GROUP of ENERGY MATERIALS

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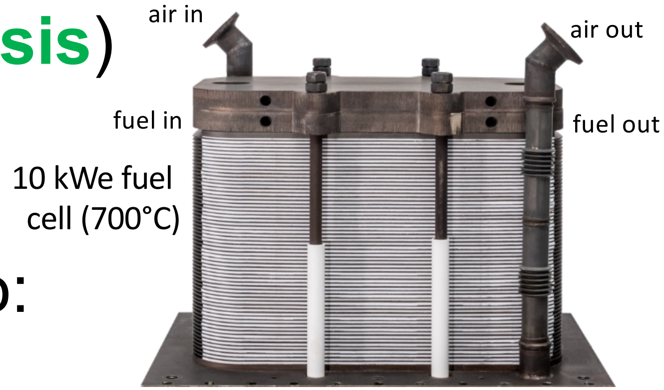
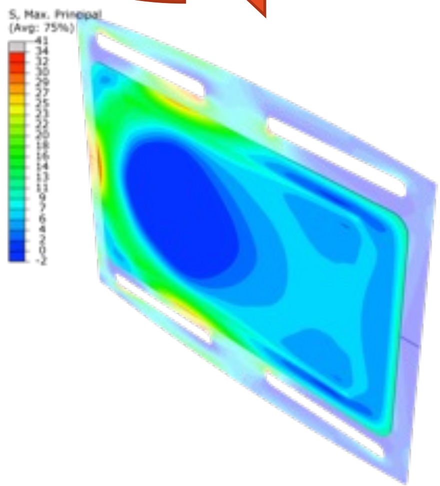
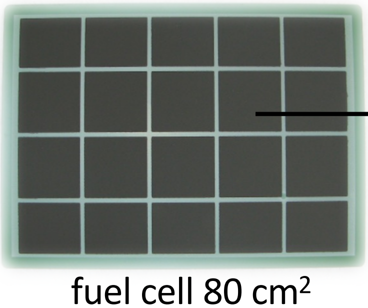
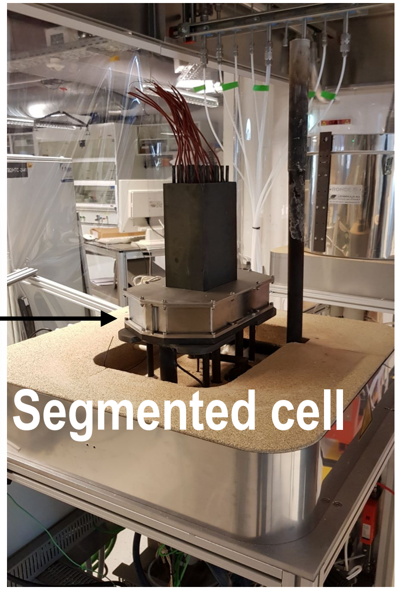
- diagnostics laboratory (**fuel cells/electrolysis**)
  - stacks ; cells ; components
  - 'high T' (700°C); 'low T' (70°C)
- coupled with modeling from micro-to-macro:
  - electrode microstructures 3D quantification
  - electrochemistry ; thermomechanics ; fluid mechanics
  - thermal integration, system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









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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,…
- 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 F Maréchal)
- Life Cycle Analyses (with IPESE, Prof F Maréchal, HESSO Sion)
- see https://www.epfl.ch/labs/gem/student-projects/
- contact : jan.vanherle@epfl.ch

Jan Van herle

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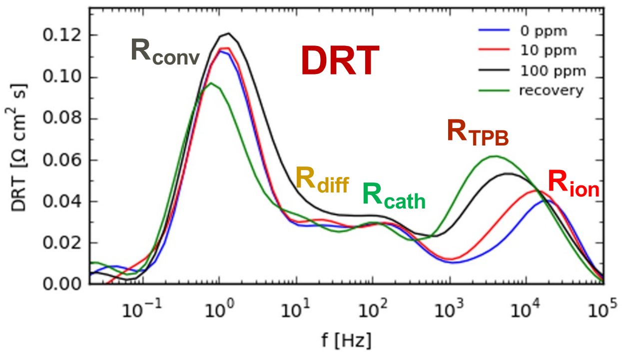
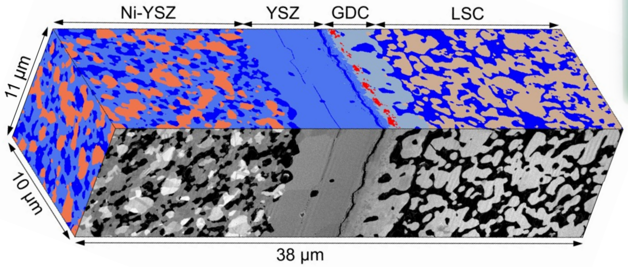
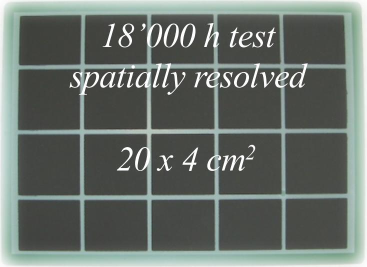
Contaminant poisoning

