



Newcastle  
University



Civil Engineering  
and Geosciences

# Understanding bioelectricity generation and biodiversity in Microbial Fuel Cells

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Krishna Katuri, Ian Head, Keith Scott, Tom Curtis

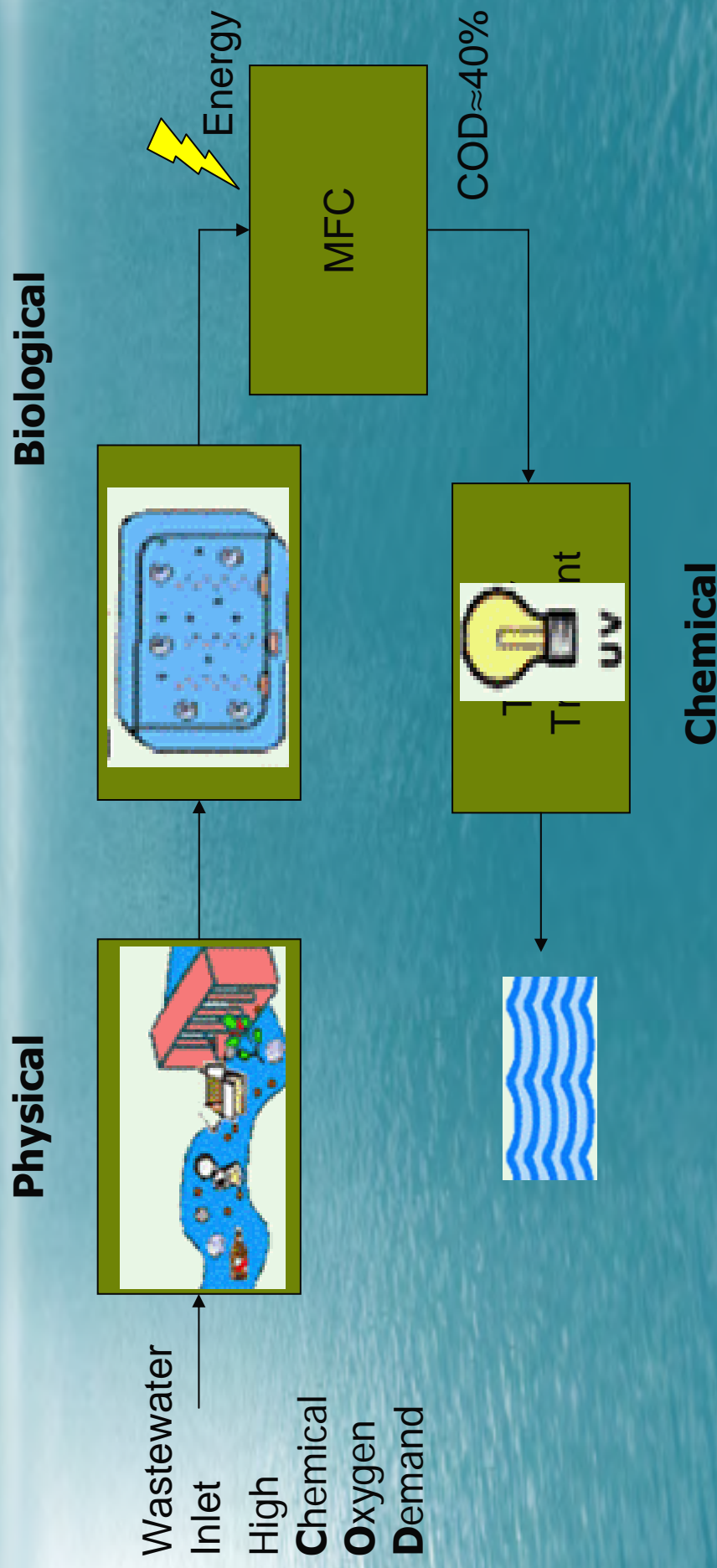
**Future Energy: Chemical Solutions**

**12-14 September, 2007**

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- Introduction
- Aim and objectives
- Methodology and experimental set-up
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- Conclusions
- Future Work

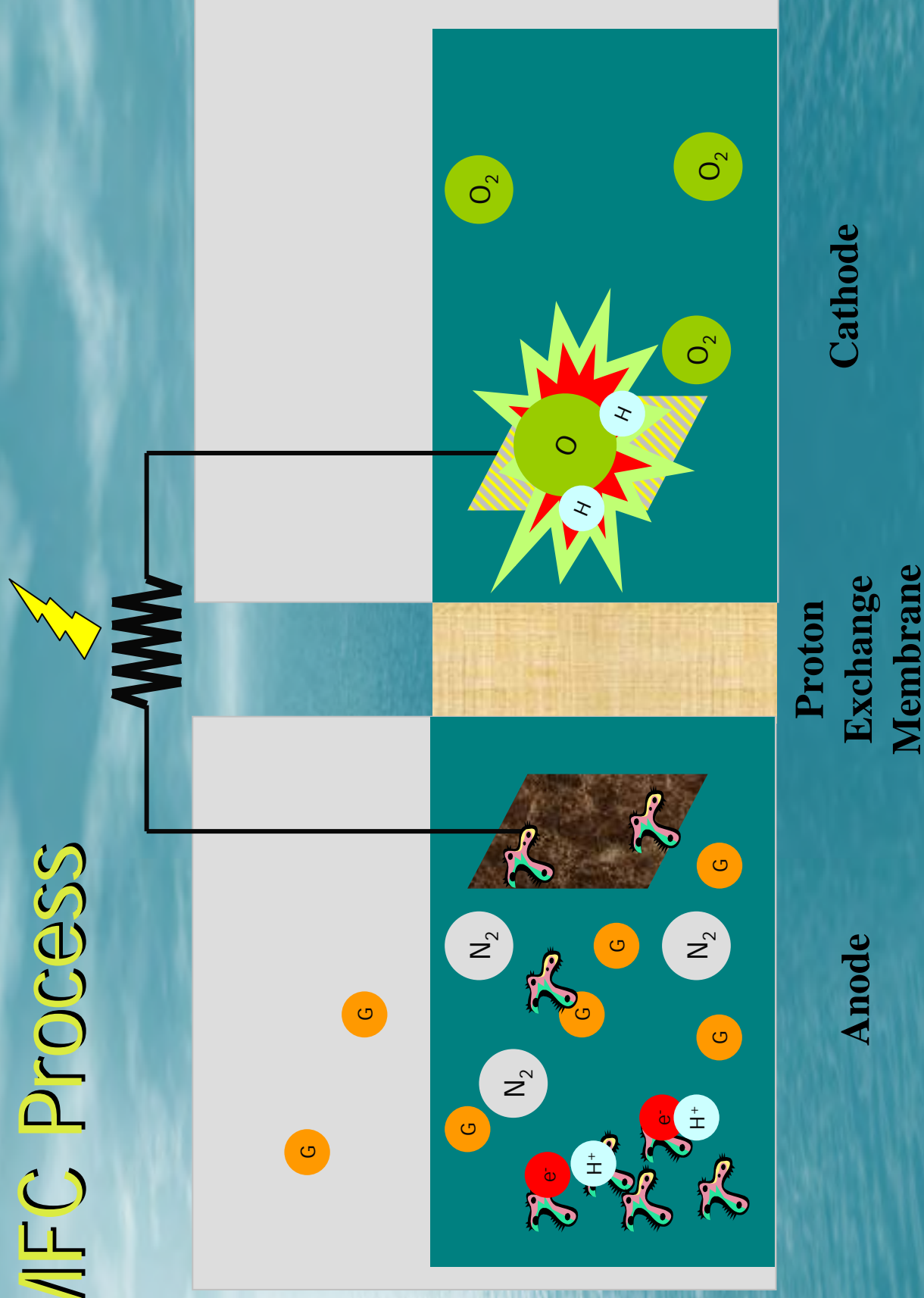
# Wastewater Treatment Systems



Images taken from  
[www.rdn.bc.ca](http://www.rdn.bc.ca)



# MFC Process

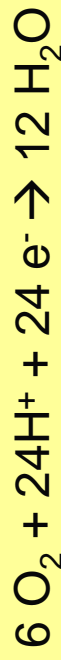


# MFC Reactions

$\text{CO}_2$



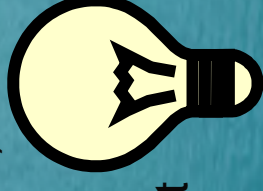
$\text{H}^+$



$\text{H}_2\text{O}$

$\text{e}^-$

Electrode (Anode)



Electrical Circuit

$\text{e}^-$

Electrode (Cathode)

# MFC development areas

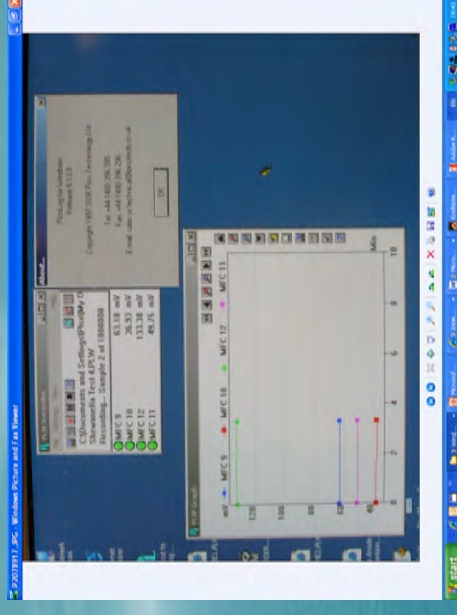
- To determine the relationship among bacterial density, substrate and power output (Rabaey et al, 2004)
- To study the impact of the bacterial metabolic losses in power output (Logan et al, 2006)
- To clarify bacterial metabolism (Park et al, 2001)



