Electrochemical systems as core engines of the MELiSSA loop

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Lausanne, June 8th 2016

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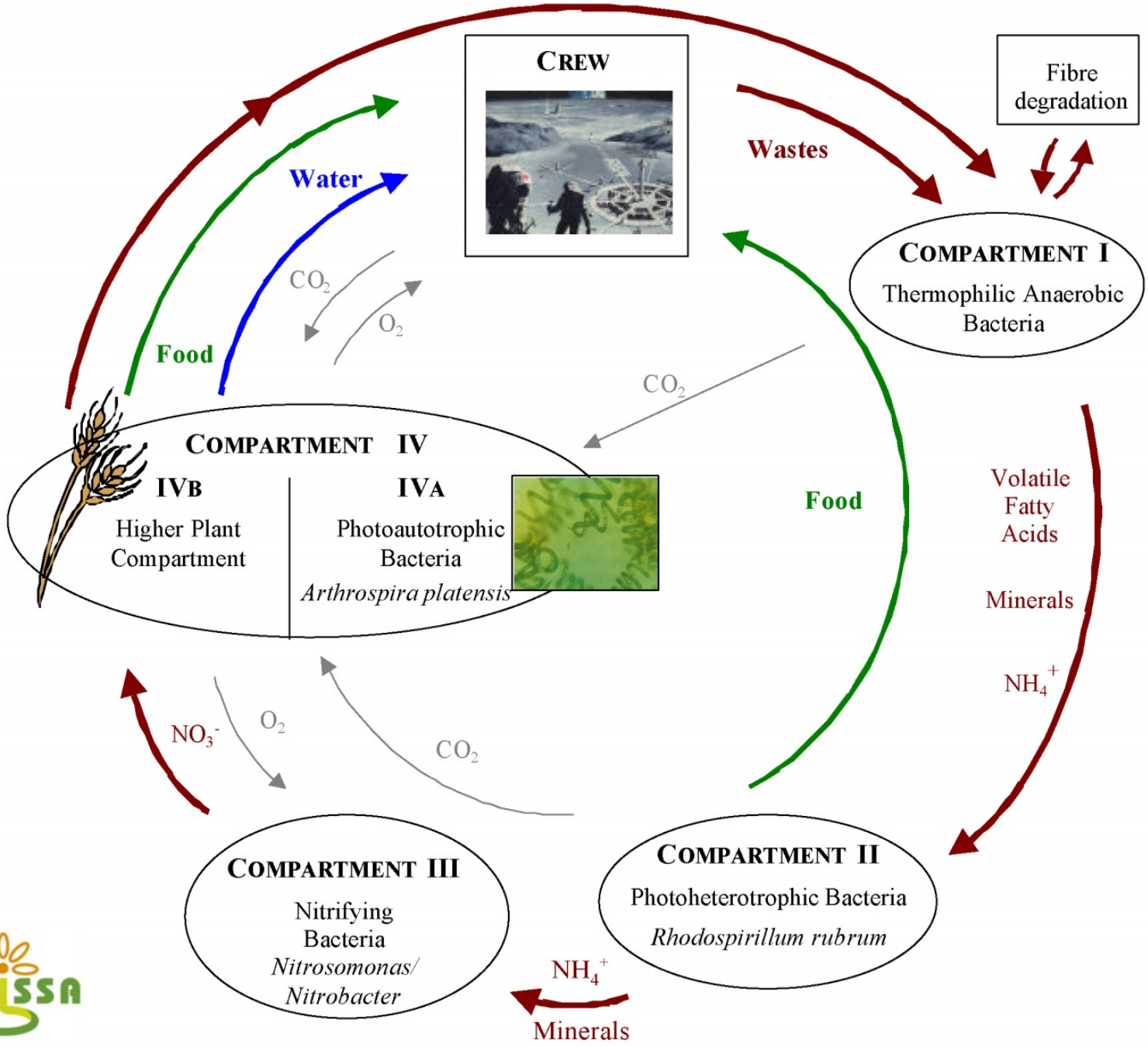
Non Edible Parts of Higher Plants



Needed!

- Acid
- Base
- Oxygen
- Hydrogen peroxide
- Anti-fouling agents
- Energy

Unwanted!

- Viruses
- Bacteria
- Calcium and Magnesium in wrong place
- Trace contaminants
- Recalcitrant organics
- Simple organics: VFA

