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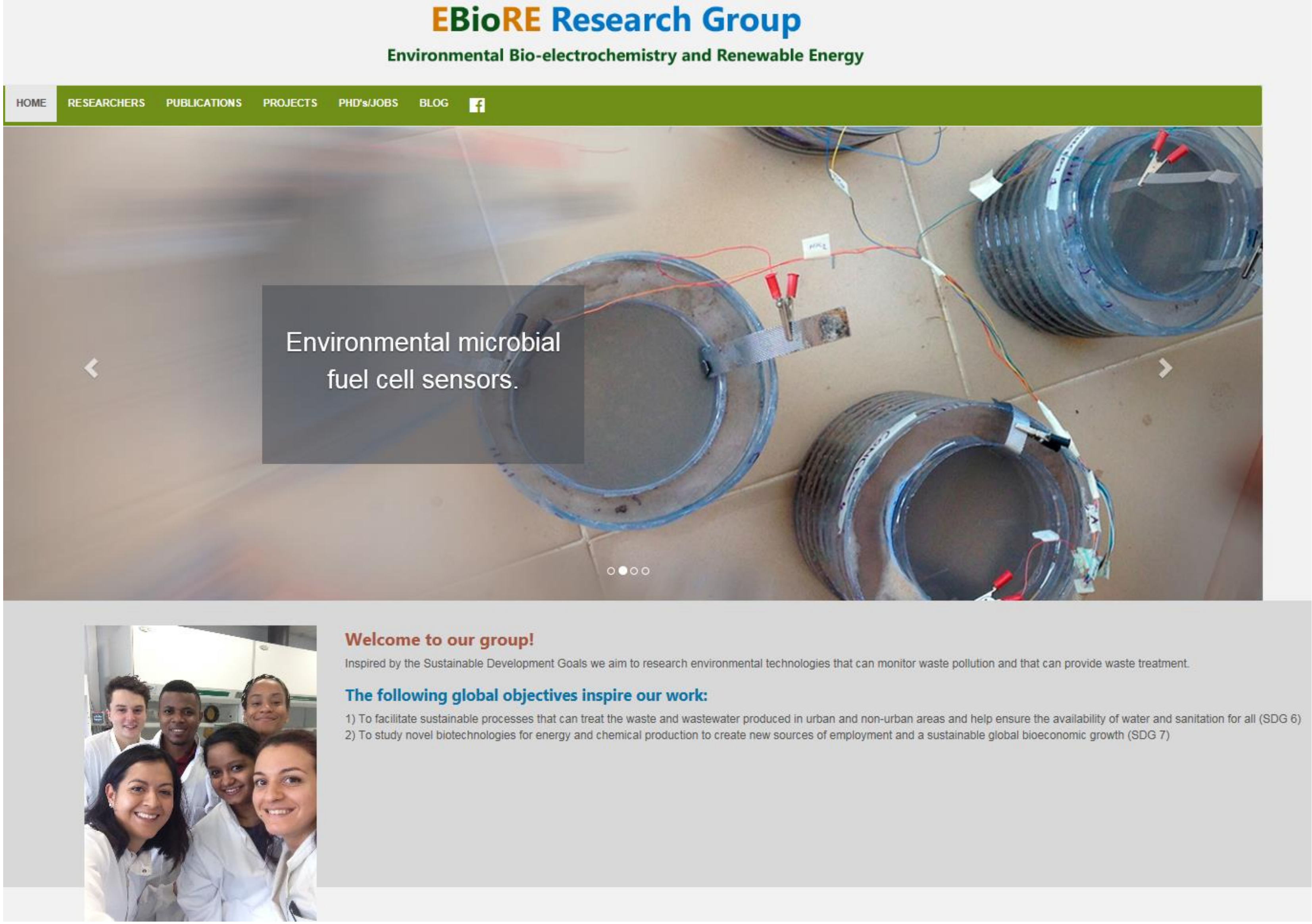
Continuous monitoring of water quality using an *in situ* microbial fuel cell

Dr. Sharon Velasquez Orta

12th July, 2017

Agenda

- Introduction
- Results from case 1
- Results from case 2
- Outlook



EBioRE Research Group

Environmental Bio-electrochemistry and Renewable Energy

Environmental microbial fuel cell sensors.

Welcome to our group!

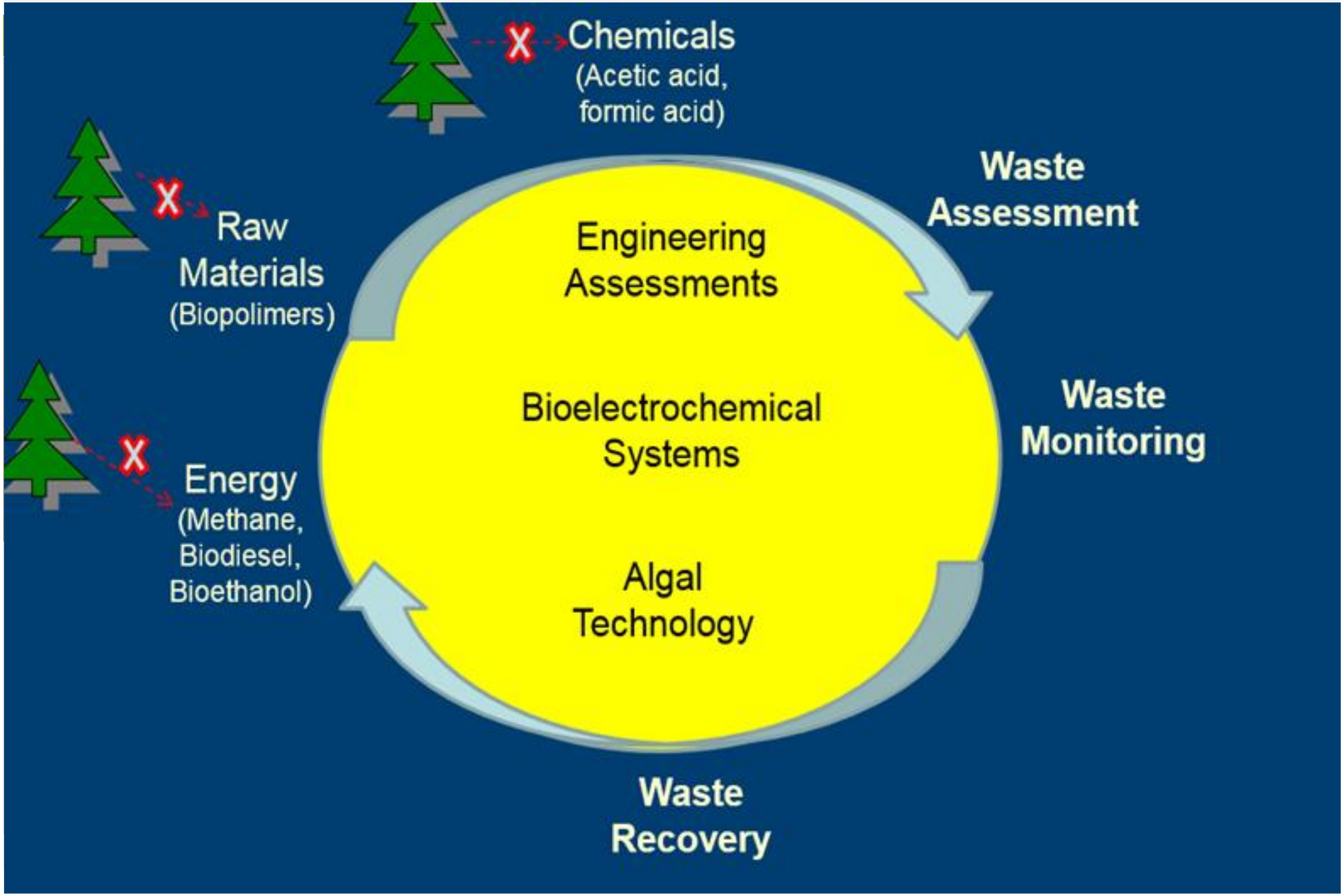
Inspired by the Sustainable Development Goals we aim to research environmental technologies that can monitor waste pollution and that can provide waste treatment.

