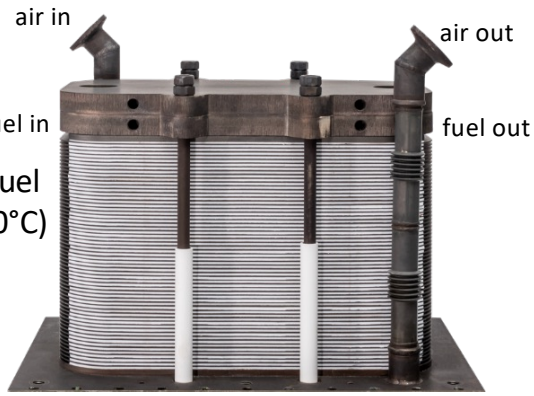
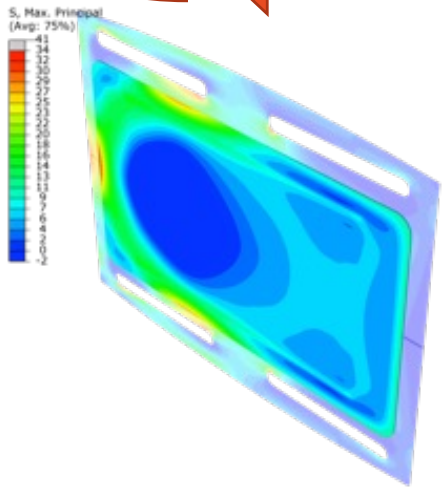
GROUP of ENERGY MATERIALS

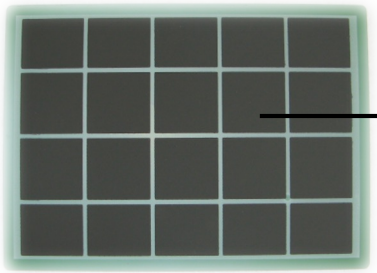
MER Jan Van herle
gem.epfl.ch

- diagnostics laboratory (**fuel cells/electrolysis**)
  - stacks ; cells ; components
  - 'high T' (700°C); 'low T' (70°C)
- coupled with modeling from micro-to-macro:
  - electrode microstructures 3D quantification
  - electrochemistry ; thermomechanics ; fluid mechanics
  - thermal integration, system optimisation



validation





ceramic cell 80 cm^2

GROUP of ENERGY MATERIALS

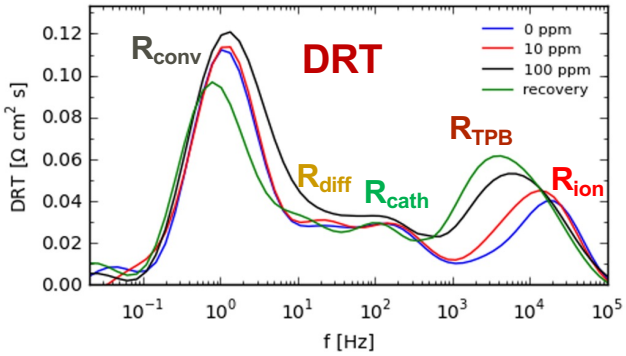
Examples of projects:

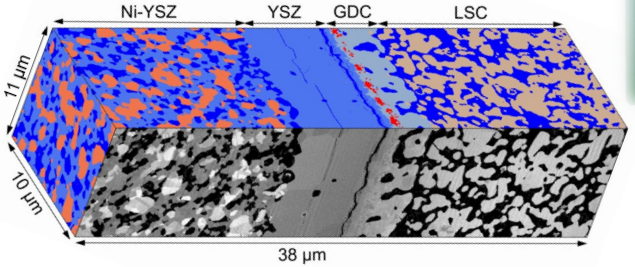
- Energy vectors : H_2, CH_4, (m)ethanol, ammonia NH_3, biofuels,…
- Dimensioning of components : heat exchangers, fuel reformer, catalytic reactor, flow fields...
- Testing of fuel cells / electrolysers. Data analysis
- **Steam** electrolysis (100% elec. efficiency). Alcaline **water** electrolysis.
- Fabrication of layers : ink-jet printing, PVD, spray coating,…
- Bio-electro-methanation (organic waste-waters => bio-methane)
- Automation, control of test devices (e.g. recirculation loops,…)
- Electrochemical Impedance Spectroscopy (EIS)
- Electron microscopy investigations (SEM/TEM)
- Techno-economic analysis (with IPESE, Prof François Maréchal)
- Life Cycle Analyses (with Prof Manuele Margni, HESSO Sion)
- see https://www.epfl.ch/labs/gem/student-projects/
- contact : jan.vanherle@epfl.ch

