Solid oxide Fuel cell

Students: *Maria Dolores, Abalos*
Pierre, Creusot

Supervisors: *Julia Schmale (EERL)*
Andrea Baccarini (EERL)
Luc Conti (INERGIO)

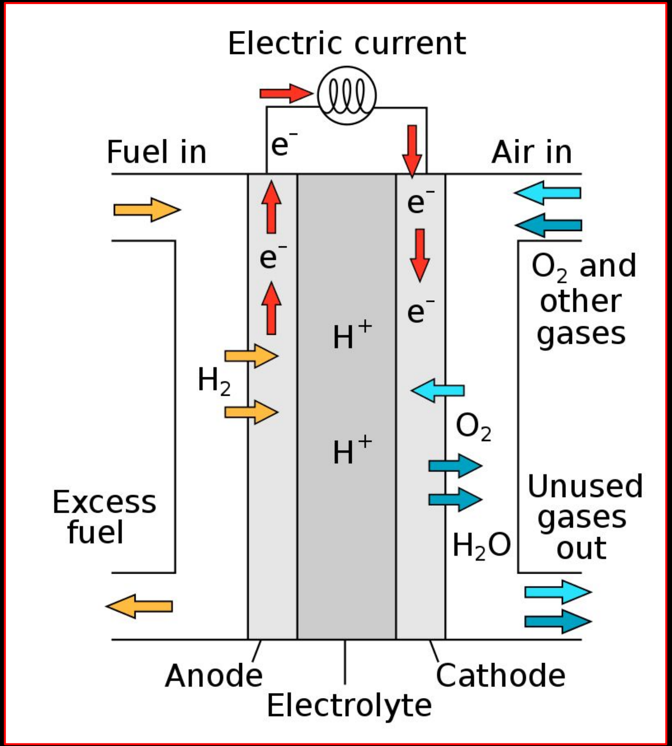
1. Introduction

Fuel cells

A fuel cell works like a gas-filled battery.

- Chemical fuel **directly** converted into electricity through redox reaction
- Reduction of O_2 in cathode and Oxidation of fuel in anode.
- Electrons travel between electrodes through external circuit
- Ions (usually H^{+-}) travel through the electrolyte
- SOFC has a solid oxide or ceramic electrolyte

We work on the project in collaboration with INERGIO, a start-up that develops **a new technology of fuel cell**



Classic proton conductor FC. (Wikipedia)

Solid oxide Fuel cells (SOFC)

- **Main advantage:** flexibility in the fuels: propane for example:

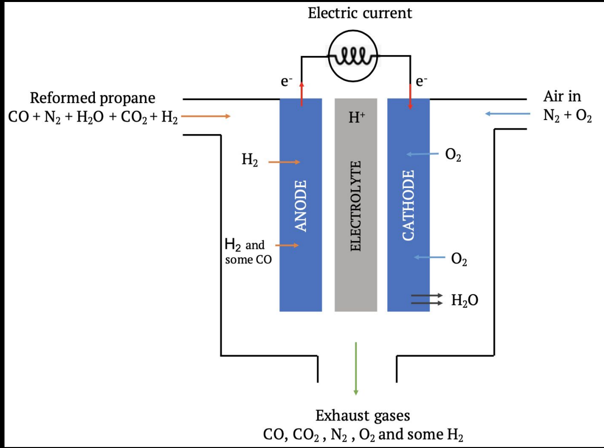
Partial oxidation of propane:

$$C_3H_8 + \frac{3}{2}O_2 \longrightarrow 3CO + 4H_2$$

Full oxidation of propane:

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$

- **Main drawback:** high temperature operation (at least 600 °C) and some fuels exhaust carbon monoxide.