The following global objectives inspire our work:

1) To facilitate sustainable processes that can treat the waste and wastewater produced in urban and non-urban areas and help ensure the availability of water and sanitation for all (SDG 6)
2) To study novel biotechnologies for energy and chemical production to create new sources of employment and a sustainable global bioeconomic growth (SDG 7)

EBioRE Research Group

Environmental Bio-electrochemistry and Renewable Energy



Chemicals
(Acetic acid,
formic acid)

Raw
Materials
(Biopolimers)

Energy
(Methane,
Biodiesel,
Bioethanol)

Engineering
Assessments

Bioelectrochemical
Systems

Algal
Technology

**Waste
Assessment**

**Waste
Monitoring**

**Waste
Recovery**

Worldwide issues

- Esrey *et al* surveyed 142 studies on 6 major waterborne diseases and estimated that there were 875 million cases of diarrhoea in developing countries.
- Waterborne diseases are largely transmitted from contaminated water sources containing faecal matter.
- Conditions are most severe in sub-Saharan Africa. Here 42% of the country’s population is without improved water and 64% without improved sanitation.

S.A. Esrey, J.B. Potash, L. Roberts, C. Shiff, Health Benefits From Improvements In Water Supply and Sanitation: Survey and Analysis of the Literature on Selected Diseases in: B.o.S.a.T. Office of Health, U.S. Agency for International Development, under WASH Task No. 035 (Ed.), WASH - Water And Sanitation Health, Washington DC, 1990.
M.A. Montgomery, M. Elimelech, Water and Sanitation in Developing Countries: Including Health in the Equation, Environmental Science & Technology 41 (2007) 17-24.

Water monitoring methods

- Laboratory-based monitoring
- Field kits
- Probes: dissolved oxygen, pH, UV-vis, etc.
- Biosensors have increased in popularity as an alternative to the traditional BOD tests

  – Expensive and/or time consuming

Biosensors

- Biosensors have variations in the biological receptor alongside differing types of transducing elements.
- Examples of bio-receptors include enzymes, micro-organisms, antibodies and organelles.
- The transducing element of a biosensor also varies, with conductometry, amperometry and potentiometry used as microbial sensors.

