SolydEra

Inst. Mech.Engin.

Group of Energy Materials (GEM)

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Efficient energy conversion including CO_2 capture

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Content

- Solid oxide fuel cells (SOFC) with CO_2 capture
  - Oxycombustion
  - Microturbine addition for extra power generation
- Reversible SOFC-Solid oxide electrolysis (SOE)
- Methanation ($4\ H_2 + CO_2 \Rightarrow CH_4 + 2\ H_2O$)
  - Integrated heat recovery for higher efficiency
- Waste gasification to clean syngas
- Microbial $CO_2 \Rightarrow CH_4$ electrocatalysis

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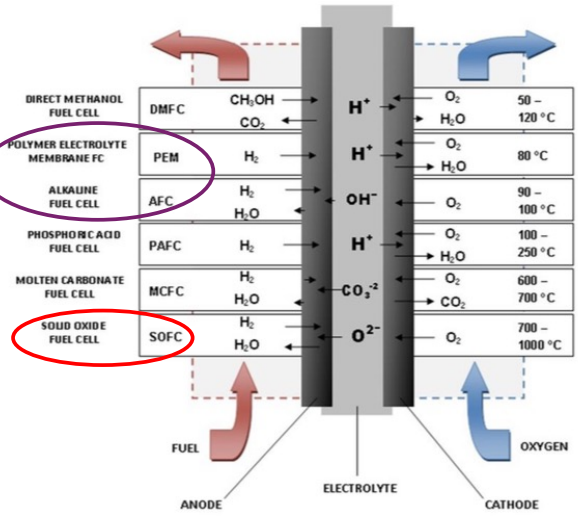
Fuel cell technologies overview

Recent work at EPFL-GEM

Main research at EPFL-GEM



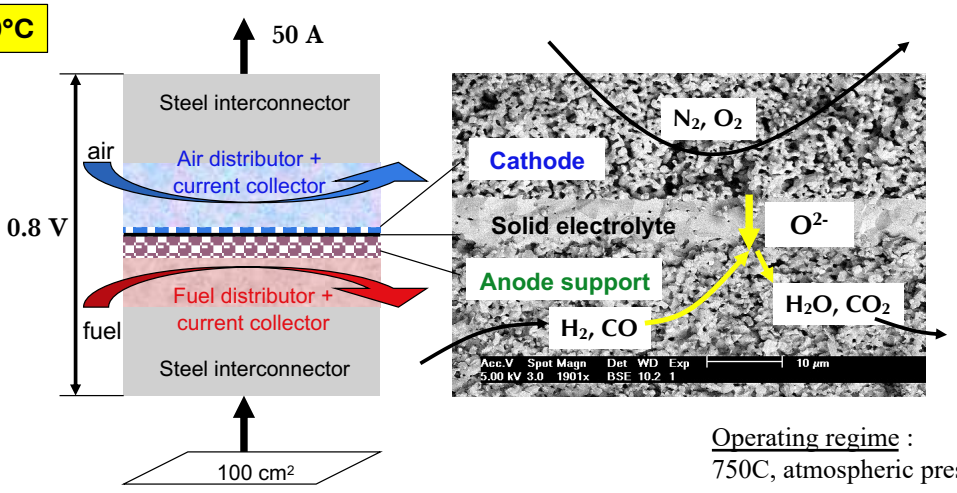
Available sizes	Electrical efficiency	Applications
10 W - 1 kW	20-30 %	Portable electronic systems
1 kW - 100 kW	~45 %	Vehicles, small CHP systems
100 W - 10 kW	60-70 %	Space vehicles
100 kW - 10 MW	~40 %	CHP systems
100 kW - 10 MW	~50 %	CHP systems
1 kW - 10 MW	~60 %	CHP systems

A fuel cell is a 'gas battery', converting a fuel flow continuously into electricity and heat.
An ambient temperature fuel cell runs on H_2. A hot fuel cell typically runs on natural gas.