# Aim

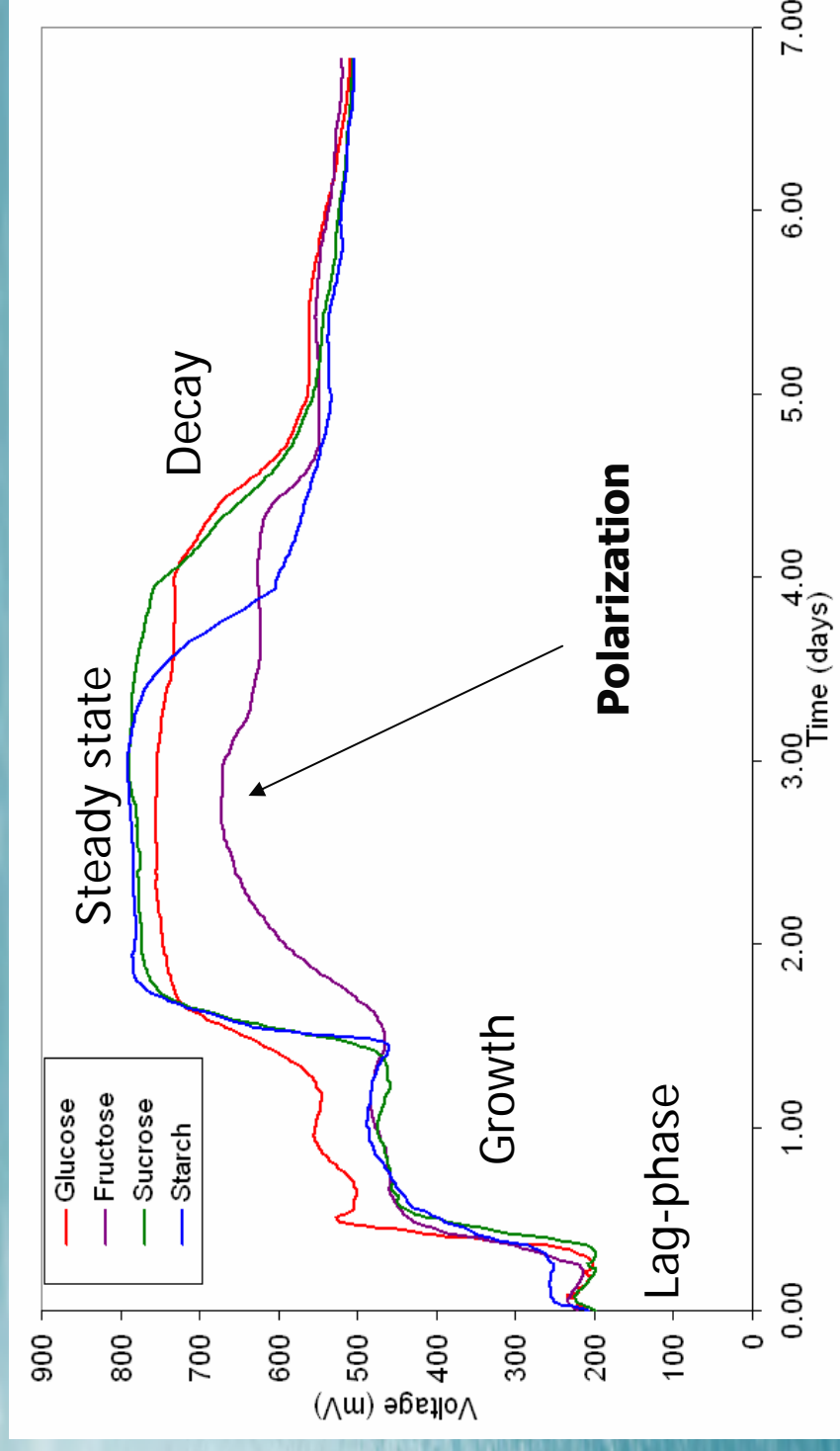
To evaluate the effect of different organic compounds on bioelectricity production and microbial diversity in Microbial Fuel Cell Technology

