Urine-tricity Project

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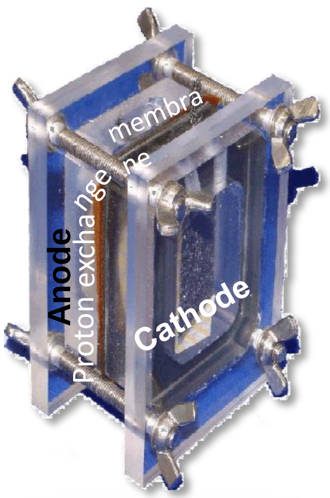
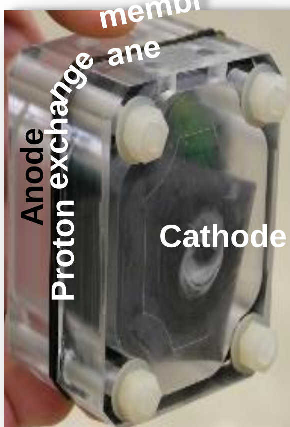
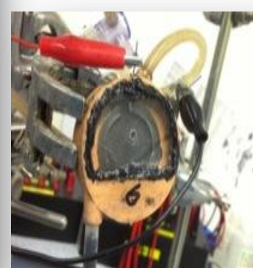
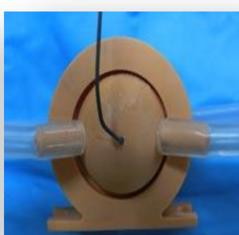
Microbial Fuel Cells

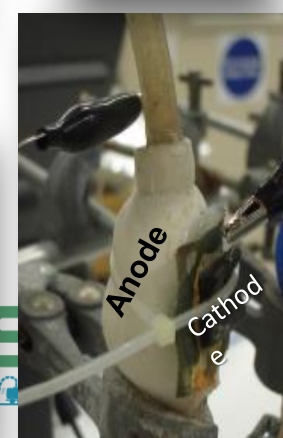
- By definition, it is a system, which *converts microbial (bio-chemical) energy directly into electricity*
- In other words, it is a *bio-battery* that never runs out, as long as the microbes are kept fed
- The feedstock (fuel) can be any organic matter, even waste
- This renders the MFC technology competitive for waste utilisation *via* energy recovery





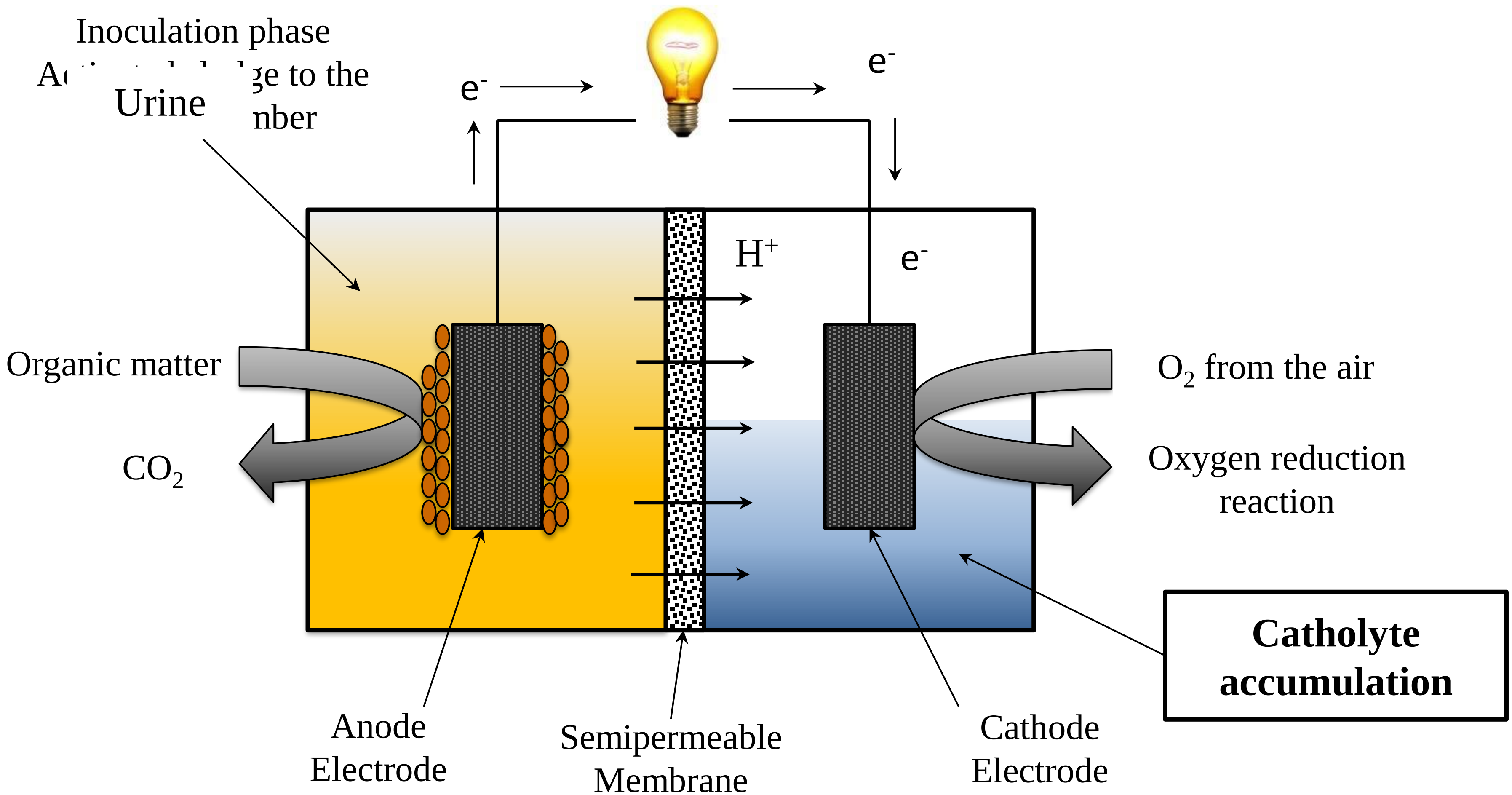






Fuel Cell with bacteria

How do they work?