Jan Van herle

EPFL GROUP of ENERGY MATERIALS

Contaminant poisoning

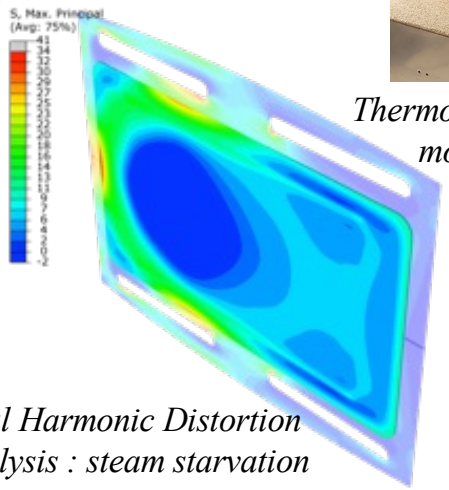




11'000 h stack; 3D-EDX

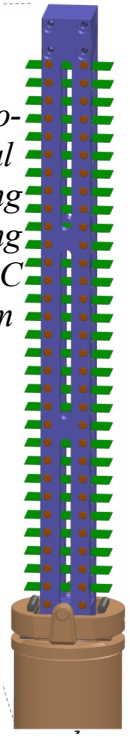
18'000 h test
spatially resolved
20 x 4 cm²

