Autonomous Sensors Powered by Mud

Energy Harvesting & Water Monitoring with Low Cost Wastewater Microbial Fuel Cells

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Background & Motivations

Context & Issues :

6 CLEAN WATER AND SANITATION

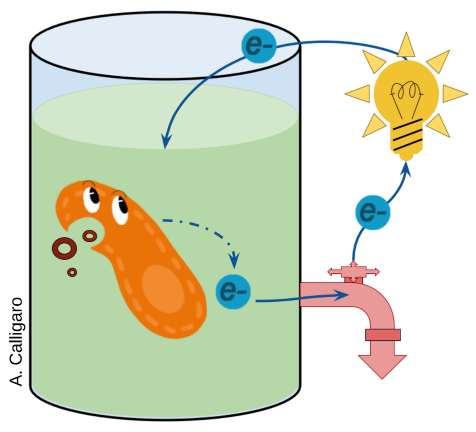
11 SUSTAINABLE CITIES AND COMMUNITIES

United Nations Sustainable Development Goals 2030

In a context where 75% of the world's population will be living in cities by 2050, and access to drinking water and sanitation systems are major challenges, Microbial Fuel Cells (MFCs) are a potential solution for electrical power generation and wastewater treatment [1,2,3]. MFCs are also promising harvesters for providing sensors located in aquatic environments with a constant flow of energy [4].

We investigated the possibility of using the MFC technology in the context of the AQUAPOLE wastewater treatment plant facility of the Grenoble metropolis

Grenoble metropolis wastewater treatment plant facility(AQUAPOLE)



Using Microbial Fuel Cells

- harness electroactive bacteria to produce electricity
- possible to metabolize a variety of organic wastes
- a clean sustainable technology

State of the Art

- different organic wastes & cells tested in the laboratory [3]
- **few implementations in wastewater plants** or in the food industry [3]
- water quality sensors & benthic **autonomous sensor** node systems [4]

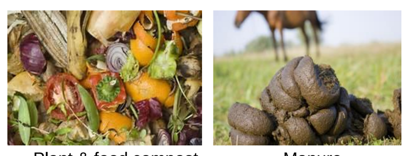
Our research question : Is there a use for MFC technology to monitor & recycle the organic wastes from a 500000 inhabitants Grenoble metropolitan area ?

Urban Wastes & Wastewaters

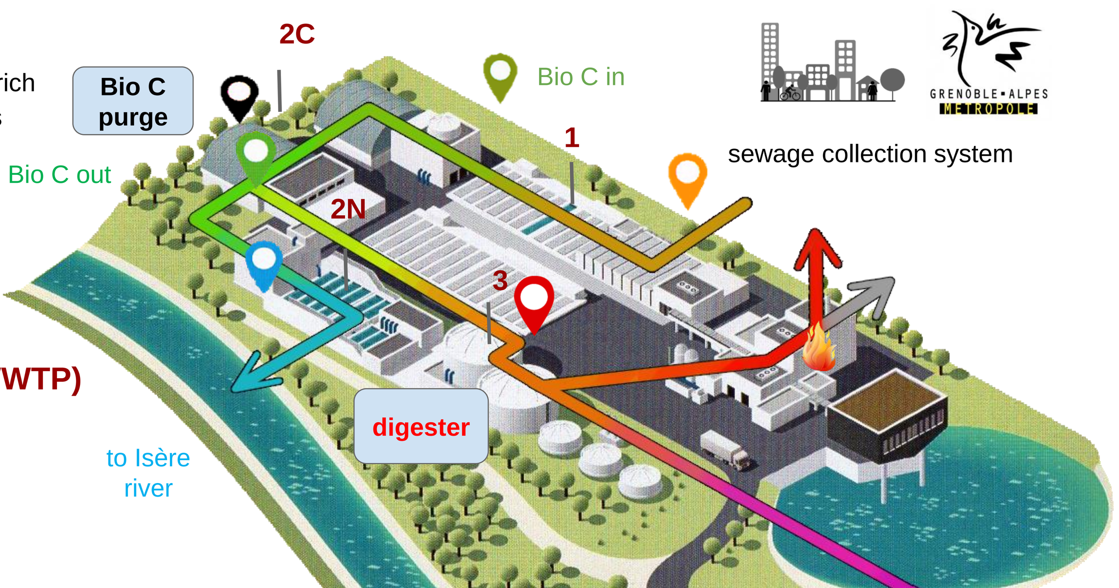
Grenoble's metropolis wastewater treatment plant (AQUAPOLE)