Microbial sensors

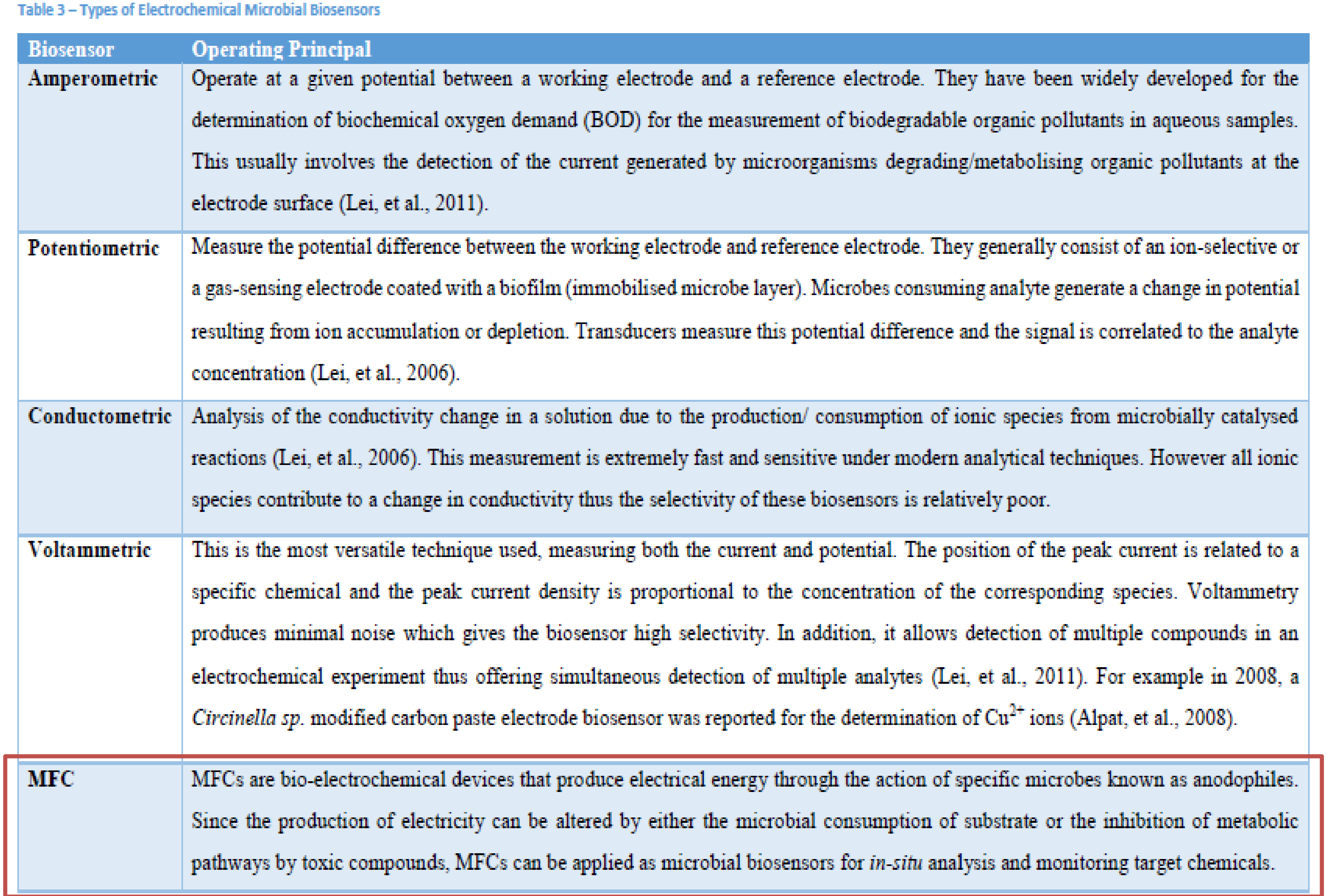
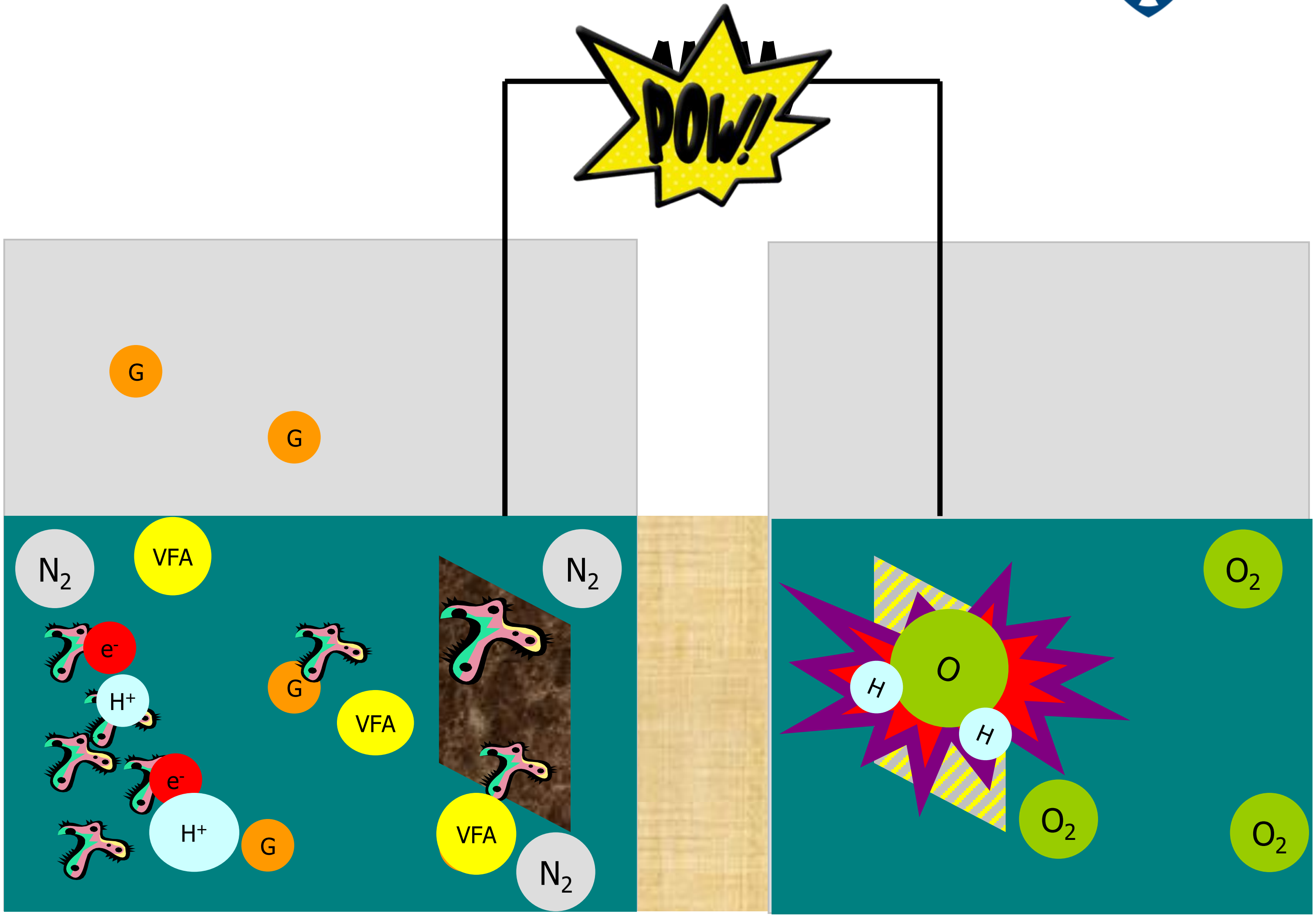


Table 3 – Types of Electrochemical Microbial Biosensors

Biosensor	Operating Principal
Amperometric	Operate at a given potential between a working electrode and a reference electrode. They have been widely developed for the determination of biochemical oxygen demand (BOD) for the measurement of biodegradable organic pollutants in aqueous samples. This usually involves the detection of the current generated by microorganisms degrading/metabolising organic pollutants at the electrode surface (Lei, et al., 2011).
Potentiometric	Measure the potential difference between the working electrode and reference electrode. They generally consist of an ion-selective or a gas-sensing electrode coated with a biofilm (immobilised microbe layer). Microbes consuming analyte generate a change in potential resulting from ion accumulation or depletion. Transducers measure this potential difference and the signal is correlated to the analyte concentration (Lei, et al., 2006).
Conductometric	Analysis of the conductivity change in a solution due to the production/ consumption of ionic species from microbially catalysed reactions (Lei, et al., 2006). This measurement is extremely fast and sensitive under modern analytical techniques. However all ionic species contribute to a change in conductivity thus the selectivity of these biosensors is relatively poor.
Voltammetric	This is the most versatile technique used, measuring both the current and potential. The position of the peak current is related to a specific chemical and the peak current density is proportional to the concentration of the corresponding species. Voltammetry produces minimal noise which gives the biosensor high selectivity. In addition, it allows detection of multiple compounds in an electrochemical experiment thus offering simultaneous detection of multiple analytes (Lei, et al., 2011). For example in 2008, a *Circinella sp.* modified carbon paste electrode biosensor was reported for the determination of Cu^{2+} ions (Alpat, et al., 2008).
MFC	MFCs are bio-electrochemical devices that produce electrical energy through the action of specific microbes known as anodophiles. Since the production of electricity can be altered by either the microbial consumption of substrate or the inhibition of metabolic pathways by toxic compounds, MFCs can be applied as microbial biosensors for *in-situ* analysis and monitoring target chemicals.