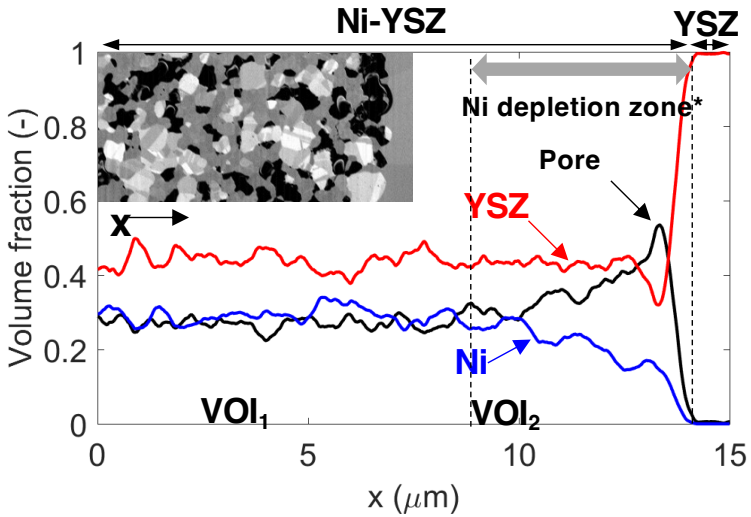
Segmented SRU



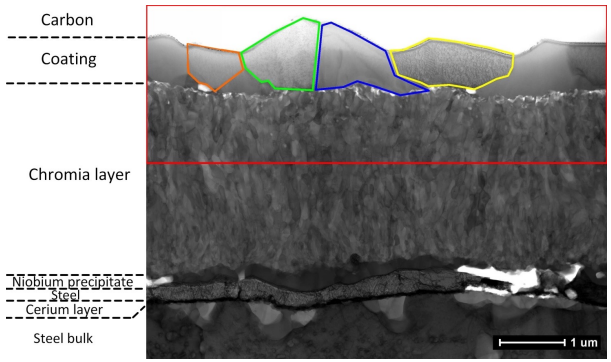
Thermomech. modeling

Thermo-mechanical testing
4-p bending
800°C
Air, H_2, steam

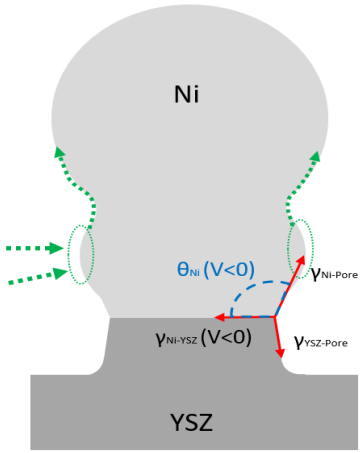




PVD coated MIC; TEM-EDX

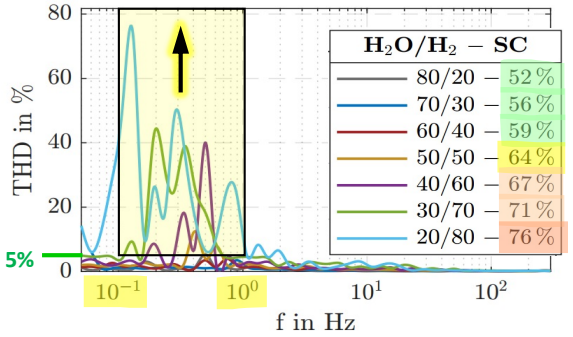


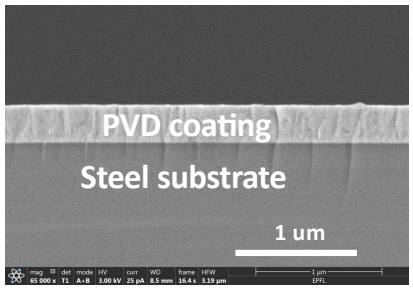
Ni catalyst wetting



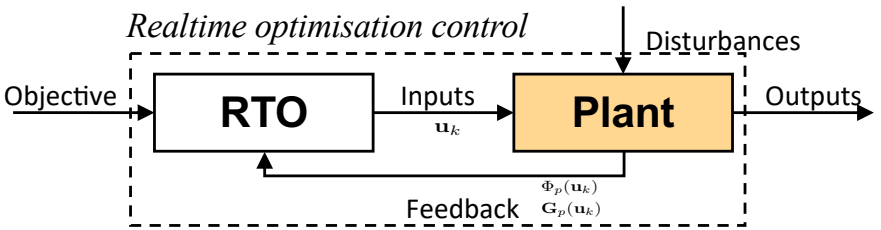
SOEC polarization

Total Harmonic Distortion Analysis : steam starvation





Realtime optimisation control



Past master semester projects

- 76. (JUN2019) Study of the oxidation of Co-Ce coated steels for SOFC interconnects by SEM-EDX
- 82. (JUN2020) PEFC electrochemical stack model
- 87. (JAN2022) Design exploration of a SOFC-battery hybrid power supply for 50 pax electric aircraft
- 91. (JUN2022) Multi-objective optimization and economic analysis of an EV charging station using SOFC
- 92. (JUN2022) Cooling strategies of a PEM fuel cell using CFD
- 96. (JUN2022) Anionic membranes screening and analysis / gas crossover
- 105. (JUN2023) Protective coatings for Solid Oxide Cell (SOC) interconnect by ink jet printing
- 107. (JUN2023) LCA of Anionic Membrane Water Electrolysis
- 114. (JAN2024) Degradation analysis of single-cell accelerated stress tests via electrochemical impedance spectroscopy and distribution of relaxation time methods
- 117. (JAN2024) Insitu growth of Ni-Fe electrocatalysts on porous transport layer for O_2 evolution reaction in alkaline conditions
- 120. (JUN2024) Assessment of lithium vs sodium batteries
- 122. (JUN2024) Understanding Solid Oxide Electrolysers (SOE) fault conditions footprint by using Electrochemical Impedance Spectroscopy (EIS) and Total Harmonic Distortion (THD) diagnostic tools
- 123. (JUN2024) Performance and stability of metal-supported Solid Oxide Electrolysis Cells
- 125. (JUN2024) Investigating Solid Oxide Cells degradation via advanced 3D microscope reconstruction analysis: from image segmentation to microstructural characterization

Past master thesis projects (1)

- 48. (SEP2020) **CGN-Lausanne**, Layout of a H_2-electrical propulsion for a 1.8 MW ship
- 49. (SEP2020) Using NH_3 in SOFC (*publication*)
- 56. (AUG2021) **Swisshydrogen**, Development of compact FC range extender for automotive applications
- 59. (JAN2022) Modeling and experimental investigation of critical conditions in reversible solid oxide cells using State-of-Health online monitoring
- 60. (JAN2022) Design and optimisation of a heat exchanger network for an integrated reversible SOFC system
- 61. (FEB2022) **Stadler**, Development of a simulation tool to optimize the design of hybrid propulsion systems on railway vehicles
- 64. (JUN2022) Conception et expérimentation d'un réacteur bioélectrochimique produisant du biogaz riche en méthane à partir d'eaux usées
- 65. (JUL2022) Stability of methane reforming catalysts towards sulfide contaminants

Past master thesis projects (2)

- 67. (AUG2022) **Michelin**, Modélisation d'une pile à combustible à membrane polymère PEMFC
- 68. (AUG2022) **Engie**, Thermodynamic modeling of Hydrogen Refueling Station
- 72. (FEB2023) **Voltiris**, How can greenhouses become carbon neutral and self-sufficient? (=> Thesis Award)
- 74. (FEB2023) Two-Phase Simulation of AEM Electrolyser Flow Channels (=> Patent application)
- 75. (FEB2023) Membrane Electrode Assembly Simulation of AEMEL
- 77. (MAR2023) **EH Group**, Modelling and dimensioning of a PEMFC active humidifier
- 79. (JUL2023) LCA of improved SOFC - Focus on operation phase and end-of-life
- 80. (AUG2023) **Safran**, Instrumentation de pile à combustible PEMFC
- 87. (AUG2024) Life cycle assessment of electrolyzer and fuel cell technologies
- 90. (AUG2024) **Beyond Aero**, Aviation Energy Efficiency: Hybridization Strategies for Battery and Fuel Cell Systems
- 91. (AUG2024) CFD modelling and analysis of ejectors for the recirculation of fuel in a SOC system
- 92. (AUG2024) **Schindler**, Approaches for energy storage and reuse in an elevator
- 94. (AUG2024) Characterisation and analysis of PEMFC cells and stacks
- 95. (NOV2024) **Berkeley**, Development of active composite interlayer in solid-state batteries to prevent their failure