*SOFC proposed by the startup **INERGIO***

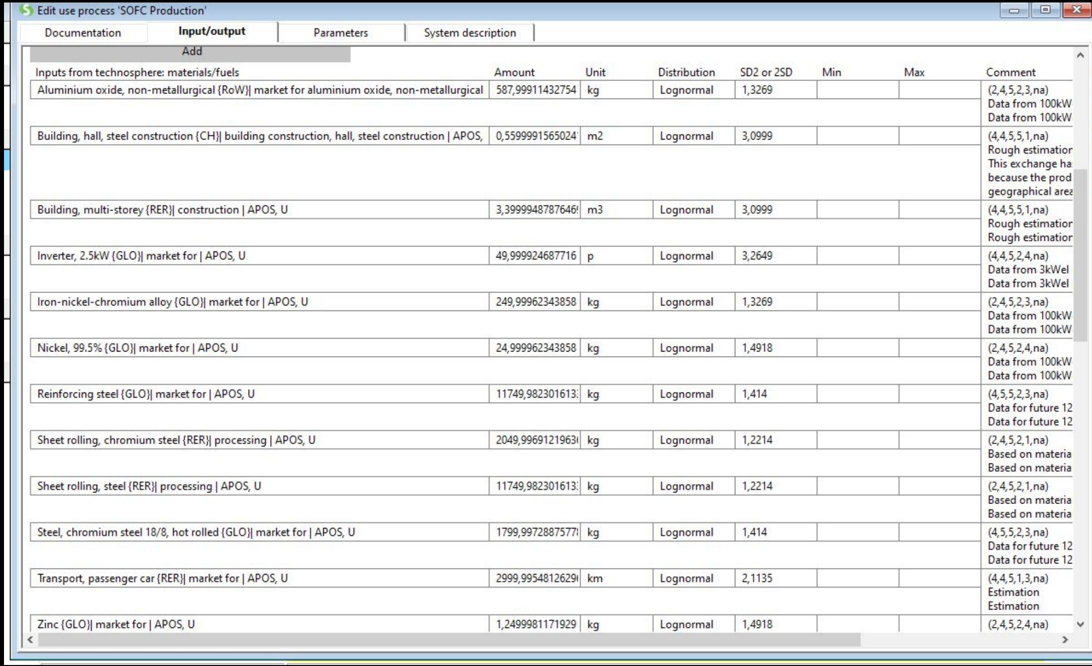
Evaluate INERGIO's SOFC as a <u>safe</u> and <u>eco-friendly</u> <u>off-grid power supply</u> that could be used in remote areas where <u>environmental conditions could be harsh.</u>

2.Life Cycle Assessment (LCA) of the SOFC

LCA Processes

The goal of a LCA is to analyze the **impact** of a product on the environment through its whole lifetime. Different factors can influence the impact, we call them processes

- Processes of production: inventory of input materials. How are they extracted ? From where and how are they transported ? How much energy used for the crafting ? From which energy mix and other...
- Processes of use: Mass of fuel used, mass of greenhouse gas emitted. Energy used for maintenance.
- Processes of disposal: How is it disposed of ? Recyclable ?


Edit use process 'SOFC Production'

Documentation | Input/output | Parameters | System description

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Aluminium oxide, non-metallurgical {RoW}| market for aluminium oxide, non-metallurgical	587,99911432754	kg	Lognormal	1,3269			(2,4,5,2,3,na) Data from 100kW Data from 100kW
Building, hall, steel construction {CH}| building construction, hall, steel construction | APOS,	0,5599991565024	m2	Lognormal	3,0999			(4,4,5,5,1,na) Rough estimation This exchange ha because the prod geographical area
Building, multi-storey {RER}| construction | APOS, U	3,3999948787646	m3	Lognormal	3,0999			(4,4,5,5,1,na) Rough estimation Rough estimation
Inverter, 2.5kW {GLO}| market for | APOS, U	49,999924687716	p	Lognormal	3,2649			(4,4,5,2,4,na) Data from 3kWel Data from 3kWel
Iron-nickel-chromium alloy {GLO}| market for | APOS, U	249,99962343858	kg	Lognormal	1,3269			(2,4,5,2,3,na) Data from 100kW Data from 100kW
Nickel, 99.5% {GLO}| market for | APOS, U	24,999962343858	kg	Lognormal	1,4918			(2,4,5,2,4,na) Data from 100kW Data from 100kW
Reinforcing steel {GLO}| market for | APOS, U	11749,982301613	kg	Lognormal	1,414			(4,5,5,2,3,na) Data for future 12 Data for future 12
Sheet rolling, chromium steel {RER}| processing | APOS, U	2049,9969121963	kg	Lognormal	1,2214			(2,4,5,2,1,na) Based on materia Based on materia
Sheet rolling, steel {RER}| processing | APOS, U	11749,982301613	kg	Lognormal	1,2214			(2,4,5,2,1,na) Based on materia Based on materia
Steel, chromium steel 18/8, hot rolled {GLO}| market for | APOS, U	1799,9972887577	kg	Lognormal	1,414			(4,5,5,2,3,na) Data for future 12 Data for future 12
Transport, passenger car {RER}| market for | APOS, U	2999,9954812629	km	Lognormal	2,1135			(4,4,5,1,3,na) Estimation Estimation
Zinc {GLO}| market for | APOS, U	1,2499981171929	kg	Lognormal	1,4918			(2,4,5,2,4,na)

SOFC's production processes. Software: Simapro used with the Ecoinvent database.

