridium cellulolyticum and G. sulfurreducens

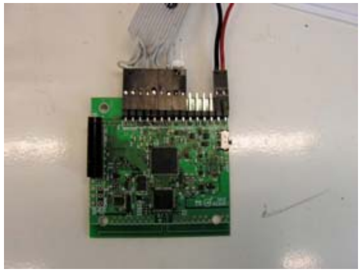
Self powered speckled sensors for Integral measurements

Wastewaters treatment and monitoring
Brewery, chocolate industry, food processing, meat processing, paper recycling, starch processing, swine, farm manure, corn stover, landfill leach ate, macro algae, chlorella, ocean sediments, oils spillage, organics from streams, ponds, lakes, swamps, methane from mines

Substrates
Acetate, Arabitol, Azo Dye, Carboxymethyl cellulose, cellulose, cystein, ethanol, fulfural, galactitol, glucose, glucuronic acid, lactate, nitrilotriacetic acid, phenol, propionate, ribitol, sodium formate, sodium fumarate, sorbitol, sucrose, xylitol, xylose, humic acids



Pollutants treatment and monitoring
Nitrate, sulfides, sulphates



MFC in Edinburgh. Advantages

- Horizontal location of multi compartmental zones having an enlarged pathway of substrate from inlet to outlet and thus enhanced mass transfer. (Fedorovich, 2009)
- Close location of anodic and cathodic electrodes minimizes a distance between them and hence reduces an internal resistance of MFC(Patented).
- New flexible cathodes (Patented)
- Diverse substrates. Novel electrogenic bacteria (Fedorovich, 2009)
- Continuously working MFC construction, long-term operation
- Clearly seen possibility for enhancing a sustainable power
- Highest maximum power
- Suitable for environmental applications

Conclusions

MFC can be used as a platform technology for environmental studies with speckled computing

MFCs are capable to solve simultaneously two tasks: electricity generation for ENS and environmental sensing.

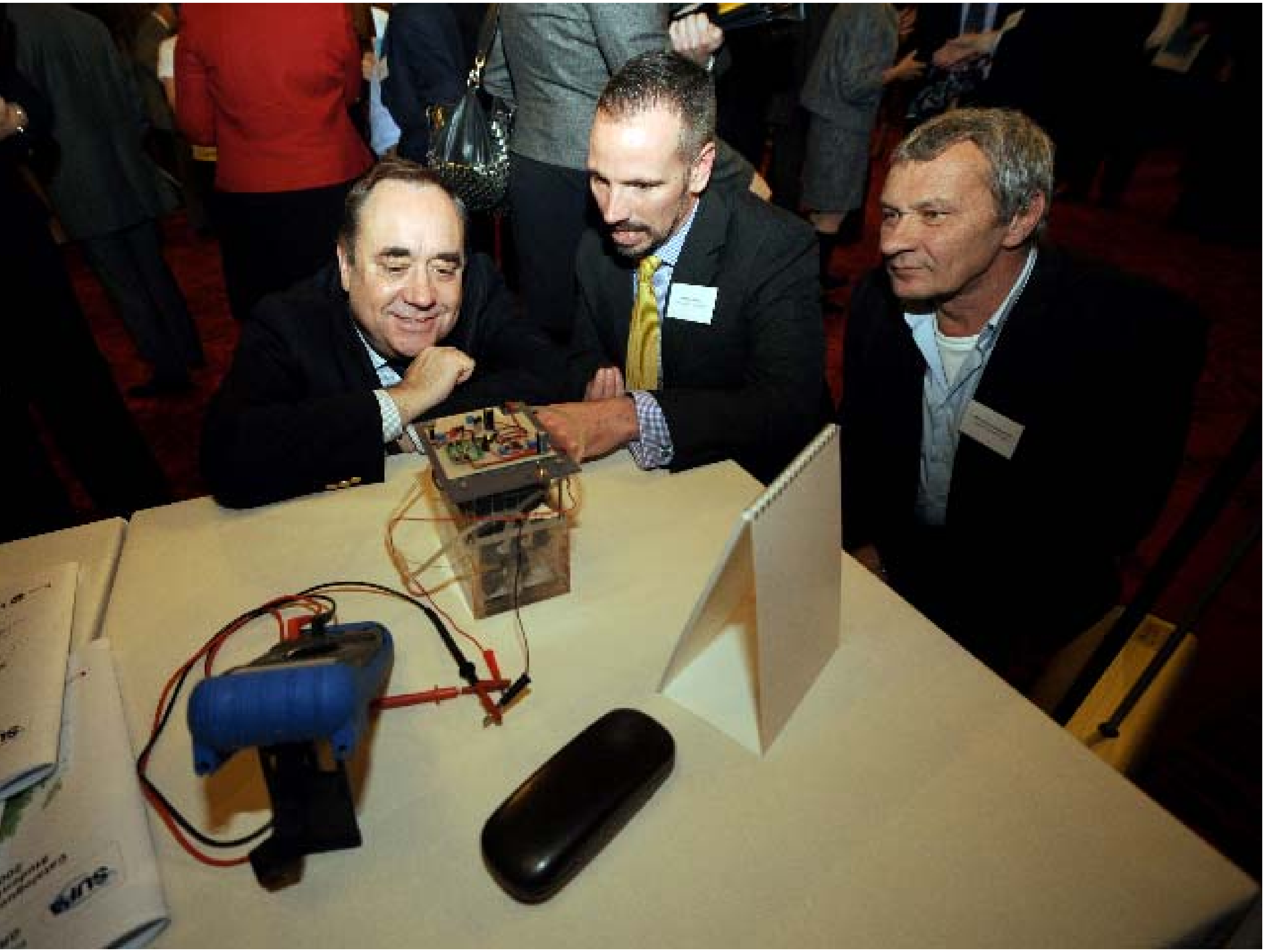
•MFC challenges:

– Improve sustainable power output

– Stability of parameters during long term operation

– Bacteria starvation and inhibition.

- Calibration for different environmental conditions and substrates. Specialized bacteria



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