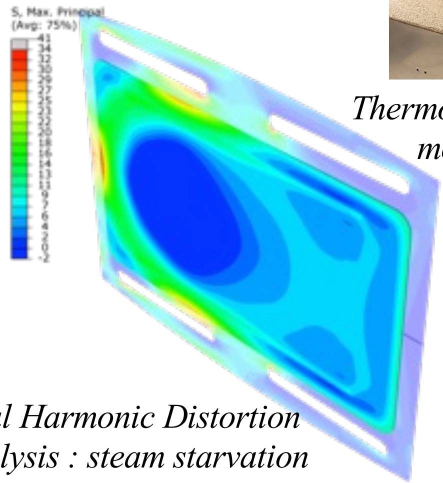




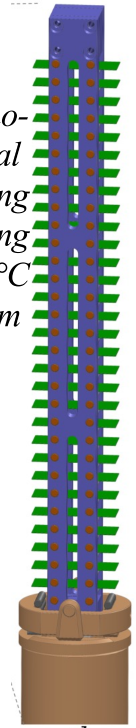
11'000 h stack; 3D-EDX



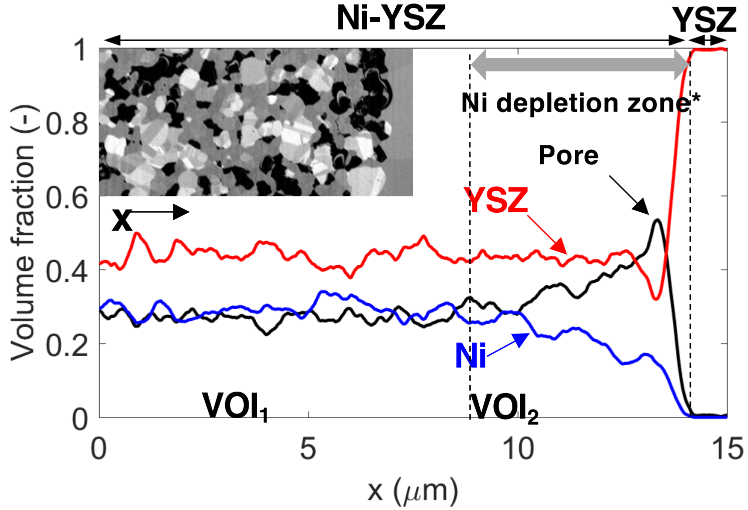
Segmented SRU



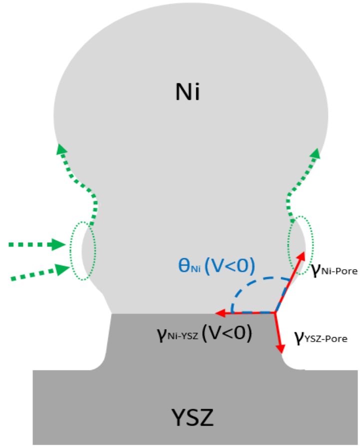
Thermomech. modeling



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

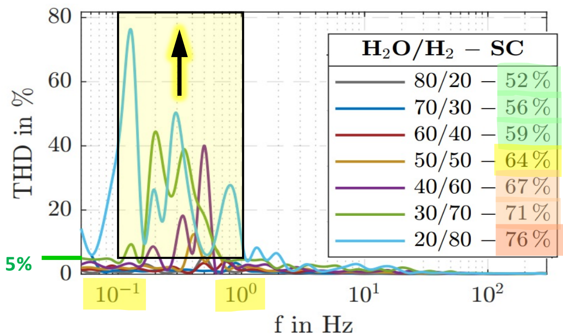


Ni catalyst wetting

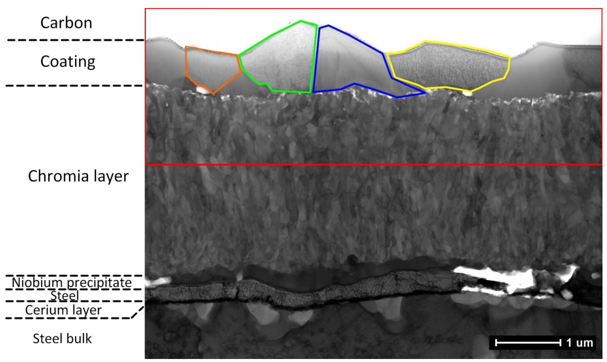


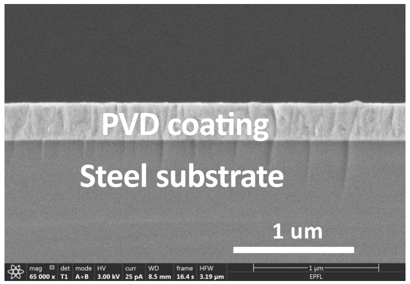
SOEC polarization

Total Harmonic Distortion Analysis : steam starvation

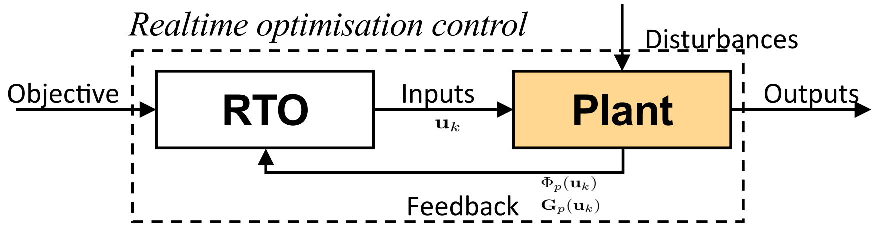


PVD coated MIC; TEM-EDX





Realtime optimisation control



Past master semester projects

- 76. (JUN2019) Study of the oxidation of Co-Ce coated steels for SOFC interconnects by SEM-EDX
- 78. (JAN2020) Cleaning of biomass derived gases for Solid Oxide Fuel Cell applications
- 79. (JAN2020) Development of a pressure damping device for an evaporator coupled with a SOE
- 82. (JUN2020) PEFC electrochemical stack model
- 84. (JUN2021) Analyse techno-économique de la production d'H2 vert pour les bus CarPostal à Sion
- 86. (JUN2021) Long-term performance and degradation mechanisms of methane pre-reforming catalysts
- 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
- 94. (JUN2022) SOC Degradation from the Perspective of Metal-Ceramic Interface Energy
- 95. (JUN2022) Accelerated stress testing (AST) of electrochemical devices
- 96. (JUN2022) Anionic membranes screening and analysis / gas crossover
- 100. (JUN2022) Power-to-Gas perspectives for H2 and CH4 - Seasonal solutions storage in Switzerland
- 101. (JAN2023) Performance losses of SOFC exposed to sulphide contaminants
- 105. (JUN2023) Protective coatings for Solid Oxide Cell (SOC) interconnect by ink jet printing
- 107. (JUN2023) LCA of AEMEL

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Past master thesis projects (1)

- 48. (SEP2020) Leonardo Gant, CGN-Lausanne, Layout of a H_2-electrical propulsion for a 1.8 MW ship
- 49. (SEP2020) Suhas Nuggehalli, Using NH_3 in SOFC for Heavy Duty Transport (*publication*)
- 50. (MAR2021) Retrofuture-EV (F), Integration study of an energy converter to an electric traction system in an automotive retrofit.