Examples

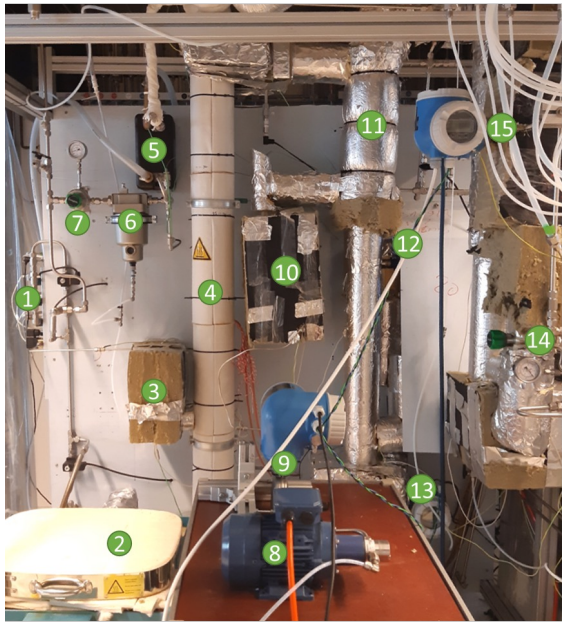
Student project proposals

Scaling an existing 5 kW methanation reactor to a 20 kW power-to-methane system

Jan Van herle

$$4H_2 + CO_2 \rightarrow H_2O + CH_4$$
$$3H_2 + CO \rightarrow H_2O + CH_4$$

- Tasks:
  - Use existing reactor simulation code to dimension the scale-up version of the reactor.
  - Design the BoP of the 30 kW methanation unit.
  - Design the cooling water manifold: CAD and CFD simulations.



Reaction Gases
1. Gas Supply
2. 1st Injection Gas Pre-heater
3. 2nd Injection Gas Pre-heater
4. Reactor
5. Condenser
6. Condensate Separator
7. Back-pressure Controller

Cooling System
8. Make-up Pump
9. Make-up Water MFM
10. Water Pre-heater
11. Steam Separator
12. Recirculating Pump
13. Recirculating MFM
14. Vapor Back-pressure Controller
15. Vapor Mass Flow Meter

[1] P. Aubin, L. Wang and J. Van herle, "Evaporating water-cooled methanation reactor for solid-oxide stack-based power-to-methane systems: design, experiment and modeling," *Chemical Engineering Journal,* 2023.

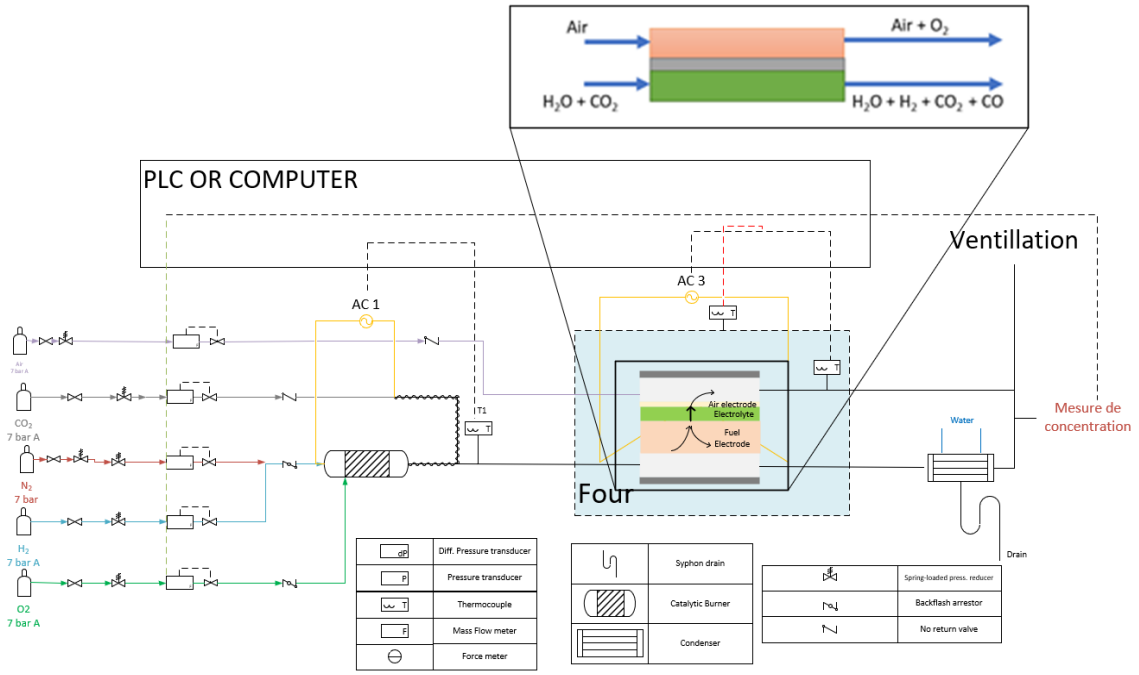
Control of the outlet composition in co-electrolysis of steam and CO_2

Jan Van herle

Co-electrolysis: $nH_2O\ (steam) + mCO_2 \leftrightarrow nH_2 + mCO + \frac{n+m}{2}O_2$

- Depending on the post-process, the modular number (M) will vary:

$$M = {H_2 - CO_2}/{CO_2 + CO}$$



- **Tasks:**
  - Use a single cell setup to develop a control algorithm based on the target modular number for a specific power input.
  - Test on a stack.

