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Microbial electrochemical Cr(VI) reduction in a continuous flow system

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SESSION 25: Challenges and research in remediation

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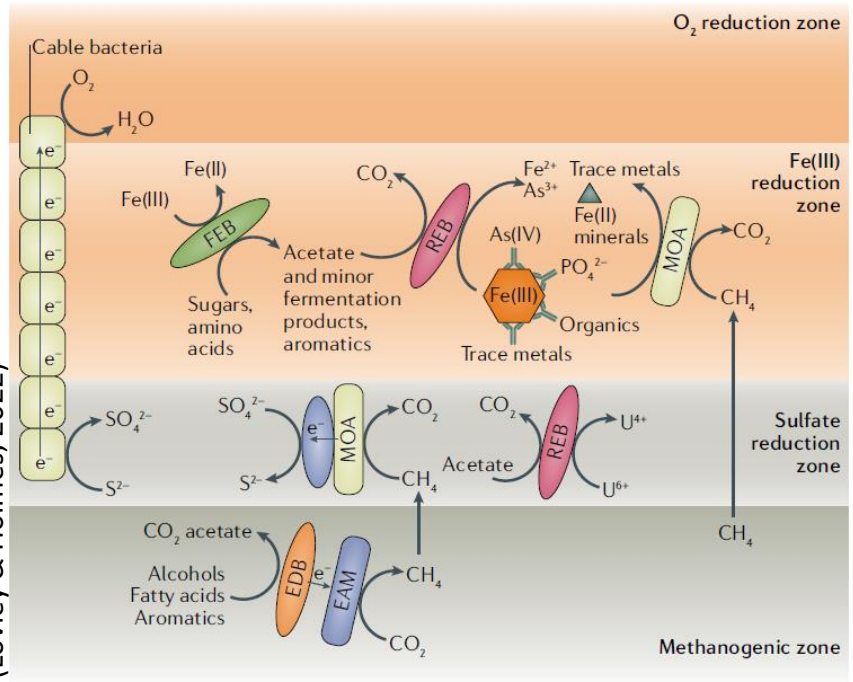
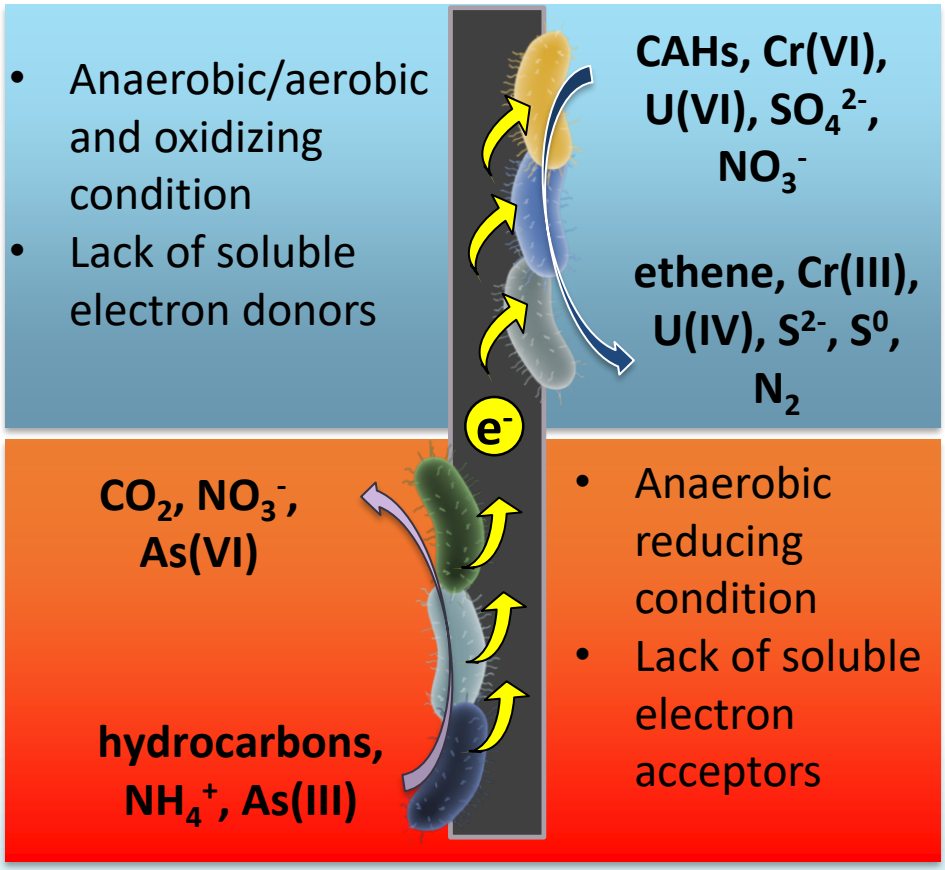
Microbial Electrochemical Remediation (MER)
Electroactive bacteria (EAB)

Ability to transfer electrons outside the cell from/to other cells and solid materials/minerals