MFCs



Anode

Proton Exchange Membrane

Cathode

MFCs

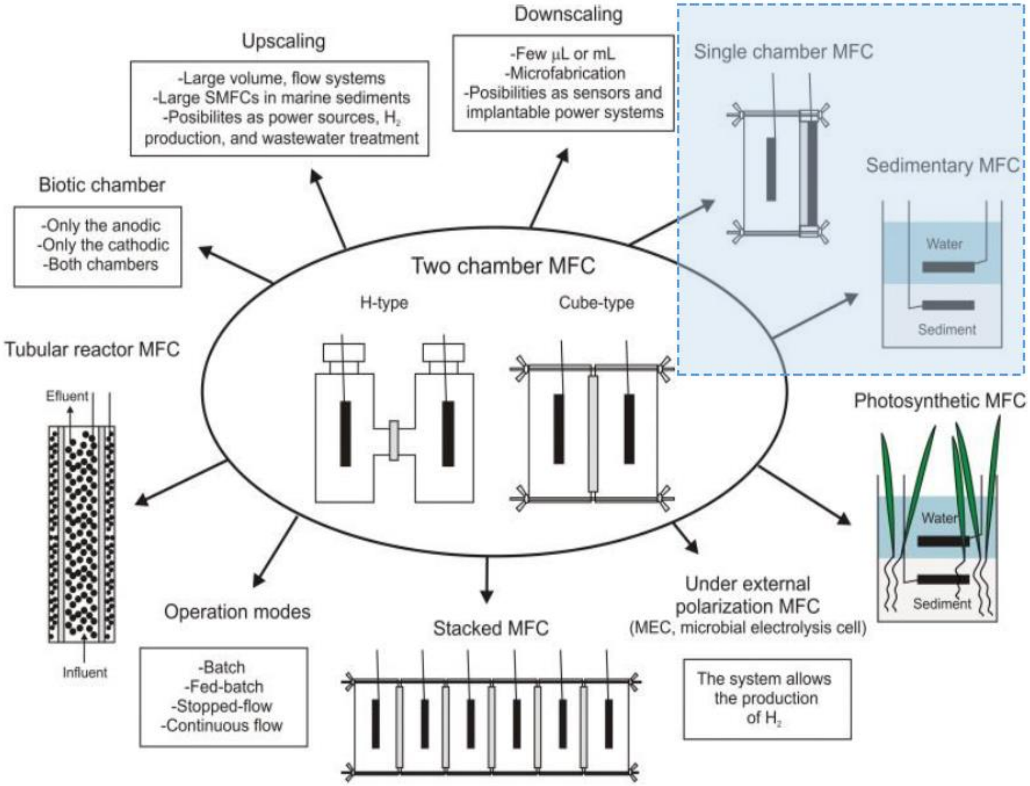
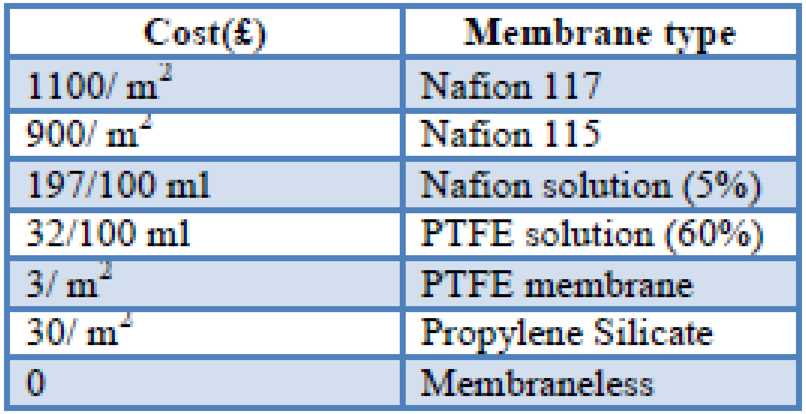
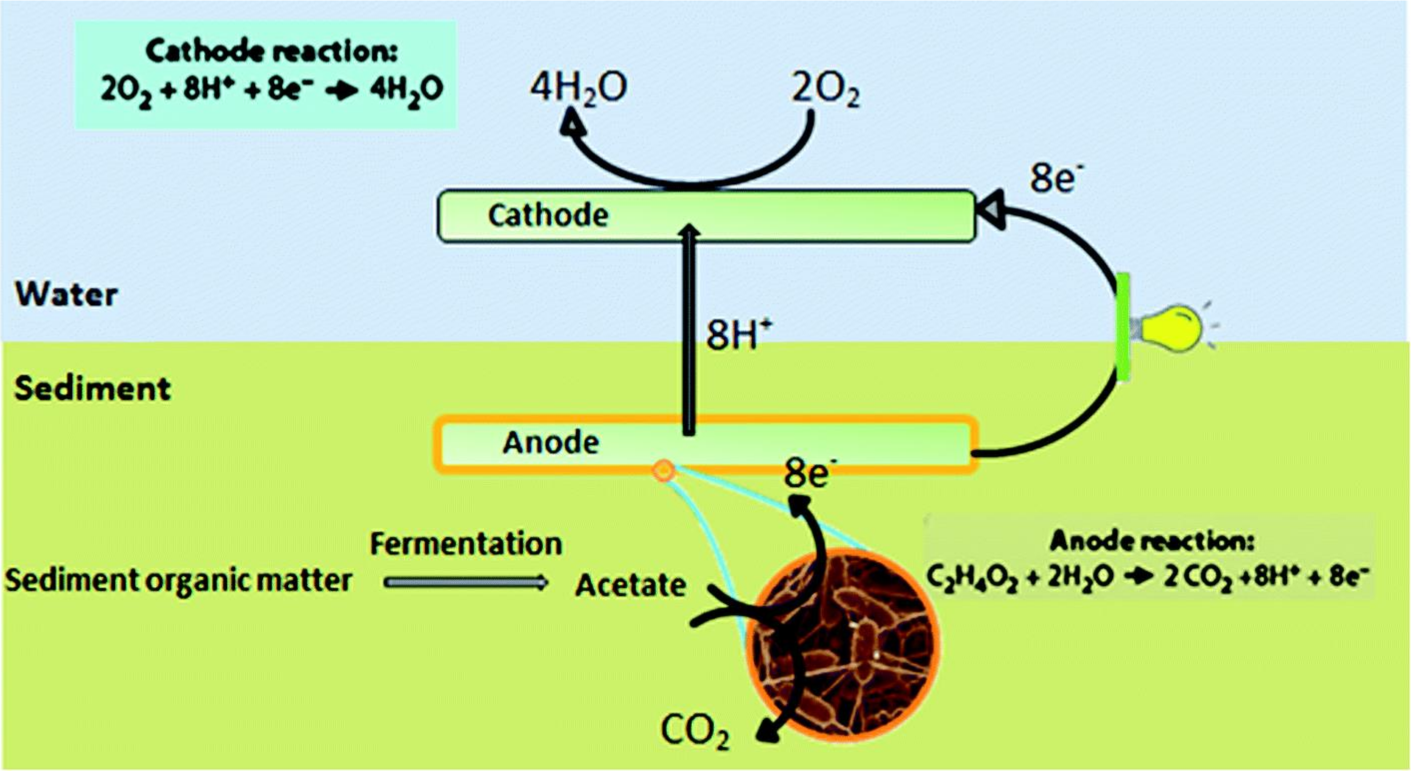


Figure 7 - MFC architecture, construction aspects and operation modes (Abrevaya, et al., 2015)



Cost(£)	Membrane type
1100/ m^2	Nafion 117
900/ m^2	Nafion 115
197/100 ml	Nafion solution (5%)
32/100 ml	PTFE solution (60%)
3/ m^2	PTFE membrane
30/ m^2	Propylene Silicate
0	Membraneless

Sediment Microbial Fuel cell (SMFC)



A. Zabihallahpoor, M. Rahimnejad and F. Talebniaab. ‘Sediment microbial fuel cells as a new source of renewable and sustainable energy: present status and future prospects’. RSC Adv., 2015,5, 94171-94183.