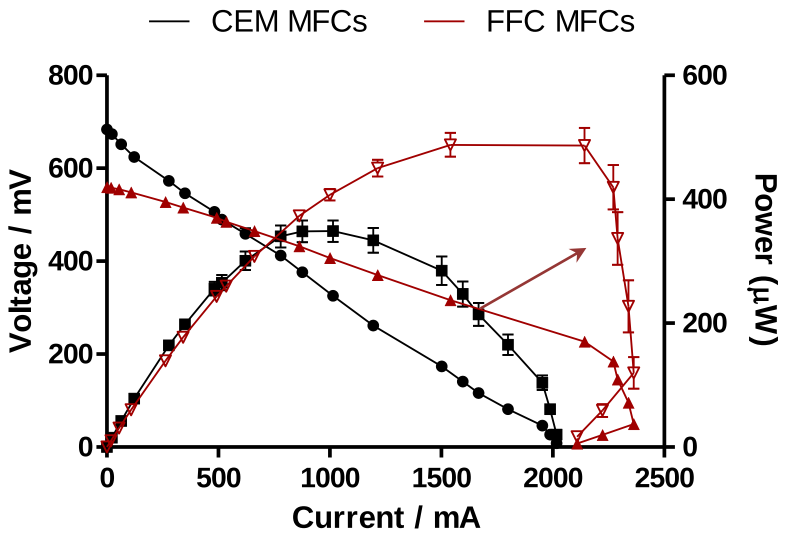
MFCs treating urine

Optimizing MFCs materials at an affordable cost

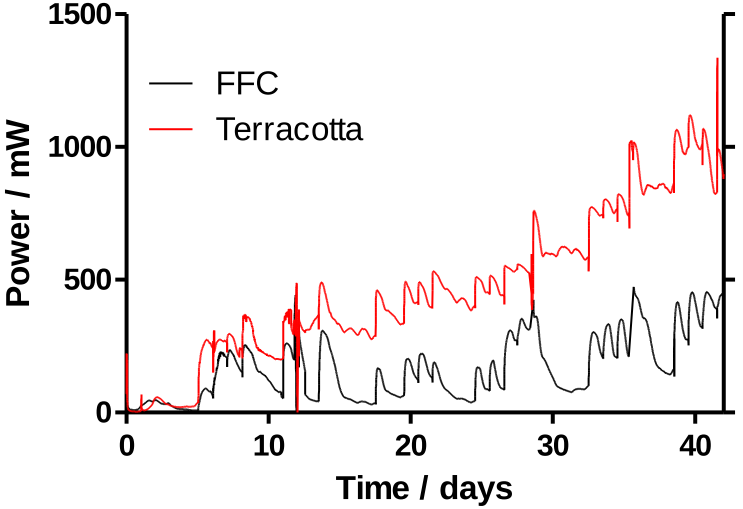
– **Ceramic** material outperformed commercially available cation exchange **membrane** (CEM)

– Composition, porosity and thickness of the ceramic affect the MFC power output

FFC Terracotta



Comparison Individual FFC vs. Terracotta



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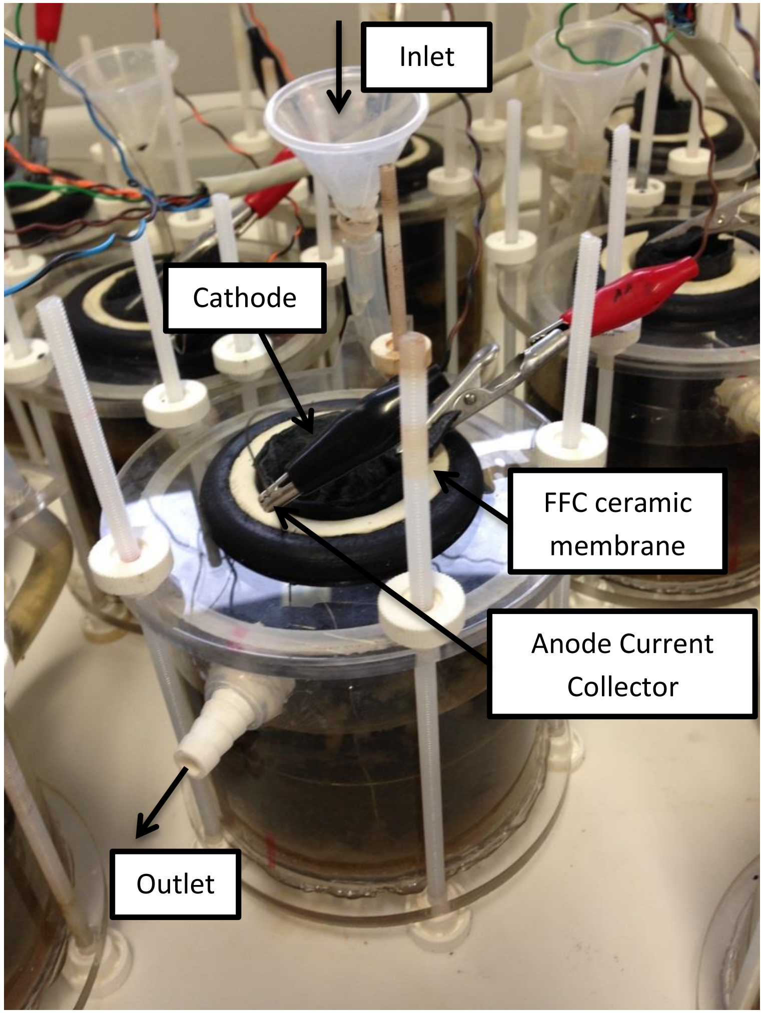
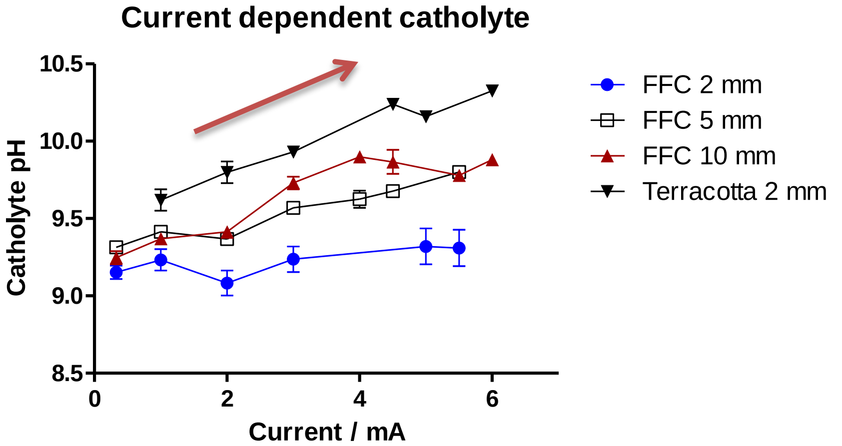