# Experimental Set-up

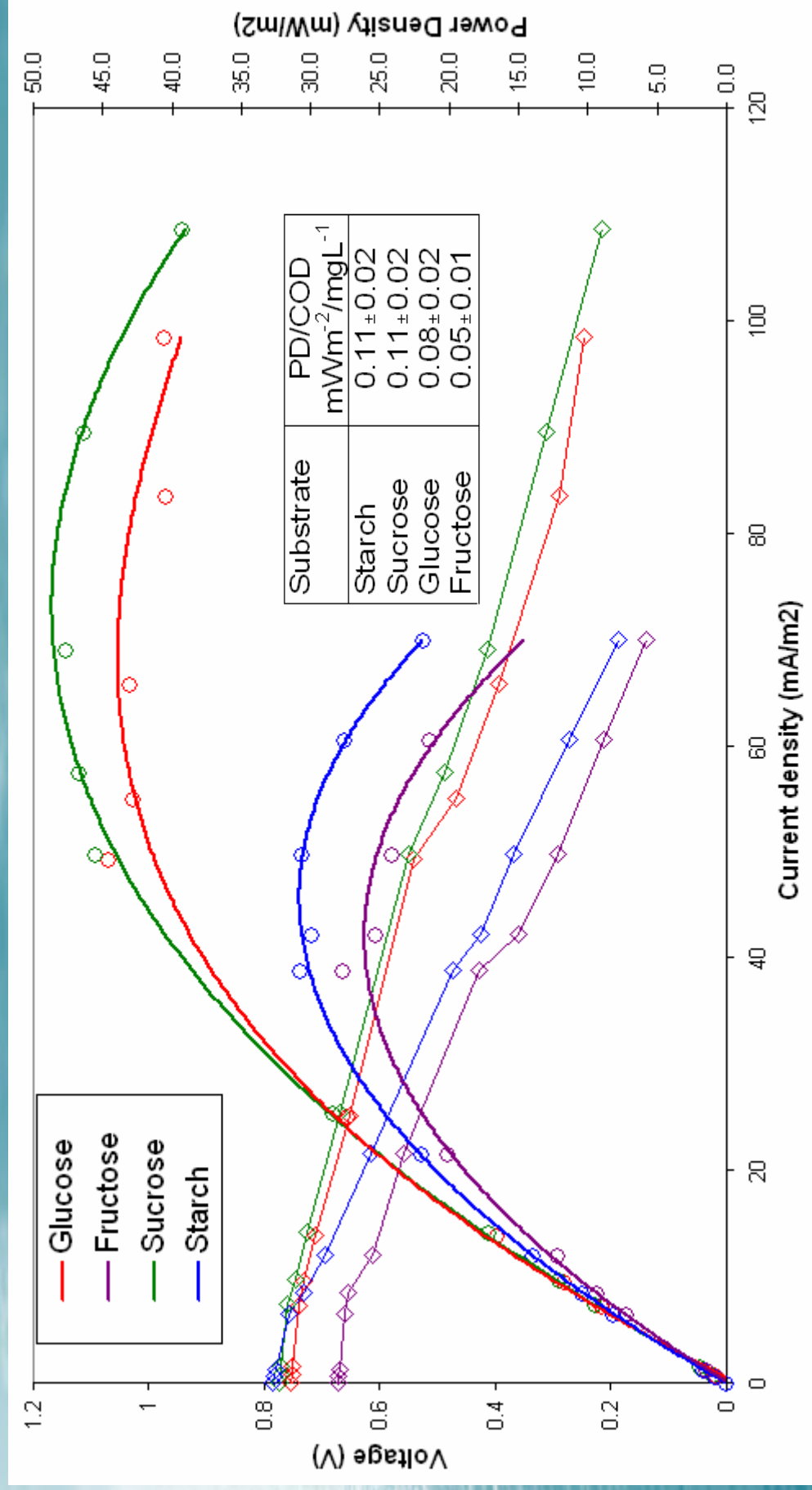




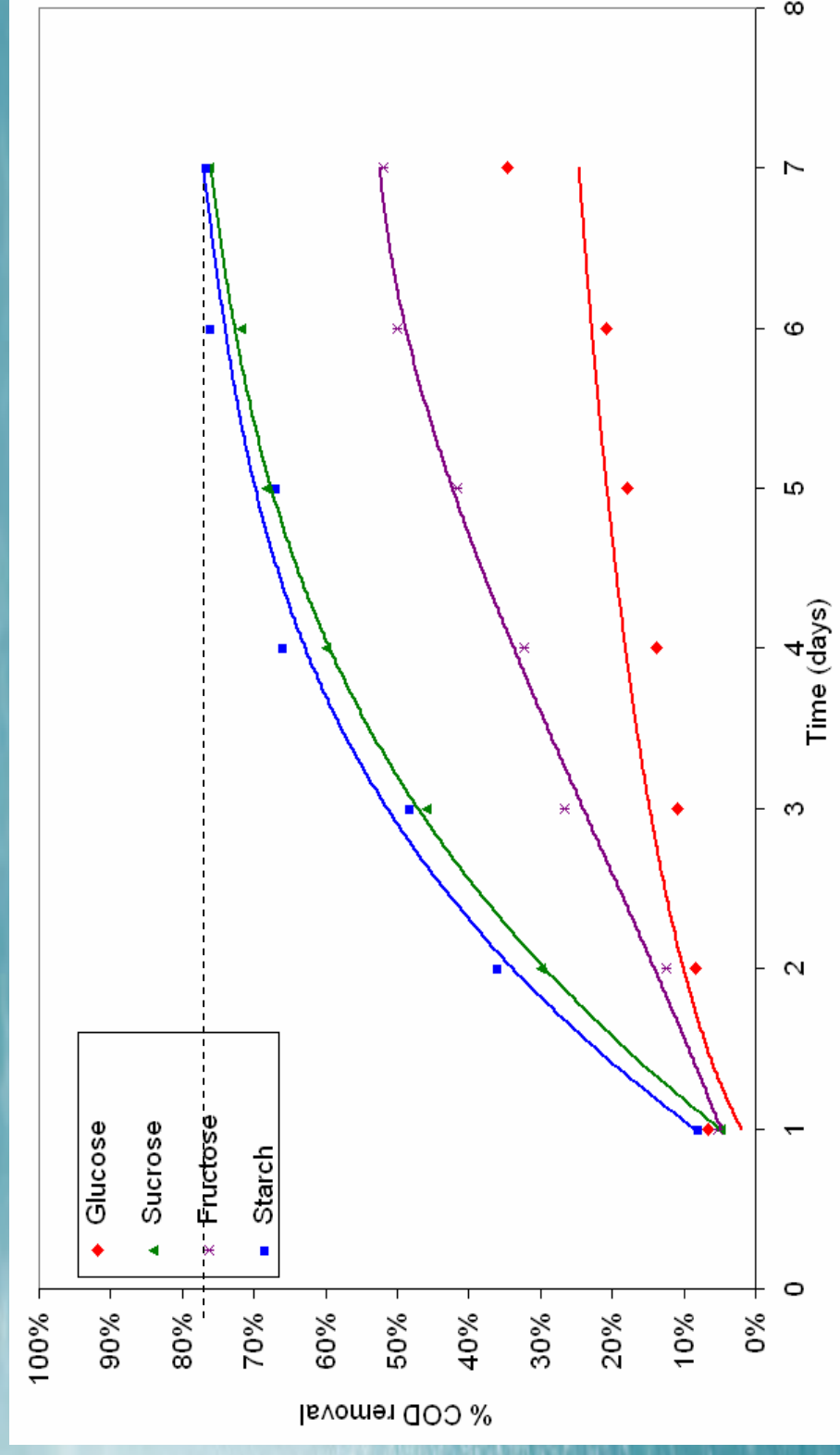
# Voltage Production



# Power Densities & Voltage Losses



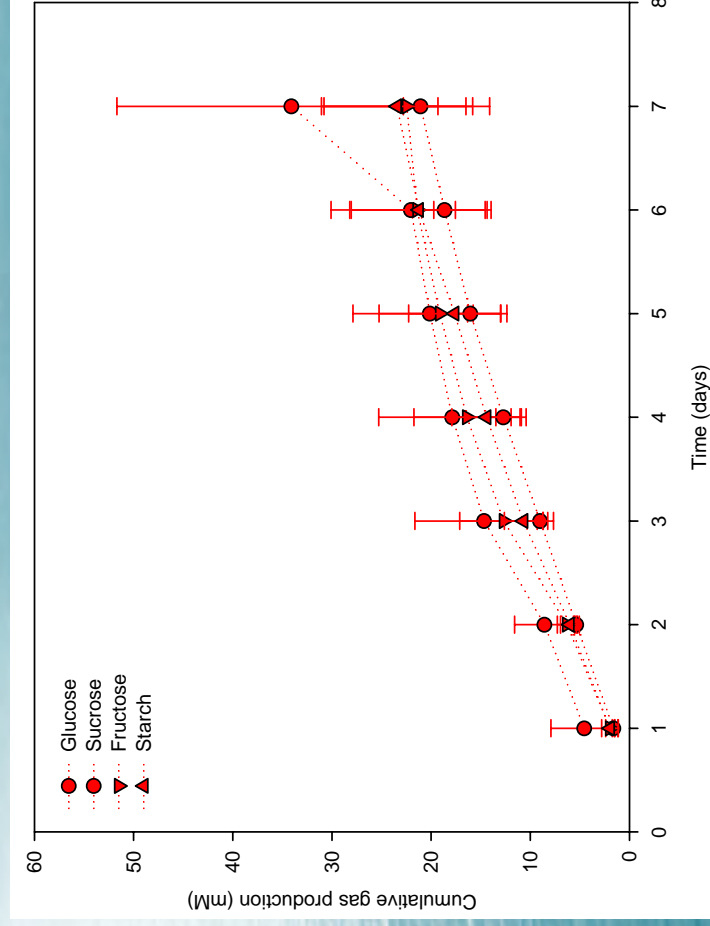
# COD Removal



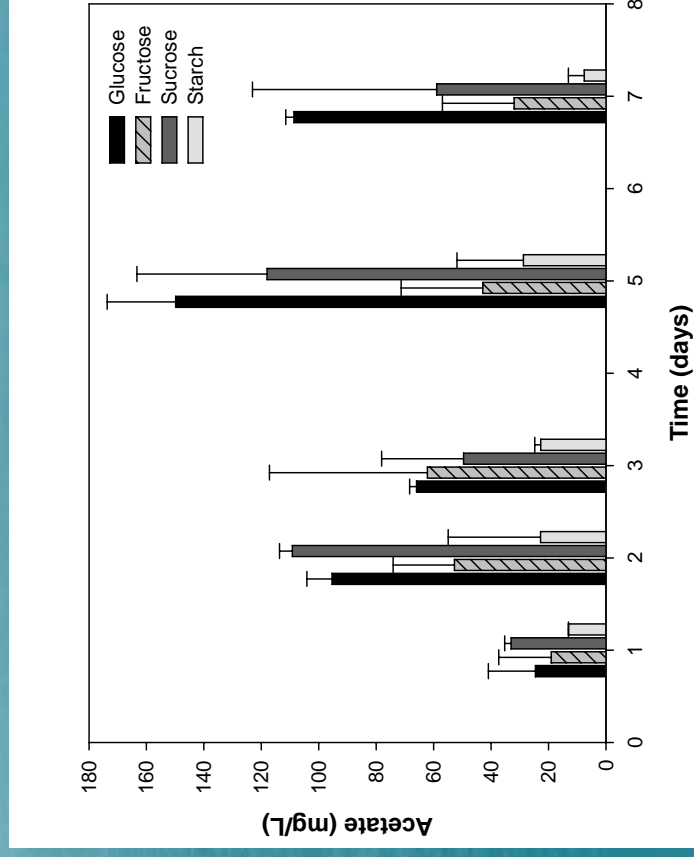


# By-products: VFA and Biogas

CO<sub>2</sub>



Acetic, propionic & butyric acids



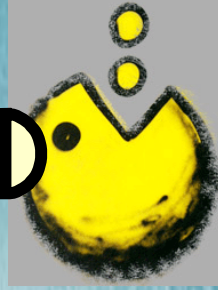
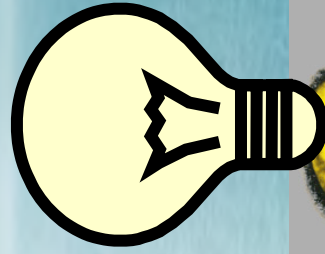
# Conclusions

- ✓ Substrate complexity influences microbial fuel cell performance and bacterial enrichment
- ✓ Polysaccharides produced greater PD/COD than monosaccharides and had higher COD removals
- ✓ MFC microorganisms in the biofilm and bulk liquid had significant differences according to the substrate used and location
- ✓ There is an bacterial enrichment were pseudomonas predominate and act as the catalyst

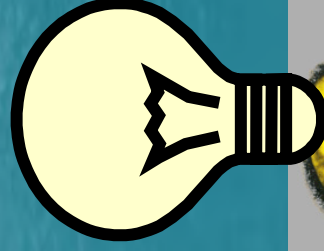
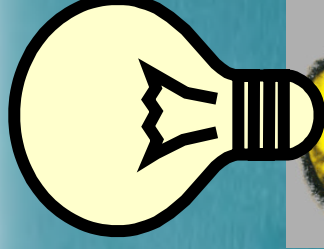
# Acknowledgements

- CONACyT, México (Grant 196298)
- European Union for Transfer of Knowledge award on biological fuel cells (contract MTKD-CT-2004-517215)