Functional unit for comparison

- A functional unit (FU) will define quantitatively the function the product will fulfill.
- The processes and results will be quantified according to the FU
- The same FU should be used for comparative analysis (SOFC vs Solar panels vs Diesel Genset)

In our case two FU:

1. Full-time operation of 100W during 48'000h (4'800 kWh)
2. Full time operation of 100W during 220'000h (22'000 kWh)

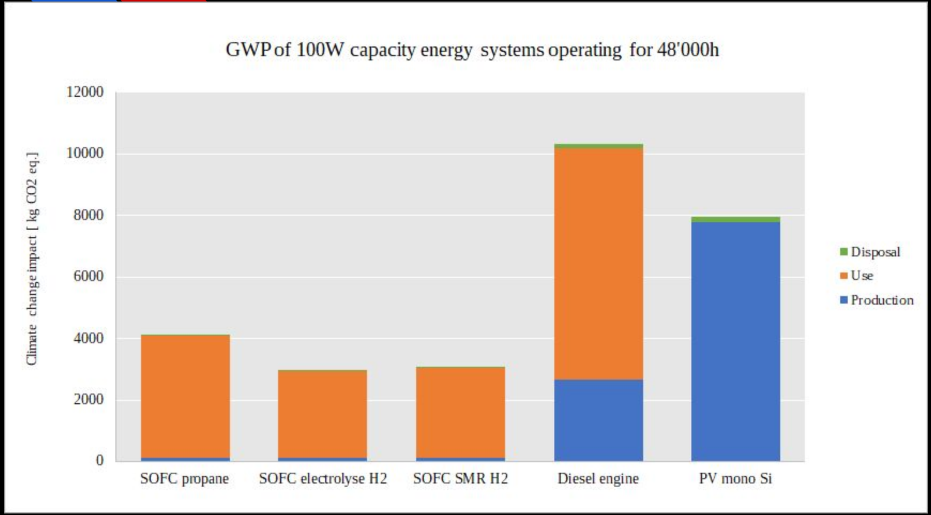
In other words, our goal is to know what is the impact of a SOFC operating full-time during 5 or 25 years ? Compared to a solar panel and a Diesel genset.

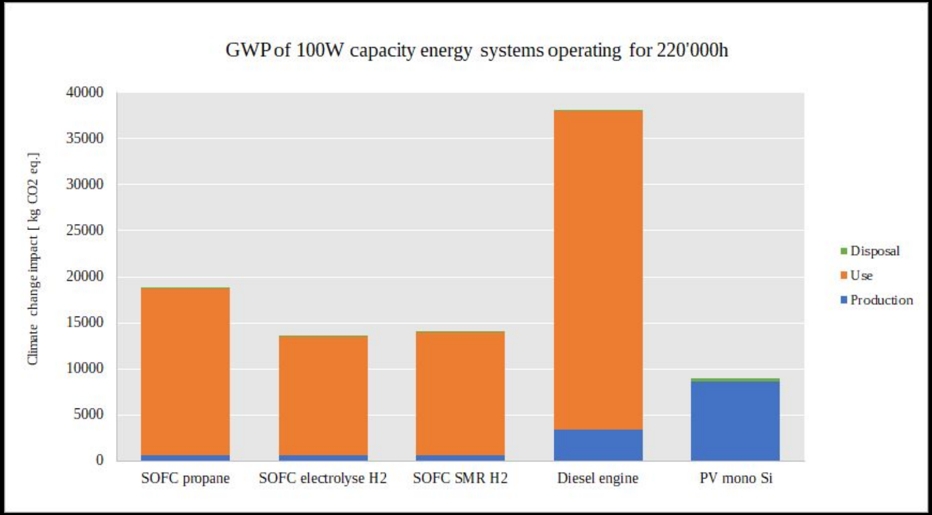
InoPower 1.0 by INERGIO

Solar panel mono-Si
kitsolaire-discount.com

Onan QD 6000 RV

Results and Discussion





- Low CO_2 eq impact for the SOFC with different fuels compared to other power supply technologies in both scenarios.
- In a 25 year scenario, the production impact of solar panel buffers with time.
  Production impact of solar panels mainly due to extraction of silicon.
  The solar panel is oversized in order to be self sufficient as off-grid solution and produce 100W Watt constantly with little days of shutdown.
- The Diesel genset has high production impact mainly from aluminium production and transformation.
  Big use impact also due to its lower fuel-to-electricity energy conversion efficiency (18%).