=> mobility application => stationary application

SOFC (solid oxide fuel cell)

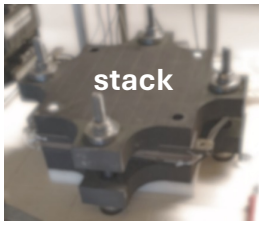
700-800°C

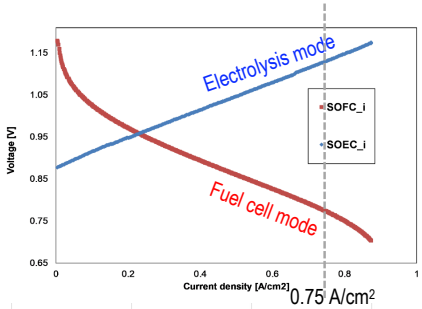


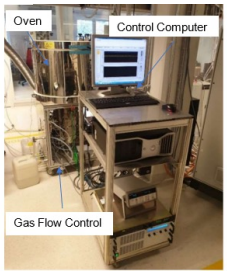
Operating regime :
750C, atmospheric pressure

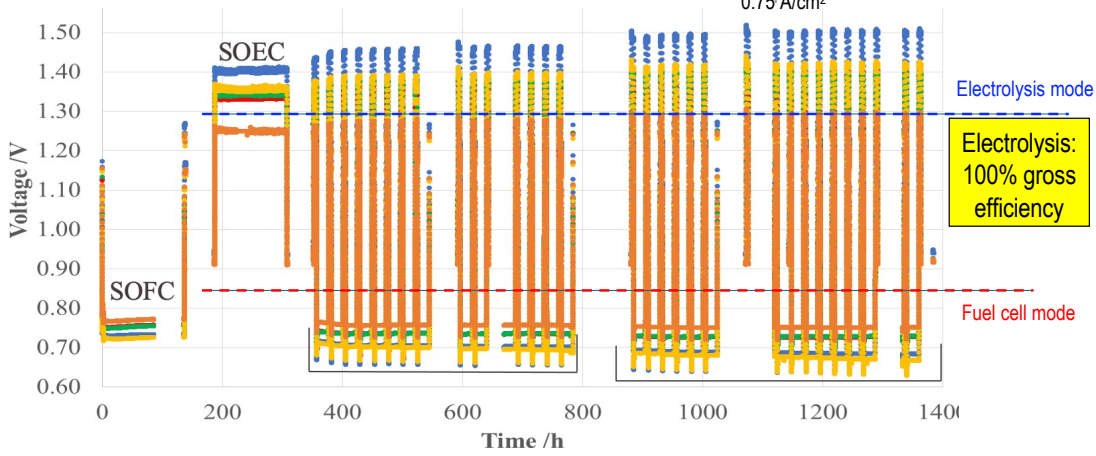
Reversing the flows, the fuel cell becomes a **solid oxide electrolyser (SOE)**, converting H_2O (steam) and CO_2 back to fuel (H_2, CO) : electrical 'Power-to-Gas' storage

Fully reversible operation validated ✅









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rSOC EU project 'SWITCH'

SWITCH – 'Smart ways for in-situ totally integrated and continuous multisource generation of hydrogen'

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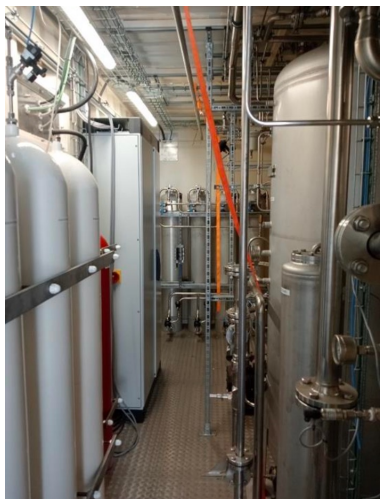
SWITCH (2020-2024)

https://switch-fch.eu/



- **75 kWe** steam electrolyser / **20 kWe** fuel cell
- < 40 kWhe/kg H_2 electrolysis mode
- Output up to 8 bar dry pure H_2
- Fuel cell mode > 60% elec. efficiency
- All safety & control developed