SMFCs

- SMFCs can serve as sustained power sources for many low-power instruments (i.e. seismic detectors, monitoring devices and oceanographic instruments
- Charge capacitors can be used if higher power levels are needed
- No need of any exogenous microorganism or electron shuttles addition - *power is derived from the metabolism of the microorganisms in the environment*
- The sustainability of the system does not relate through if the system is batch or continuous but is related to the source of the substrate

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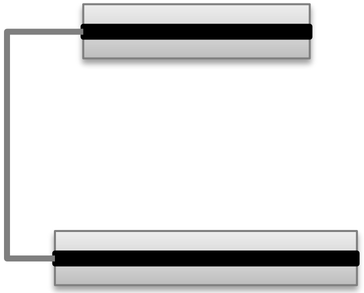
- Can be used as online biosensor for the detection of organic or toxic compounds
- Changes in the organic substrate in the sediments changes MFC performance

Case study 1: Construction of electrochemical biosensors for water stream pollutants monitoring and power generation

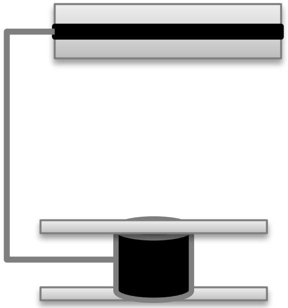
X Christodoulou, S Velasquez

- Two SMFC reactor configurations in a set up using water and sediment from Tyne river

Reactor 1: Carbon cloth

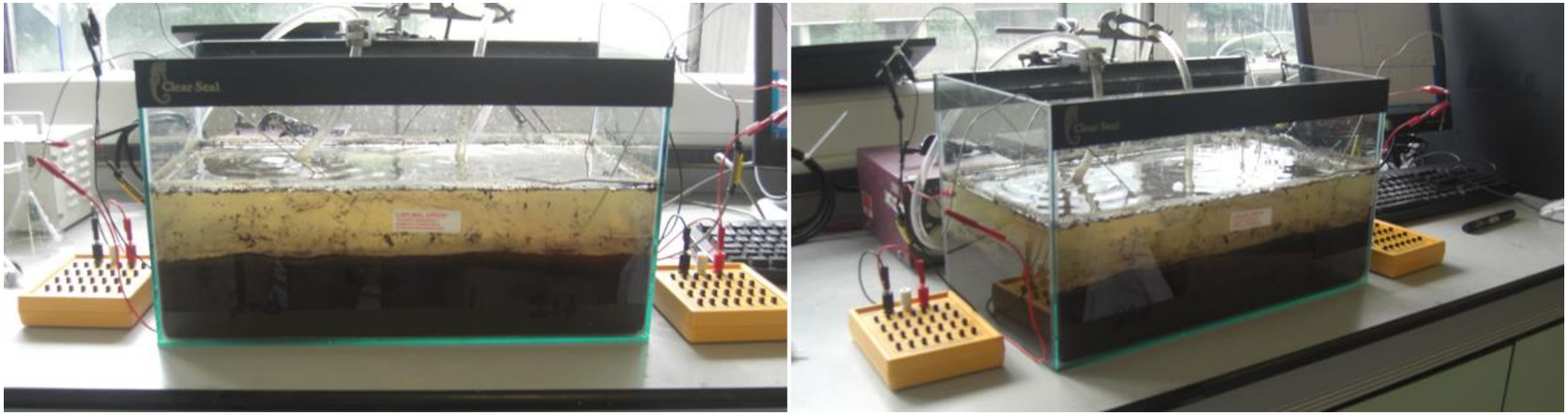


Reactor 2: Carbon granules



Active anode area = 144 cm^2

Active cathode area = 100 cm^2



Case study 1: Construction of electrochemical biosensors for water stream pollutants monitoring and power generation

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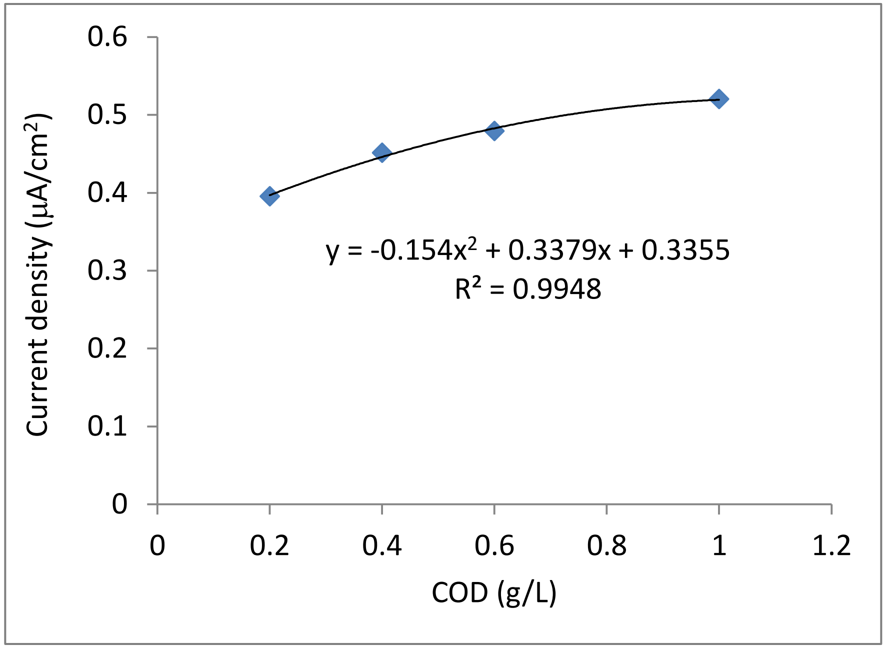
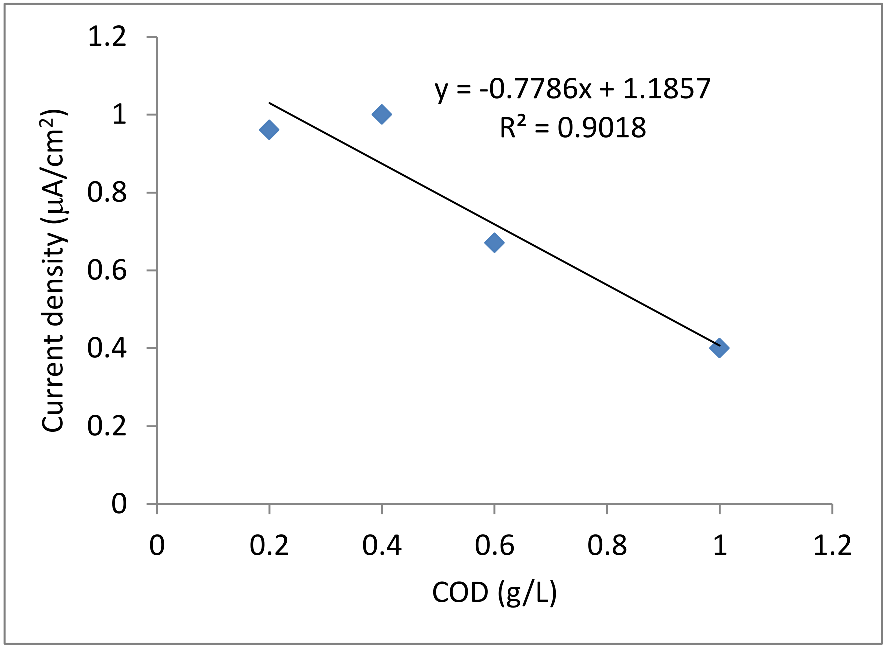