- 51. (MAR2021) RUAG (CH), Trade-off, Design and Model-Based Performance and Safety Analysis of Energy Storage Subsystems for Spacecrafts.
- 53. (MAR2021) Etude de faisabilité et conception d'un banc d'essai moteur à hydrogène
- 56. (AUG2021) Marco Belfanti, Swisshydrogen, Dvpmt of compact FC range extender for automotive applic.
- 58. (AUG2021) Network Analysis of Hydrogen Fuel Cell Automated Vehicles for Goods Delivery
- 59. (JAN2022) Gerald Hammerschmid, 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) Martin Gay (Stadler), Development of a simulation tool to optimize the design of hybrid propulsion systems on railway vehicles, and application in a case study on shunting locomotives
- 62. (MAR2022) Power-to-Gas applications for seasonal storage in Switzerland based on H_2 and CH_4
- 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 dimethyl sulfide

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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
- 69. (SEP2022) Liebherr, THERMOMECHANICAL FATIGUE DAMAGE MODEL FOR ICE EXHAUST MANIFOLDS
- 70. (SEP2022) Hitachi, Mechanical and Thermal Optimization of Novel Power Semiconductor Modules
- 72. (FEB2023) How can greenhouses become carbon neutral and self-sufficient? (=> Thesis Award)
- 73. (FEB2023) Optimal integration of Clean Carbon Conversion gasification plant in District Heating Network
- 74. (FEB2023) Zoé Mury, Two-Phase Simulation of AEM Electrolyser Flow Channels (=> Patent)
- 75. (FEB2023) Khaled Lawand, 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
- 81. (AUG2023) Liebherr, Engine Design modelling combining Statistical Approaches and Artificial Intelligence
- 82. (AUG2023) Stadler, Electrical Modelling of the Auxiliary Consumptions in Trains
- 83. (AUG2023) BG Conseils, CCUS solutions with biogas plants, scale considerations

Examples

Master thesis proposals

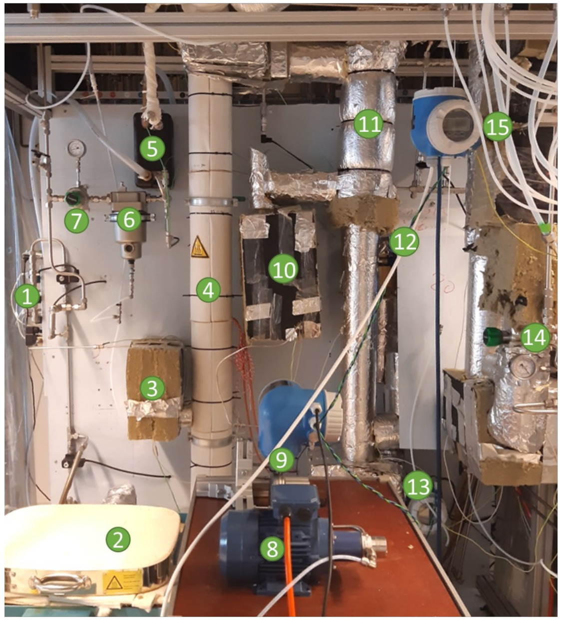
EPFL

Scaling an existing 2-10 kW methanation reactor for a future 10-30 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:
  - Complete additional test on the existing reactor to improve conversion. This should help the path towards scaling.
  - Use existing reactor simulation code (and improvements) to estimate dimensions of 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