Energy harvesting from wastes

Recycling wastes from local communities, rich in organic matter & natural microorganisms



Plant & food compost   Manure



WasteWater Treatment Plant (WWTP)

1. Physical treatment (suspended solids)
2. Biological treatment (bacteria)
   Carbon & **N**itrogen removal
3. Sludge digester (biogas production)

Laboratory measurements

Chemical (COD) & Biological (BOD5) Oxygen Demand of the organic matter

bio Carbon basin

digester sludge

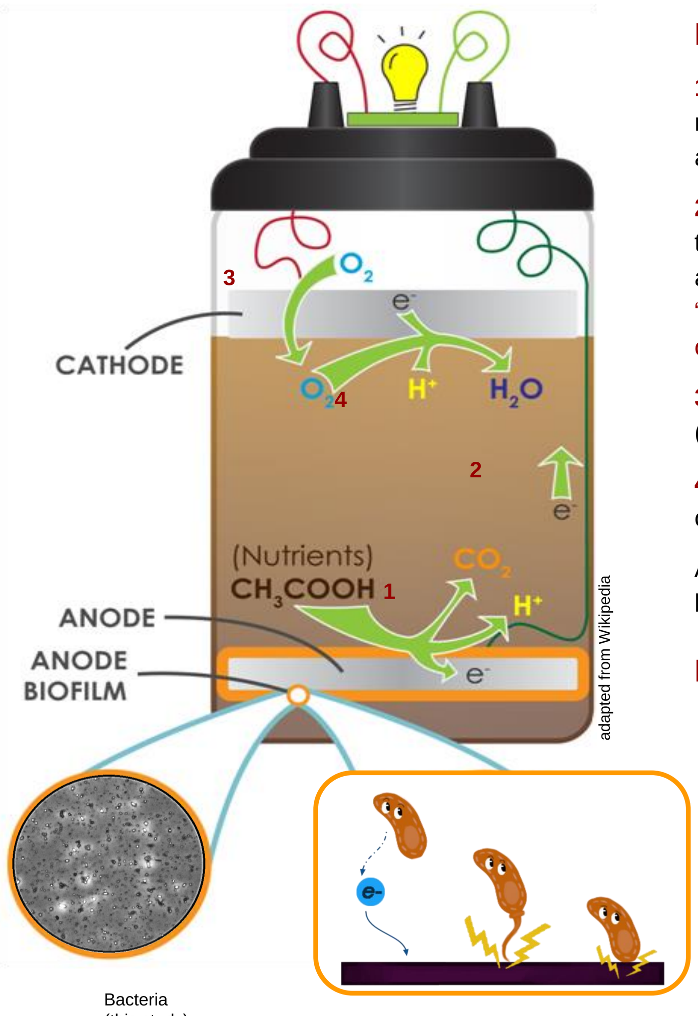
	COD	BOD5
	c (O_2) (mg/L)	
inlet station	314	126
bio C in	91	23
bio C purge	**407**	**144**
bio C out	29	5
to river	12	3
digester	**20**	

Modeling biomass energy use

estimated MFC / measured Biogas / WWTP operation

Wastewaters 40 t/day COD, thermo limit 18t/day BOD5, 50% yield	53 GWh/yr 5 GWh/yr
Biogas actual production 40% yield	17 GWh/yr Grenoble City Gas
Operation of the wastewater plant (pumps)	30 GWh/yr electricity

How MFCs Work



Bacteria (this study)

Transfer of electrons from the bacteria (hypothesis)