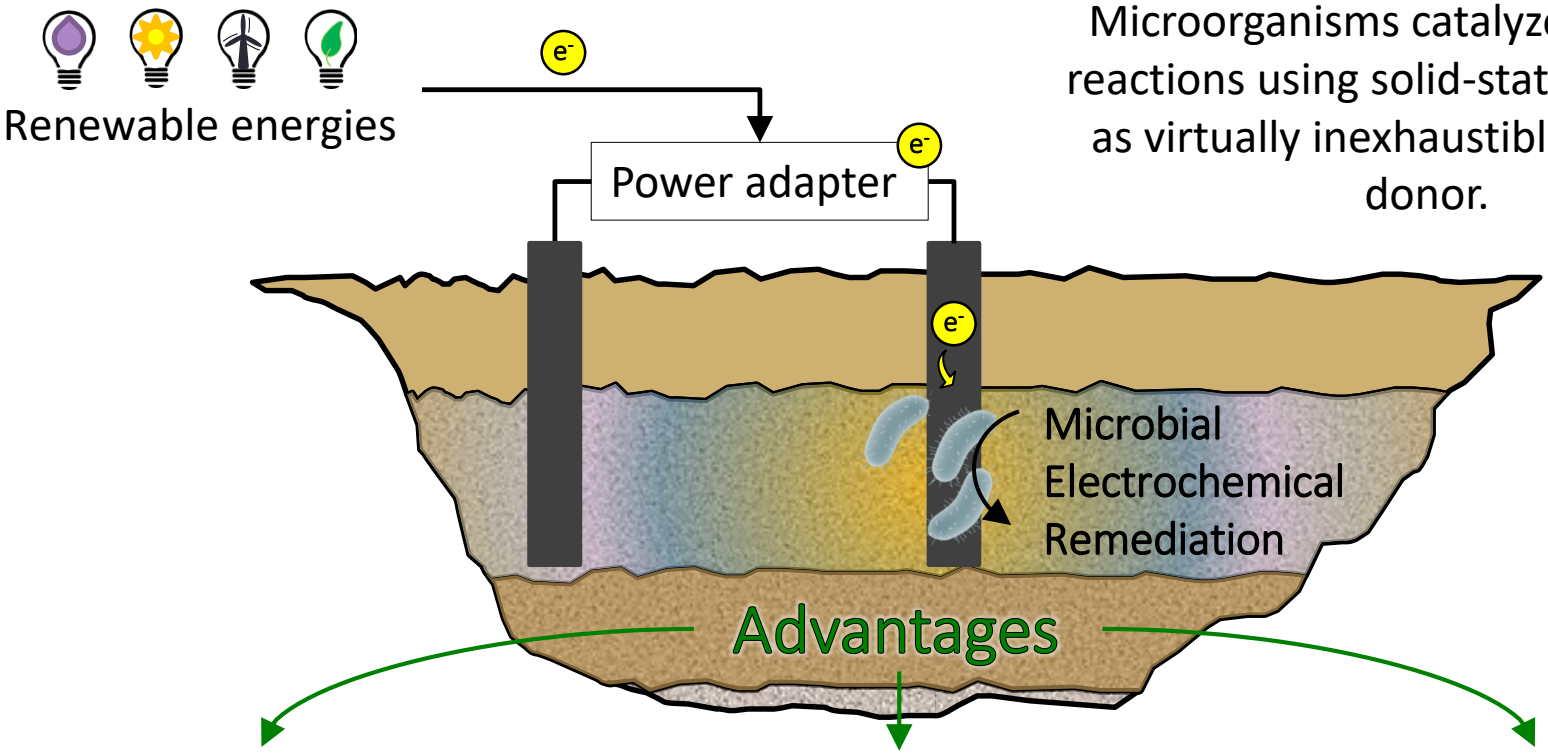


(Lovley & Holmes, 2022)

FEB: Fermentative Electroactive Bacteria
REB: Respiratory Electroactive Bacteria
MOA: Methane-Oxidizing Archea
EDB: Electron-Donating Bacteria
EAM: Electron-Accepting Methanogens



Microbial Electrochemical Remediation (MER)



Microorganisms catalyze reduction reactions using solid-state electrodes as virtually inexhaustible electrons donor.