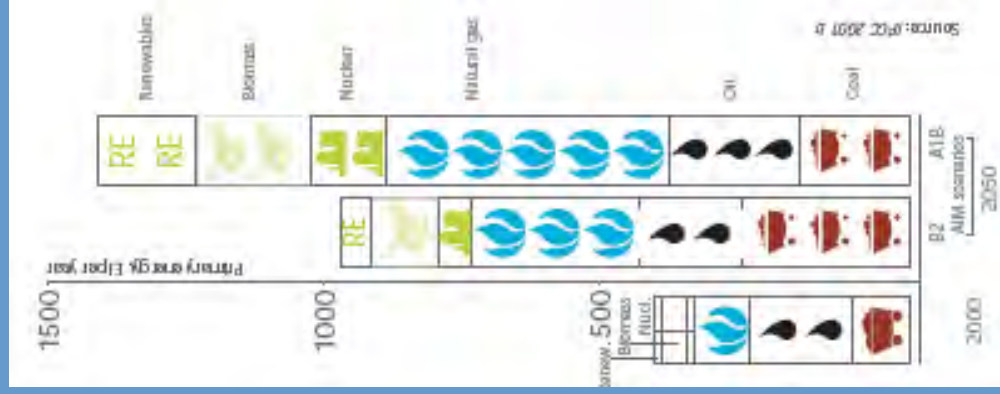
THANK YOU



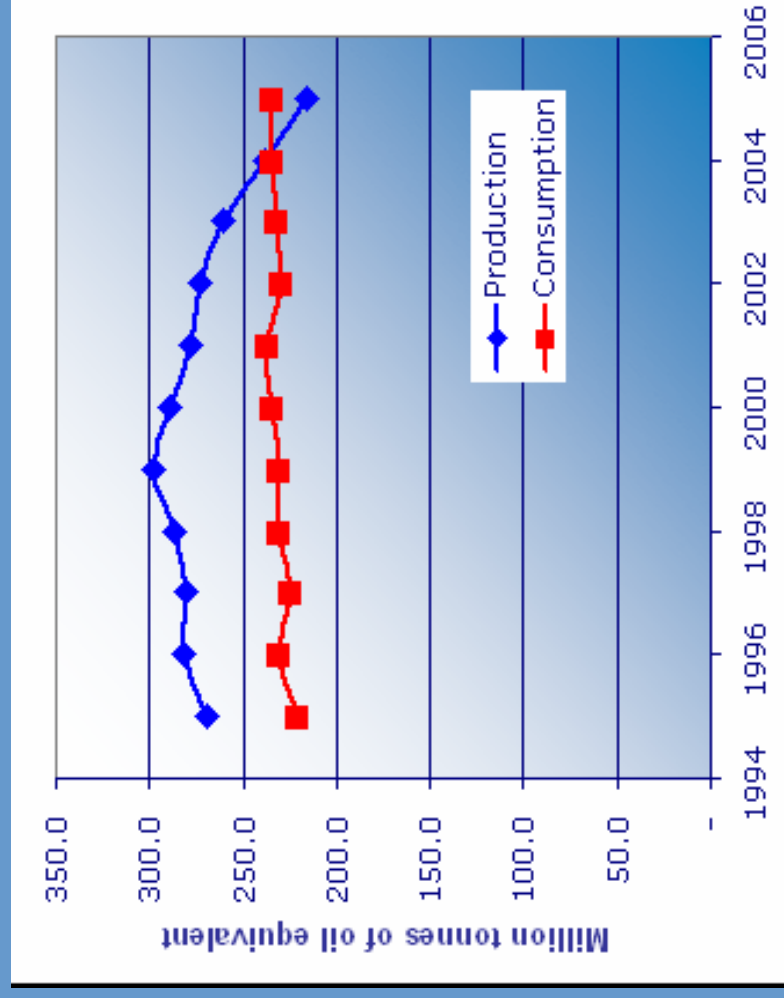
# Microbial fuel cells (MFCs) extract sustainable energy from wastewater

*Huaining Hu and Prof. John M. Andresen*  
School of Chemical and Environmental Engineering  
University of Nottingham  
University Park, NG7 2RD

# Energy Requirements



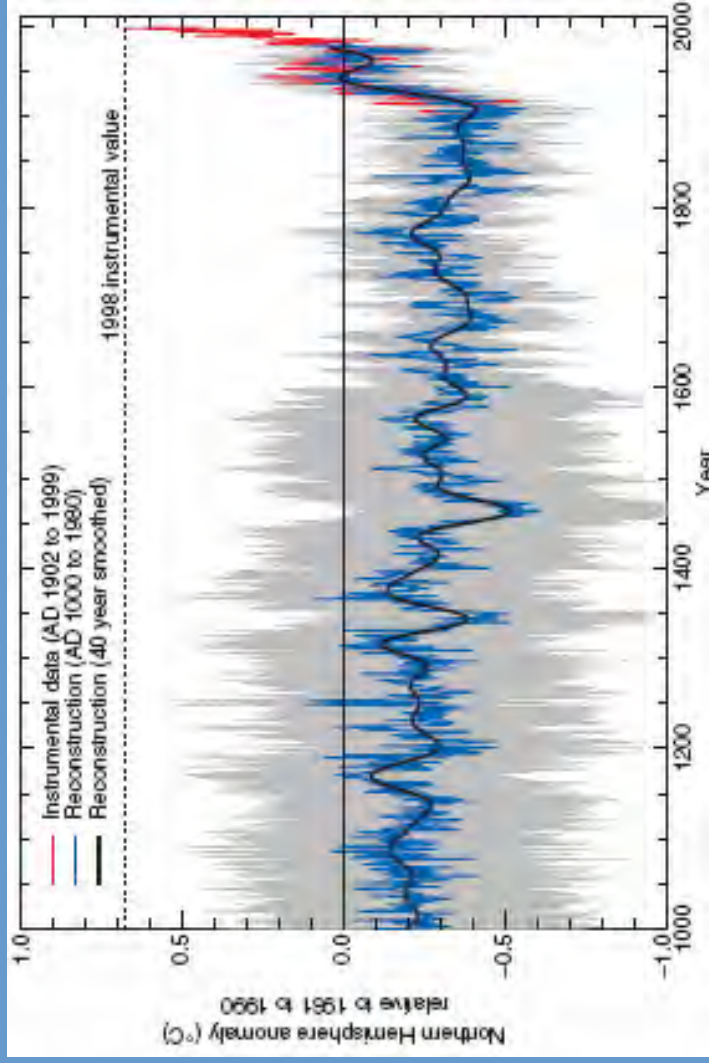
World Business  
Council for Sustainable  
Development, 2001



- UK energy production peaked in 1999, and 2005 was the first year in recent history that UK imported more than it produced.
- At the same time UK “wasted” 22 million dry tons of organic matter in waste water



# Environmental Issue: Global Warming?



Intergovernmental Panel on Climate  
Change (IPCC) report



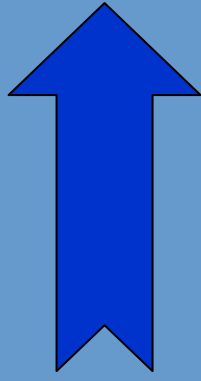
Briksdals Glacier Norway 2001



Briksdals Glacier Norway 2005

# Cost pressures

- UK energy costs will come under great pressures due to increased import
- Carbon emissions are going to carry an increasing price tag
- Customers are going to pick suppliers that focus on sustainability



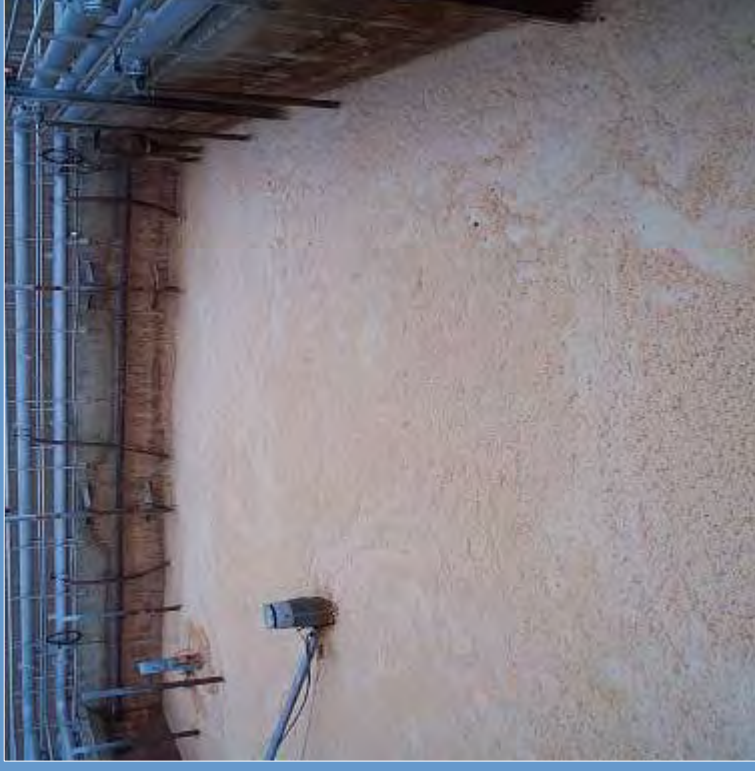
**Profit from Within**

# Energy in Waste Water



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- UK – 347,000 km of sewers both by domestic use and by industrial use
- 9000 sewage treatment stations
- 20 billion litres of household and industrial wastewater per day
- Costs £9 million for everyday treatment