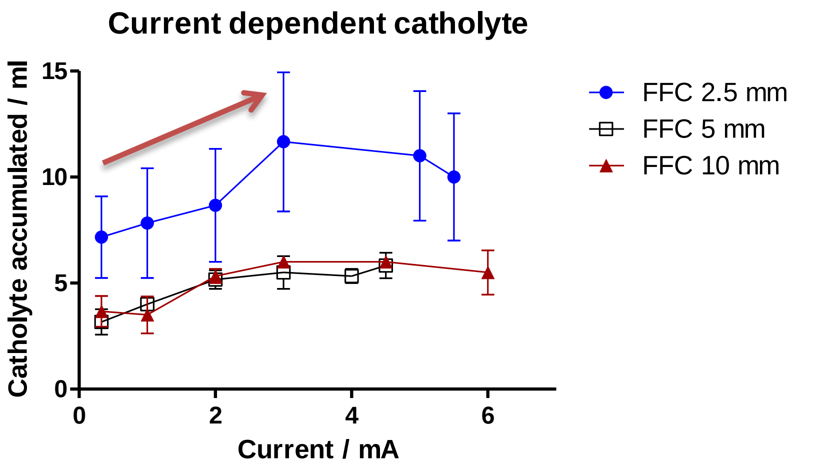
- Cylindrical design.
- Anode outside – Around the cylinder.
- Cathode inside the cylinder.
- Cathode chamber initially empty.
- Easy catholyte accumulation
- Ceramic properties affect the catholyte quality and quantity.

MFCs treating urine

Catholyte generation

- Catholyte quality varies with:
  - Porosity/composition/properties of the ceramic membrane
  - Ceramic thickness
- Catholyte pH increases with:
  - **Electricity generation** from the MFC
  - Accumulation time
- Pathogen killing agent





MFCs treating urine

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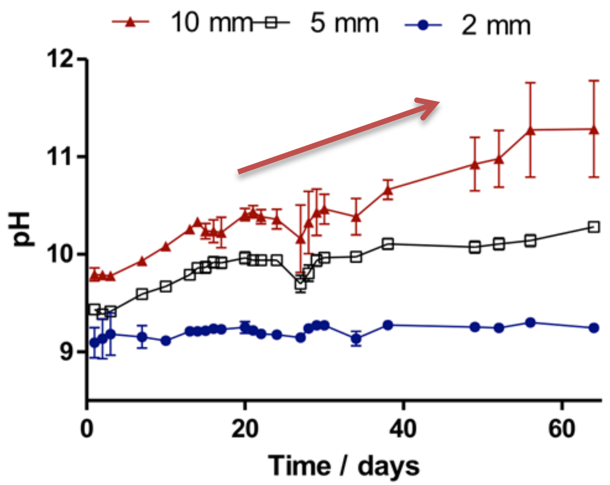