2.85 kg NaOH needed per kg NH_3-N nitrified

~60 g N/ISS.d needs ~171 g/d

0.16 kg NaOH needed per kg organics-C fermented

~2400 g C/ISS.d needs ~130 g/d

~5 kg H_2O_2 needed per kg organics-C oxidized

~2400 g C/ISS.d needs ~12500 g/d

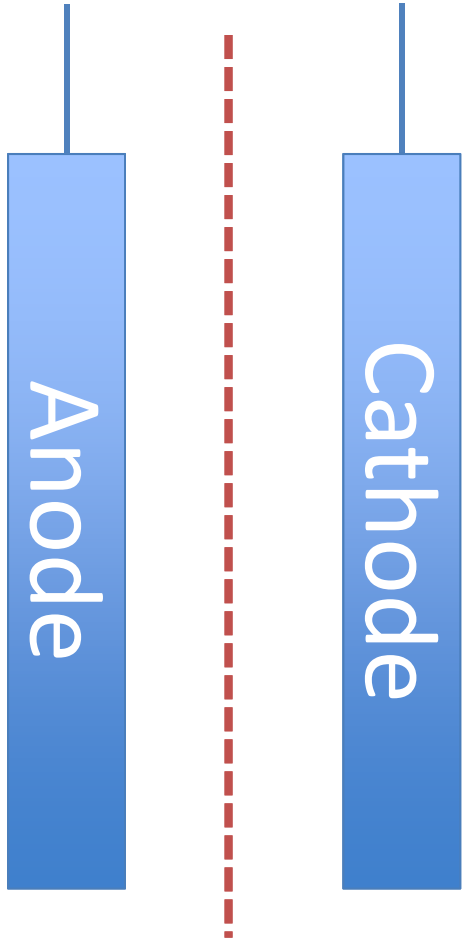
one-trick pony

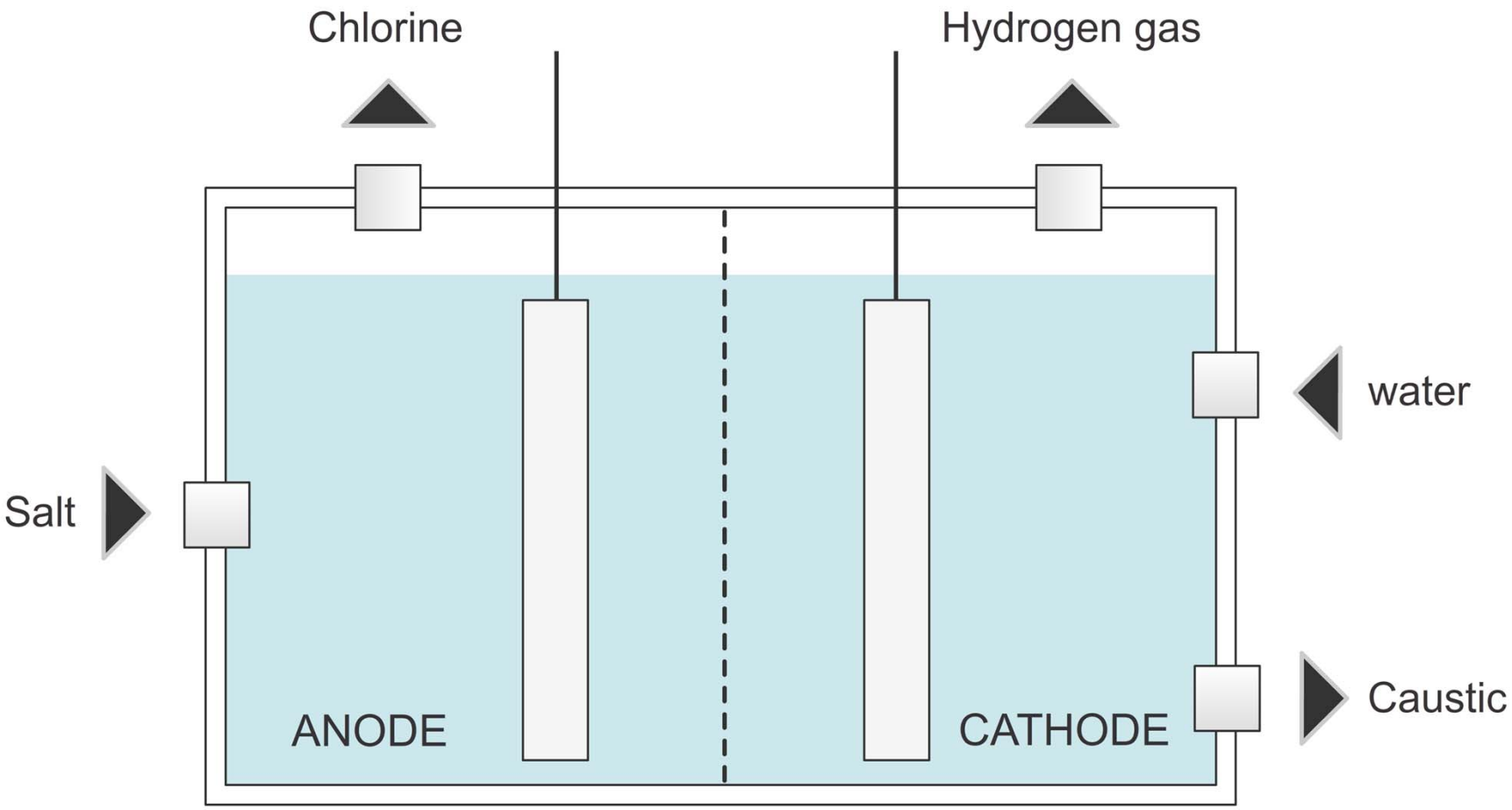
Syllabification: one-trick po·ny

noun *informal*: A person or thing with only one special feature, talent, or area of expertise.

An electrochemical cell

- Anode
  - Oxidation occurs
- Cathode
  - Reduction occurs
- Separator
  - Ion exchange membrane
    - Cations
    - Anions





77 000 000 tons

121 000 000 000 kWh

Tim Lacoere

- Input:
  - ~3.3 kWh
  - 1.73 kg NaCl
- Output
  - 1 kg chlorine
  - 1.1 kg NaOH
  - (H_2)

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Available at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/watres

Electrochemical oxidation of reverse osmosis concentrate on mixed metal oxide (MMO) titanium coated electrodes

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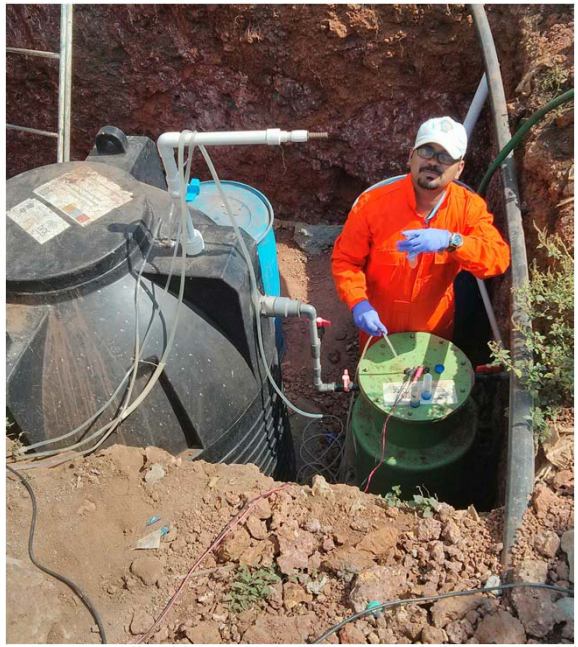
ABSTRACT

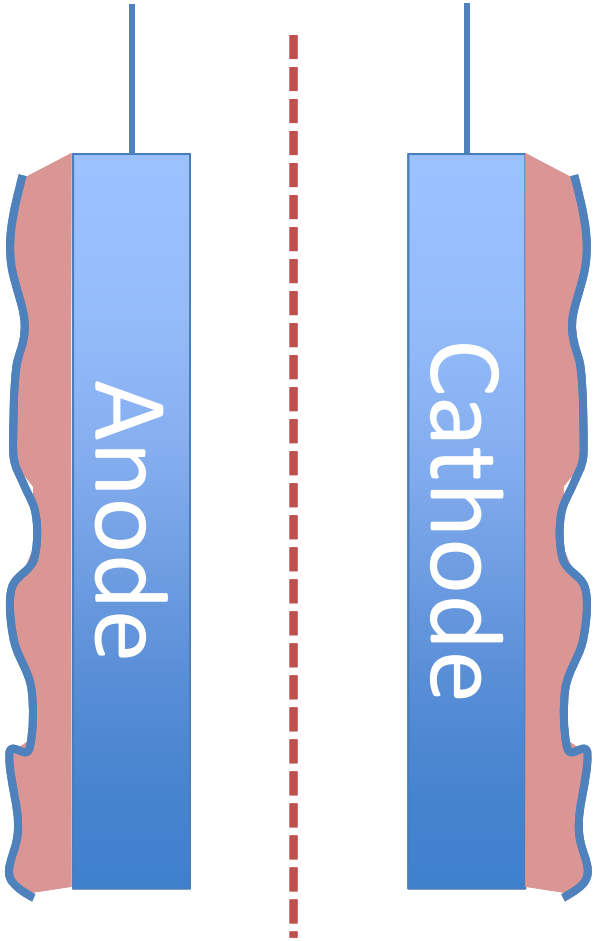
Reverse osmosis (RO) membranes have been successfully applied around the world for wastewater reuse applications. However, RO is a physical separation process, and besides the clean water stream (permeate) a reverse osmosis concentrate (ROC) is produced, usually representing 15–25% of the feed water flow and containing the organic and inor-