Winner of International Energy Agency (IEA) H_2 Technology Collaboration Programme (TCP) **Award of Excellence 2024.** https://www.ieahydrogen.org/hydrogen-tcp-awards/

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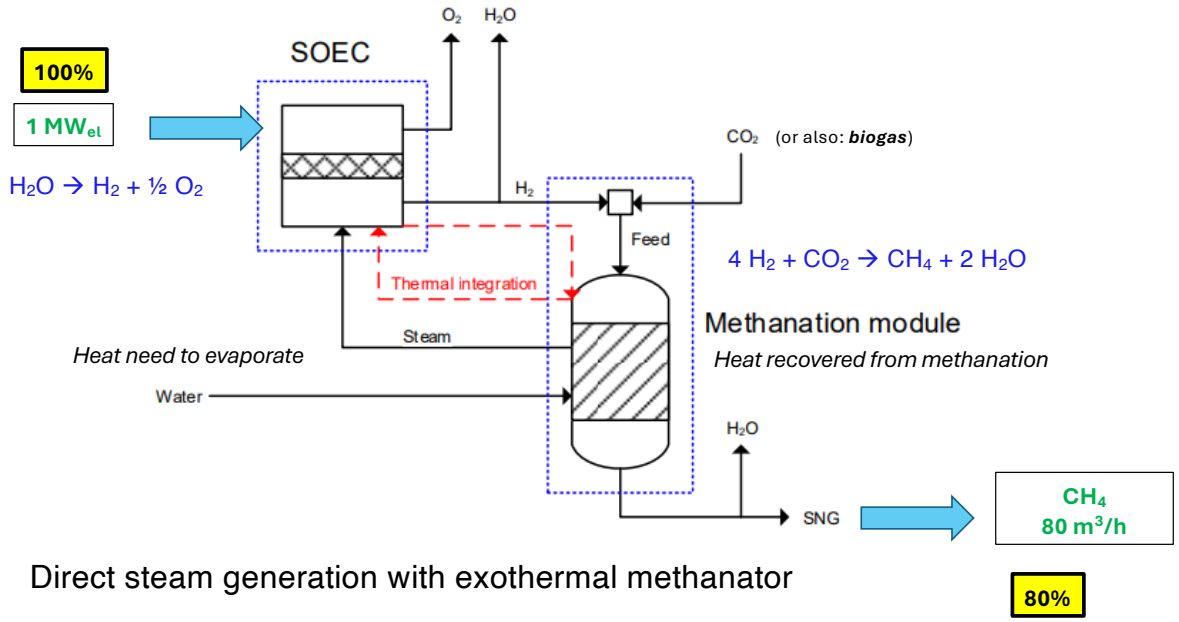
Integrate methanation

Key features & motivation to use solid oxide technology in energy conversion

1) Power-to-Gas using CH_4 and the natural gas grid
2) Regenerate CH_4 from CO_2 via **methanation** with green H_2
3) The most efficient electrolysis to provide H_2 is from **steam** (20-30% less electricity need than from **water** electrolysis) : **SOE**

   ? Where is the heat for **steam** production coming from ?
4) => **steam** is provided from the downstream **methanation heat** => integrated system => highest efficiency (**lower OPEX**)
5) When electricity is not stored but demanded, the same system can **switch** to the **reverse** mode (fuel cell - **SOFC**) – **only 1 CAPEX** (not 2)
6) Closed loop between CH_4 and CO_2 – virtually no emissions

(Methanation) heat-integrated Power-to-CH_4



Direct steam generation with exothermal methanator

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(fossil) CH_4-to-CO_2-to-CH_4 (green)

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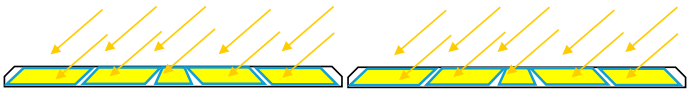