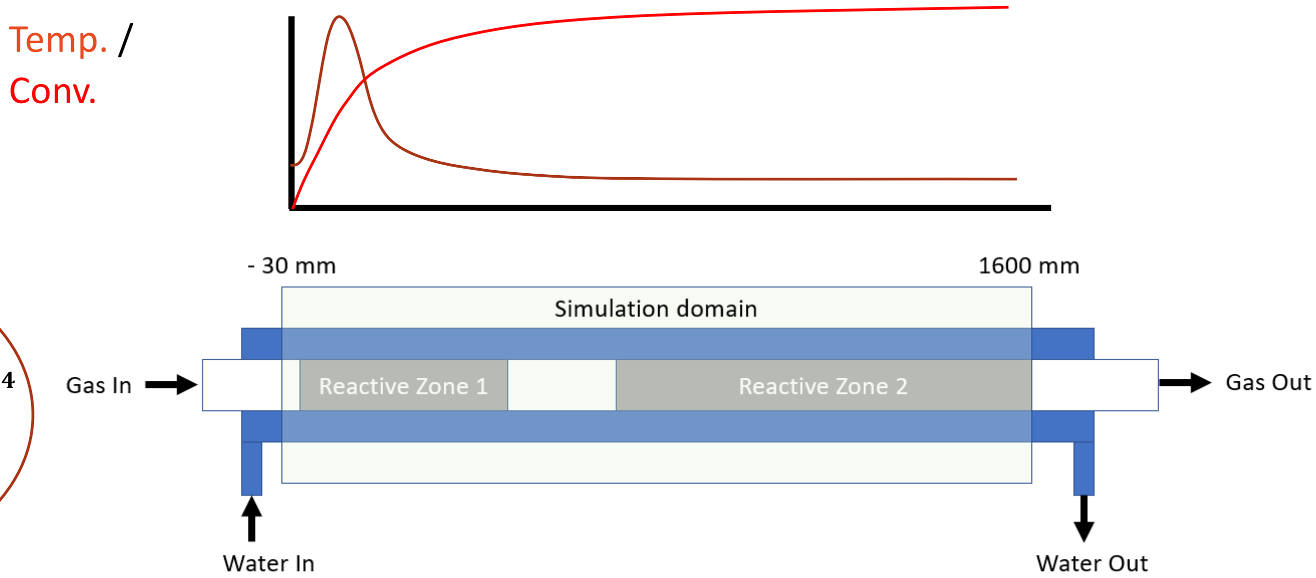
[1] P. Aubin, L. Wang and J. Van herle, "Evaporating water-cooled methanation reactor for solid-oxide stack-based power-to-methane systems: design, experiment and modeling," *Chemical Engineering Journal,* 2023.

Dynamic modelling of a 2-10 kW methanation reactor

Jan Van herle

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

Highly Exothermal

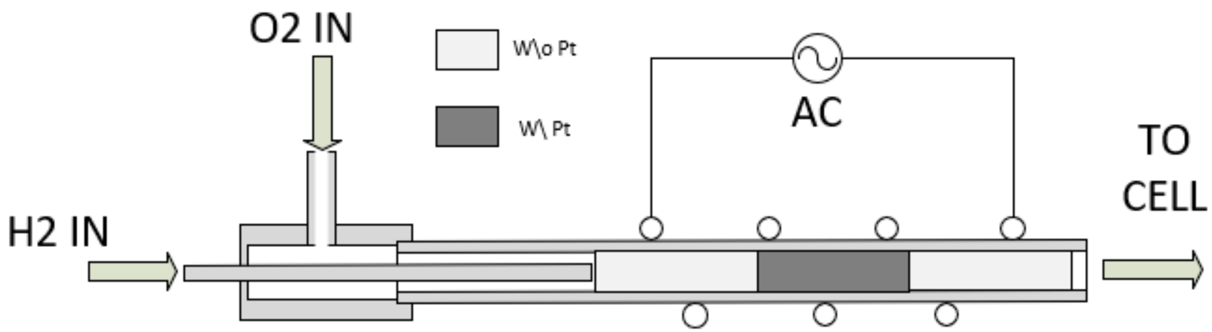


- Tasks :
  - Modify the existing steady-state version of the reactor model.
  - Parametric study
  - Investigate the difference of dynamic response between the methanation of CO_2 and syngas.
  - Connect model to existing Aspen Plus SOE unit and methanation models.
- **Skill requirement:**
  - Familiar with programming language and logics, Matlab (Aspen is a plus)

Design and characterization of a catalytic oxy-combustion reactor for stable steam production

Jan Van herle

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$



- **Combustion must be:**
  - **SAFE**
  - Stable
  - High conversion
  - no catalyst reaching the single cell

- **Tasks:**
  - Select different catalysts and supports for testing
  - Identify the performance of each combination based on the capacity/volume required to convert most of the oxygen (limiting the oxygen at the outlet) with degradation tests.
  - Design, build and test the chamber.