Asclepios

3. Exhaust gasses treatment

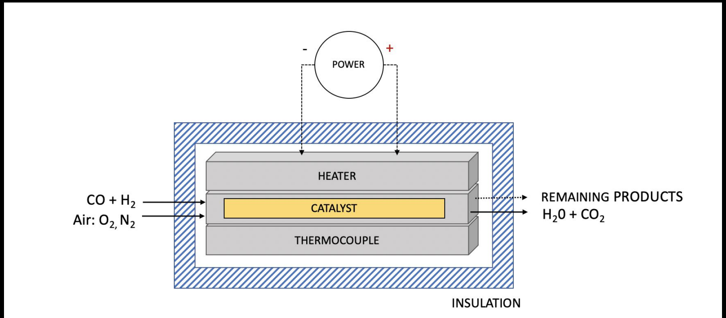
Purpose of activity

- **Objective:** **ensure that the exhaust gases are treated efficiently in order to be harmless**

- *Swiss law OPair Art.146*: " Emissions of carbon monoxide should not exceed 500 mg/m^3 "
- Carbon monoxide is a poisonous gas that has no smell or taste.
- Breathing it in can make you unwell, and it can kill if you're exposed to high levels.
- Greenhouse gas

- The chemistry behind the post combustion chamber:

$$CO + \frac{1}{2}O_2 \longrightarrow CO_2$$



Scheme of post combustion chamber

Study the output of the post combustion chamber (CO remaining)

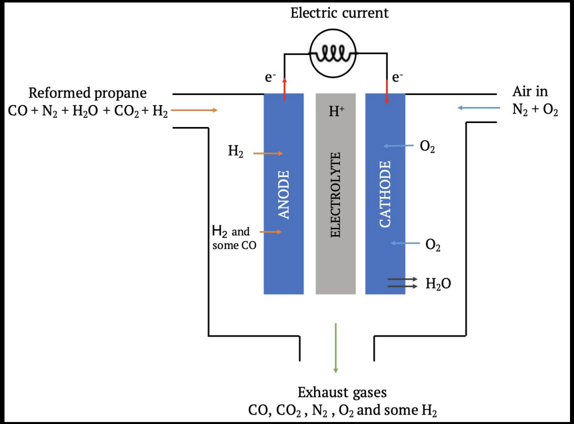
Formalisation of the project

1. **Temperature and mass inflow :** Important to test these operational conditions for CO combustion
   → Find the range of **completeness of the reactions** (no CO remaining)

2. **Dilution limit for the real SOFC:** Evaluate the functional range for real CO combustion in the SOFC
   → Find the range of **completeness of the reactions** (no CO remaining)

→ *NOTES FOR THE PROJECT:*

- For the **mass inflow (1)**: the volumetric ratio between the oxygen and the other reactants is fixed to 2.
  → ratio tested in test 2



SOFC proposed by the startup ***INERGIO***

Test 1: Suitable operational parameters for CO combustion

$$V^{-}_{CO\ combustion} = V^{-}_{CO_2} + V^{-}_{O_2} + V^{-}_{N_2}$$

PROCEDURE EXPERIMENT:

- Fix values for **air + CO mass inflow** and **temperature** supply to the reaction
- Wait so that the reaction is stable

$$V^{-}_{CO_2} = V^{+}_{CO}$$

$$V^{-}_{O_2} = \frac{1}{2} \cdot V^{+}_{O_2} = \frac{1}{2} \cdot V^{+}_{air} \cdot 0.205$$

$$V^{-}_{N_2} = V^{+}_{N_2} = V^{+}_{air} \cdot 0.795$$

CALCULATIONS:

$$\dot{m}_{CO\ burned} = \frac{Power\ autonomy\ [\mathrm{W}]}{\Delta H\ [\mathrm{W \cdot s\ /\ kg}]}$$

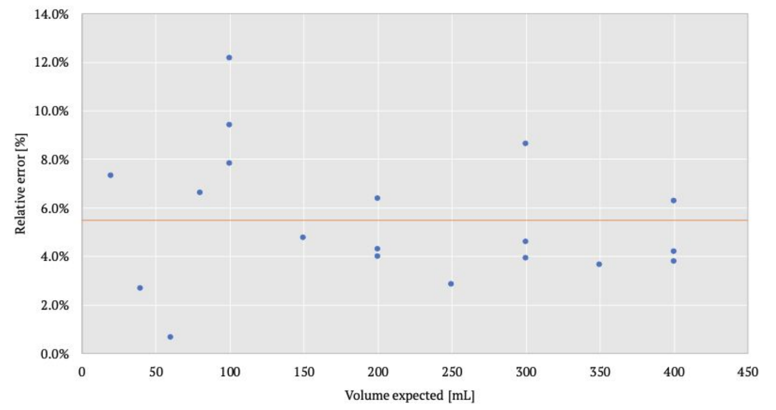
$$\dot{m}_{CO\ burned} : \begin{cases} = \dot{m}^{+}_{CO} & := \text{Complete combustion} \\ < \dot{m}^{+}_{CO} & := \text{Incomplete combustion} \end{cases}$$

- **Is there CO remaining at the outlet of the post combustion chamber ?**
  1. The **volume** should correspond to the expected one stoichiometrically
  2. The **power** should correspond to the enthalpy of the reaction
  3. A CO sensor is placed closed to the post combustion chamber which indicates when the concentration is above 20 ppm which is a first indicator of CO concentrations above this limit.