BILL & MELINDA GATES foundation

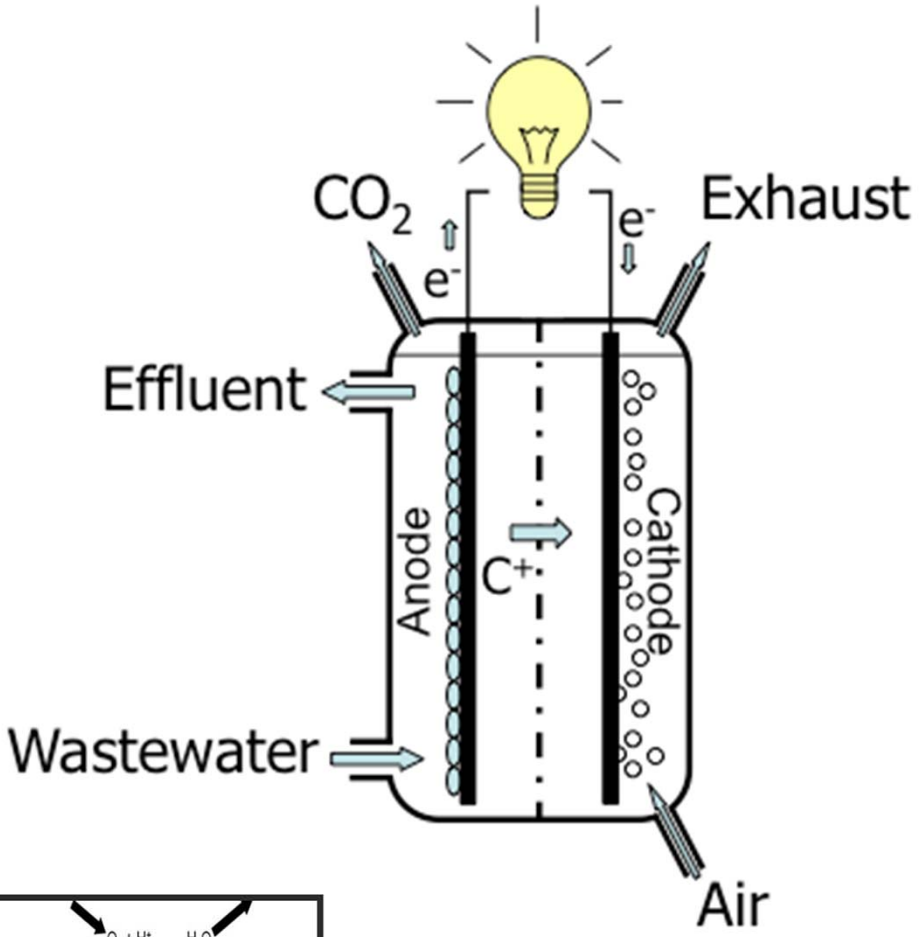
A bioelectrochemical cell

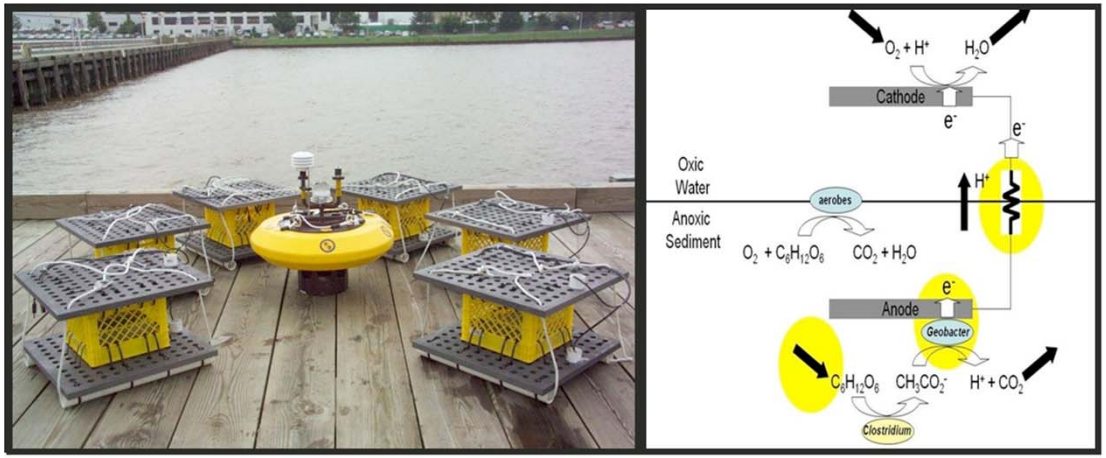
- Anode
  - Oxidation occurs
- Cathode
  - Reduction occurs
- Separator
  - Ion exchange membrane
    - Cations
    - Anions