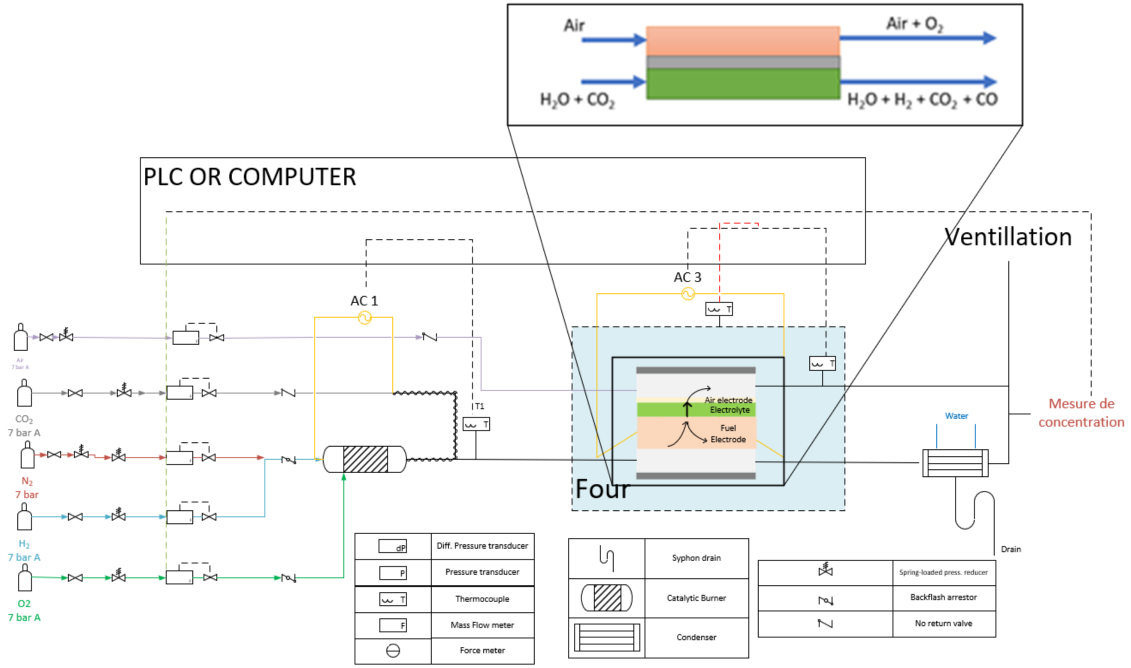
Control of the outlet composition in co-electrolysis of steam and CO_2

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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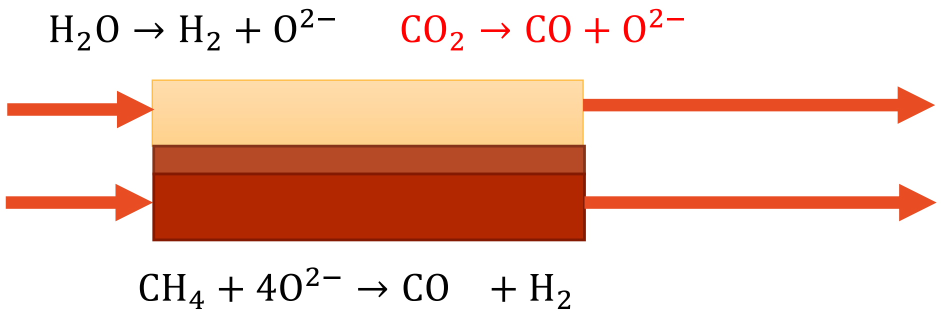
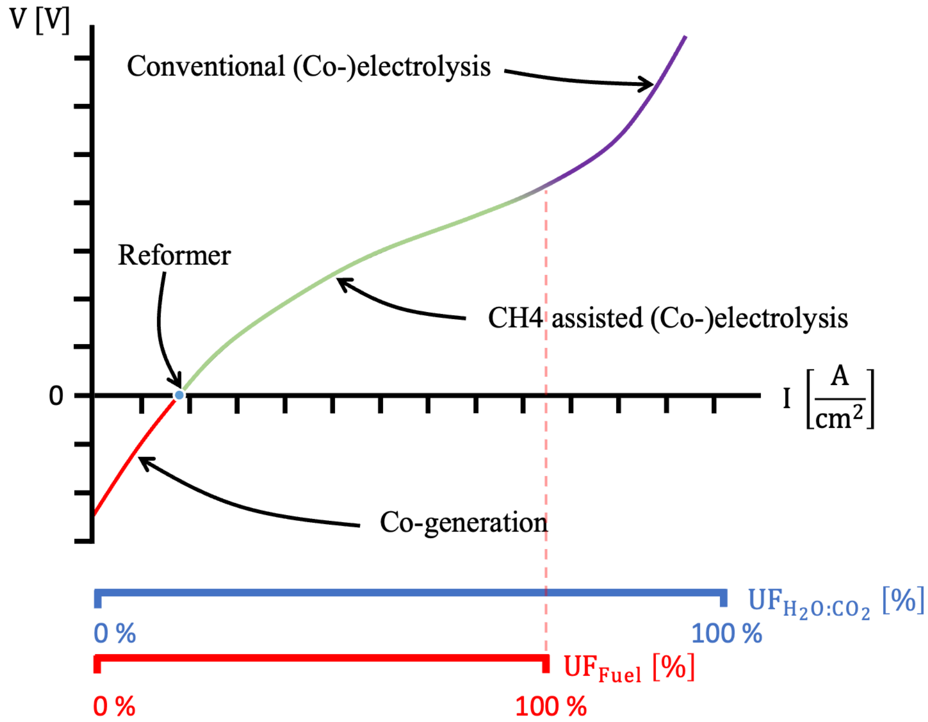
Investigation of methane-assisted electrolysis and co-electrolysis: conceptual, experimental and system analysis