- mediated
- pili ("nanowires")
- direct

Microbial Fuel Cells (MFC), *a sustainable process*

1. consortium of natural electrogenic bacteria in the biofilm around the anode metabolize nutrients (oxydation) and transfer electrons to the graphite felt anode ACTIVATED CARBON BIOEPURATION (biocatalist)

2. electron flow through the external circuit, resulting in electrical power transferred to the receptor load : ELECTRICAL ENERGY HARVESTING. It is a fuel cell and not a simple BIOBATTERY as long as the organic nutrient "fuel" is sustainably supplied to the cell (direct flow of water, or by recycling of organic wastes in "batch mode")

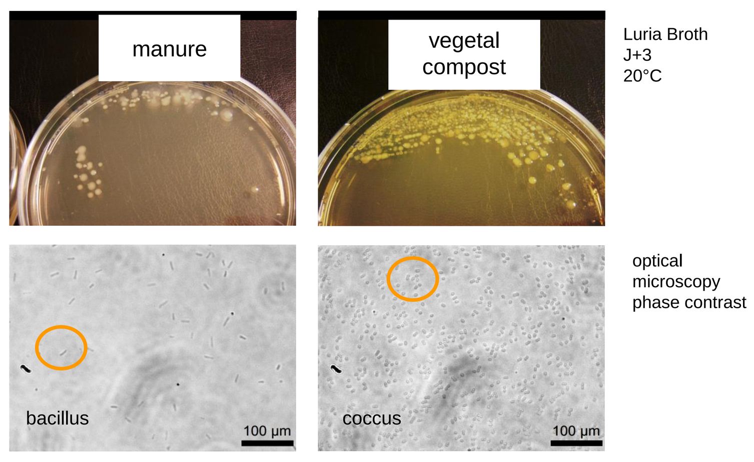
3. H^+ protons flow from the anode to the cathode within the cell electrolyte (mud of wastewaters) of a single-chamber Fuel Cell

4. at the air-cathode, electrons from the external circuit and H^+ protons from cell material combined reduce O_2 to form H_2O water

A RENEWABLE, NON-POLLUTING cell (constituents and reaction byproducts, CO_2 and H_2O)

Microbial activity

Observation of different consortia of bacterial strains (this study)



MFC Characterization & Field Trials

Electrical Characterizations in the Laboratory

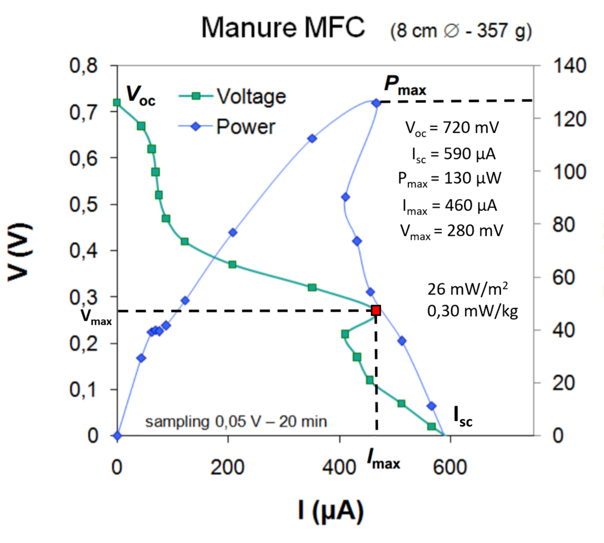
Sustainable cells

- single cell
- air cathode
- carbon felt electrodes
- *titanium wire*

Manure/algae MFC

Figures of merit MFCs : waste materials & distance inter-electrode

		MFC	V_{oc} (mV)	I_{max} (mA)	P_{max}/S (mW/m²)
organic source material 20°C		Green compost, 5cm	425	0,17	5,0
		Horse Manure 5 cm	**644**	**0,84**	**29**
		Manure/Algae, 2cm	319	0,25	7,4
		Manure/Algae, 5cm	123	0,23	3,1
		Manure/Alga, 8cm	292	0,34	30



IV - IP characteristics – (here voltage sweep from V_{CO})