Reactor 2: Carbon granules



- Maximum current density generated from river water stream in different concentrations of glucose (200, 400, 600 and 1000 mg/L)
- Reactor 1: current density increased with increased glucose concentration
- Reactor 2: current density increased from 200 to 400 mg/L of glucose ONLY
- Reactor 1 reached steady state within 2 weeks, two times faster than Reactor 2

Case study 2: Sediment Microbial Fuel Cell Biosensor for monitoring faecal pollution discharges into groundwater

S Velasquez, D Werner, J Varia, S Mgana

1. To assemble a SMFC system in a cost-efficient way.
2. To develop different types of MFC concepts.
3. To study the impact of temperature, external resistance and salinity in the response.

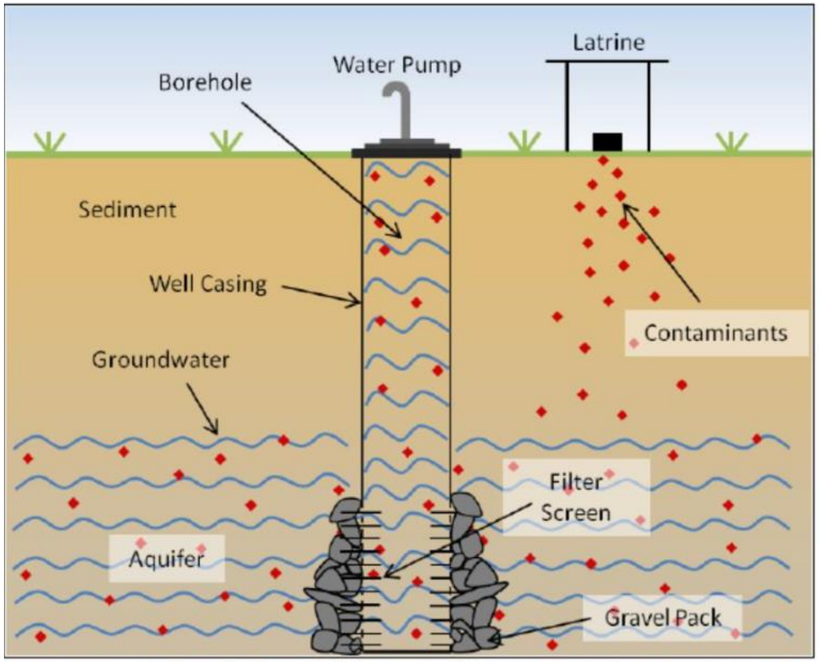
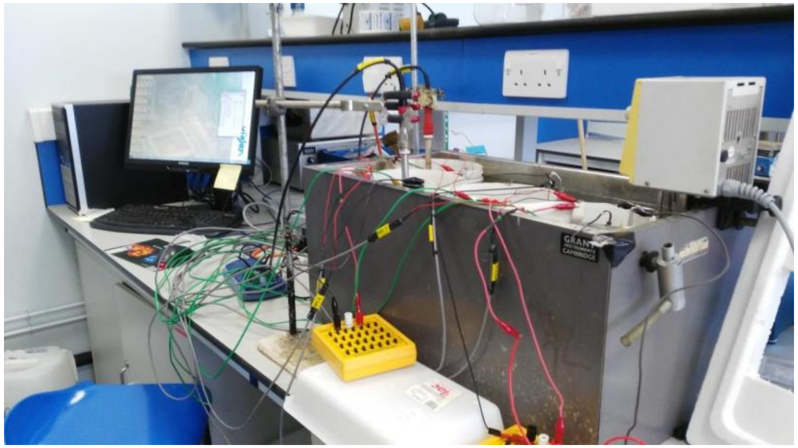
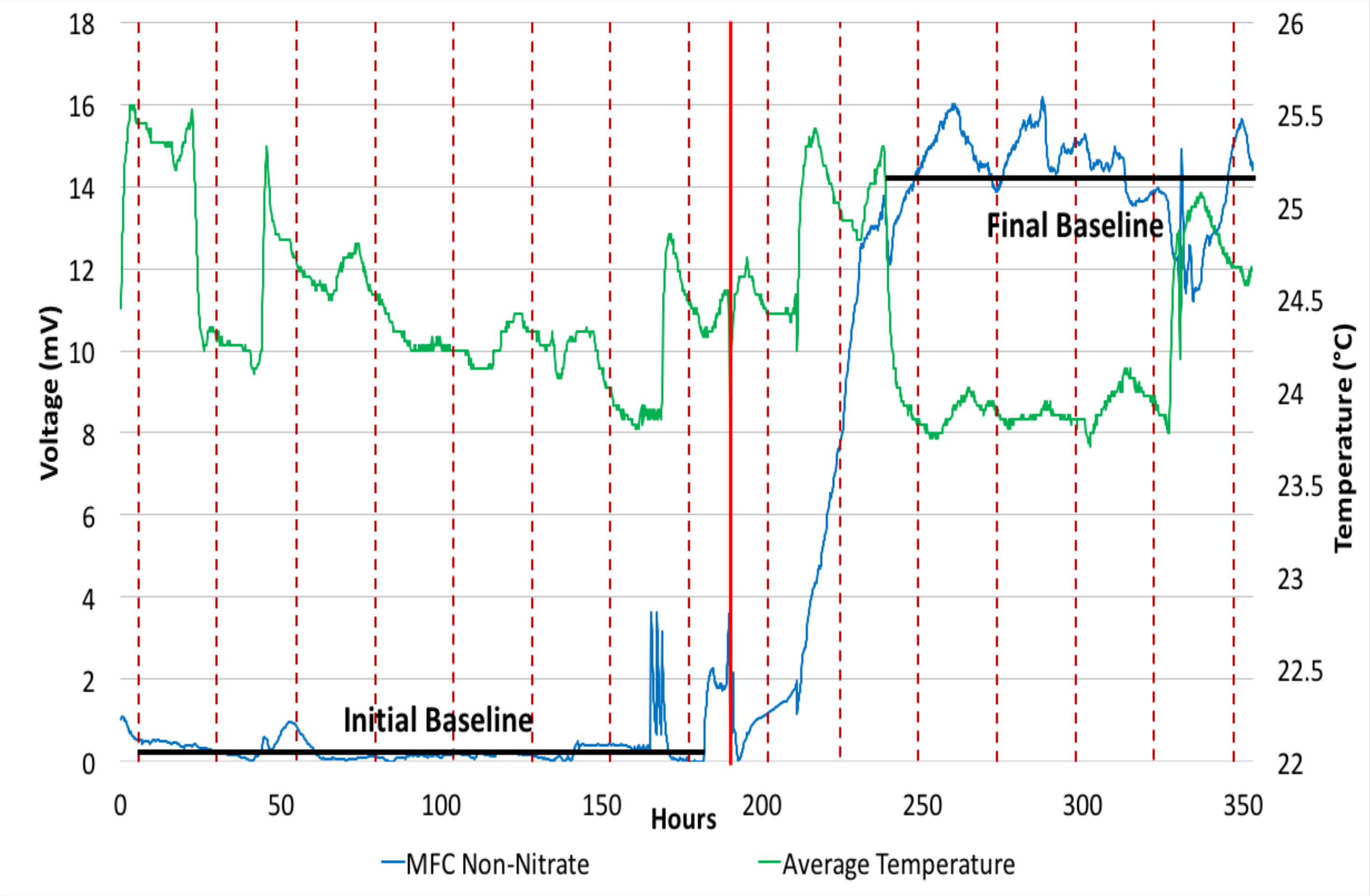