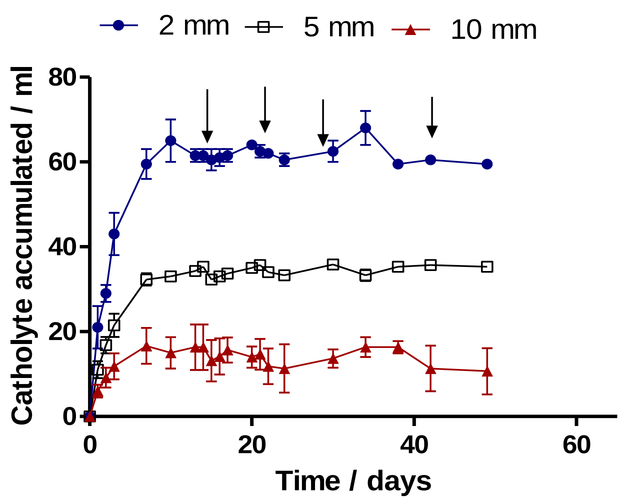

MFCs treating urine

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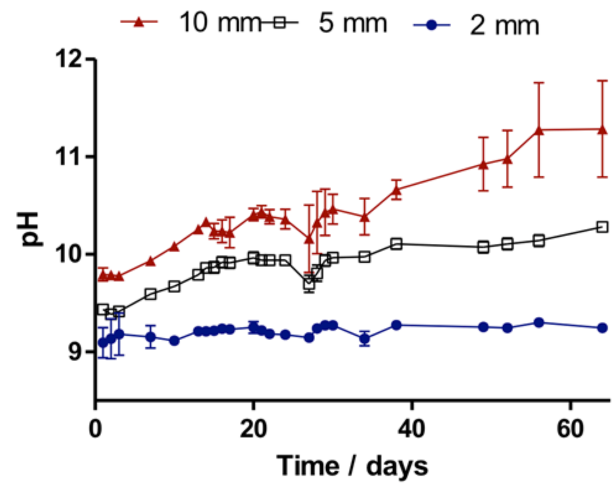
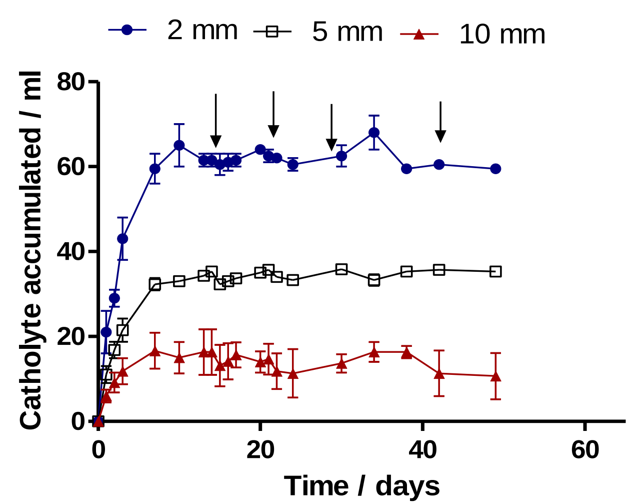
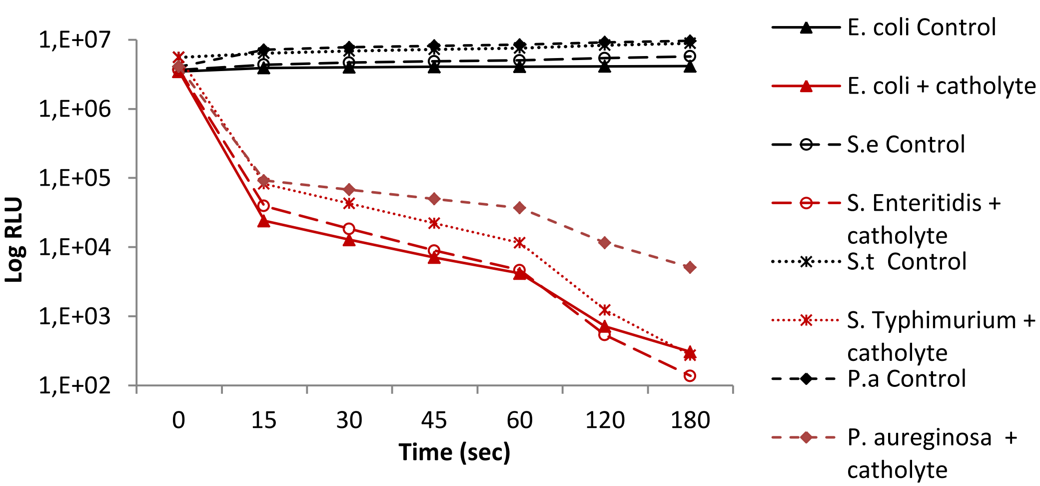