C. F. Forster, *Wastewater treatment and technology*, Thomas Telford Publishing, 2003



# Case study

- Industry “Waster” producing 200 m<sup>3</sup>/day of wastewater
- Average COD about 1,000 mg/L
- COD: 73 tons per year

Energy down the drain per  
year  
~200,000 kWh

Waste-producing industry	Characteristics of wastewater
<b>Food and beverages</b>	
Dairy	High in organic matter. $BOD_5^{(1)} = 300-2375$ mg/litre, mainly protein, fat and lactose.
Brewing and distilling	High in dissolved organic solids. $COD^{(2)} = 1500-10,000$ mg/litre. Contains nitrogen and fermented starch.
Edible oil	High in organic matter. $BOD_5 \rightarrow 20,000$ mg/litre. Contains fatty matter.
Starch processing	Dilute suspension of solids in water. Higher level of dissolved substances - nitrogenous compounds, carbohydrates, organic acids, minerals. Average $COD = 19,980$ mg/litre.
Sugar	High in dissolved organic matter. $BOD_5 \rightarrow 10,000$ mg/litre.
Meat and poultry	High in organic matter - mainly protein, fats, oils, greases.
<b>Pharmaceutical</b>	Very high in dissolved and suspended organic matter. $COD \rightarrow 300,000$ mg/litre, including vitamins. High in carbohydrates and dissolved salts.
<b>Pulp and paper</b>	High or low pH, colour, high level of suspended, colloidal and dissolved solids, inorganic fillers. Average $BOD_5 = 980$ mg/litre.
<b>Chemicals and petrochemicals</b>	High $BOD_5 \rightarrow 2500$ mg/litre. Contains metals. $COD/BOD$ ratio and compounds inhibit biological action.
<b>Textile industries</b>	Highly alkaline, coloured. $BOD_5 \rightarrow 3000$ mg/litre. High temperature. High level of suspended solids.

# Possible solution

- Microbial fuel cell:
- Microorganism converts organic materials to energy
- Cleans wastewater
- Renewable energy
- Little pollution
- Bacteria Safety:

Risk Group 1



Adapted from: Holzman, D.C. (2005) Microbe Power.  
Environmental Health Perspectives, 113(11), A745-A757

# Microbial Fuel Cells

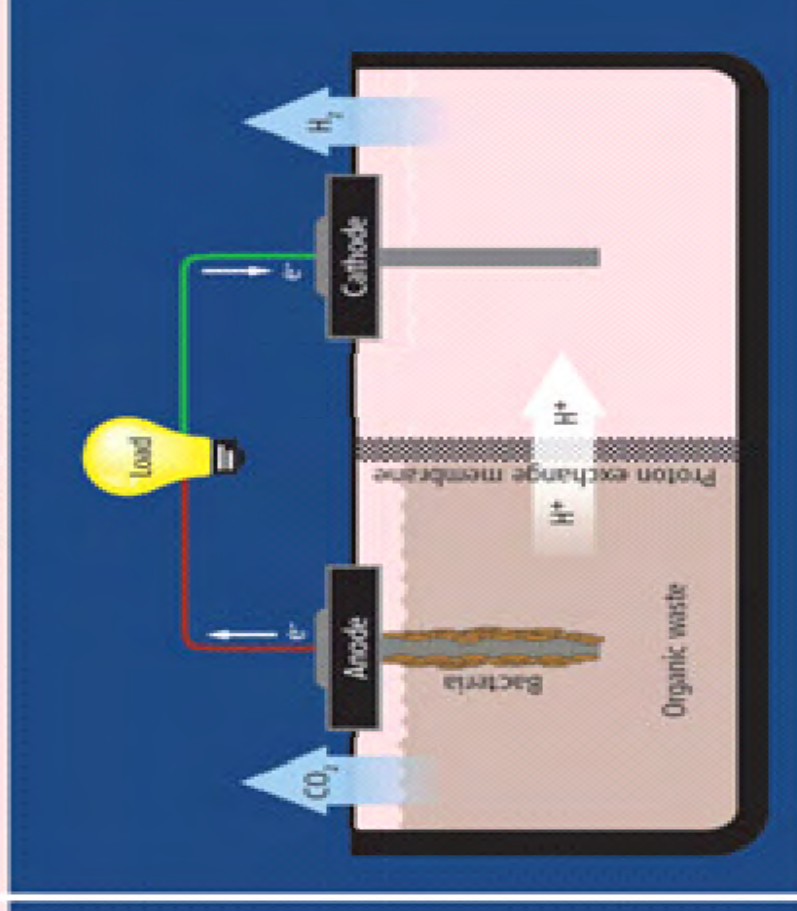
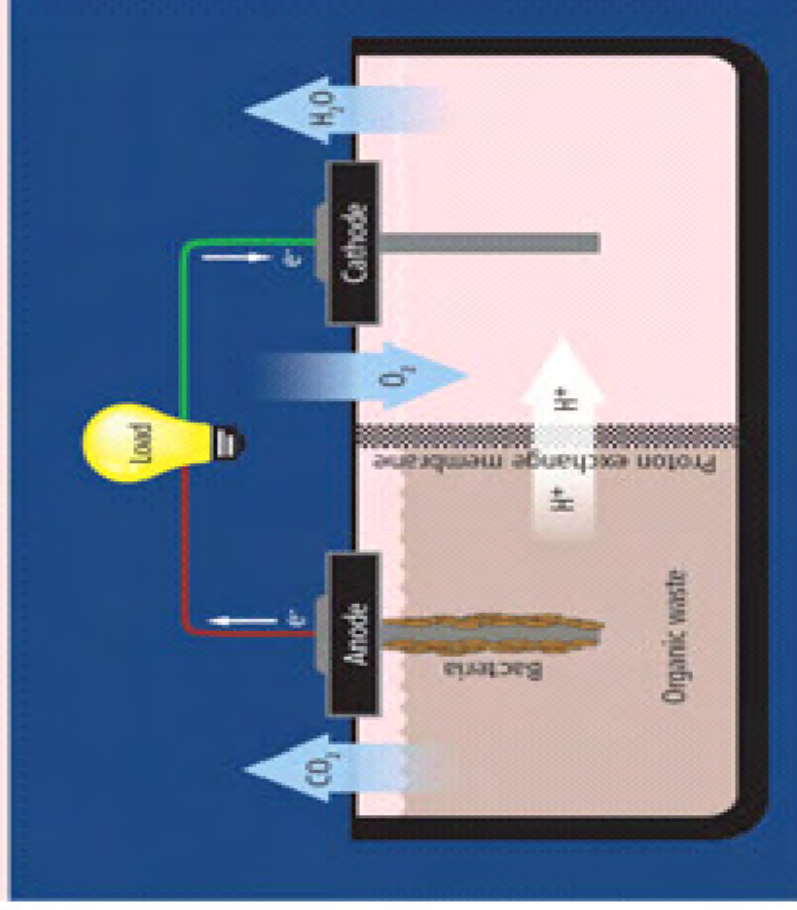
Cathode Aerobic approach

Anaerobic approach

## Microbial Fuel Cells: The Basics

Water Output

Hydrogen Output





# Current Performance



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- **Wastewater**
  - 25 mW/m<sup>2</sup>
- **Acetate**
  - 660 mW/m<sup>2</sup>
- **3.6 W/m<sup>2</sup>**
  - Glucose and nonrenewable chemical
- **Theoretically, Max power is estimated on the order of 1-6 W/m<sup>2</sup>**



# Present Limitations



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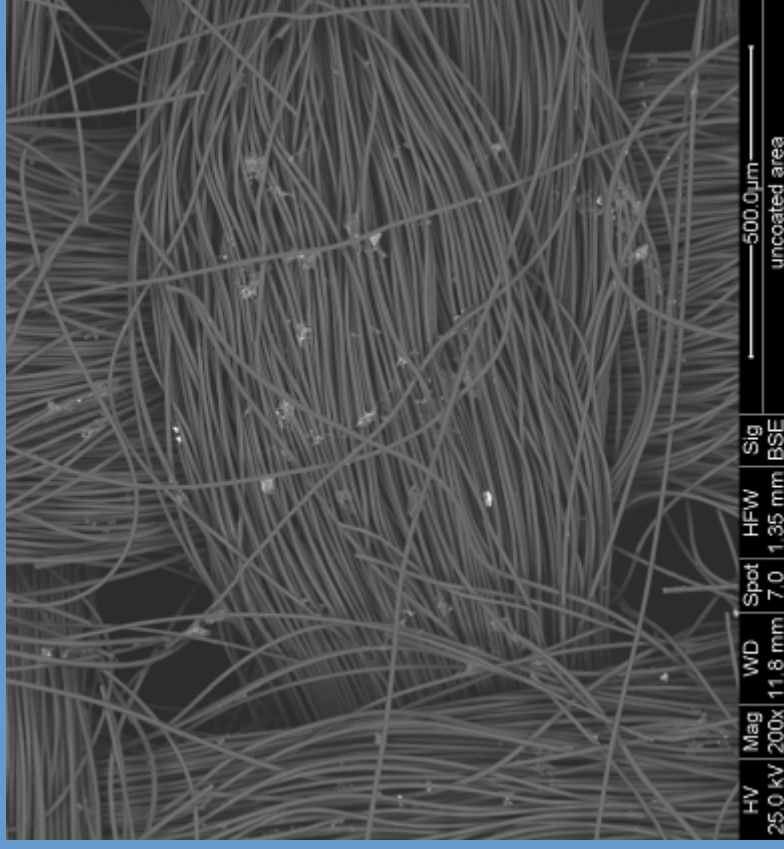
- **Low power density**
  - Microbe anode interaction
  - Electron transfer from microbe to anode
- **High internal resistance**
  - Proton transfer from anode to cathode
  - Proton exchange membrane (PEM) application
- **For industrial applications:**
  - Need to be converted to a continuous process
  - Need to operate in million litres per day scale
  - Double power output