Operation as electrolyser: $H_2O \rightarrow H_2 + ½ O_2$
- daytime, summer
- producing CH_4

PV-electricity

Electrolysis operation

Fuel cell operation

700°C

air (O_2)

N_2

O_2

$CH_4 + O_2(air) \rightarrow 2H_2O + CO_2$

Operation as fuel cell:
- nighttime, winter
- converting CH_4

Gas grid CH_4

PV

Fuel cell : $CH_4 \rightarrow CO_2$ + 60% + 30%

Electrolyser : CO_2 + + → CH_4

Methanator

$4H_2 + CO_2 \rightarrow 2H_2O + CH_4$

H_2

steam

200°C

15 bar

CH_4

H_2O

CO_2

H_2O

CO_2 recovery

Gas grid CH_4

CH_4 and CO_2 in closed loops without emissions. Suitable for buildings with PV and gas supply.

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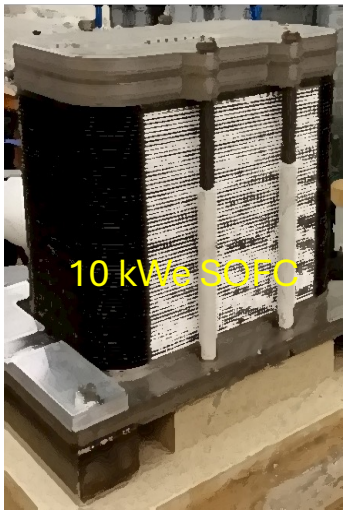
SOFC+micro gas turbine

High-efficiency gas hybrid fuel-cell turbine system with CO_2 separation



https://www.epfl.ch/labs/lamd/

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École polytechnique fédérale de Lausanne

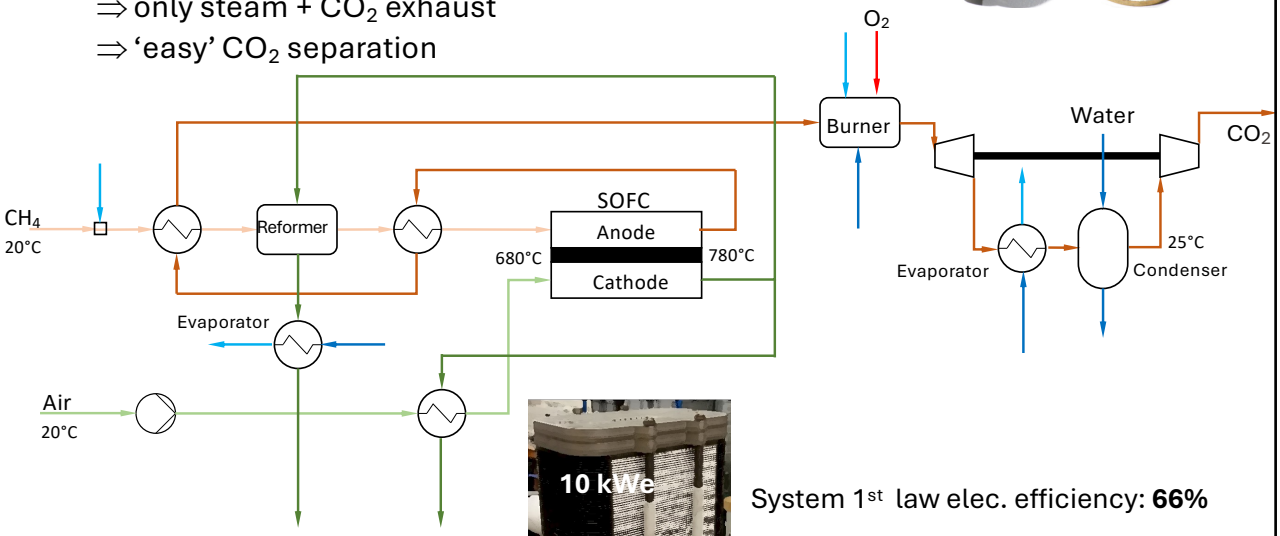
Swiss National Science Foundation

BRIDGE

Integration of micro-GT to a reversible SOC system

1 kWe

Oxy-combustion of FC exhaust
⇒ only steam + CO_2 exhaust
⇒ 'easy' CO_2 separation