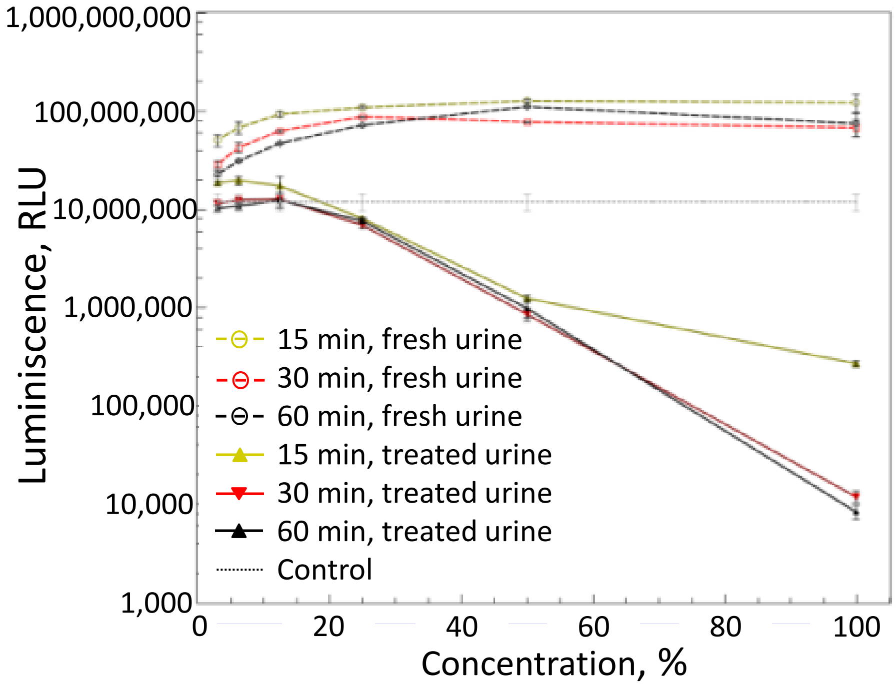


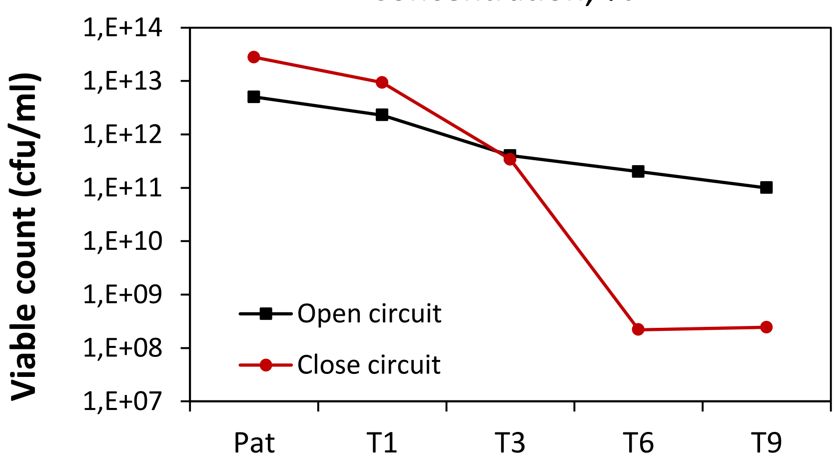


MFCs treating urine

Pathogen Killing

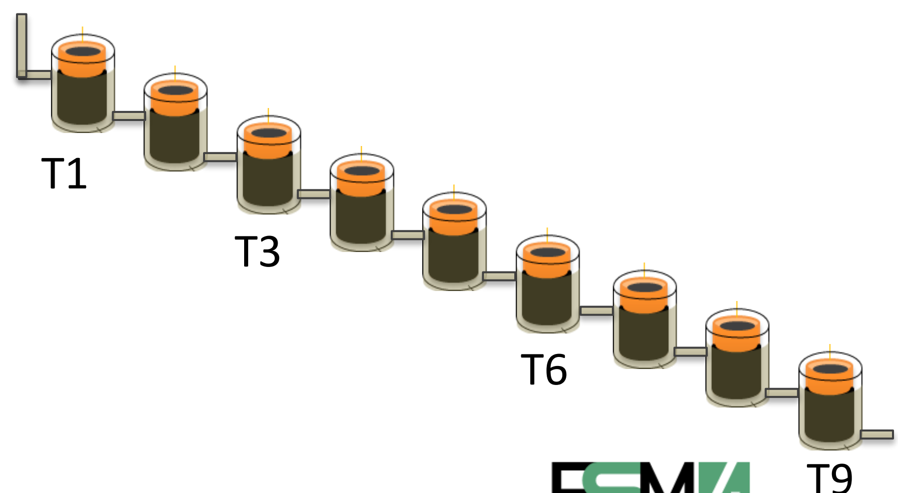
The MFC technology can kill pathogens during operation in a cascade of 9 MFCs:





- Bioluminescence and viable counts showed killing of pathogens inside the anode of MFCs generating electricity (ca. 4 log-fold).
- Further decrease could potentially be achieved with a longer cascade

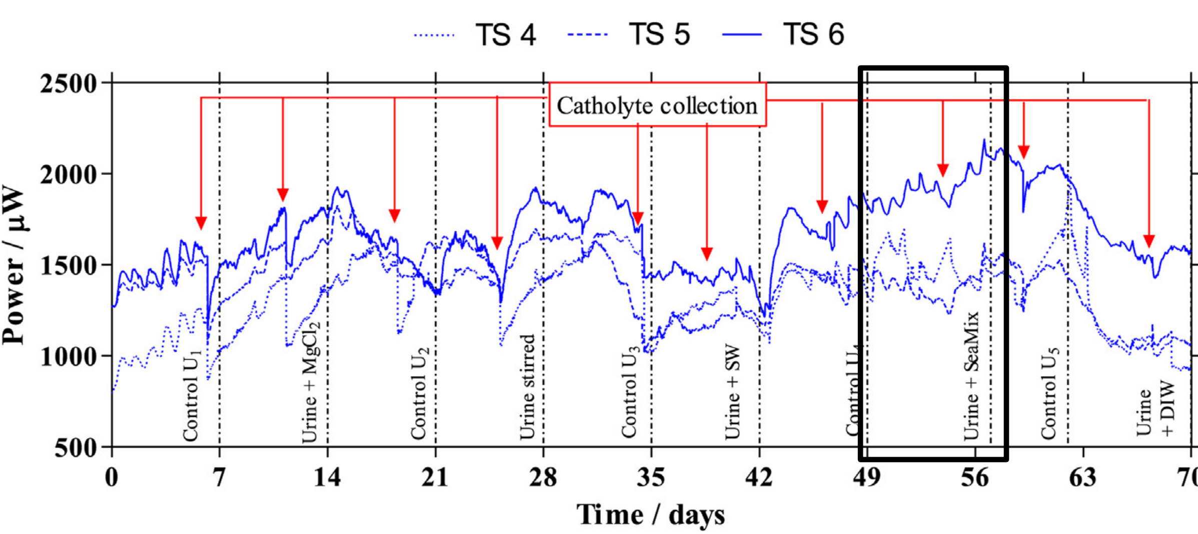
Urine with E. Coli + S. enteritidis

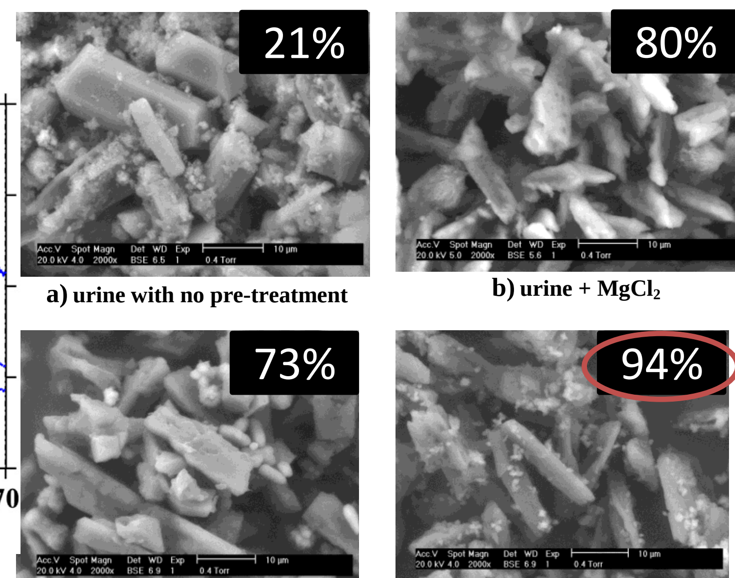


MFCs treating urine

Nutrient recovery: Struvite

- Struvite precipitation by addition of Mg sources (i.e. SeaSalts)
- Mg added to the urine before fed into the MFCs
- Increased MFC power output by 10 %
- 94 % of the solids precipitated was struvite





a) urine with no pre-treatment
b) urine + $MgCl_2$
c) urine + sea water
d) urine + SeaMix

Water Research, 109.pp. 46-53.