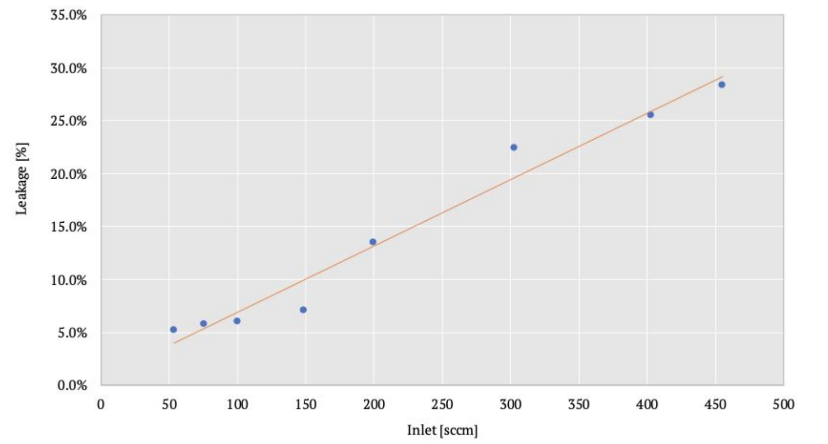
CO Detector

Errors correction

Volume error: → systematic errors:



Collecting error as a function of the volume



Leakage error as a function of the mass inflow

→ random errors: maximum determined 4%

CO detector: → random errors: literature 15%

Watt-meter: → random errors: fluctuation of 5%

Results for CO combustion

VOLUME INDICATOR:

TABLE I: Completeness of CO combustion at 650°C: volume indicator.

	20 sccm	30 sccm	50 sccm	75 sccm
Collected volume [mL]	117.79±4.71	188.97±7.56	278.26±11.13	395.25±15.08
Expected volume [mL]	115.89	186.27	292.48	438.72

POWER INDICATOR:

TABLE II: Completeness of CO combustion at 650°C: power indicator.

	20 sccm	30 sccm	50 sccm	75 sccm
Reaction power [W]	2.70±0.01	4.27±0.13	11.00±0.3	15.30±0.46
Expected power [W]	4.32	6.32	10.53	15.79

Test 2: SOFC post combustion chamber feasibility range for CO combustion dilution

PROCEDURE EXPERIMENT:

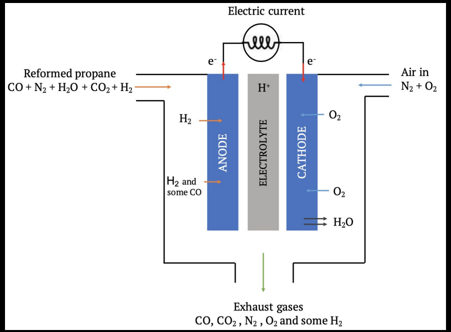
- Usage of similar operational conditions as in test 1
  - **Temperature**: 700°C
  - **Propane injected:** 6.5 sccm this is at maximum equivalent to 20 sccm of CO
- **Nickel catalyst** will be used in order to ensure the treatment in the post combustion chamber

CALCULATIONS:

- **How much can we dilute and the combustion still ensured?**

A CO sensor is placed closed to the post combustion chamber which

indicates when the concentration is above 20 ppm which is a first indicator.