Modeling

- over-potential at low current *I*
- internal resistance
- mass-transport-limited @ high *I*
- large variability
- slow kinetics (see hysteresis & video)

MFC-"fatigue" while transferring to load

Prototype MFCs for Field Trials

digester anaerobic sludge "benthic"-configuration

bio C purge wastewaters "floating" air-cathode

Figures of merit MFCs : waste materials & distance inter-electrode

	Wastes - MFC	V_{oc} (mV)	I_{max} (mA)	P_{max} (uW)
AQUAPOLE C-air J+8 10°C batch aeration 50 cm² electrodes 5 L	**Digester sludge** (8 cm)	433	0,04	9
	Bio C purge wastewater (4cm)	452	0,09	23
	Bio C purge wastewater (8cm)	497	0,11	34
Ref [3] COD 200 mg/L	? Bio C in		0,90 0,23	540 140

comparable to the published literature [3]
No evidence of COD removal within 1 month

Wastewater Microbial*Bio*Cell (0,5L)

- renewable material (C-felt, *Ti-wire*)
- 670 mAh theory (ΔCOD = 407 mg/L)
- 0,35 V , I = 0,11 m A
- Theoretical lifetime : **more than 8 months !**

Wastewater plant characteristic times

- Wastewater flow 2,3 m³/s
- sludge 20 days digester

LIMITS : kinetics too slow !

ADVANTAGE : a sensor for microbial activity

sensitive but … *selective ?*

Sensor Nodes Powered by MFCs

Demonstration of a benthic MFC from local Paladru lake & Brittany ocean

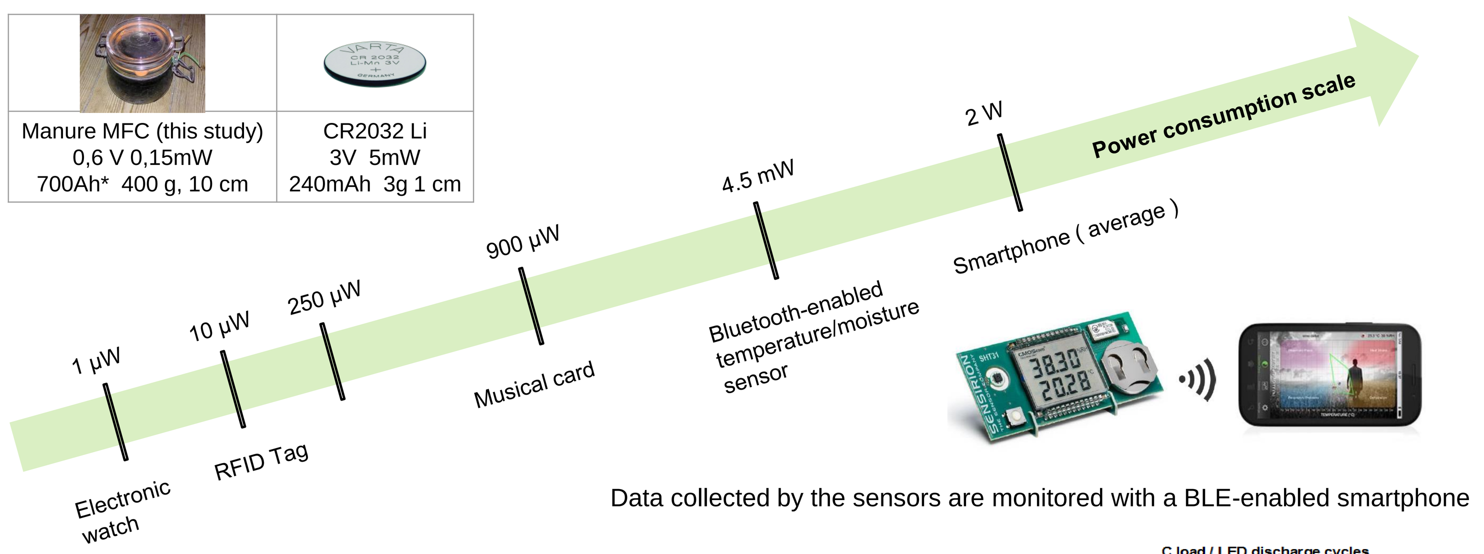
- 0,3 V, 10 mW/m² (Paladru), comparison to literature (sea waters) [4]
- locations without light, movement, wind : ex aquatic environments
- "deploy and forget" applications, for "clean" sensors (no batteries)