MFCs in a Stack

Electricity generation

- Miniaturization of MFCs increases the efficiency

4cm

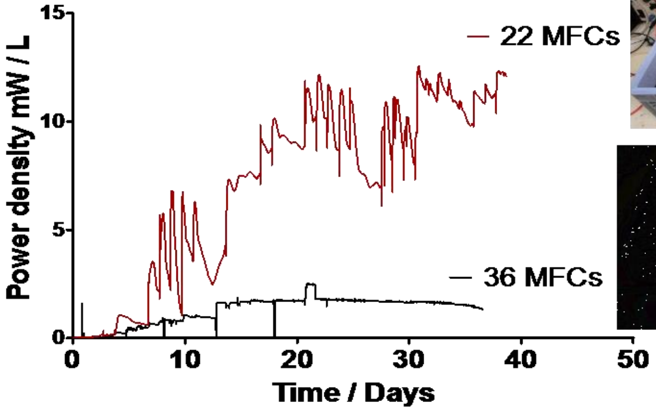
10cm

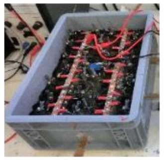
Large MFC

1.5cm

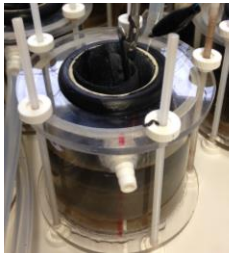
7cm

Small MFC



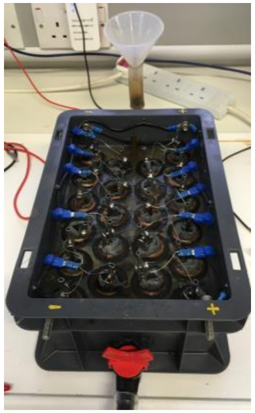


- Scaling up multiple MFCs into modules, modules connected fluidically and electrically, but maintaining isolation



1 MFC
100ml

Multiple MFCs into a module



22 MFC
5L

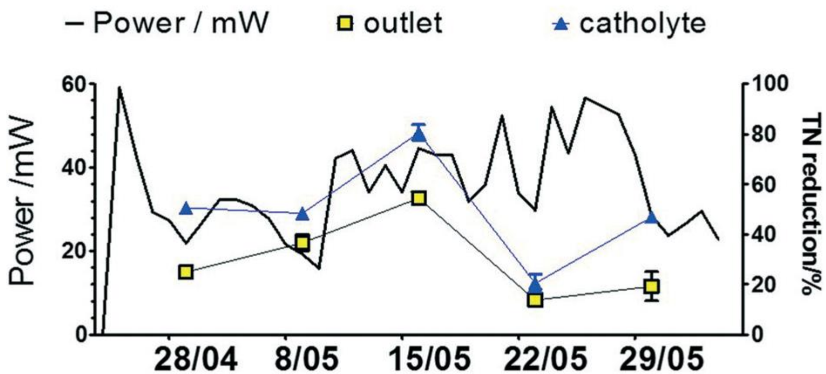
Multiple modules into a stack

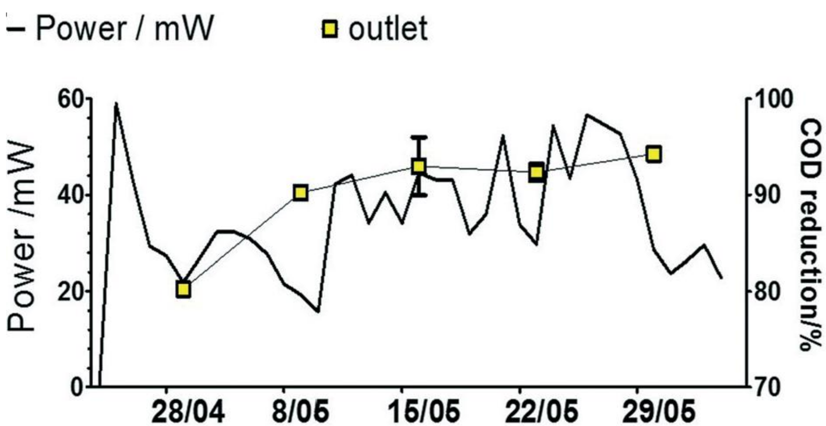
440 MFC
100L

Field Trials

PEE POWER™ Urinal on-campus, U.W.E., Bristol, U.K.