*SOFC proposed by the startup **INERGIO***

Results for dilution

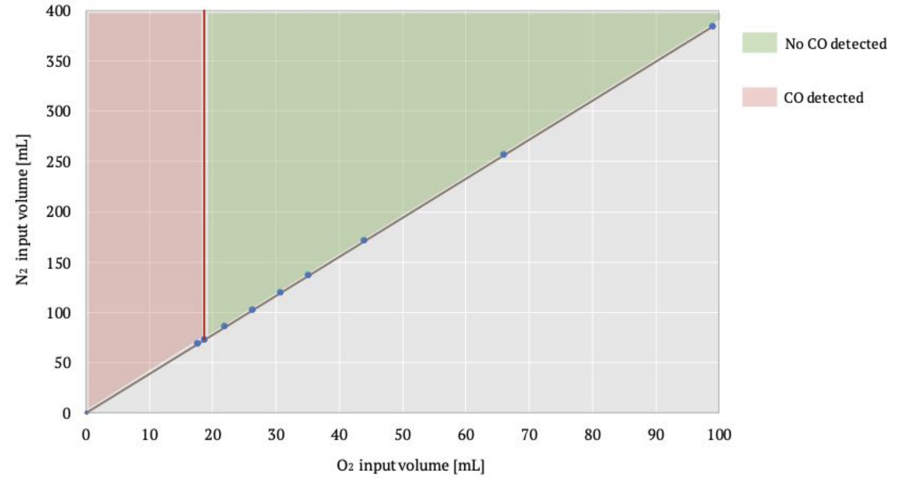
- Equation corresponds to air ratio

$$y \simeq 4 \cdot x.$$

- Lower limit at 150 sscm of air
  Stoichiometry expected 50 sccm

- Upper flammability limit not reached

- To follow: try different combinations of O2 and N2 within the green zone to find functionality range



CO, from reformed gas, dilution elimination limits for the post combustion chamber

4. SOFC in extreme environments

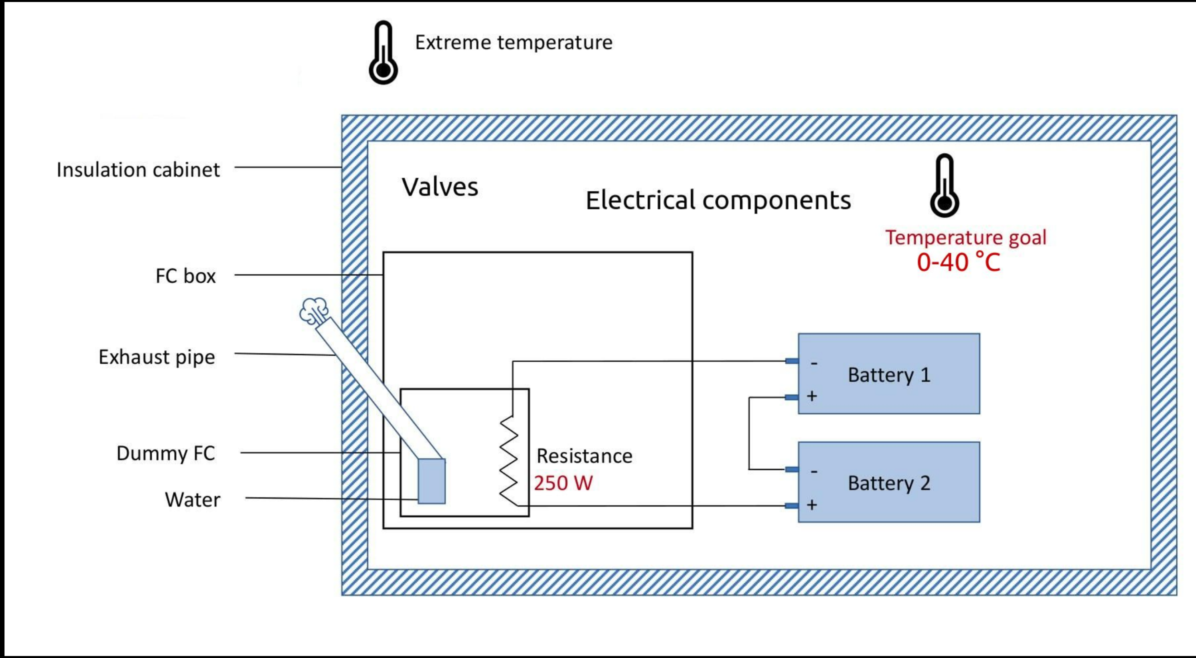
Cold Chamber Experiment

The goal is to test if SOFC can operate well under extreme environment. Here consider low ambient temperature for - 20°C ~ - 40°C.

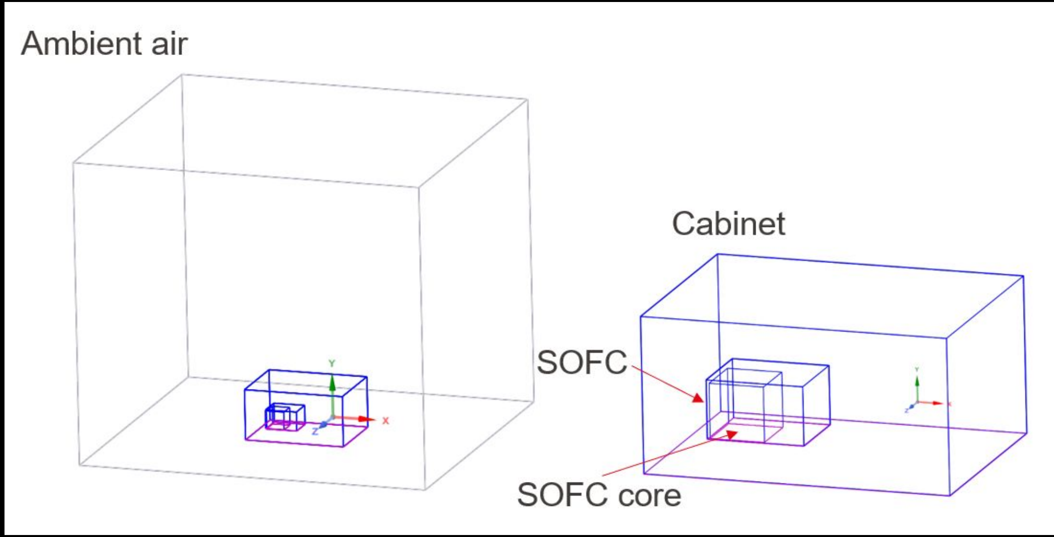
To fulfill this goal, we need to craft a insulation cabinet.

