DEMOSOFC: first industrial size biogas-fed SOFC plant in Europe

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DEMOSOFC

FCH2-JU PROJECT

FCH

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

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Imperial College London

H2020 Fuel Cells and Hydrogen 2 Joint Undertaking under Grant Agreement No. 671470 Demonstration of large SOFC systems fed with biogas from WWTP

WASTE WATER + SOFC = ENERGY

SOFC:

Highest efficiency in energy recovery from biogas 50-56%

Industrial size SOFC plant in Europe (110 kW_e + 55 kW_{th}) fed by biogas from sewage sludge

FCH FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

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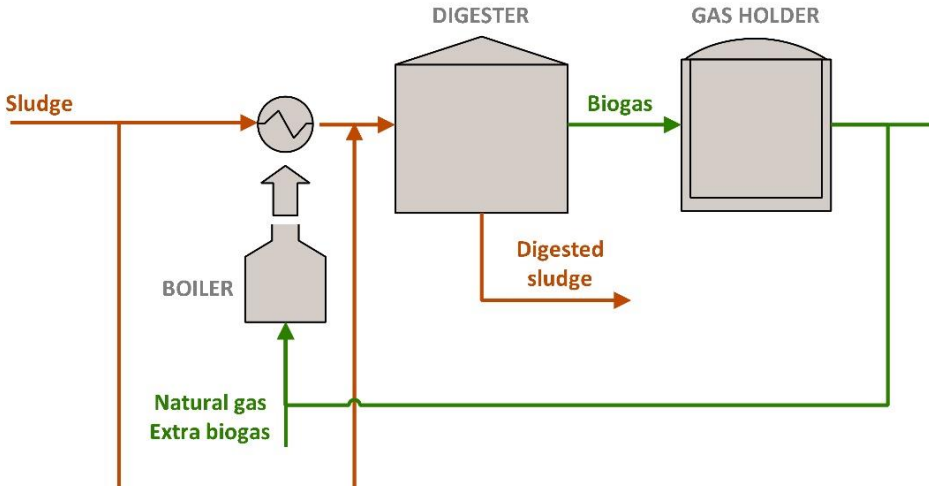
Gas holder
Sludge HEX room
Biogas
Electrical
HRU water
Cmp air
DEMOSOFC
Electrical connection
Grid interface

Plant layout



Buildings works done at the SMAT site

- **Construction of a concrete basement with underground piping to host the cleaning system and the SOFC modules**

  Underground biogas pipes duct are separated from others for safety reasons

DEMOSOFC site before the project start

Concrete basement

Buildings works done at the SMAT site

- Construction of a 100+ meters biogas pipeline to transfer biogas from the gas holder area to the DEMOSOFC area, and exchange water for heat recovery, compressed air and electrical connections.

Piperack

Buildings works done at the SMAT site

- **Construction of a dedicated building with 3 dedicated rooms for:**
  - Electrical cabinets
  - Heat recovery pumps and collectors
  - Control room
- **Construction of other side-buildings for auxiliary gases and UPS.**