# Electrode materials



Left: carbon cloth rolled, for anode

right: carbon cloth with 5g/m<sup>2</sup> Pt (Catalyst)  
for cathode



SEM image of Carbon cloth



# MFC Tube reactor



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- Two tubes combine together, effective volume 2.7L
- Anode material stucked on the wall of the external tube
- Cathode material wrapped on the wall of the inner tube
- Wastewater go through the space between anode and cathode



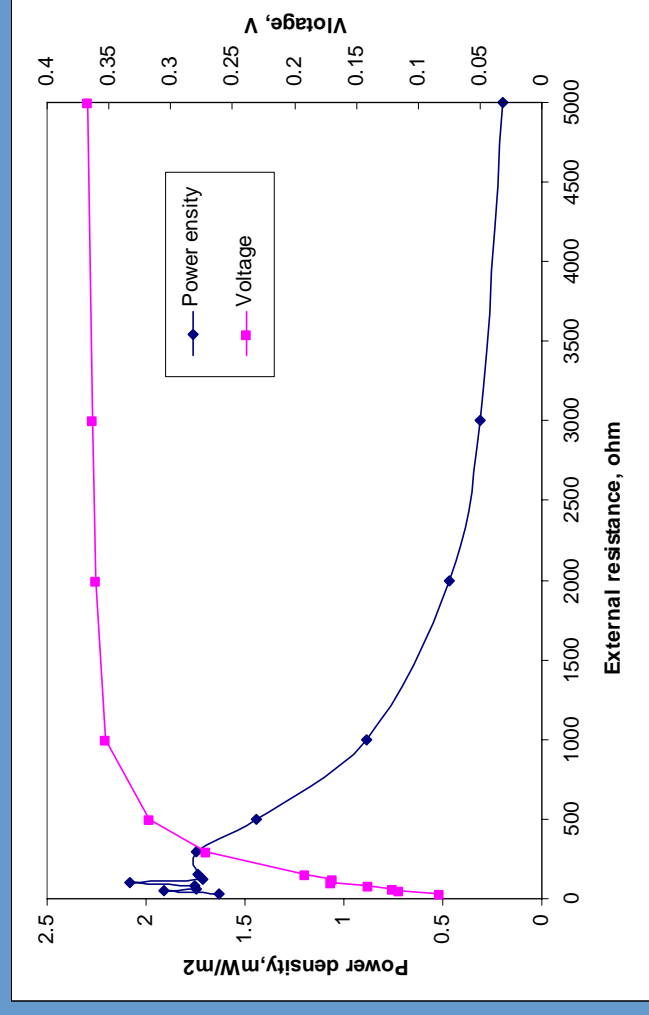
# Results based on MFC tube



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## Aerobic MFC

- Hydraulic Retention Time (HRT)= 1h  
(flow rate 2.7L/h)
- Air flow rate= 0.9L/min
- Wastewater COD removal rate per run 11%
- External resistance changed from 30-5000  $\Omega$ , at optimal 100  $\Omega$ :
  - Max 2.09 mW/m<sup>2</sup> based on anode surface 0.14 m<sup>2</sup>
  - Voltage: 0.17V

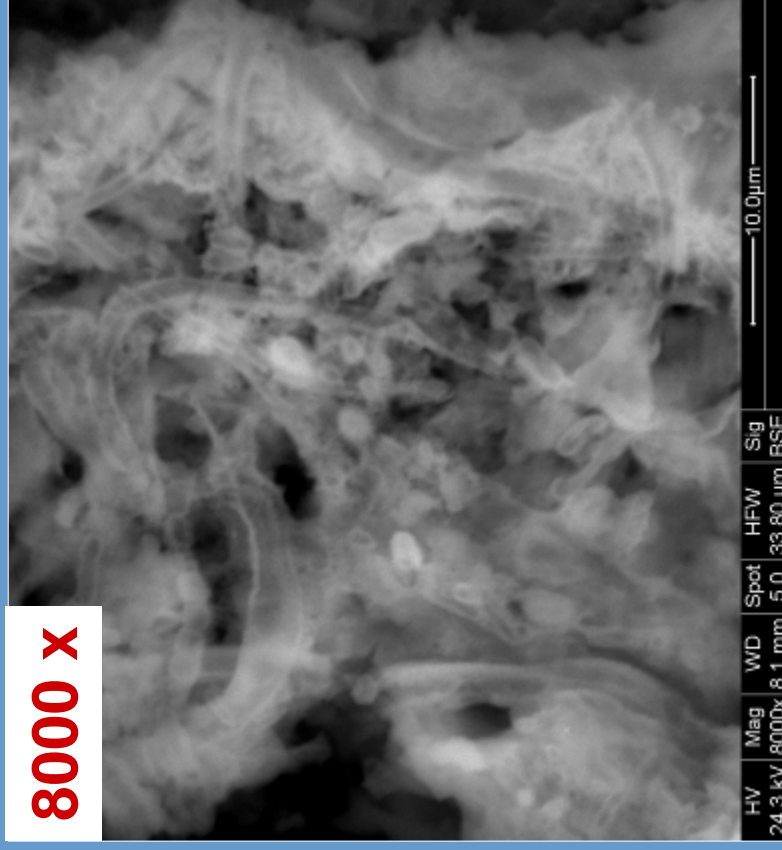


# SEM results of anode in Cathode aerobic MFC

**4000 x**



**8000 x**



bacteria on carbon cloth



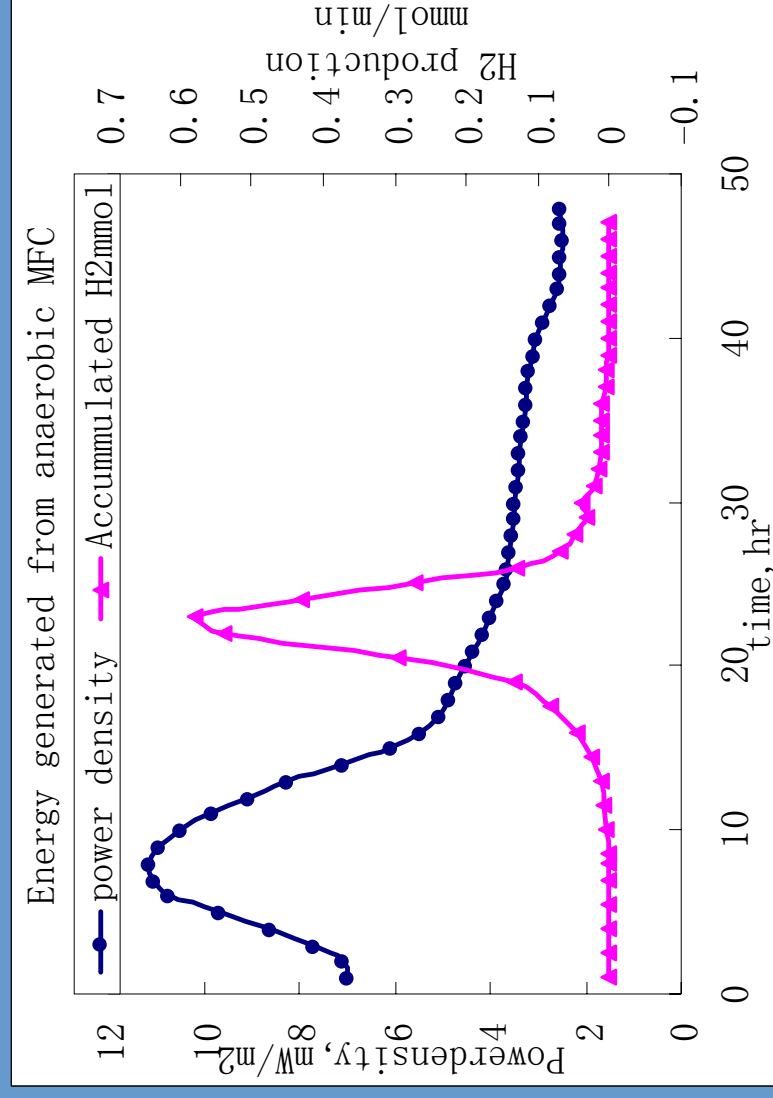
# Results based on MFC tube



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## Anaerobic MFC:

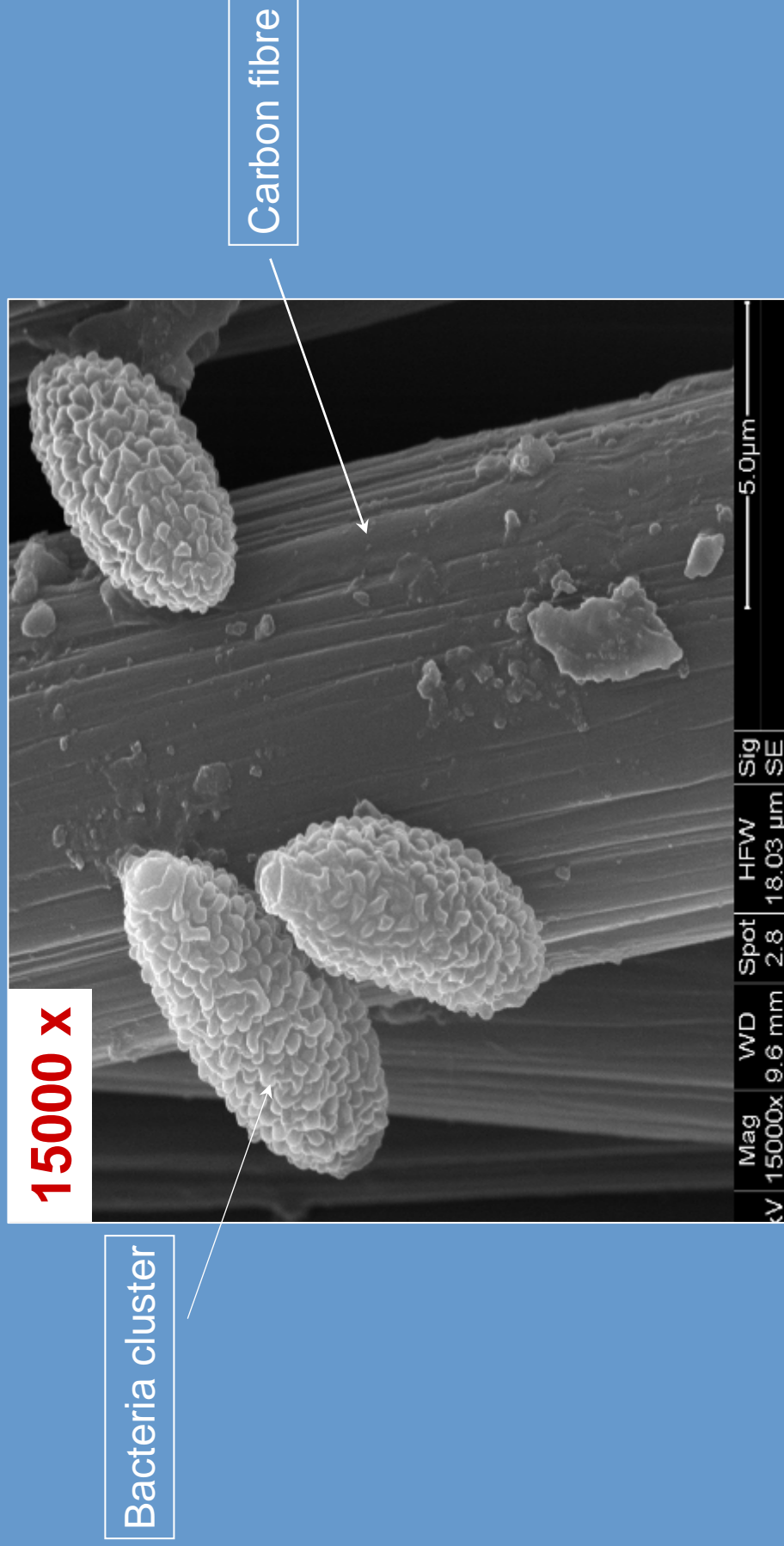
- HRT=0.5h (Flow rate 5.4L/h)
- Wastewater COD removal rate after 2 days was 77.5%, COD removal per run was 0.8%
- Max 0.4V, Max 11.5 mW/m<sup>2</sup>
- There are peak areas for both electricity output and also H<sub>2</sub> production rate
- The H<sub>2</sub> recovery rate based on the current production at the peak is 30.2%
- The Coulombic efficiency for the case of the figure shown is 0.11%
- the overall H<sub>2</sub> efficiency was 30.2% \* 0.105%=0.032%
- The H<sub>2</sub> yield  $Y_{H_2}$  1.44mg H<sub>2</sub>/g-COD



# SEM results of anaerobic MFC



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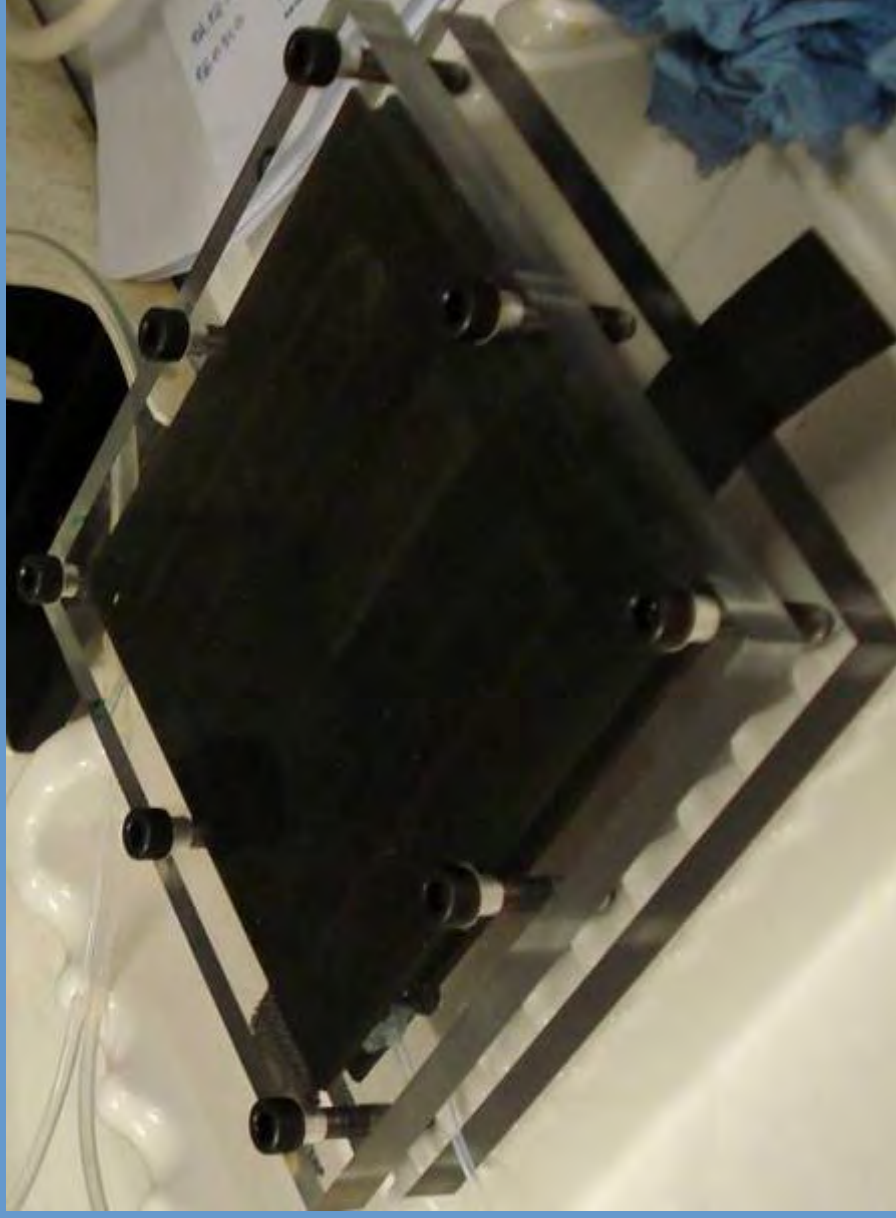
Anaerobic bacteria form clusters on anode

# MFC channel reactor



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- Single channel MFC, total effective volume 13.25mL
- Channel was made by Polydimethylsiloxane (PDMS) material
- Anode and cathode sheet were located between the channel