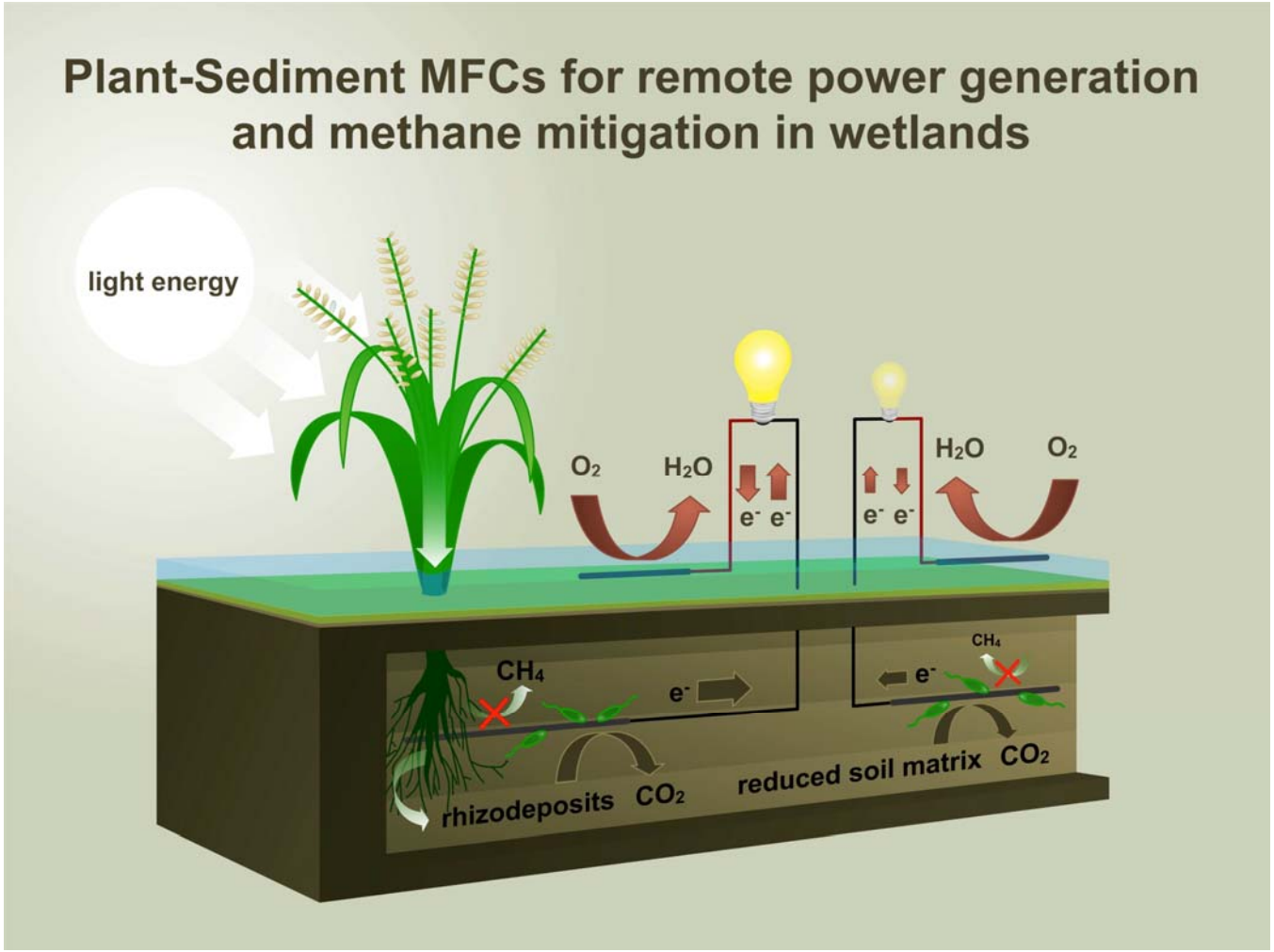
Microbial fuel cell – energy from wastewater

Current through VFA
Low cell yield



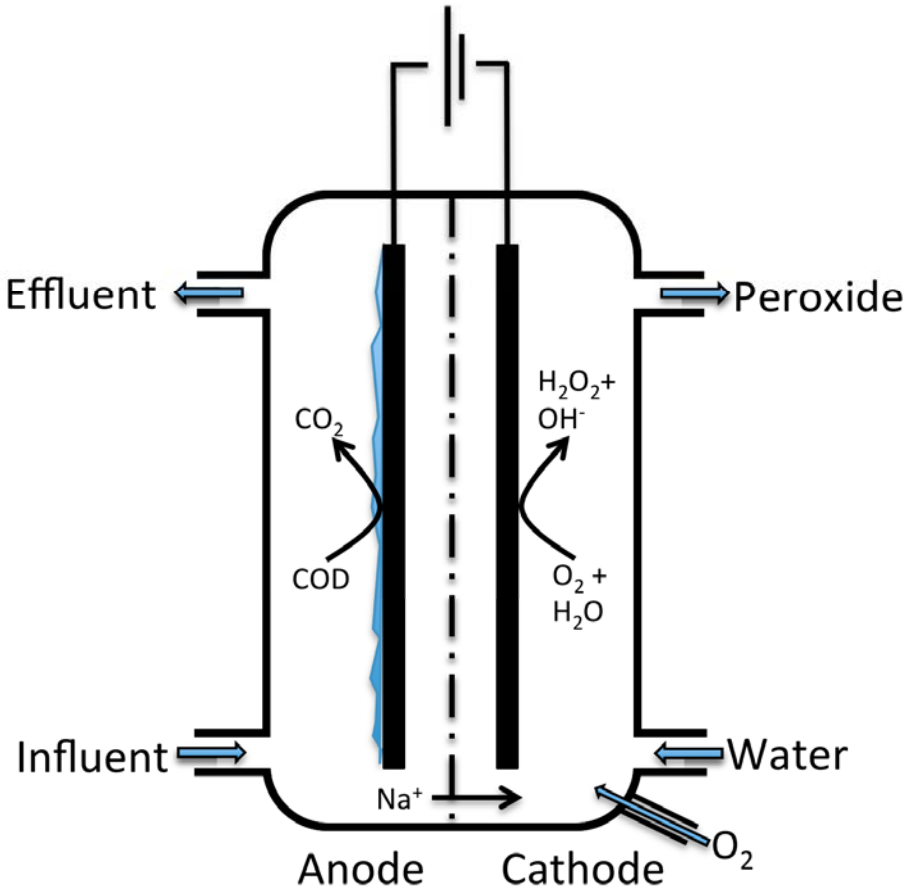


Plant-Sediment MFCs for remote power generation and methane mitigation in wetlands