Technical buildings

Buildings works done at the SMAT site

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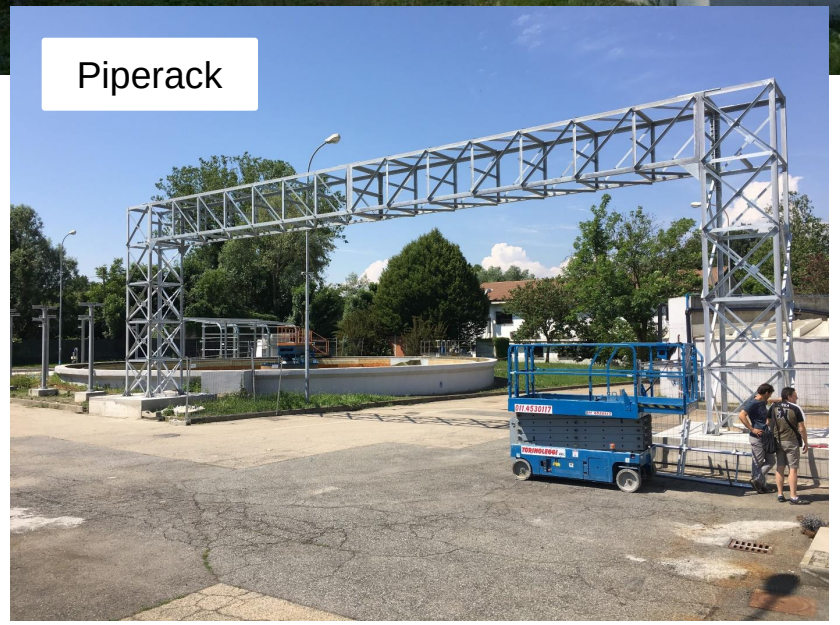
DEMOSOFC site before the project start