- 8 Modules: 288 units (50 mW average power production)
- Direct powering of 4 LED lights (1.2 W)
- Low flow rate (5-10 users/day ~ 2.5-5 L/day)
- Up to 90 % COD reduction and max. 50 % Total Nitrogen reduction



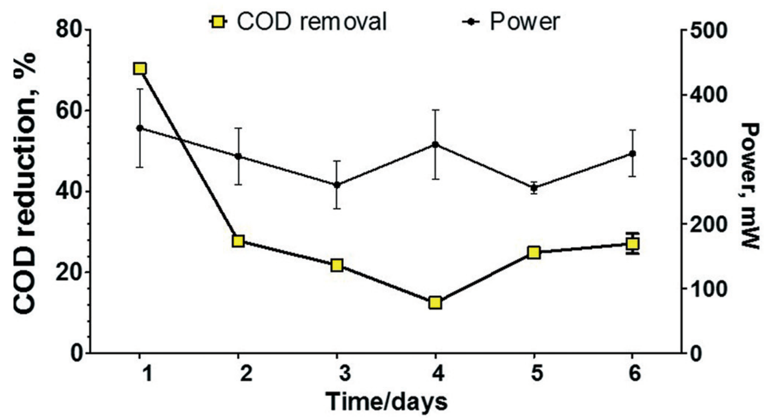


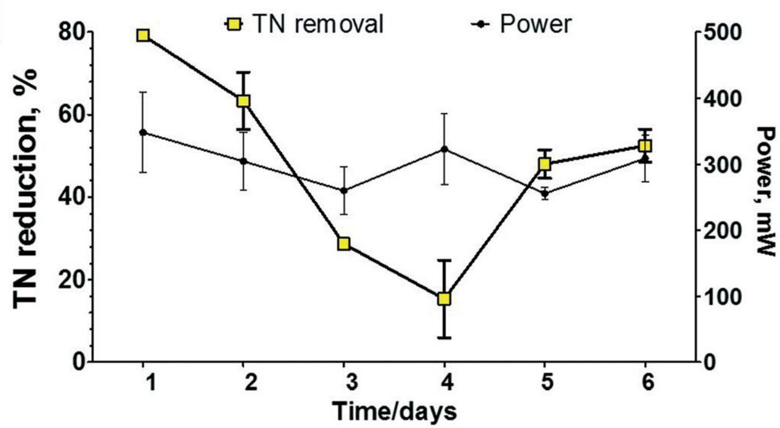
Environ. Sci.: Water Res. Technol. (2016) **2**, 336-343.

Field Trials

PEE POWER™ Urinal, Glastonbury Festival 2015, U.K.

- 12 Modules: 432 units (1 mW/MFC = ca.400mW) for direct powering of 6 LED lights (2.5W)
- High flow rate (825 users/day).
- Urinal processed more than 2,500 litres of urine during the festival (~ 300L/day)
- Up to 70 % COD reduction (average 30%) and 15%- 79% Total Nitrogen reduction





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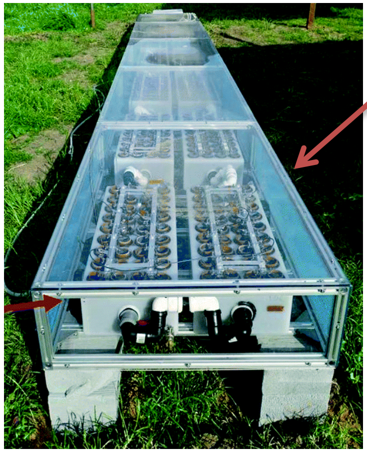


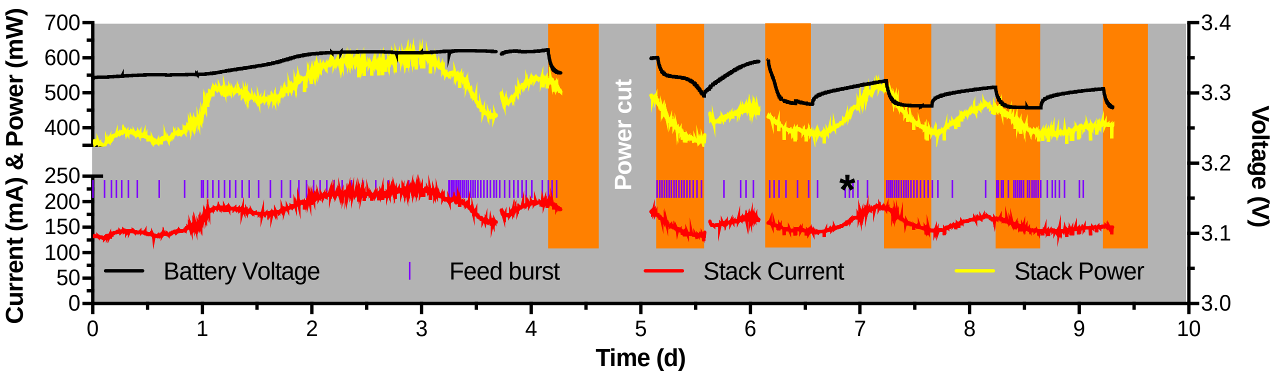
MFC Modules

Field Trials

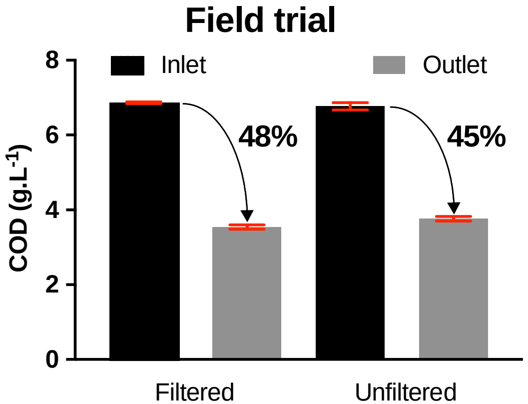
PEE POWER™ Urinal, Glastonbury Festival 2016, U.K.