Figure 2 - Scenario illustrating the potential contamination route of groundwater from water wells from nearby latrines



- Velasquez-Orta et al. 2017 Microbial fuel cells for inexpensive continuous *in-situ* monitoring of groundwater quality. *Water Research*

Case study 2: Sediment Microbial Fuel Cell Biosensor for monitoring faecal pollution discharges into groundwater



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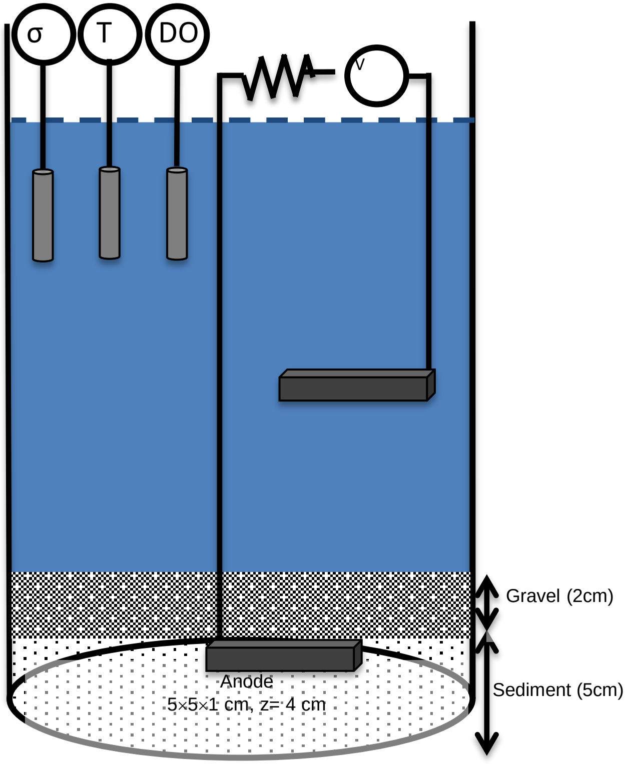
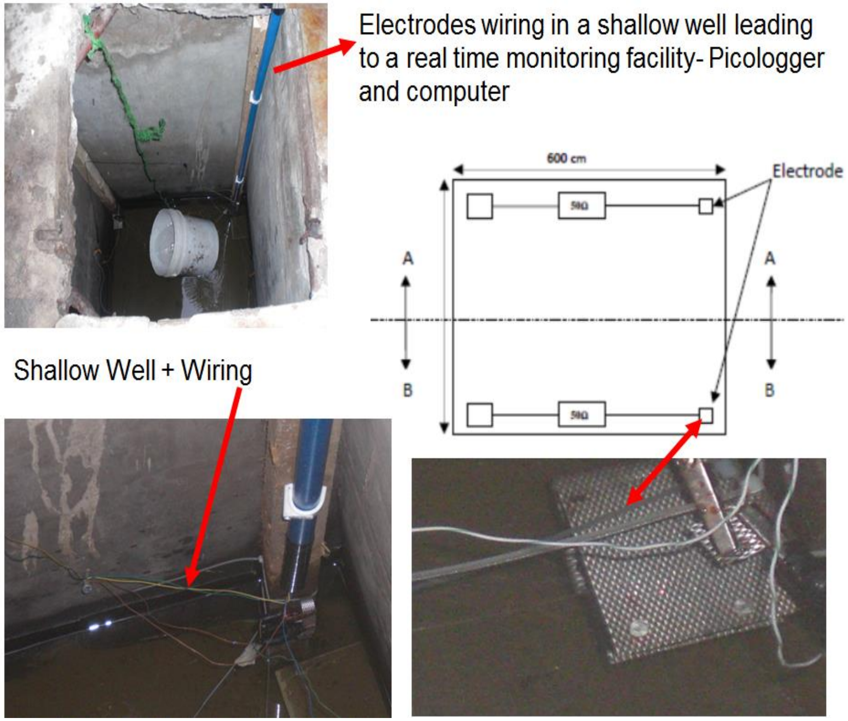




Electrodes wiring in a shallow well leading to a real time monitoring facility- Picologger and computer