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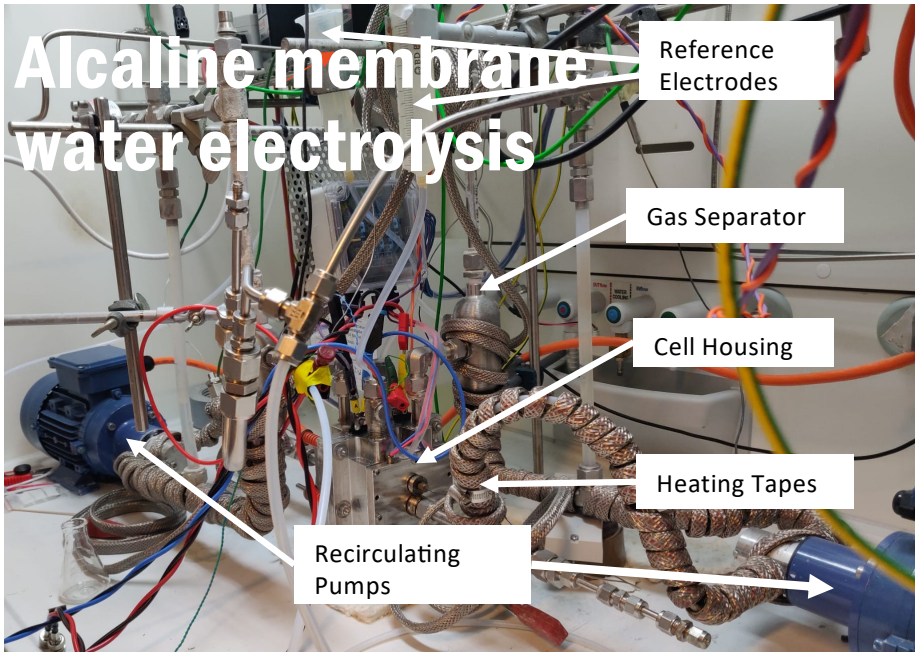
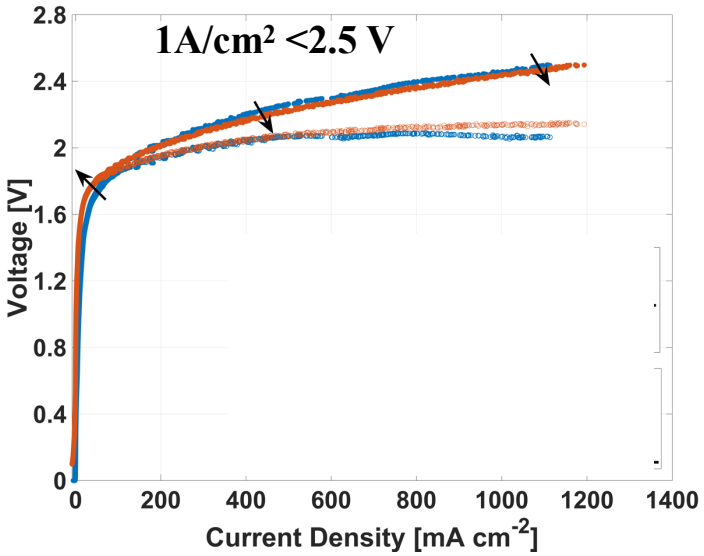
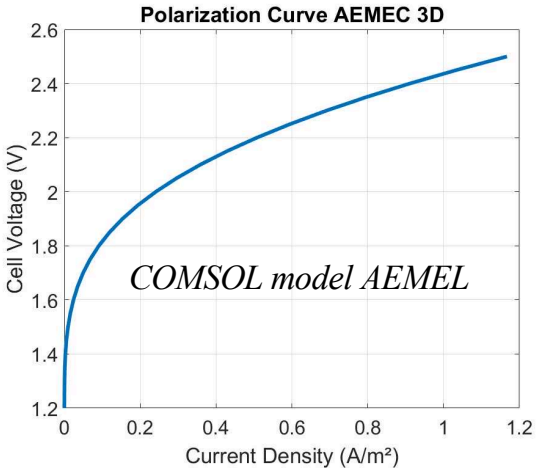
AEMEL

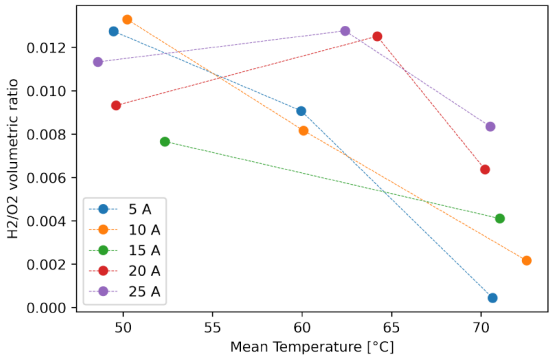


Reference electrodes, pressurization, electrolyte recirculation, gas analysis

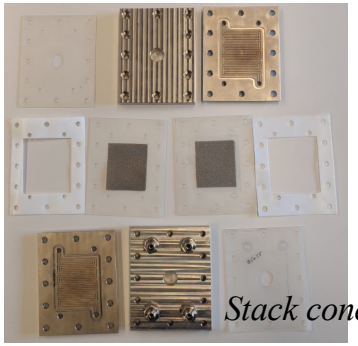


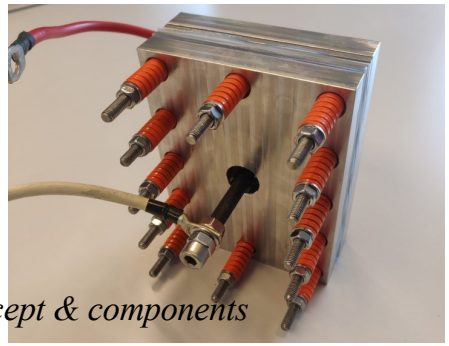


Gas crossover measurements

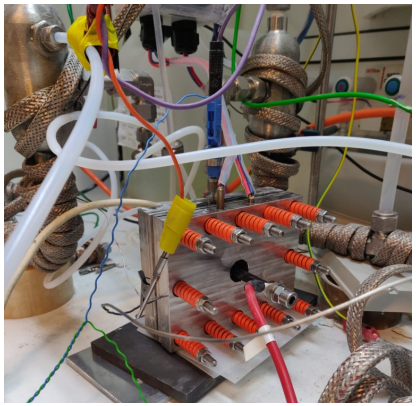


(b) Hydrogen crossover for the Fumasep FAA-3-PK-75 membrane at different current bias