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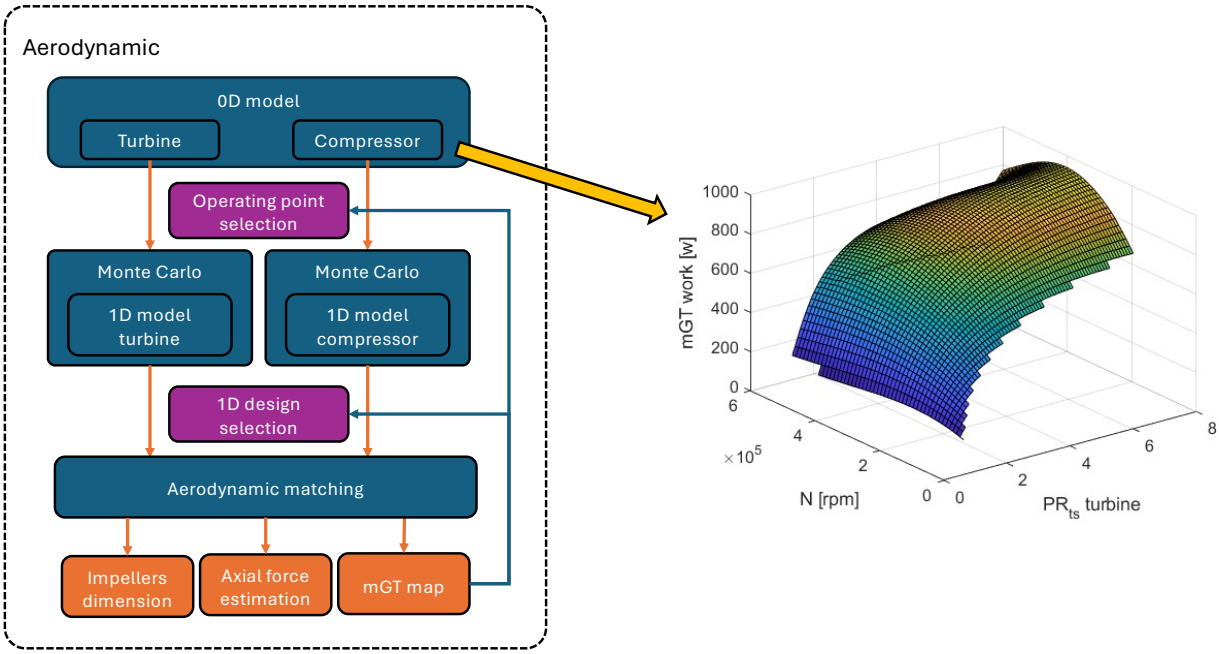
System 1st law elec. efficiency: **66%**