Jan Van herle





- Tasks

(1) Complete the literature review already started

(2) Conceptually identify the potential of such operating mode

(3) Design an experimental procedure and perform single cell tests with various inlets compositions

(4) Use the results of the previous task to finalize a system level analysis.

- Prerequisites: Knowledge of Aspen Plus (& Aspen Custom Modeler) would be advantageous but not required.

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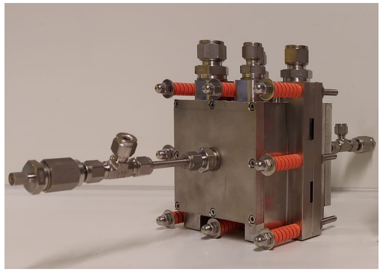
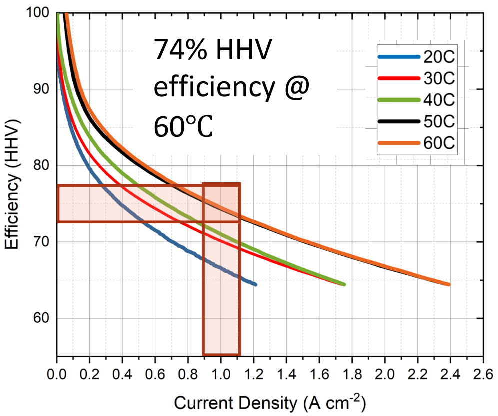
Alcaline membrane water electrolysis