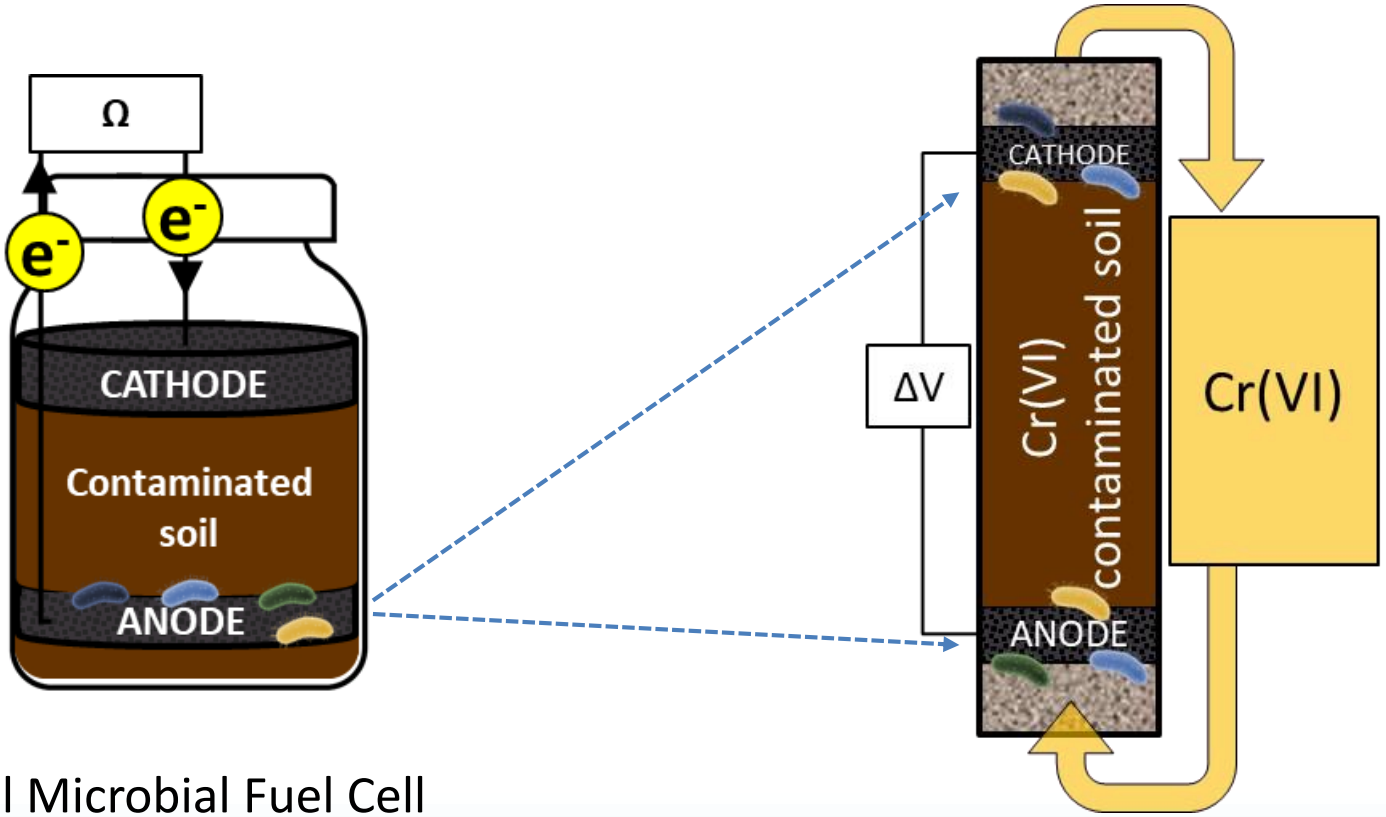
Advantages

- Easy electrons delivery and distribution
- Avoid formation of unwanted products (CH_4)
- Biosensor for the degradation process

MER Experimental procedure

1. Enrichments of EAB

2. Continuous-flow MER



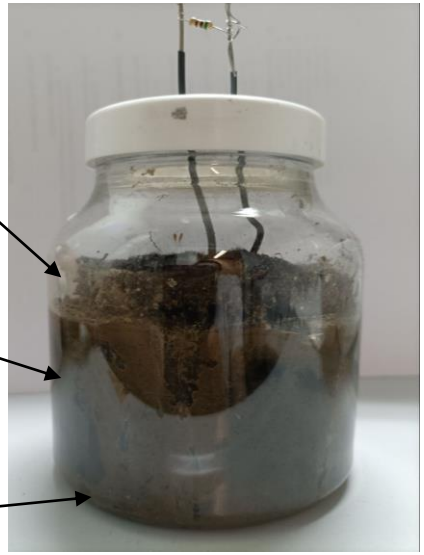
Soil Microbial Fuel Cell (SMFC)

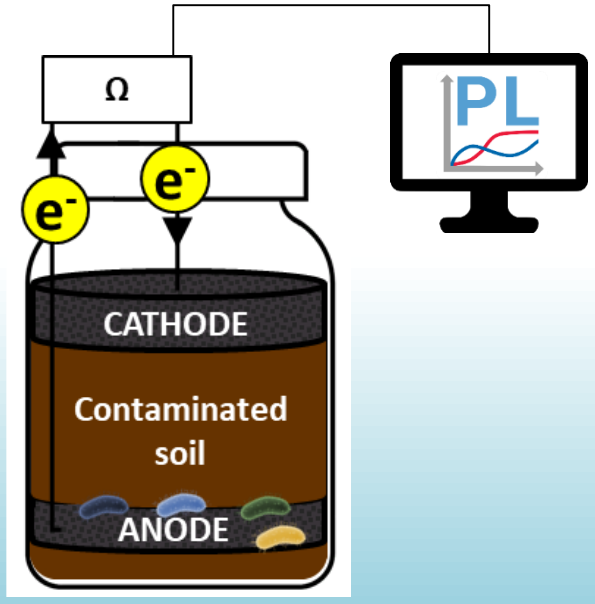
BioElectrochemical Continuous Flow system (BECF)