Two tests will be done:

1. Simulation on ANSYS
2. Experiment in a -25 °C with a dummy fuel cell for safety.

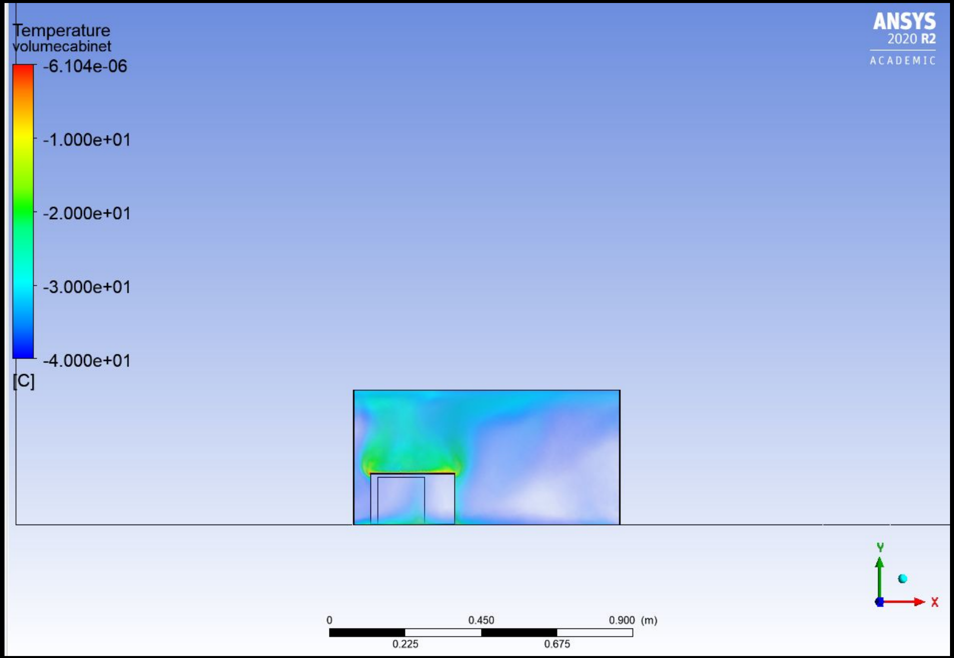


Geometry

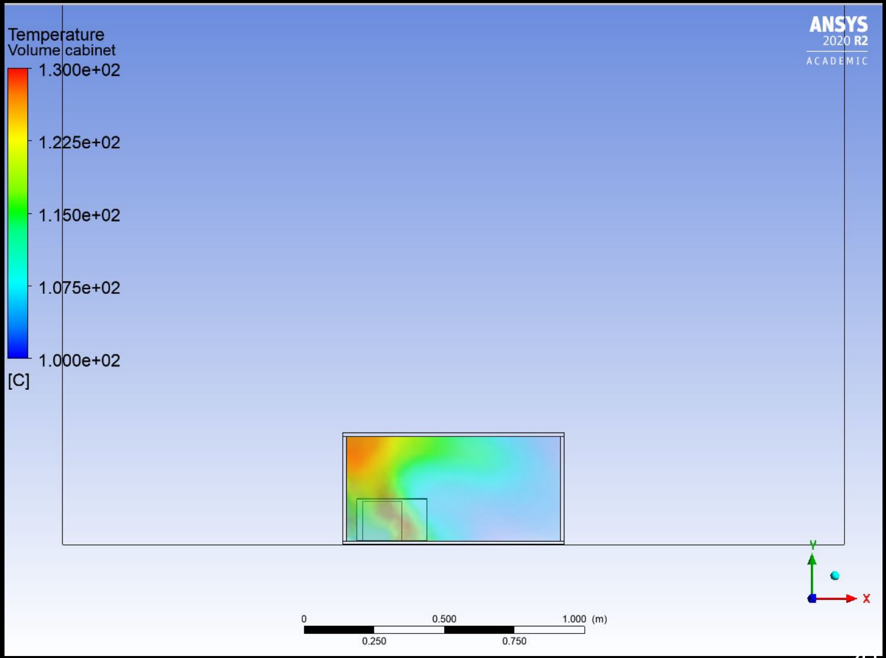


Simulation

Without insulation



With 13mm insulation



Overheating issue

First experiment done at room temperature

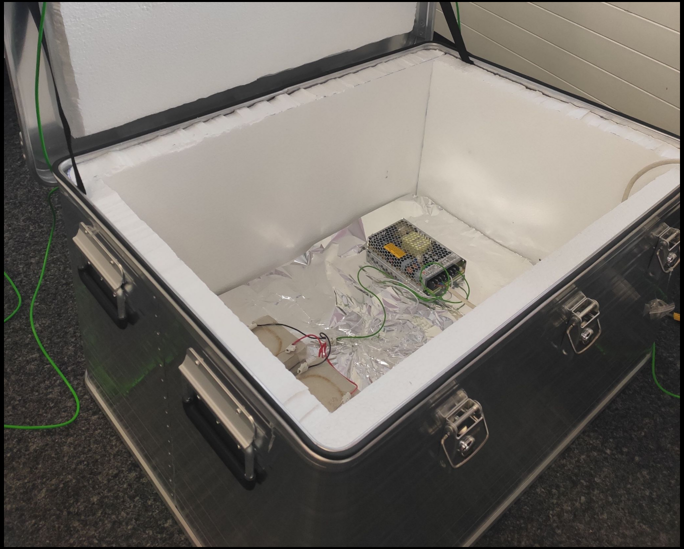
- Ambient temperature of 15 °C
- 4 cm insulation layer
- 80W of heat from resistor

The goal was to test the insulation and overheating.
85°C steady state temperature was reached.
Cooling system is needed to avoid overheating.

Second experiment with cooling system

- Reached threshold temperature of 40 °C
- Fan constantly operating but no cooling
- Temperature stagnating at 41 °C

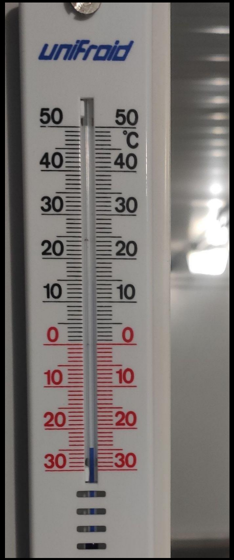