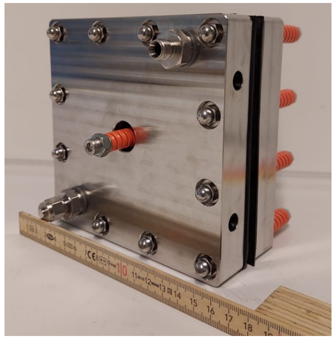
Jan Van herle

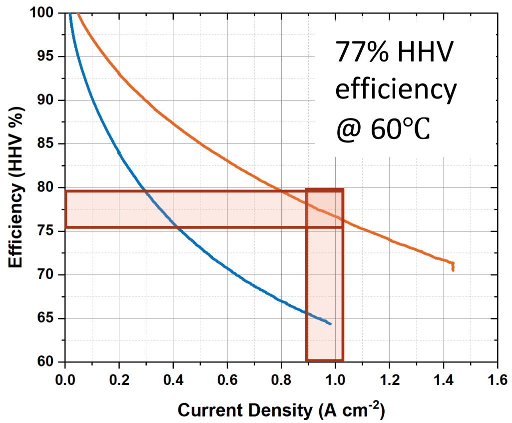
Electrochemical test setup: 25 cm²



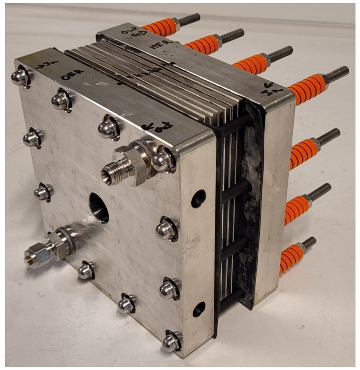


Stack SRU: 100 cm²





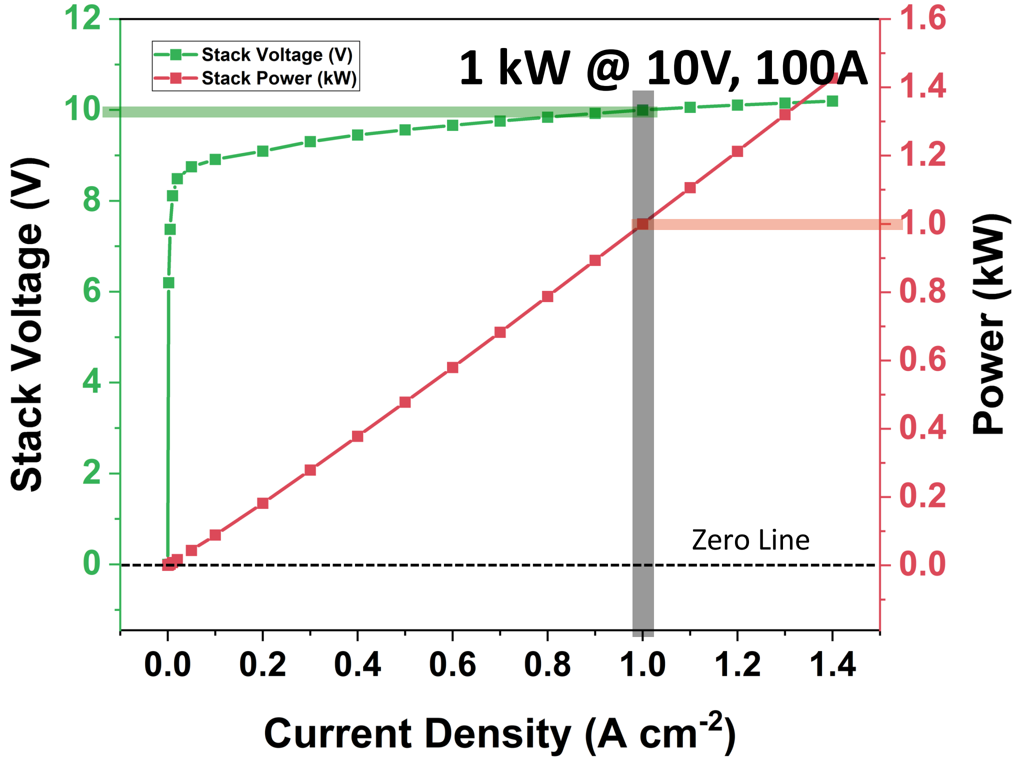
1kWe Stack PoC: 5x100 cm²



Components fabricated

First test achieved >1 kWe milestone, 75% HHV efficiency

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



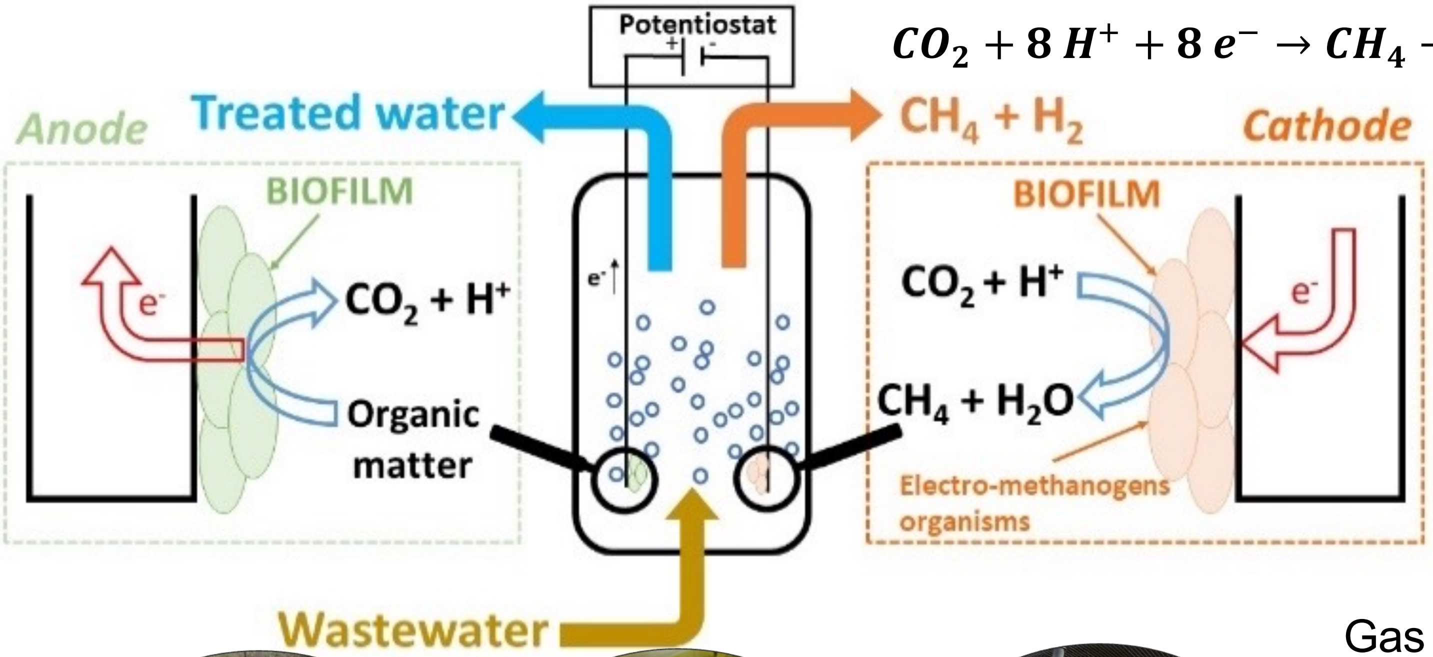
- AEMWE **stack** reached **1kW @10V, 100A** DC current.
- **P = 1.43 kWe** *@140A, less than 10.2 V =>* $\dot{V}_{H_2}$ ***= 7.7 m³/day***
- **72%-74% HHV @ 1.4 A cm^{-2}**
- Projected: **2.5A cm^{-2} <2.2V => 2.5kW @ 70 % HHV**
- with cell pitch = 4 mm : volumetric density **7 kW$_{H2}$/L** of stack.