1. Enrichments of EAB (Method_pt.1)

Soil MFCs composition:

- Cathode: Graphite felt + stainless steel wire (50 cm^2)
- Substrate: Acetate (0.05 g/L; 31 mg/kg)
- Contaminated soil: 3.13 ± 0.63 mg Cr(VI) /kg dry soil
- Inoculum: Cr(VI) contaminated soil indigenous bacteria
- Anode: Graphite granules + titanium wire (20,000 cm^2)

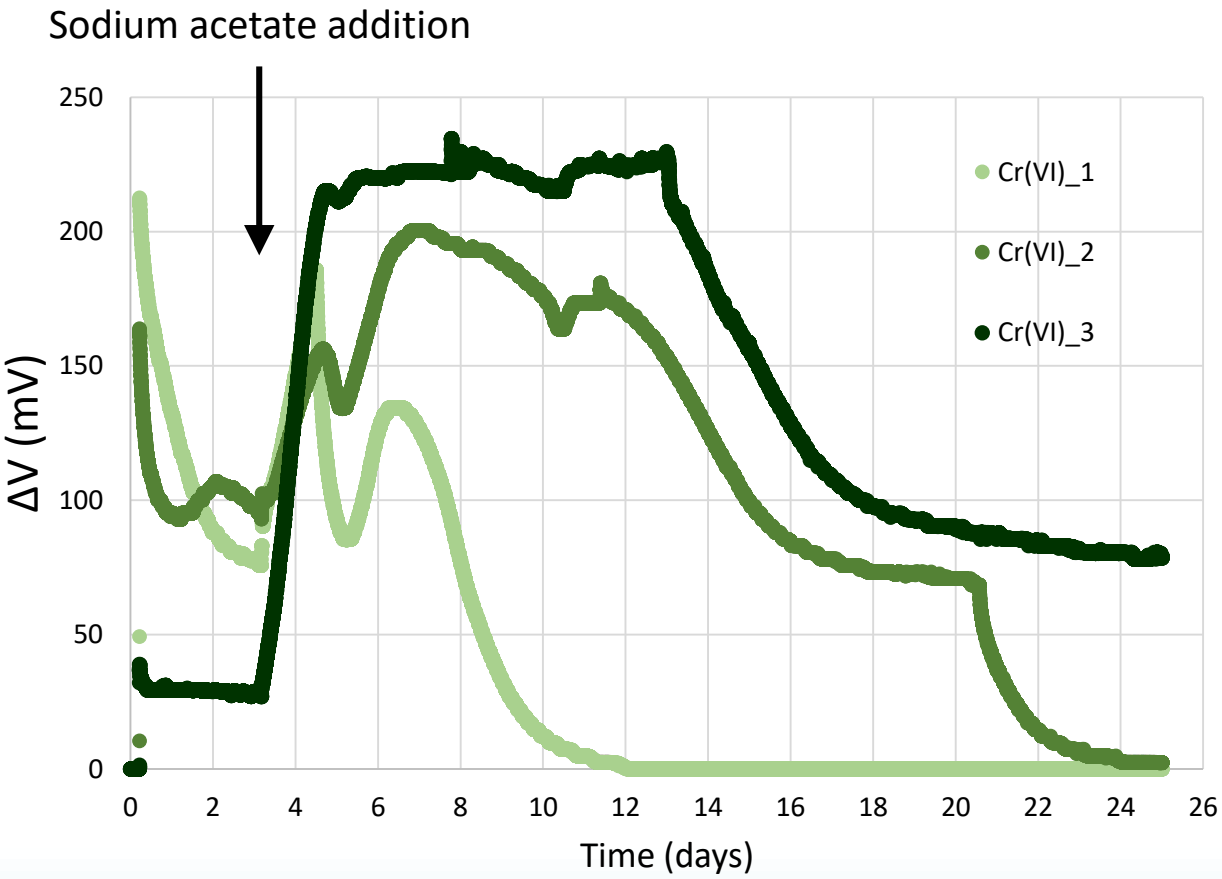




Monitoring and evaluation:

- Continuous recording of the circulating currents by datalog software
- Microbial analysis: 16S rRNA gene sequencing

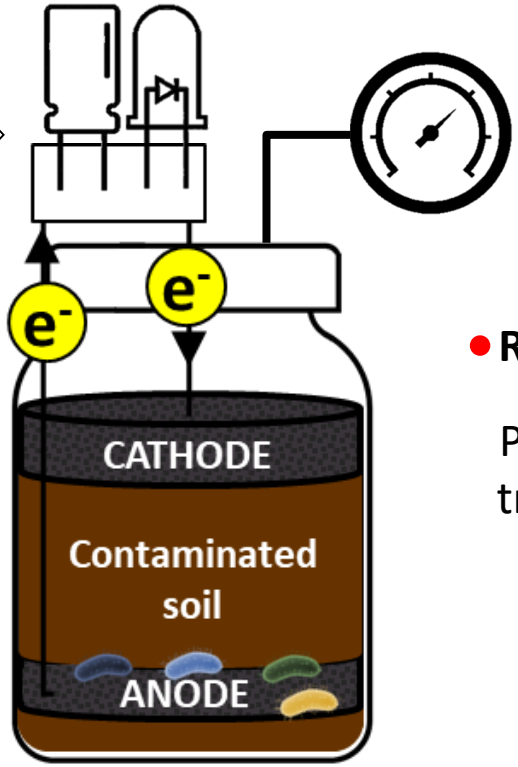
1. Enrichments of EAB (Results_pt.1)