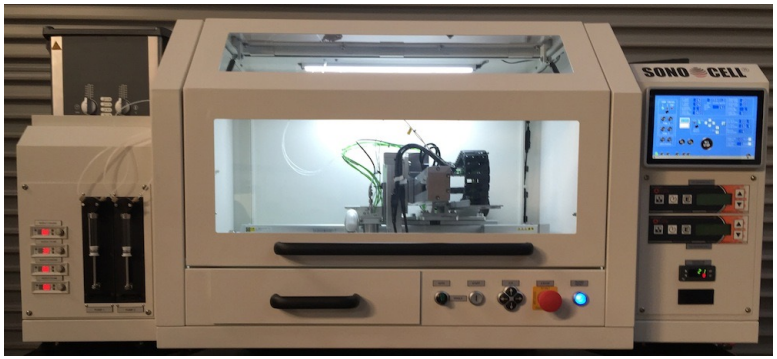




Stack concept & components



Ultrasonic spray coater for catalysts



Stack Performance @ 1 M KOH, 60 °C, 1 atm

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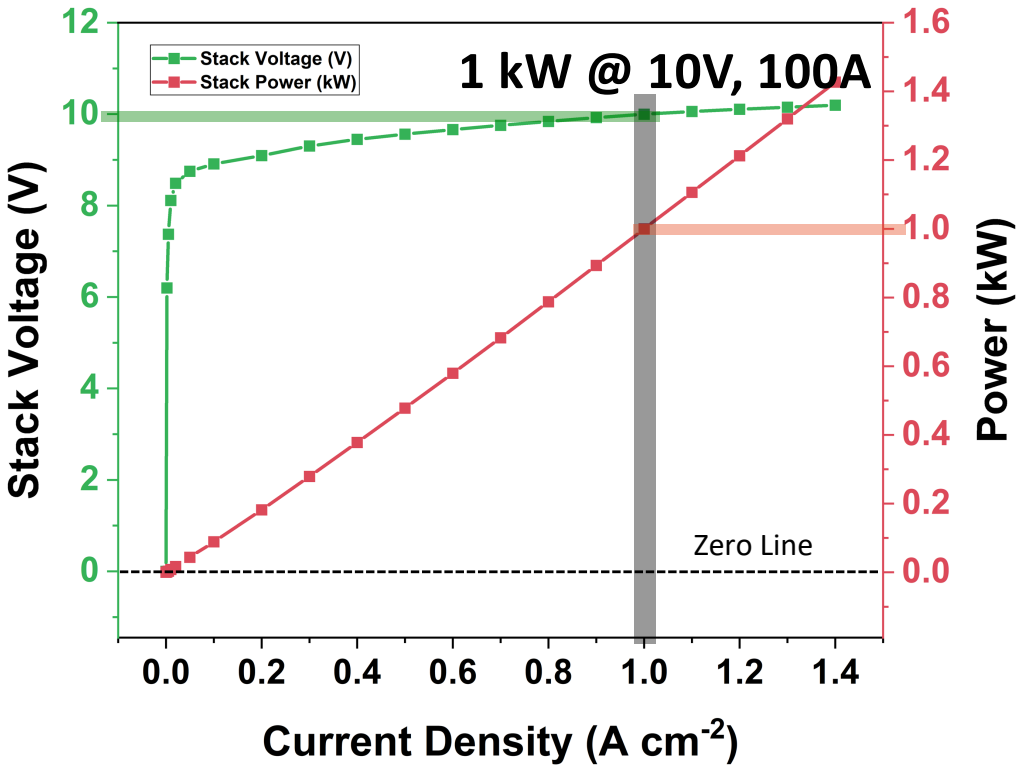
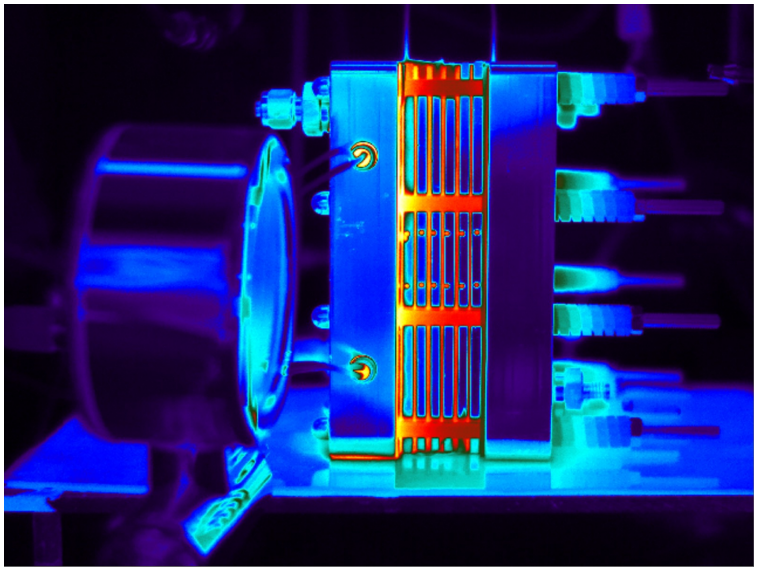