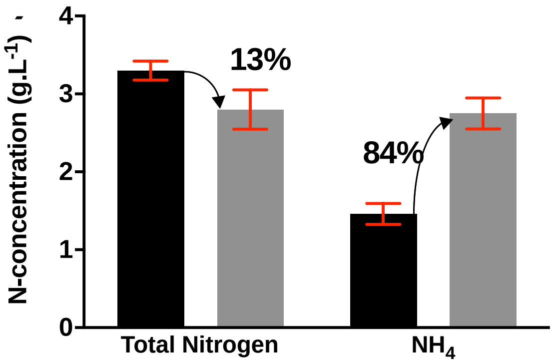
- 12 smaller modules (steady state reached after 5-6 days: 424 mW) for direct powering of 6 LED strips packaged as tubes (2.86W)
- Optimum feeding regime ~ 155 L/day (590 mW)
- Performance decreased with excessively high flow rate ~ 560 L/day
- Average 48 % COD reduction and 13 % Total Nitrogen reduction

MFC Modules



LED lights powered by the MFC stack





Commercialization

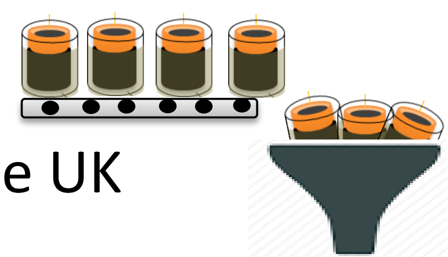
Approaches and challenges

- Aim to spin-out a company in 2017

- Manufacturing to achieve economies of scale for electrodes, ceramics and MFCs modules for stack development is a big challenge

- Currently in discussions with 10 commercial partners

- Need access to raw materials (ceramic, metals, carbon, semi-conductors) and their fabrication for MFC and electrode development

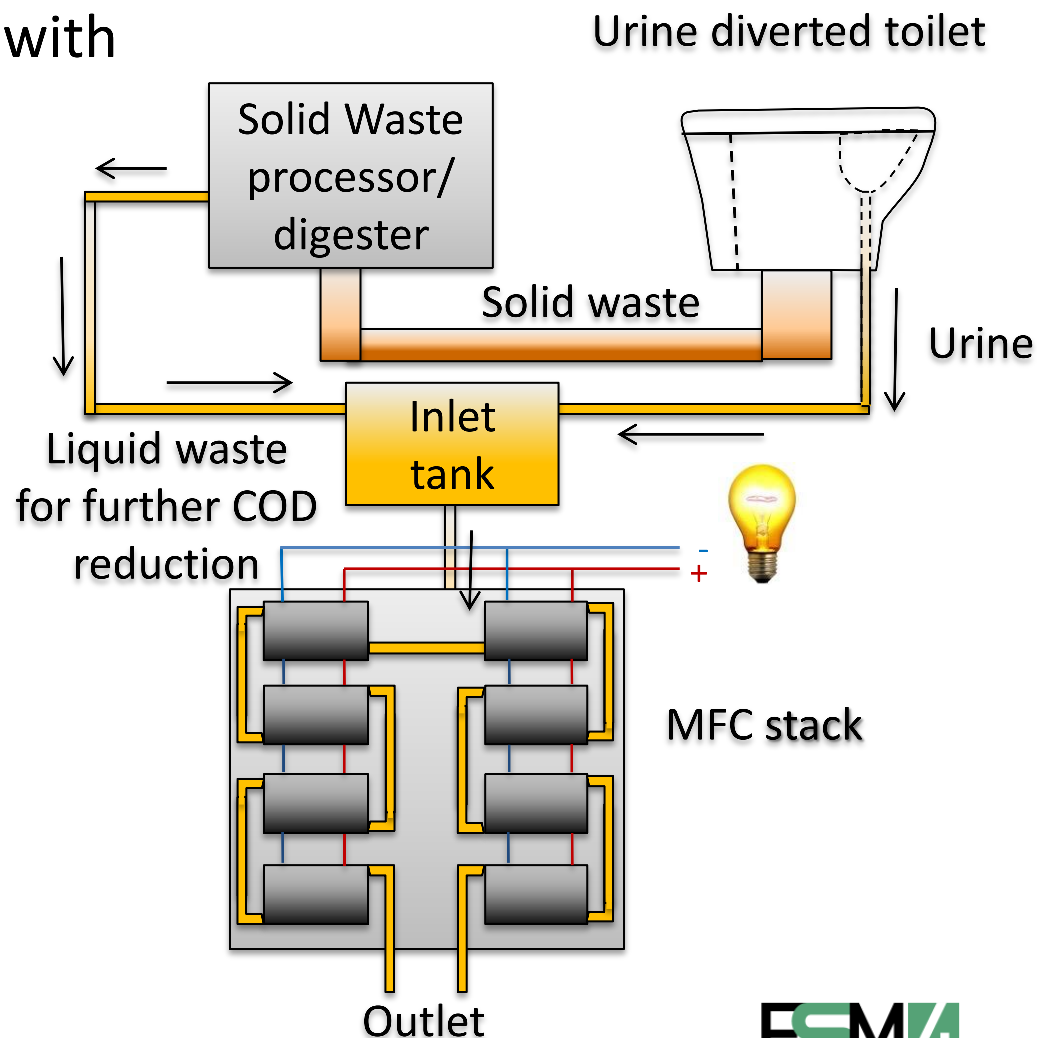


- Imminent calibration trial with 100 modules in the UK

- Calibration trial of 1000 modules outside the UK coming up

MFCs as a component to larger-scale blackwater/solid-waste treatment technologies

- Example: Collaboration with Caltech



Summary

- MFC technology is able to:

Urine

MFC Stack

- Electricity generation
  - Remote power
  - Remote lighting
  - Mobile phone charging

- Catholyte production
  - Water Re-use
  - Fertilizer
- Pathogen killing
- COD reduction
  - Dischargeable effluent
  - Fertilizer
  - New biomass
- Nutrients Recovery
  - Raw materials for manufacturing, for fertilizer
  - Nutrients for further growth
  - Struvite, P, K, NH_4^+

- Challenges:
  - Pure solid treatment is a challenge due to fluid dynamics; however can be treated if mixed
  - Mass manufacture of electrodes, ceramics and modules

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THANK YOU!!

- Electricity
- Catholyte
- Pathogen killing
- COD reduction
- Nutrients Recovery

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