Voltage production correlated to biological oxidation of acetate
→ development of an *electroactive biofilm*

1. Enrichments of EAB (Method_pt.2)

Blinker Board:
Hacker board + Capacitor + LED



Pressure gauge

- **REC** LED Flashing frequency

LED blinking frequency (Hz) is proportional to EAB power generation (mW)

- **REC** SMFC Internal pressure

Pressure (hPa) diminishing trend with time associated to bacterial oxygen consumption and/or biocathodic oxygen reduction.

$$C_2H_4O_2 + 2O_2 \rightarrow 2CO_2 + 2H_2O$$
(Aerobic portion of soil)

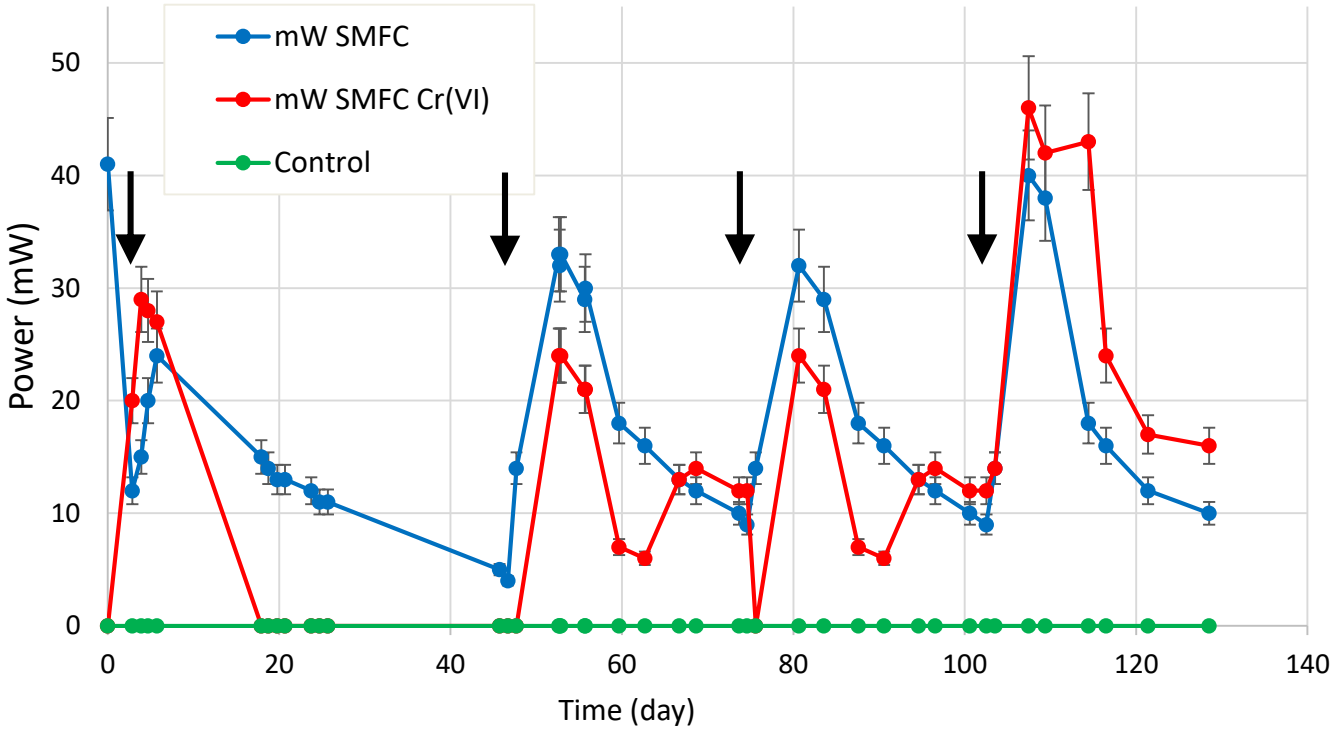
$$CH_3COO^- + 4\,H_2O \rightarrow 2\,HCO_3^- + 9\,H^+ + 8\,e^-$$
(Anode region, anaerobic)

CO_2 trapped to Na_2CO_3

$$2\,O_2 + 8\,e^- + 8\,H^+ \rightarrow 4\,H_2O$$
(Cathode region, aerobic)