- AEMWE **stack** reached **1 kW @10V, 100A** DC current
- vol. density **7 kW_{H2}/L** of stack



Corrosion-protective coatings on steels (ink-jet printing)

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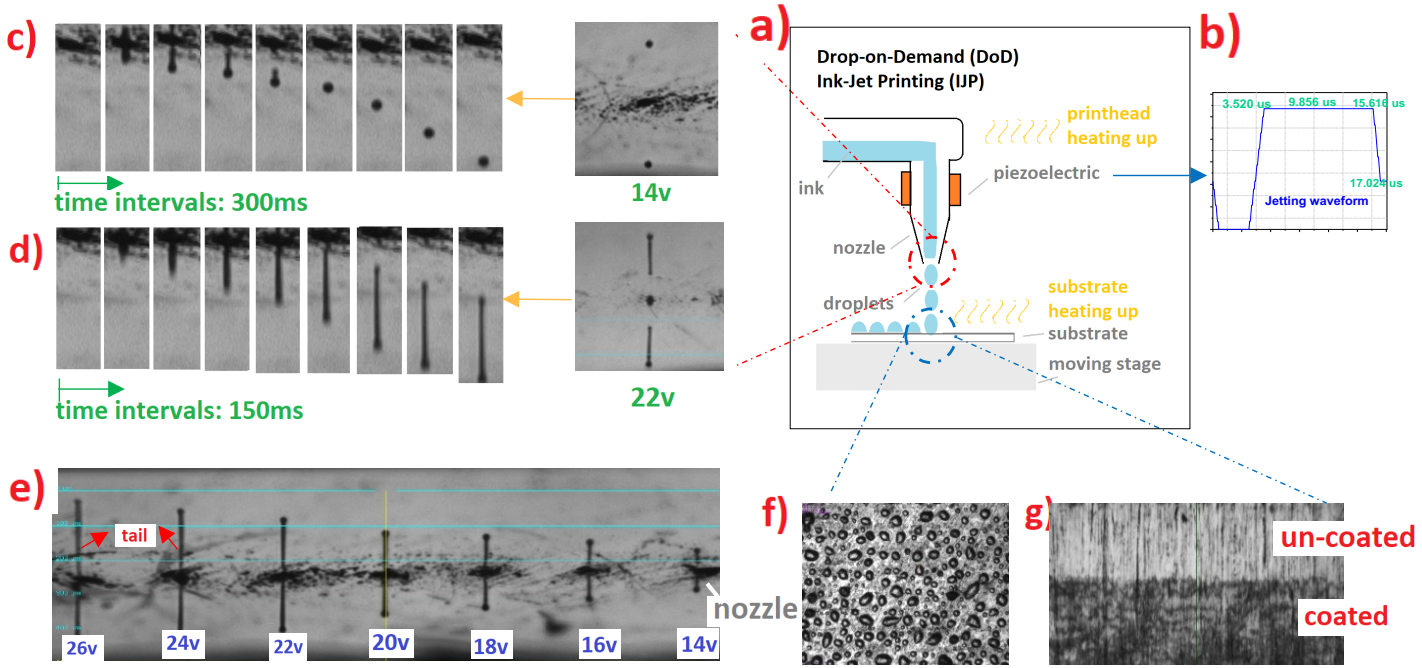
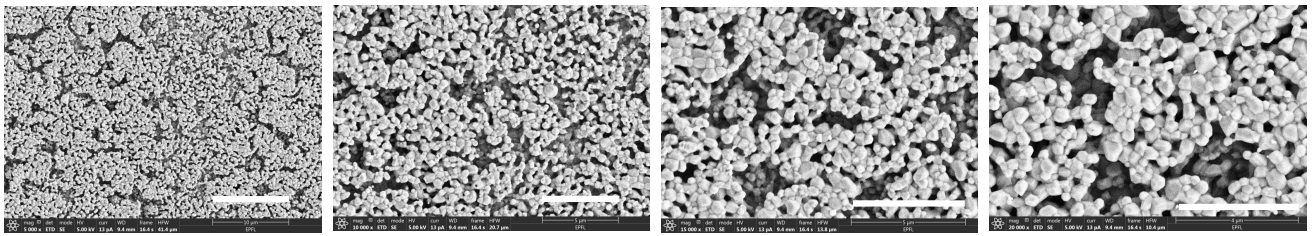