Steam (130°C)
Liquid water

Micro Gas Turbine Design Approach

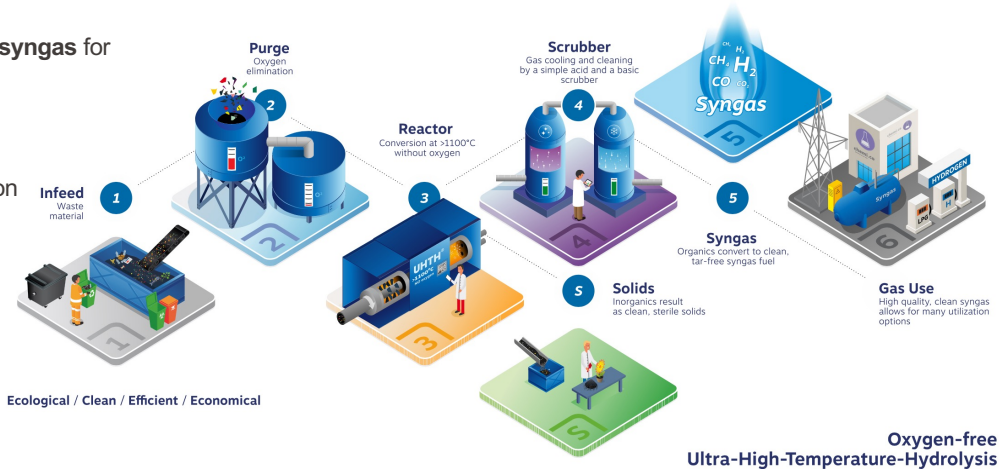


Solid waste-to-energy (C-negative)

Clean Carbon Conversion (CCC) waste gasification technology

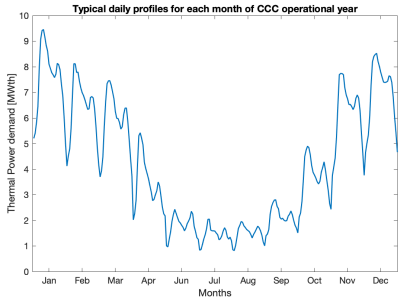
https://cleancarbonconversion.com/

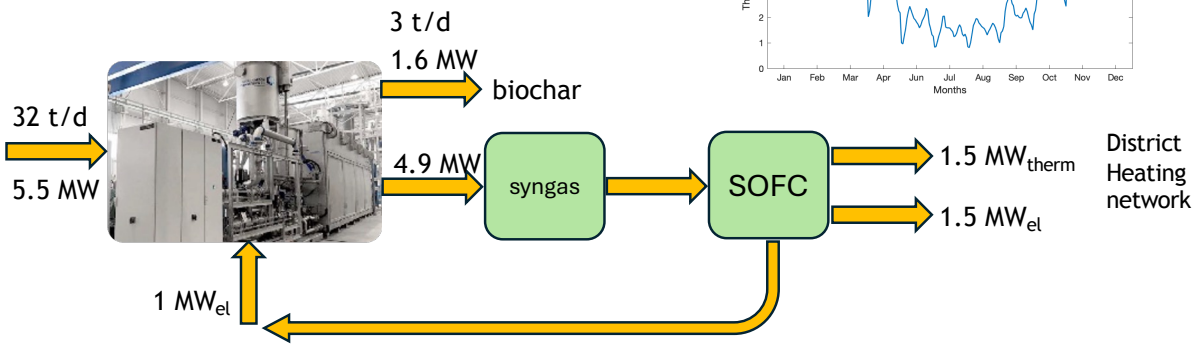
- Ultra-High-Temperature-Hydrolysis (>1100°C)
- High variety of infeed ('all solid wastes')
- Automation of process
- **Tar-free scrubbed syngas** for
  - Co-generation
  - H_2 extraction
  - CH_4 extraction
- Carbon sequestration (biochar)



Energy balance

Dynamic heat demand profile of district heating network





- The essential improvement is clean syngas production (tar-free, no fouling isues)
- SOFC, thanks to high electrical efficiency, enhances overall system performance, incl. for dynamics of heat demand