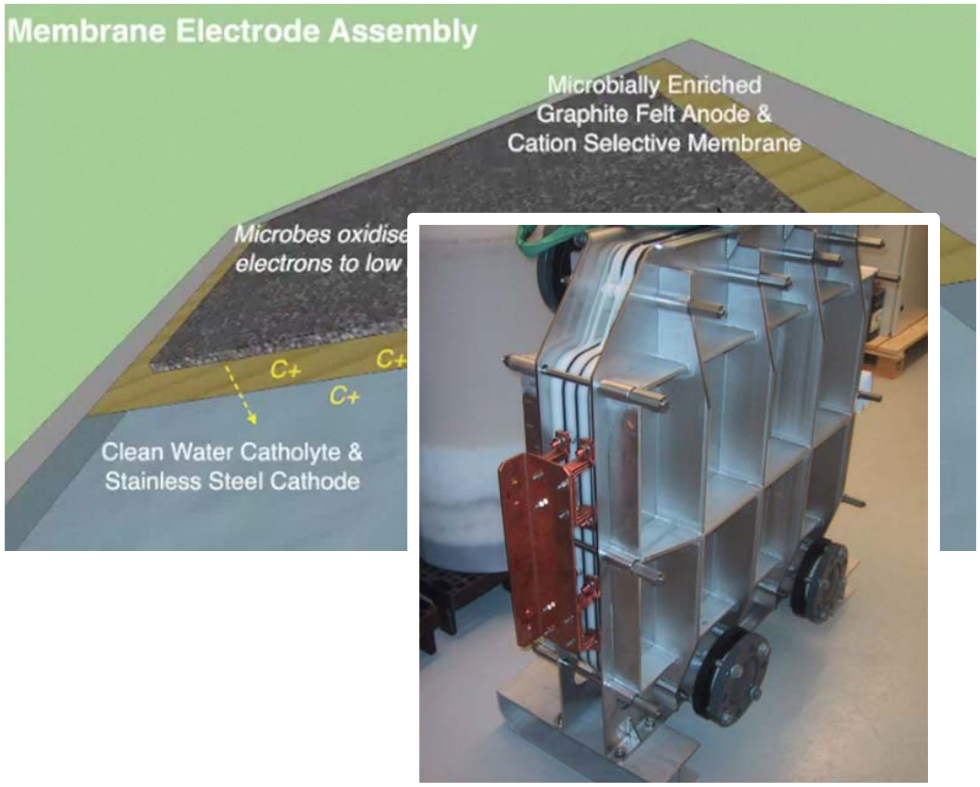
Peroxide production in BESs

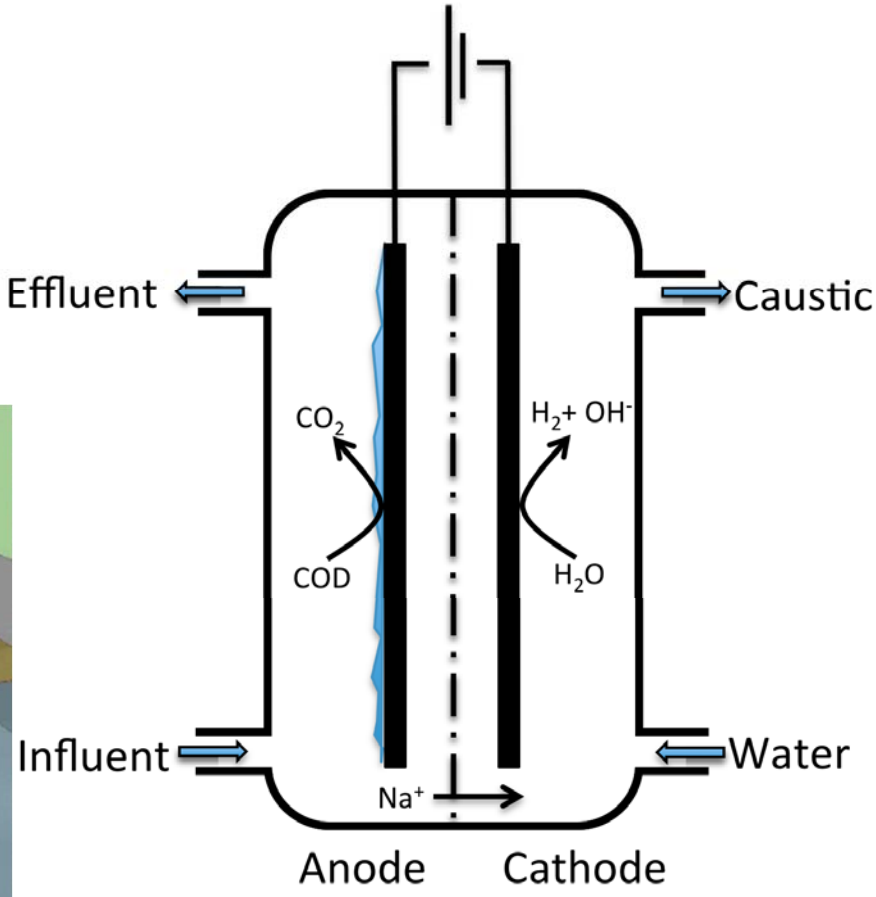
- O_2 reduction stops at H_2O_2
- Outcome:
  - COD is used
  - Peroxide is produced in alkaline solution
- 1000 A produces ~15 kg H_2O_2



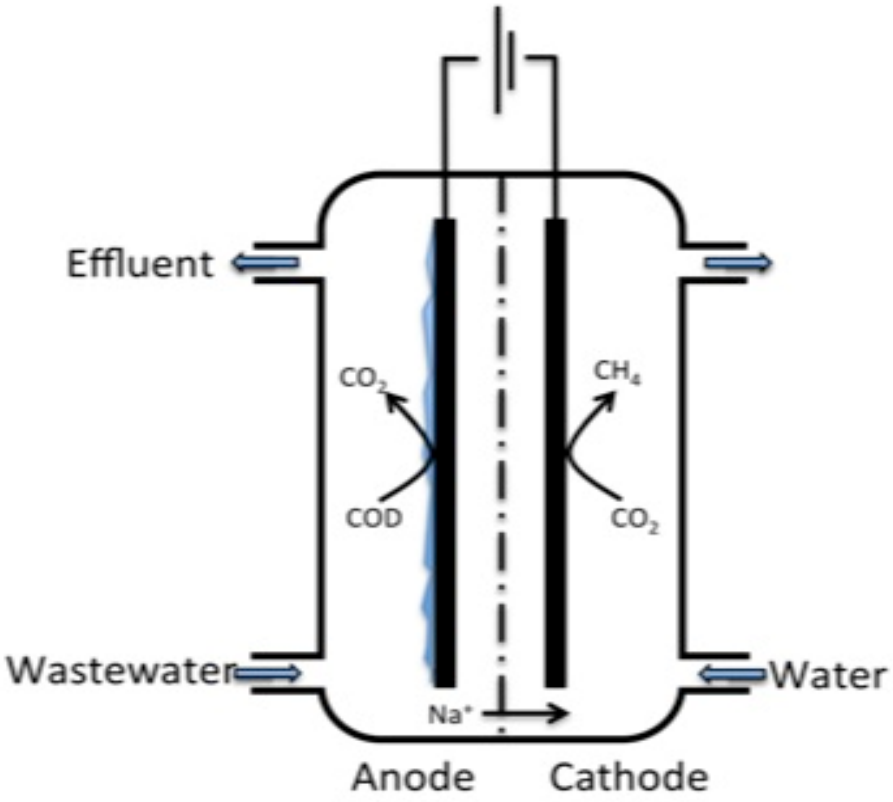
Caustic production from wastewater

- Organics oxidation in anode
- Proton consumption in cathode
- At 1000 A one produces ~35 kg caustic per day