Paladru Lake (Isère)

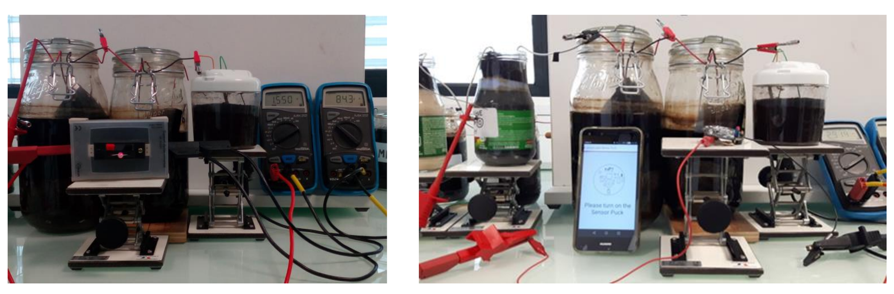
Towards low cost remote sensors powered by MFCs

- comparison of MFCs and coin batteries
- need for powering sensor AND wireless transmission of information

Manure MFC (this study) 0,6 V 0,15mW 700Ah* 400 g, 10 cm	CR2032 Li 3V 5mW 240mAh 3g 1 cm

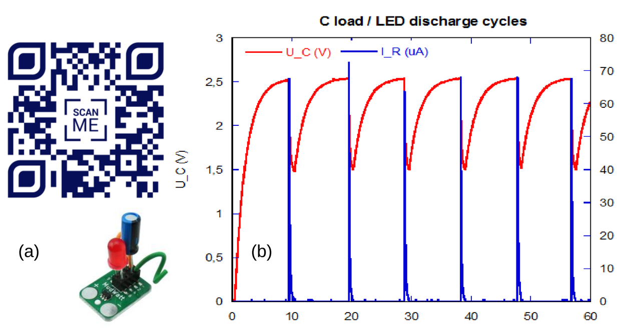


Data collected by the sensors are monitored with a BLE-enabled smartphone



Serial association of 3 MFC's to power on a LED (1,55 V, 100 µA)

Serial association of 5 MFC's : 3,0 V open circuit voltage but not enough power to power on the sensor (3,0 V, 4,5 mW)



Periodical shining a LED with a single MFE's using charge/discharge cycles with a capacitor : MudWatt circuit & video (a) - electrical model (b)

Conclusions

1

2

1. Sustainable MFCs could be used to harvest energy in the 100µW range using sewage waters from the Grenoble's wastewater treatment plant.

2. With proper power management systems, MFC's could also be used for sensor nodes with other types of waste resulting from human activity.

3. MFCs could also be used as the environmental sensor itself, as long as it can be proved to be selective [2].

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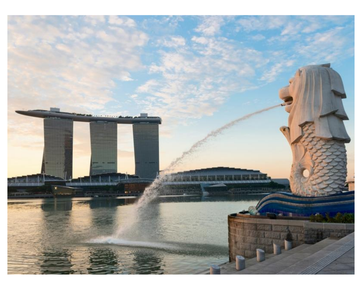

Singapore, MFC sensors for water pollutants [2]

Bibliography : [1] This study supports the United Nation SDG 2030, **[2]** H.Y. Ng, NUS, p. 24 in PUB_Innovation in Water Singapore 2016, **[3]** K. Scott & E. Hao Yu, *Microbial electrochemical and fuel cells. Fundamental & applications*, Woodhead publishing Elsevier, 2016, **[4]** T. Chailloux et al, *Energy Harvesting & Systems*, DE GRUYTER, 2016, hal-01317426.

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