The insulation is too thick for room temperature. Let's try at -25°C



First experiment

Cooling system made of two grids.
One grid is fixed with a fan and the other grid for air evacuation.
Arduino program connected to fan and thermocouple to monitor the temperature inside.

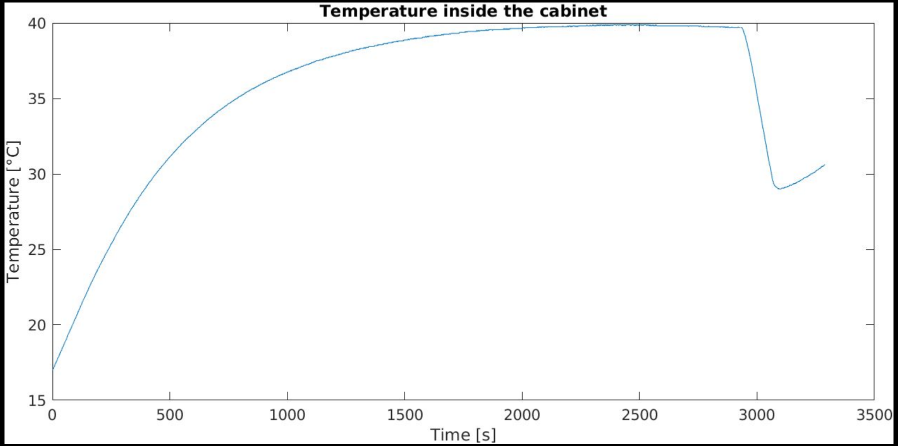
Experiment in cold chamber



Cold chamber with cooling system

- Ambient temperature of -25 °C
- 4 cm insulation layer
- 80W of heat from resistor

Results



Steady-state temperature around 40°C.
The threshold of 40°C was never reached so the code was changed to test the cooling system. Temperature dropped to 30 °C in 2 minutes.

The insulation and cooling system is working well at extreme cold conditions..
For further use of this cabinet, the insulation should be thinner considering a real 100W SOFC produces 250W of heat.

QUESTIONS ?