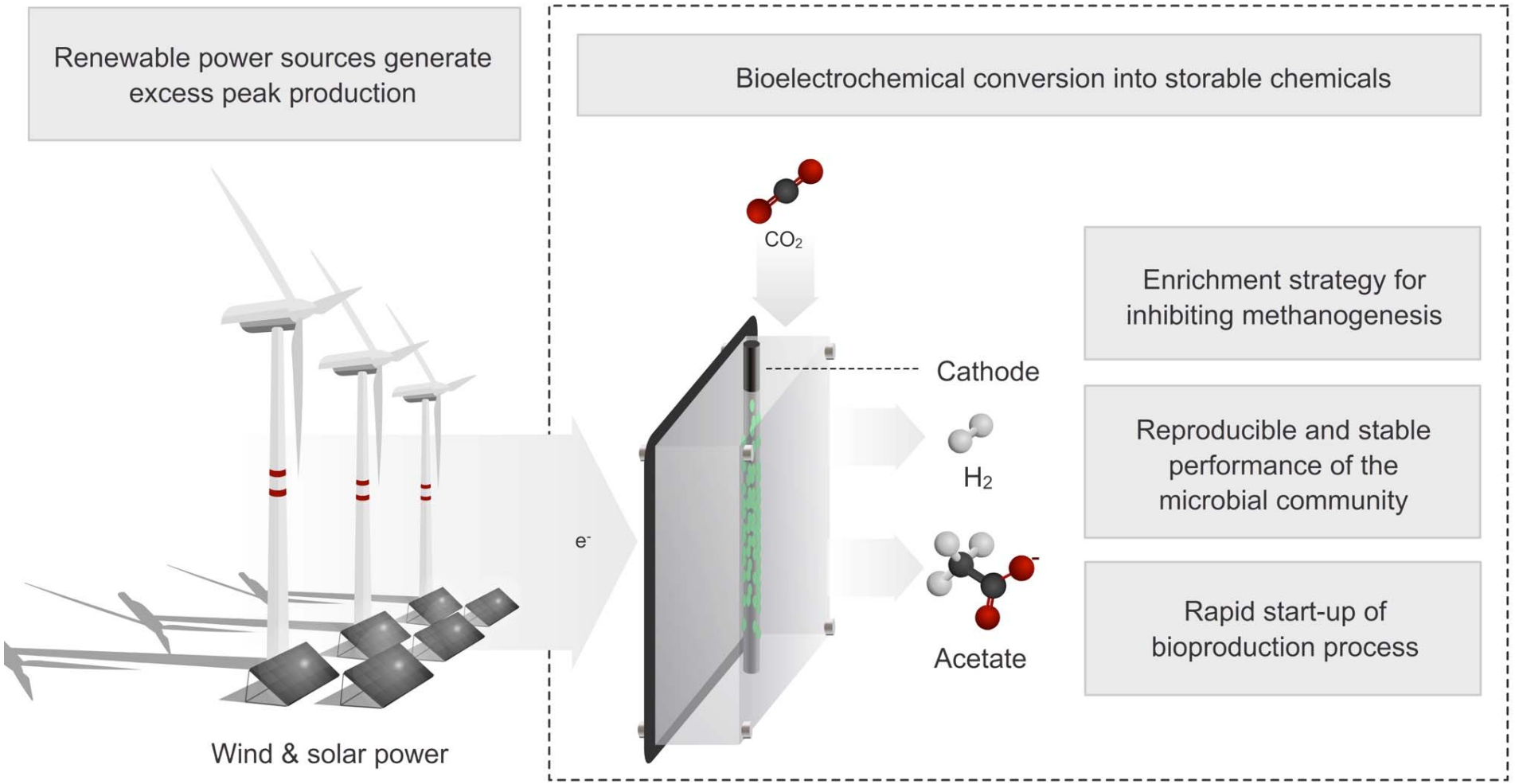


Rabaey *et al.* 2010

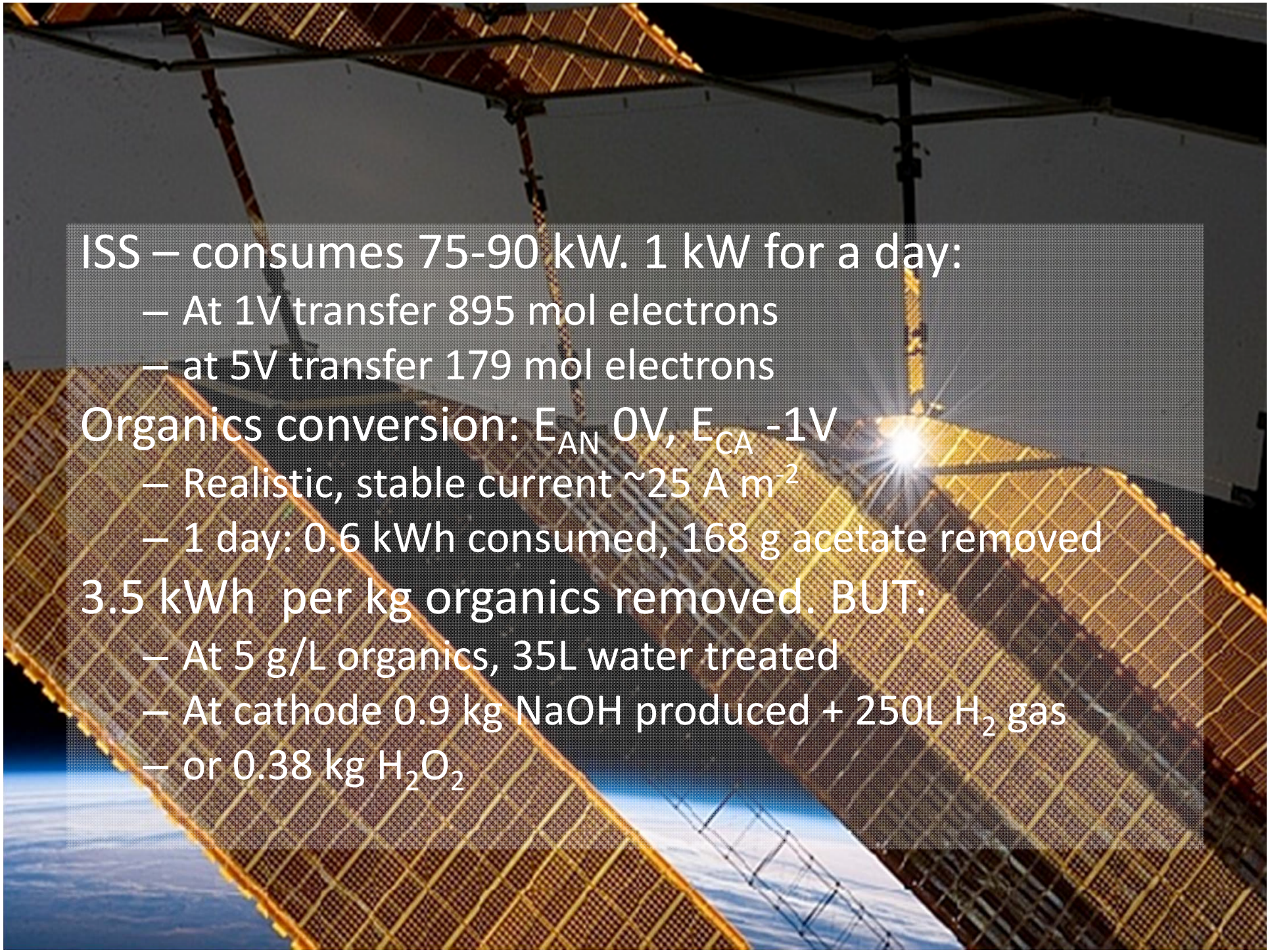


http://cambrianinnovation.com/solutions/ecovolt/

Microbial electrosynthesis