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Microbial catalysis of CO_2

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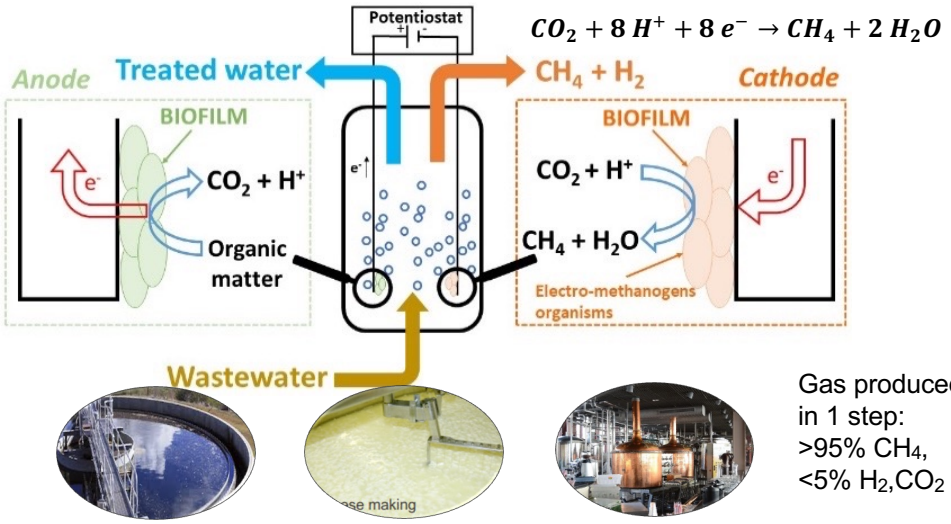
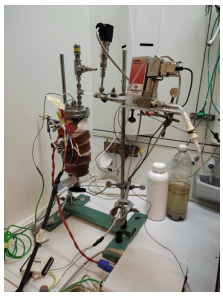
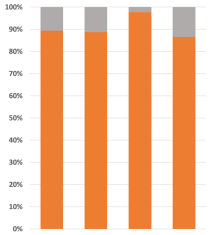
Bio-electrical systems (BES)

- In BES, the methanation of CO_2 is electrocatalyzed **in a single step at ambient P & T, using microbes as renewable catalyst**.
- The microbes - **methanogenic bacteria** (*Archaea*) - act as electron bridges to reduce the high energy step from CO_2 to CH_4. Only a small amount of electrical energy is needed to maintain microbial conversion.





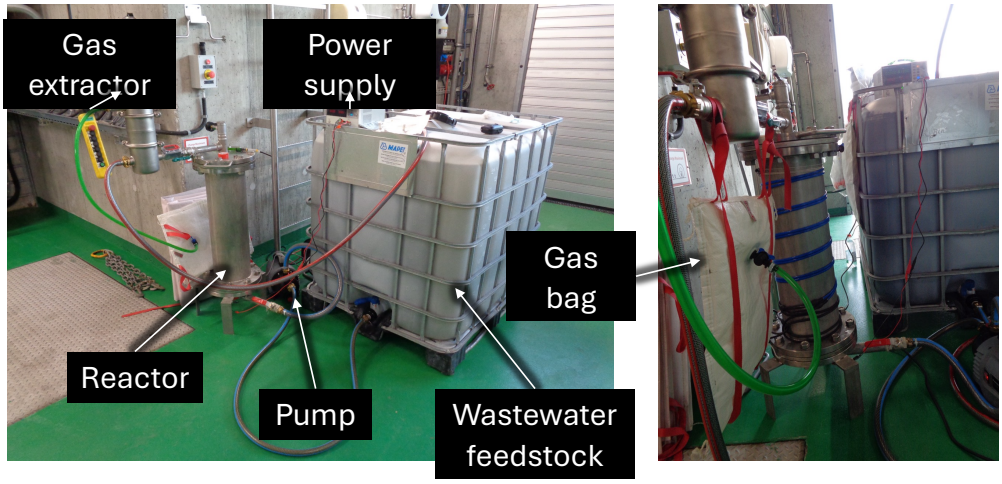


Gas produced in 1 step: >95% CH_4, <5% H_2,CO_2

The business case is lowering the **COD** (**chemical oxygen demand**) of the WW treatment

BES prototype in operation

- 30 L microbial electrolysis reactor installed in waste water treatment plant WWTP (Valais)



Perspective : turn energy-negative WWTP into energy-**positive** plant

Potential in Switzerland : double WWTP bio-CH_4 production from 1.5% to 3% of NG import