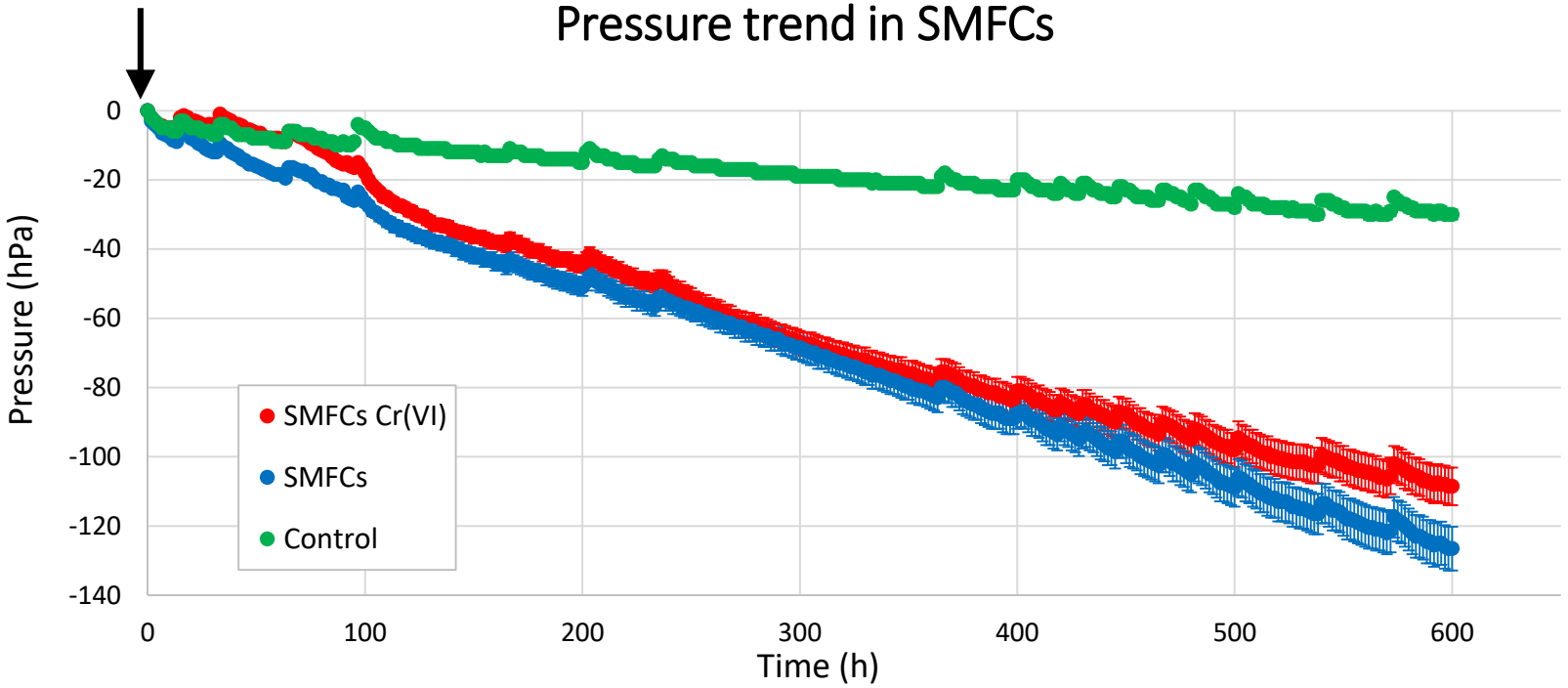
1. Enrichments of EAB (Results_pt.2)

Electrical power produced by EAB



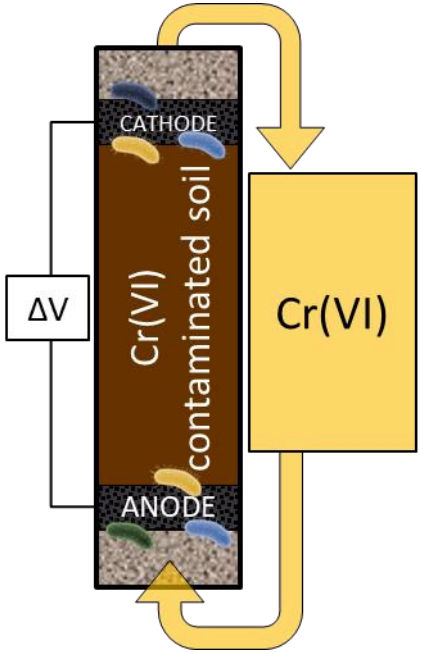
	Σ electric energy production (Wh)	Average power rate (mW/d)	Average power rate/kg soil (mW/d*kg)	Max peak power (mW)
SMFC	72.2	5.91	24.63	41
SMFC (CrVI)	54.0	4.61	19.22	46

1. Enrichments of EAB (Results_pt.2)



	Pressure variation (Δ hPa)	Oxygen consumption (mmol O_2)	O_2 consumption rate (mmol O_2/kg d.s.*d)	Trapped CO_2 (mmol C)	C mineralization rate (mmol C/kg d.s.*d)
SMFCs	- 126.5	0.040	$6.36 \cdot 10^{-3}$	6.44	1.07
SMFCs Cr(VI)	- 108.5	0.029	$4.68 \cdot 10^{-3}$	6.76	1.13
Control	- 30	0.002	$3.57 \cdot 10^{-4}$	1.85	0.31