Already at titers >0.5 M acetic acid, and production rates >0.2 kg acetic/m^2.d



ISS – consumes 75-90 kW. 1 kW for a day:

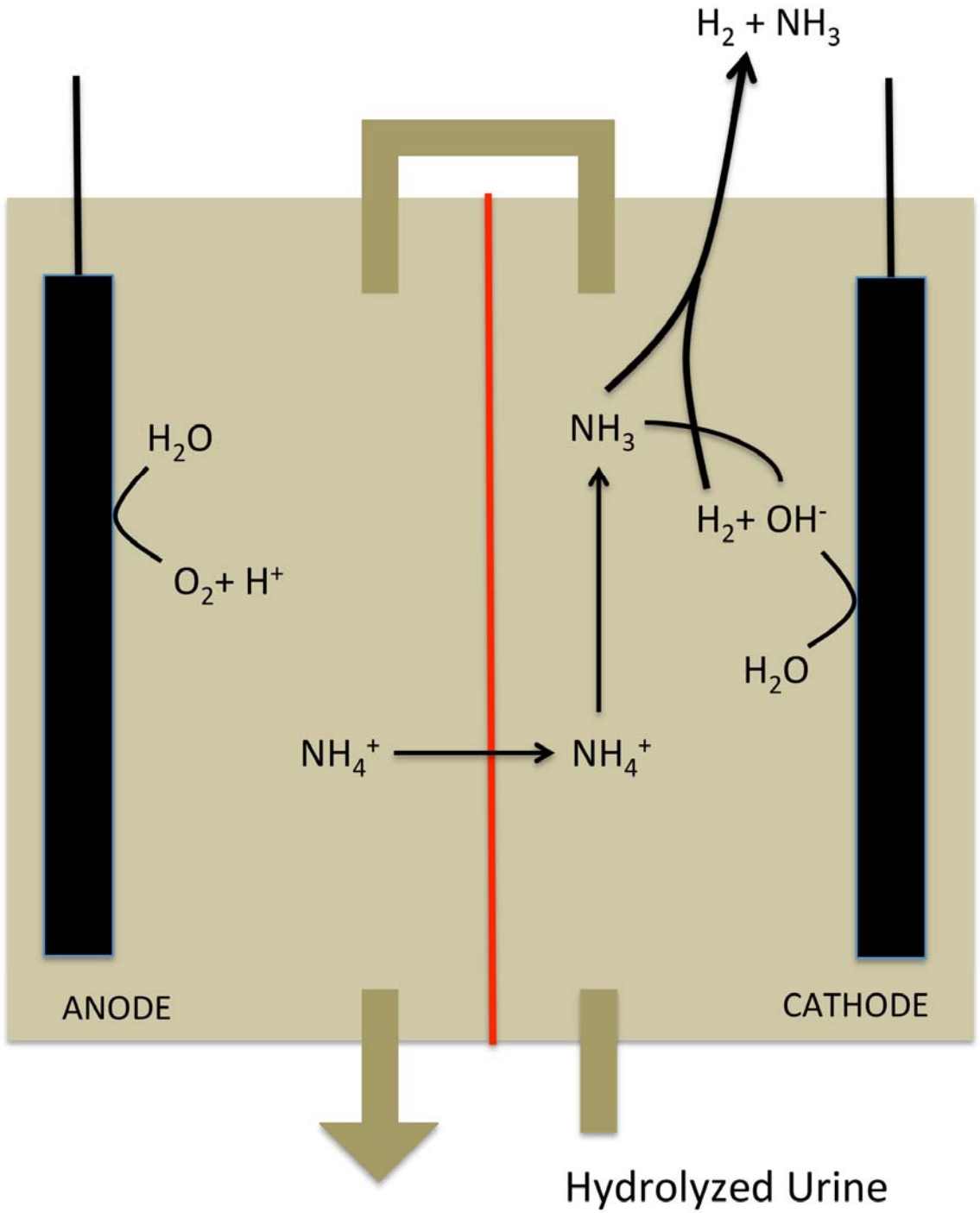
- At 1V transfer 895 mol electrons
- at 5V transfer 179 mol electrons