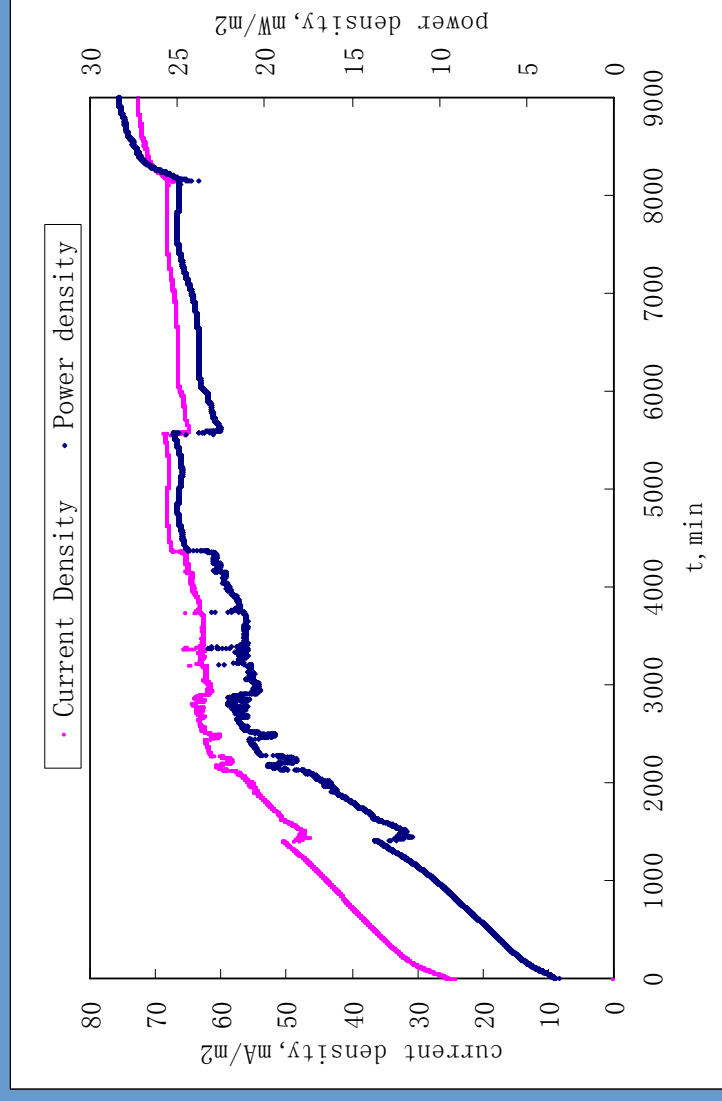


# Results based on MFC Channel



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- HRT=6.6h, flow rate 2ml/min (0.12L/h)
- Max COD removal rate in 4 days was 70.2%, COD removal per run: 0.08%
- Max 0.4V, Max 29.5 mW/m<sup>2</sup>
- Coulombic efficiency of the period in the fig can be calculated: 0.7%



# Stacked MFC device built in Ghent, Belgium



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- Two sliced MFCs pressed together, effective volume 275mL
- Biocatalyzed electrolysis process
- Add an external potential (0.3V to 0.95V) to decrease the cathodic potential to boost the H<sub>2</sub> production
- Graphite granules as anode and carbon cloth with Pt as cathode

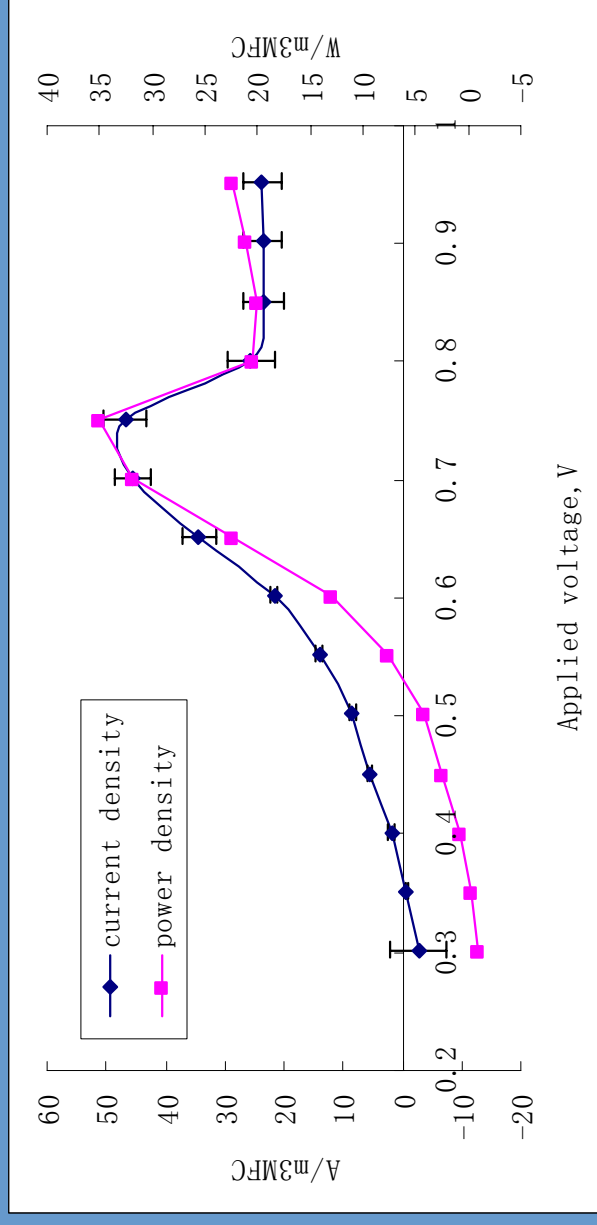


# Based on the stacked MFC



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- Influent was potassium phosphate salts buffer with 1g acetate per day
- Recirculation flow rate 1.4L/h
- The H<sub>2</sub> recovery rate based on the current production can arrived to 55% in a single day
- When applied 0.75V, maximum current density can arrive to 47A/m<sup>3</sup> which is corresponding to H<sub>2</sub> yield

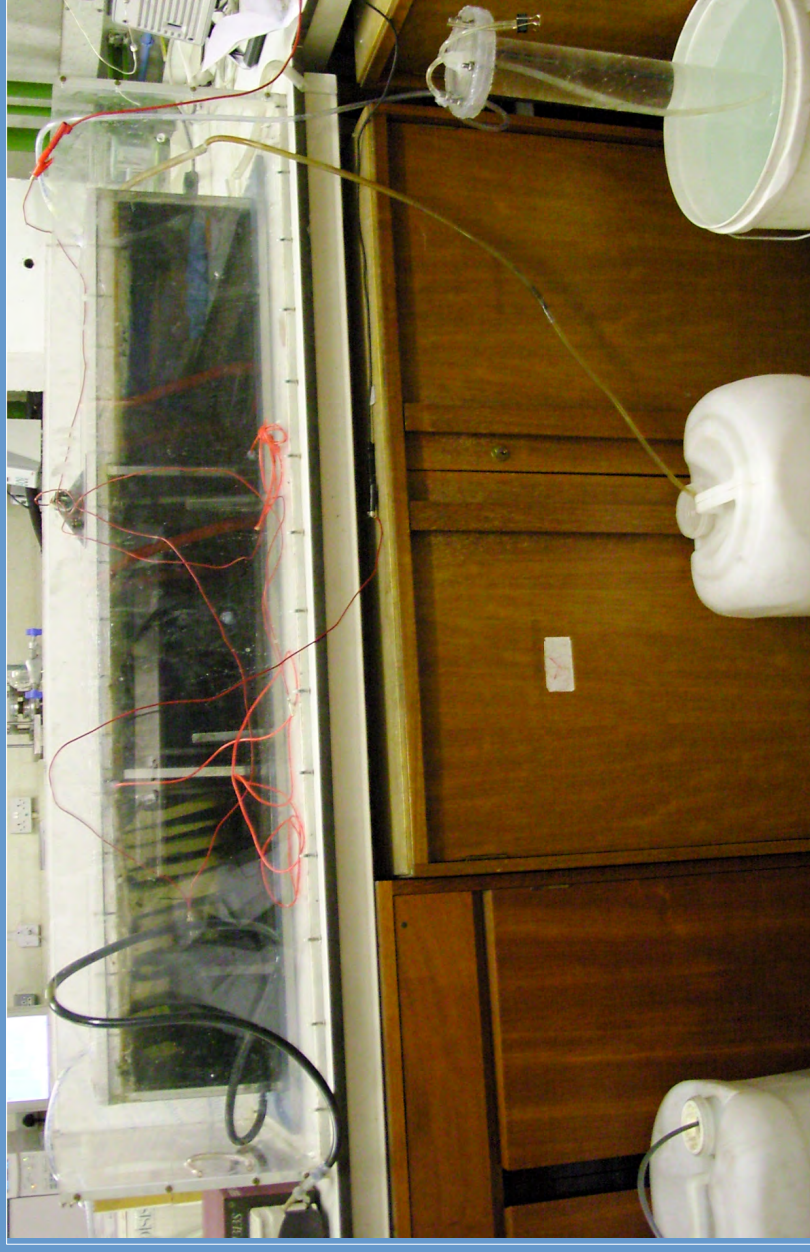


# MFC Tank reactor



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- Three chambers separate as three MFCs, total effective volume 43L
- With different anode materials: Carbon cloth and graphite granules
- Anode and cathode in the same chamber





# Conclusions

- **Channel MFC**
  - power density  $29.5\text{mW/m}^2$
  - Very poor coulombic efficiency
- **Stacked MFC**
  - Has better  $\text{H}_2$  recovery rate and  $\text{H}_2$  yield
  - But need external potential to add in
- **Aerobic Tube MFC**
  - has lower power density
  - poor efficiency to transfer electrons onto anode
  - $\text{O}_2$  penetrate from cathode to anode
- **Anaerobic Tube MFC**
  - has relatively higher power density  $11.5\text{mW/m}^2$
  - low overall  $\text{H}_2$  efficiency
- **Tank MFC**
  - Need more time to build up and modify
  - Try to increase the  $\text{H}_2$  production

# Future work



- **Electrode materials improvement**  
physical treatments: heat, pressure  
chemical treatments: acids and alkali, gases treatments
- **Reaction condition optimization**
  - Flow rate, inlet COD, PH value
  - Anode and cathode distance, surface area etc.
- **Bacteria**
  - Mixed species vs. Single species
  - Bacteria grows on cathode
- **Other applications**
  - Biosensors
  - MFC& bioreactor switch mode
  - H<sub>2</sub> purification etc.



## Promising future

- Wastewater
- Oil industry
- Food Industry
- Developing countries



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# Thank you!