Printed samples thermally cured @ 800°C



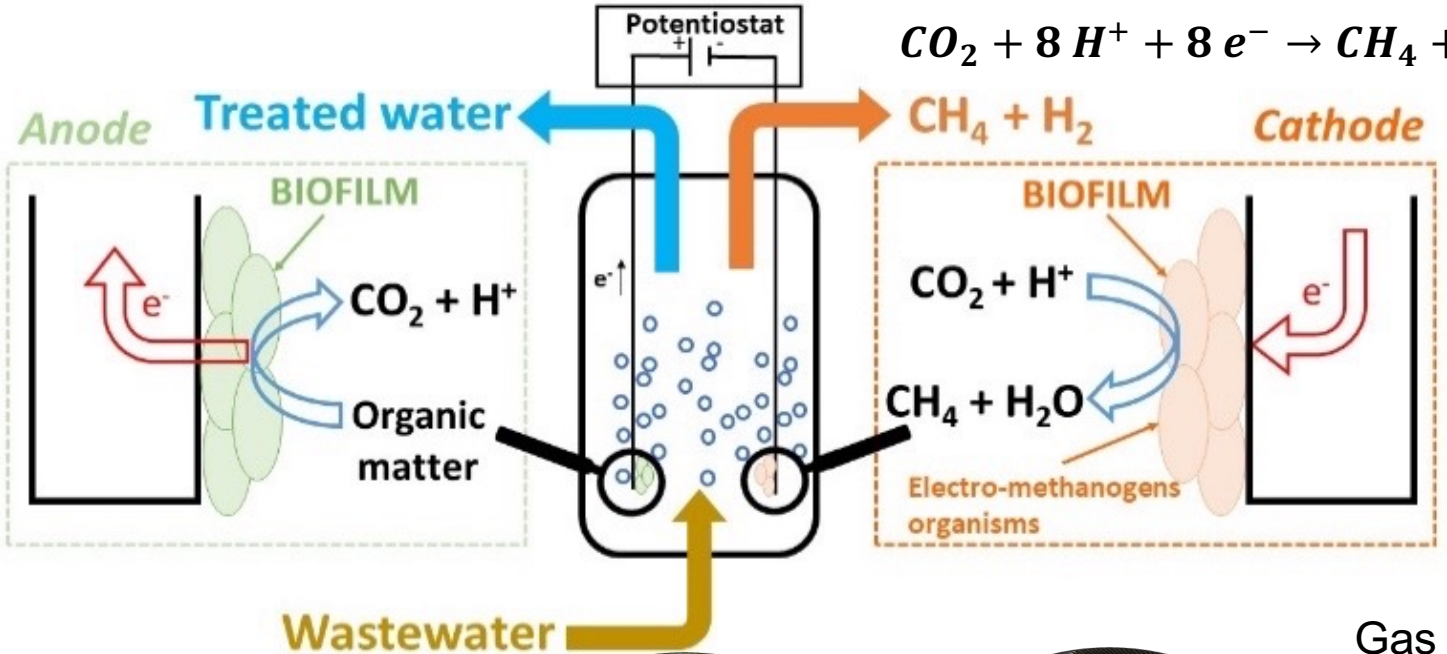
Coating

$MnCo_2O_4$

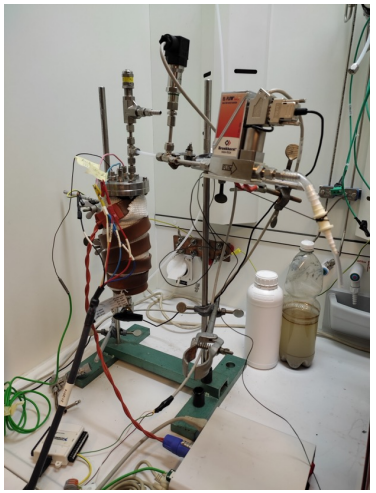
Bio-electrical systems (BES)

Jan Van herle

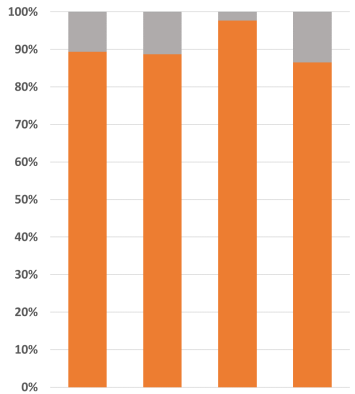
- Organic waste or CO_2 is electro-catalyzed in a single step at ambient P & T, using microbes as renewable catalyst.
- The microbes act as electron bridges to reduce the high energy step from CO_2 to CH_4. Only a small amount of electrical energy is needed to maintain microbial conversion.



$$CO_2 + 8\,H^+ + 8\,e^- \rightarrow CH_4 + 2\,H_2O$$



Gas produced in 1 step: >90% CH_4, <10% CO_2



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

PEMFC diagnostics (H_2 polymer fuel cells)

- New cell test bench + new kWe stack test bench
- Corrosion tests of components
- Electron microscopy investigations
- CFD modeling

Some stats on GEM lab (since 2002)

- 125 semester projects
- 95 master theses
- 26 PhD theses
- ME, CH, MX, EL, PH,…
- strongly project-oriented (3rd party funding)
- multiple interactions with industry and EU (35 EU projects since 2008)

Travel to Sion (1h) is covered

Sion is the sunniest spot in Switzerland