Organics conversion: E_{AN} 0V, E_{CA} -1V

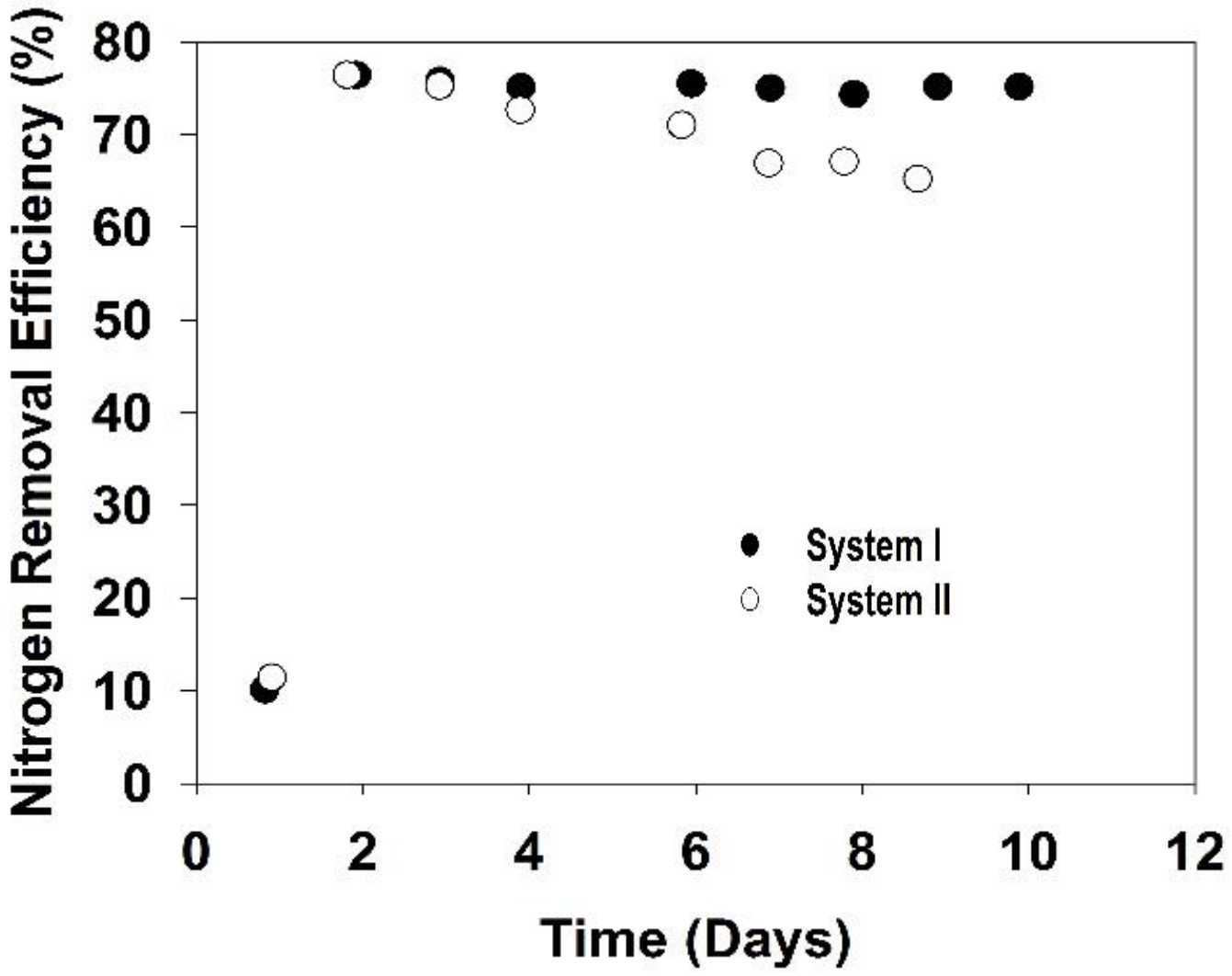
- Realistic, stable current ~25 A m^{-2}
- 1 day: 0.6 kWh consumed, 168 g acetate removed

3.5 kWh per kg organics removed. BUT:

- At 5 g/L organics, 35L water treated
- At cathode 0.9 kg NaOH produced + 250L H_2 gas
- or 0.38 kg H_2O_2


$H_2 + NH_3$
H_2O
$O_2 + H^+$
NH_3
$H_2 + OH^-$
H_2O
NH_4^+
NH_4^+
ANODE
CATHODE
Hydrolyzed Urine

EC performance with real urine



13 kWh/kg without H_2 recovery and 9 with H_2

Luther *et al.* Wat Res 2015

H_2

Urine
Caustic production

NH_3

Urine

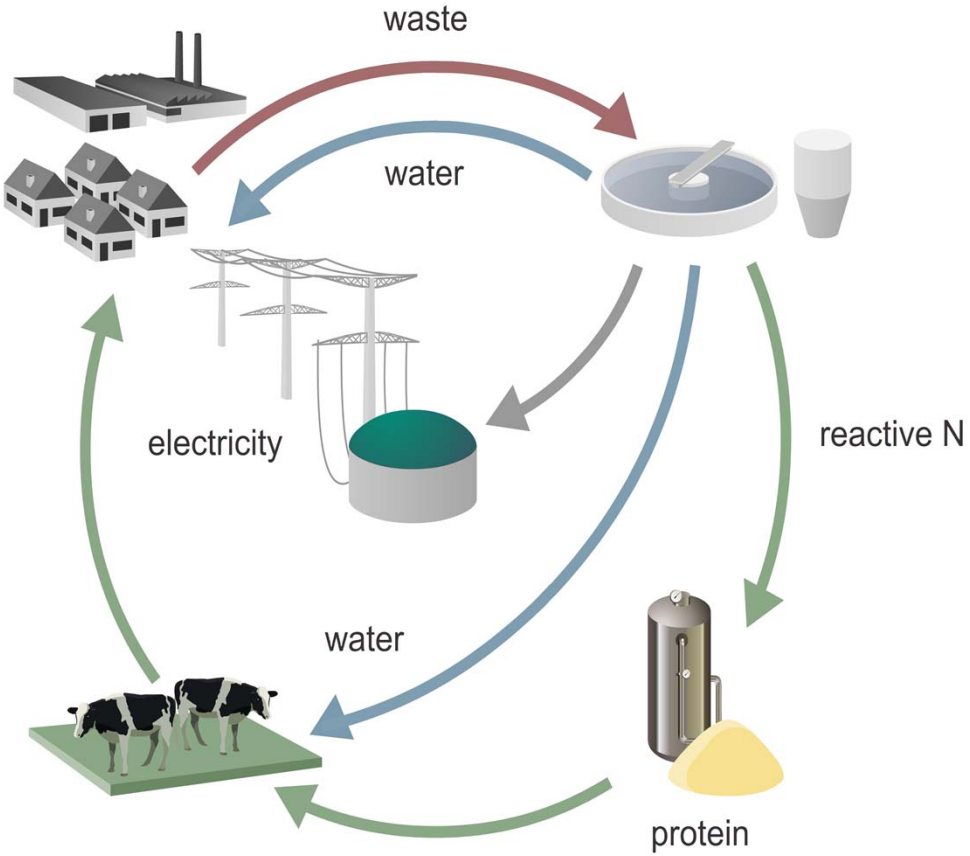
O_2

Acid/base
Plants

CO_2

Biomass
degradation

Single cell protein



Matassa *et al.* 2015

Challenges

- Longevity and selectivity of membranes
- Specificity of electrode reactions
  - DSA
  - Bio-anode
- Reactor engineering, particularly in context of solids handling

Enablers

- Ability to drive whole cycle with electricity, instead of chemicals
- Biology increasingly understood
- High level of controllability
  - Realtime
  - No “sensor” failures
- Systems simple in approach
- Self-cleaning

European Research Council
Established by the European Commission

CMET

support good ideas

Caravel-Ivan Henriques, 2016