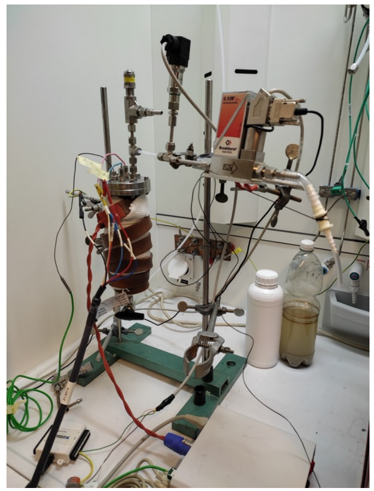
Bio-electrical systems (BES)

Jan Van herle

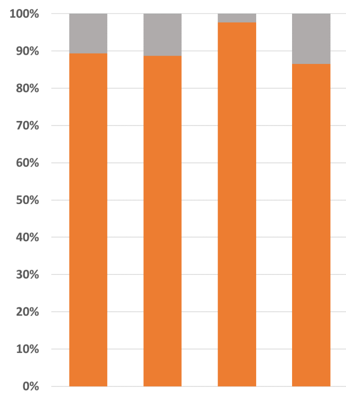
- In BES, the methanation of CO_2 is electrocatalyzed **in a single step at ambient P & T, using microbes as renewable catalyst**.
- The microbes - **methanogenic bacteria** (*Archaea*) - act as electron bridges to reduce the high energy step from CO_2 to CH_4. Only a small amount of electrical energy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

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





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

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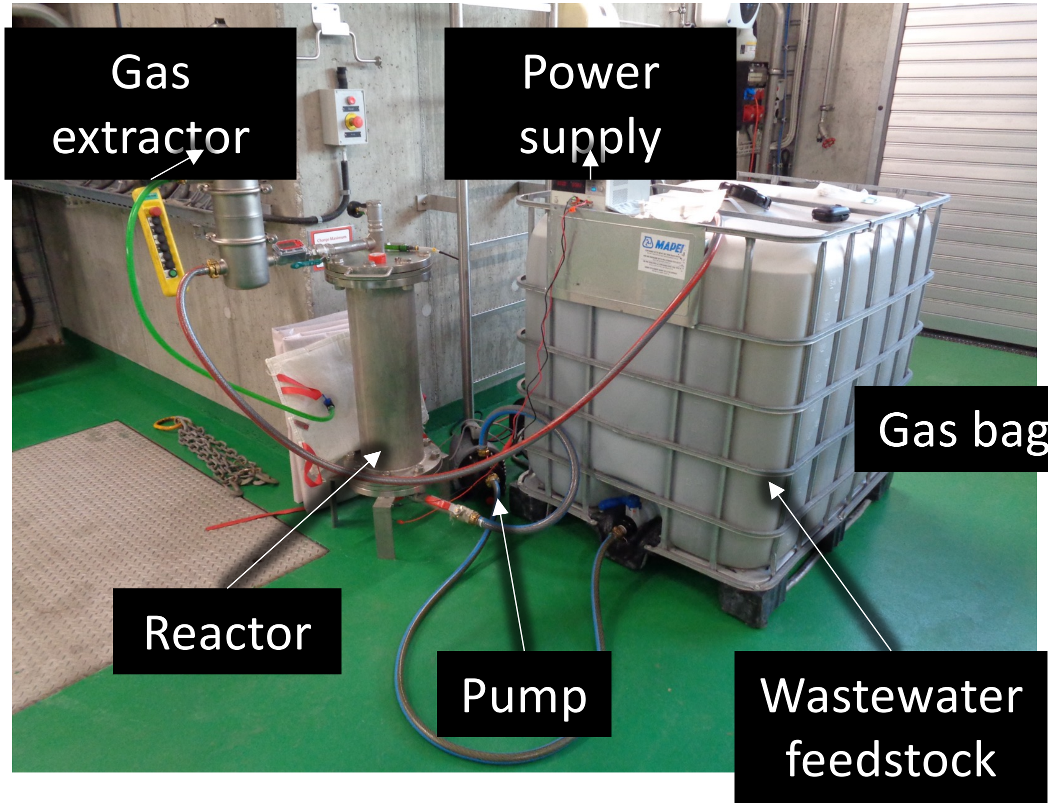
BioElectrochemical System prototype in operation

Hexem

HOLDI GAZ

gaz nat

- 30 L microbial electrolysis reactor installed in WWTP (Valais):



Started in sept 2023, currently producing biogas with 86% CH_4 (balance H_2, CO_2)

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