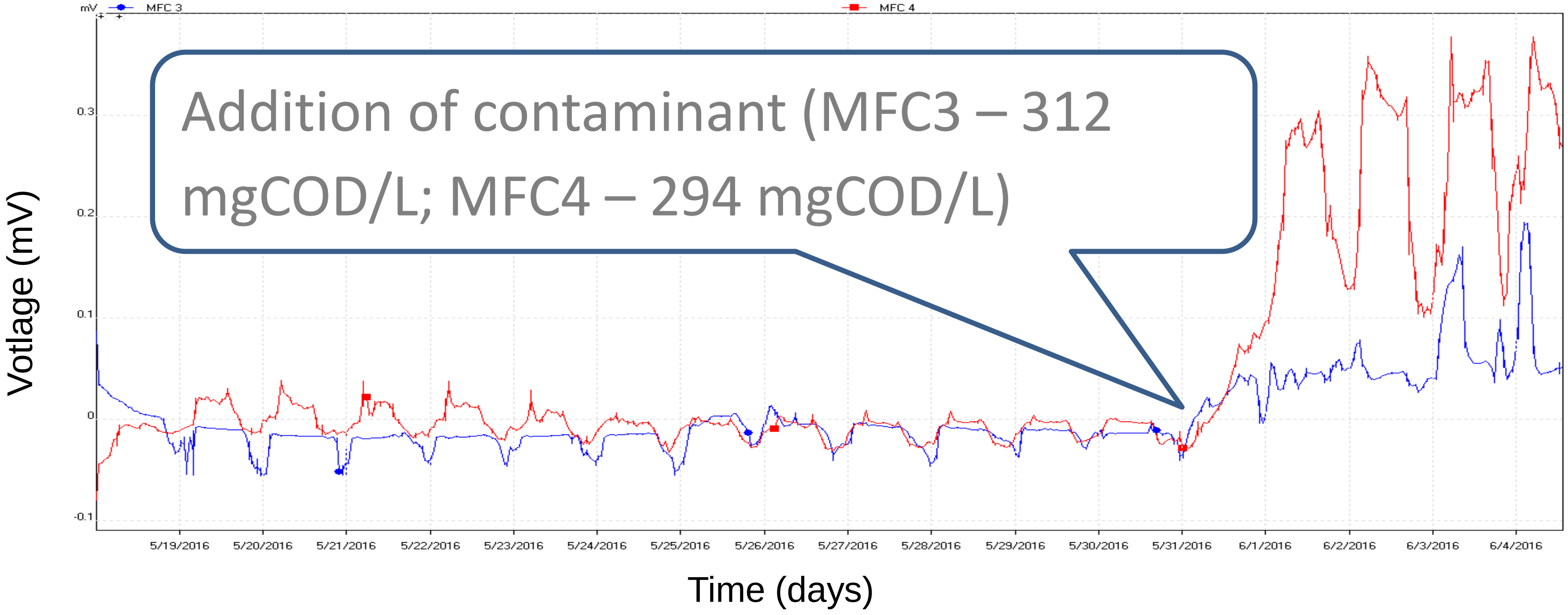
Shallow Well + Wiring

- ➢ SMFC was the best configuration within the different concepts tried.
- ➢ The system was assembled in the laboratory and field (Tanzania)

- Velasquez-Orta et al. 2017 Microbial fuel cells for inexpensive continuous *in-situ* monitoring of groundwater quality. *Water Research*

Case study 2: Sediment Microbial Fuel Cell Biosensor for monitoring faecal pollution discharges into groundwater

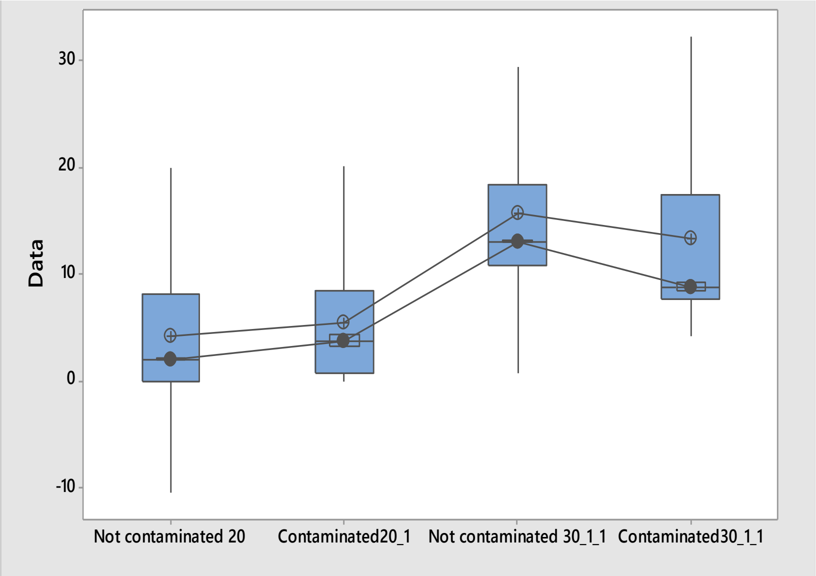
Example of MFC biosensor response



Addition of contaminant (MFC3 – 312 mgCOD/L; MFC4 – 294 mgCOD/L)

- Potential Difference (mV) of the electrolyte increases after addition of contaminant in lab-scale experiments using Tanzanian soil.

Case study 2: Sediment Microbial Fuel Cell Biosensor for monitoring faecal pollution discharges into groundwater



Source	DF	Adj SS	Adj MS	P-Value
Model	7	92.621	13.232	0.423
Linear	3	70.828	23.609	0.187
Temperature	1	64.947	64.947	0.045
Salinity	1	4.131	4.131	0.567
Resistance	1	1.75	1.75	0.707
2-Way Interactions	3	12.306	4.102	0.787
Temperature*Salinity	1	3.109	3.109	0.618
Temperature*Resistance	1	2.267	2.267	0.67
Salinity*Resistance	1	6.929	6.929	0.461
3-Way Interactions	1	9.487	9.487	0.392
Temperature*Salinity*Resistance	1	9.487	9.487	0.392
Error	8	92.534	11.567	
Total	15	185.155		

- From the variables tested, only temperature presented a statistically significant effect on the response ($p<0.05$)
- No significant changes from varying salinity and external resistance, within the tested range .

- Velasquez-Orta et al. 2017 Microbial fuel cells for inexpensive continuous *in-situ* monitoring of groundwater quality. *Submitted to Water Research*

Conclusions

- SMFCs were able to produce a current that correlated to faecal matter pollution.
- SMFCs were susceptible to a change in temperature in the environment but not to changes in conductivity or resistance within the ranges tested
- SMFCs offer an alternative to the continuous monitoring of groundwater pollution

Outlook

Further stabilise cell response by:

- Understanding the type of exoelectrogens attached to anode and cathode
  - Stabilising biofilms in the cathode and anode sides.
- Determining the rate of substrate consumption by anodic communities in the sediment at different temperatures
- Decreasing interference of temperature in cell response

https://upgro.org/2015/08/13/mit_award/

UPGro Catalyst Researcher recognised as a leading ‘Innovator under 35’ by MIT Technology Review

Posted on 13/08/2015 by RWSN Secretariat

UPGro – Unlocking the Potential of Groundwater for the Poor

A social and natural science approach to enabling sustainable use of groundwater for the benefit of the poor.

Une approche par les sciences sociales et naturelles pour une utilisation durable des eaux souterraines en faveur des populations pauvres

Newcastle University

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Graduated from PhD yesterday!

MEng students from Chemical Engineering

Science without borders student from Brasil

MEng student from Ardhi University in Tanzania

Funding:

UP Gro Unlocking the Potential of Groundwater for the Poor

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Water Research

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WATER RESEARCH

Microbial fuel cells for inexpensive continuous *in-situ* monitoring of groundwater quality

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