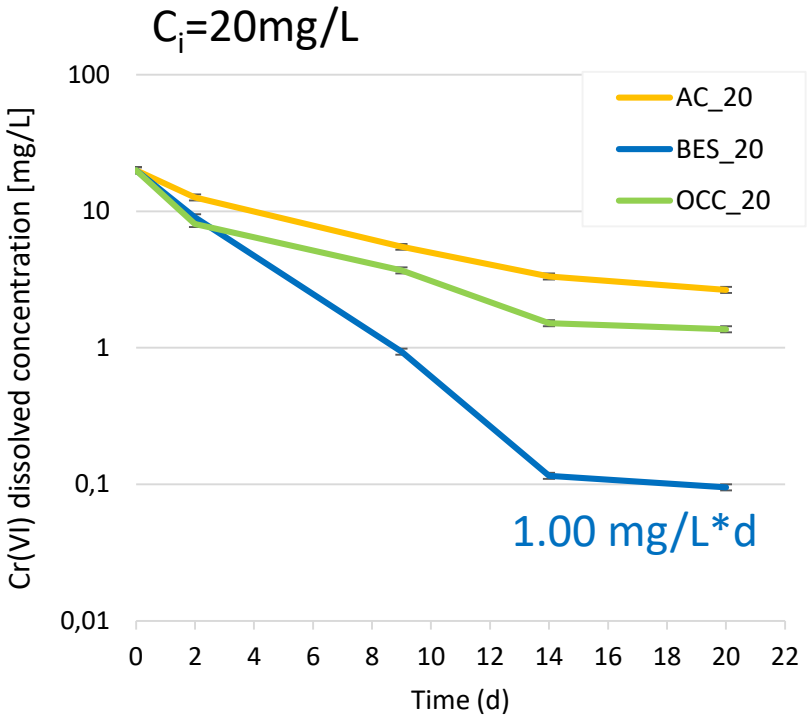
Continuous-flow MER (Method)

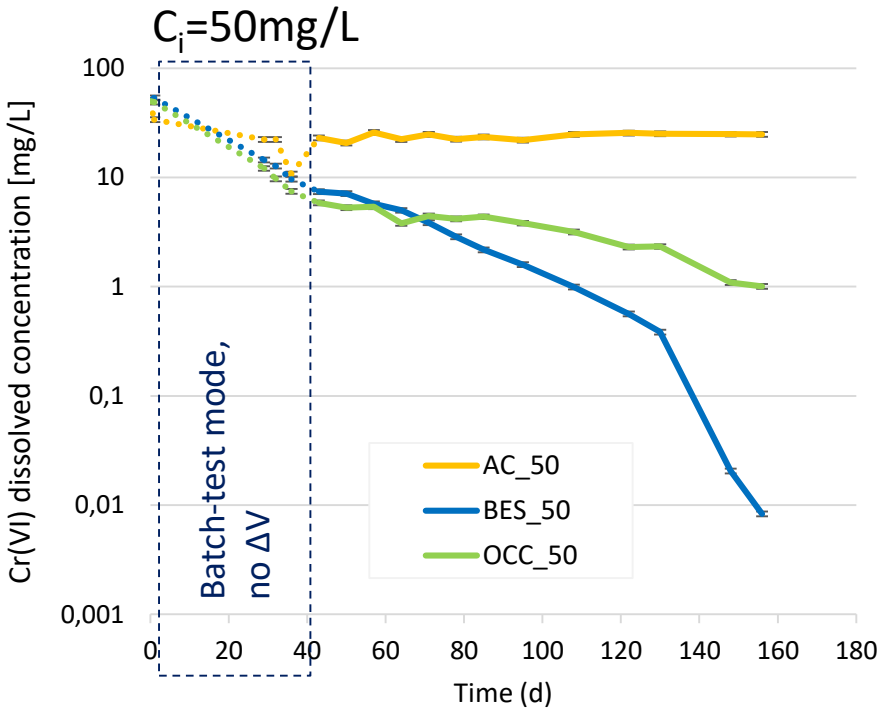


- **Electrode:** Granular graphite from Soil MFCs + Stainless steel mesh and titanium wire
- **Carbon source:** Naturally present in soil
- **Solution:** Cr(VI) contaminated tap water (20-50 mg/L)
- **Experimental condition:**
  - Applied costant voltage (0.6 V)
  - Abiotic (AC) and Open Circuit controls (OCC)
  -Flow velocity 5 m/d, Q= 0.67 mL/min

- Up-flow system has been realized to simulate a real Cr(VI) contaminated aquifer condition
- Electroactive biofilm transferred from Soil MFCs
- To the electrodes buried in soil 0.6 V has been applied
- Two different Cr(VI) concentration have been tested

Continuous-flow MER - Chemical Results

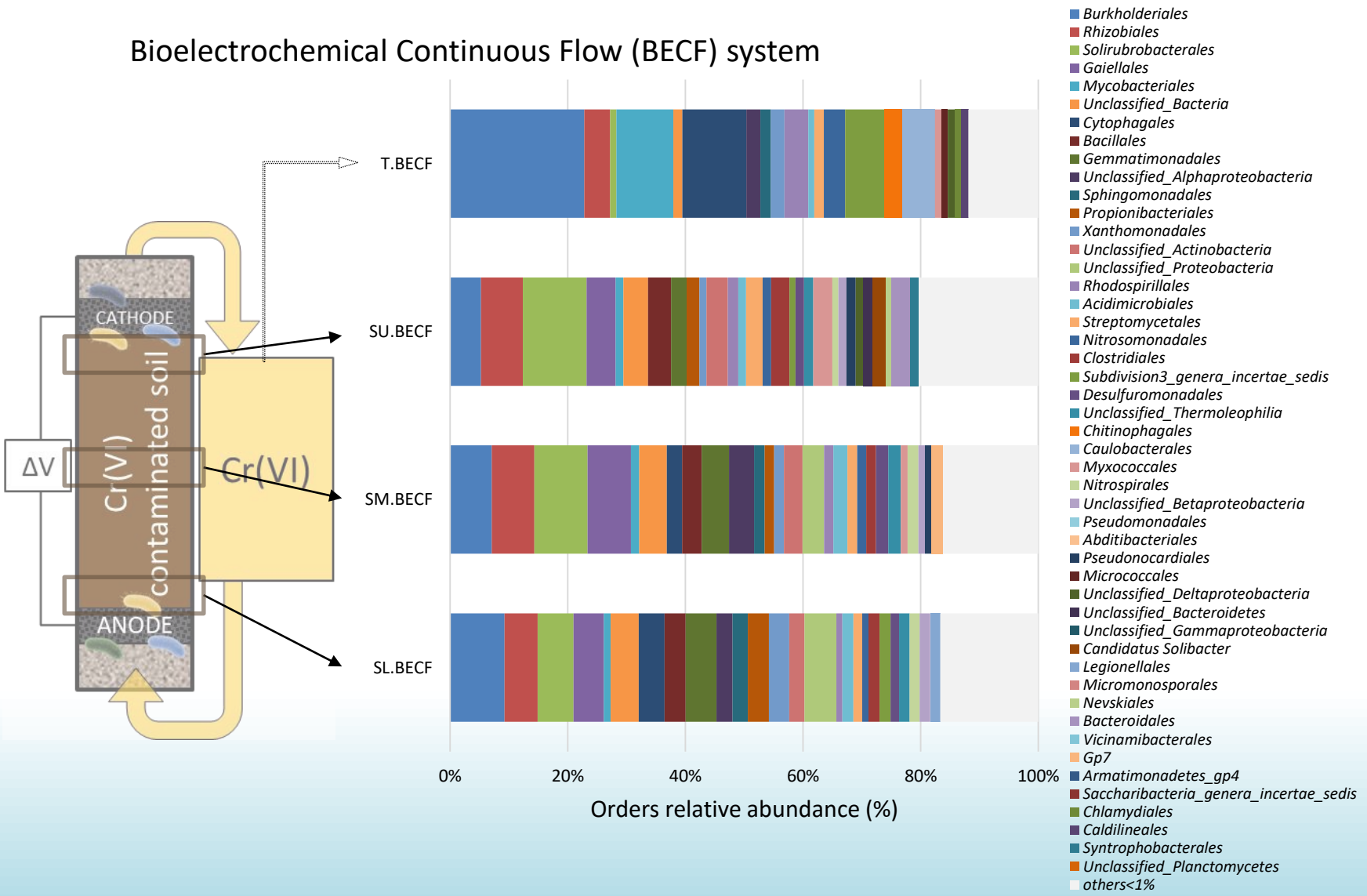




- >80% of Cr(VI) reduction in all the 3 systems
- In BES the 95% of dissolved Cr(VI) has been removed after 9 days
- 99.5% bioelectrochemical removal of dissolved Cr(VI) in 20 days equal to a removal rate of 1.00 mg/L*d.

- Batch test mode and no voltage applied
- BES and OCC same trend until 70th day of test
- 99.9% bioelectrochemical removal of dissolved Cr(VI) in 148 days equal to a removal rate of 0.34 mg/L*d.

Continuous-flow MER_ Preview results of 16S rRNA gene sequencing



Conclusion

- The **relationship** between **the bioavailability of substrate** and the **production of a potential difference** indicates the development of a community of electroactive bacteria (EAB).
- The initial phase of **EAB enrichment** proved to be fundamental in improving the **efficiency of bioelectrochemical reduction of Cr (VI)**, this approach could be considered in full-scale implementation also with other contaminants.
- Results from continuous flow-test demonstrate that the **microbial electrochemical removal of Cr (VI) can occur**, **even in the absence of organic carbon**.
- Although **bioelectrochemical treatment** needs further studies (pilot-scale and field scale) also from an economic feasibility point of view, it can represent an **innovative** and **sustainable** approach for the removal of contaminants from soil and groundwater.

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Thanks for your attention!

and many thanks to:

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