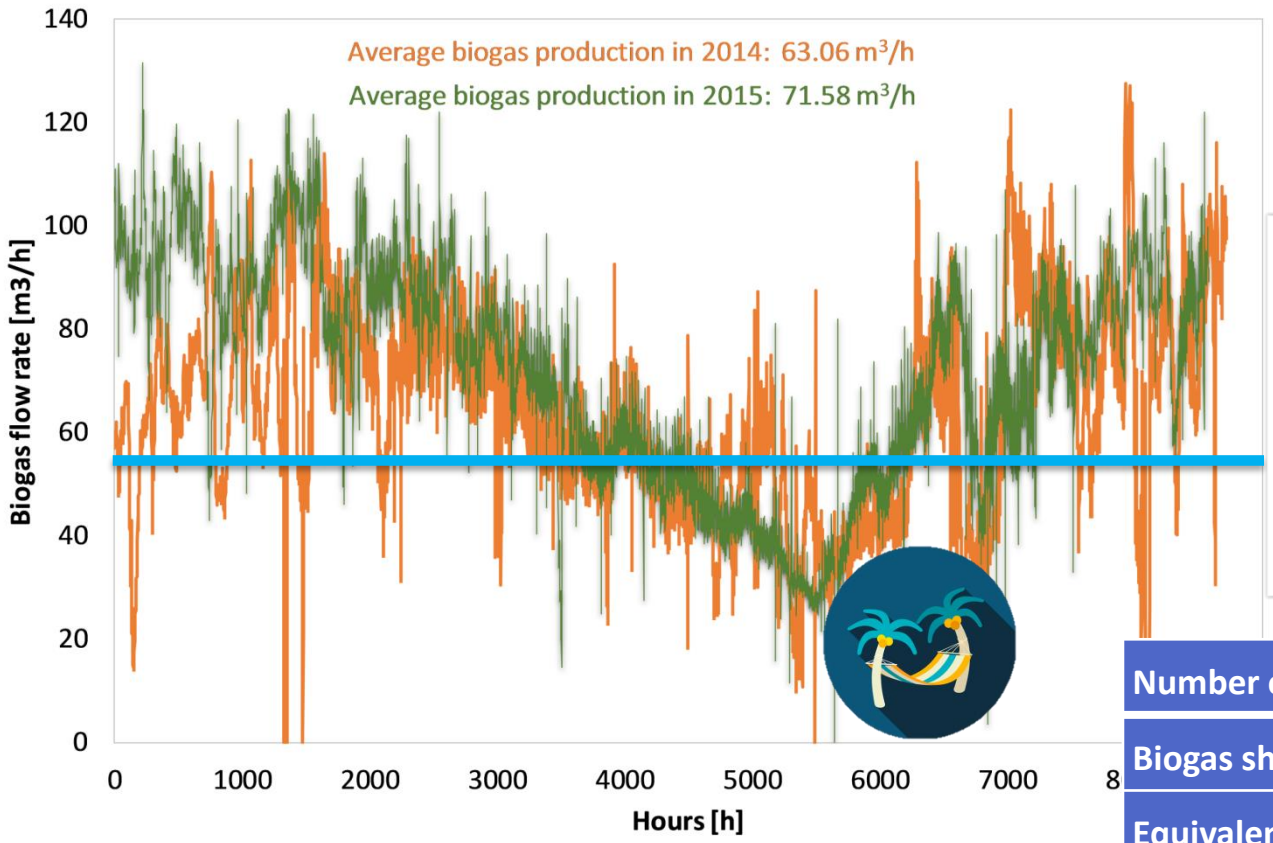
Concrete basement

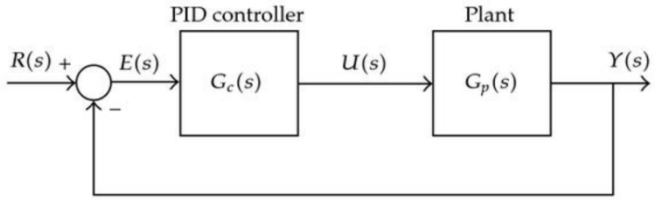
Piperack

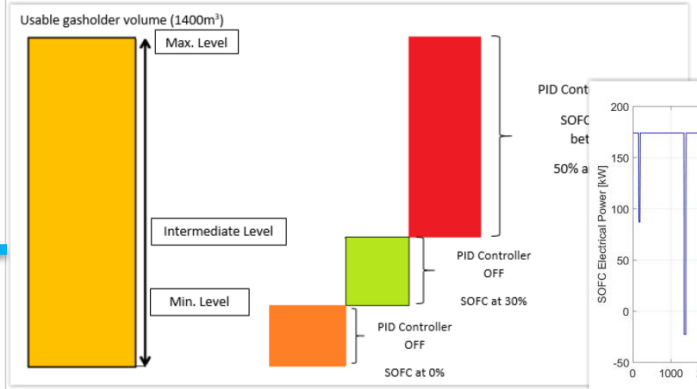


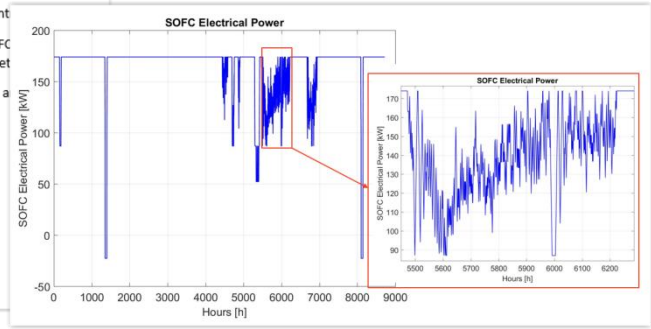
Technical buildings

Biogas production historical trend



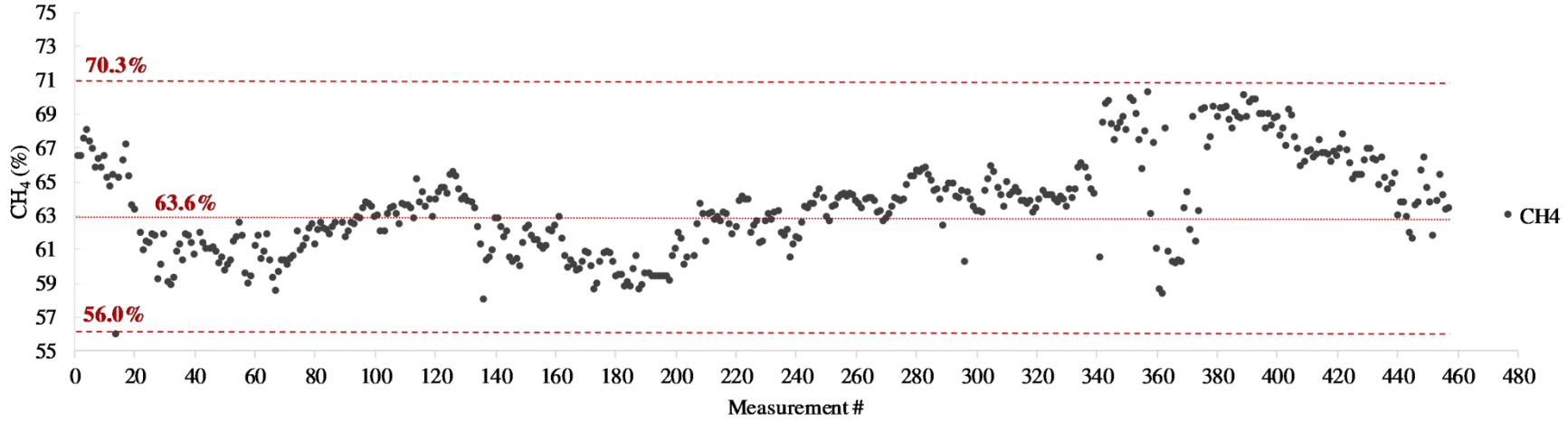




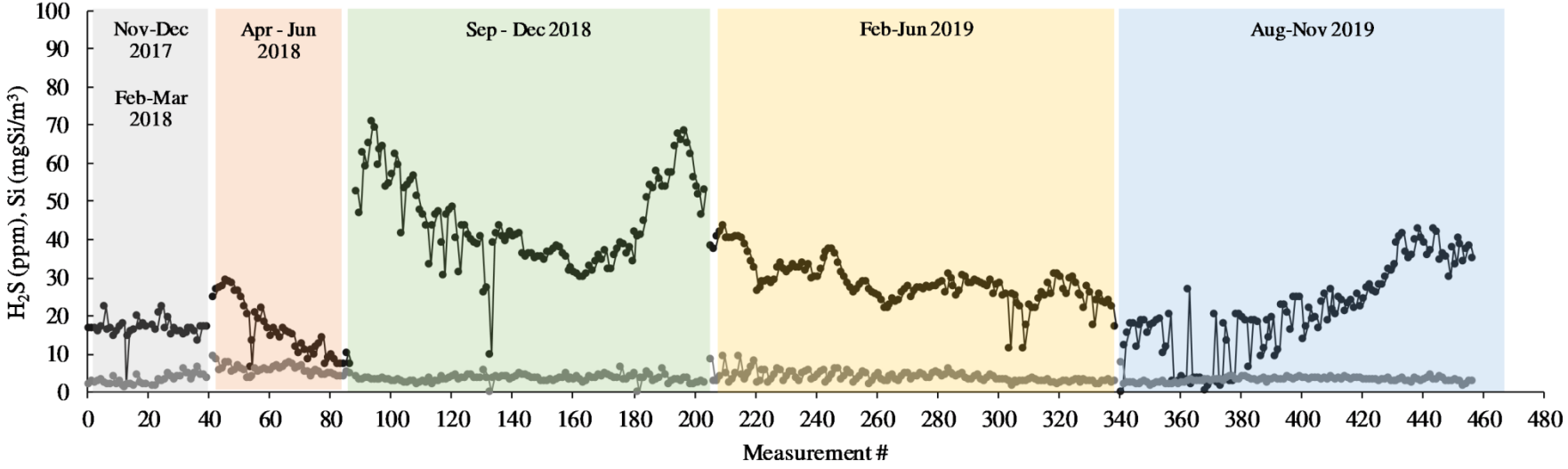


Number of modules	1	2	3	4
Biogas share for electricity production	26.7%	53.4%	76.5%	97.8%
Equivalent capacity factor at full load	100.0%	99.8%	95.7%	87.3%
Number of forced shut-downs per year	0	0	1	4
Average electrical efficiency	53.16%	53.15%	53.05%	52.66%
Average thermal efficiency	80.00%	79.96%	79.09%	77.35%

Issue: Biogas purification



	H_2S (ppm)	Si ($mgSi/m^3$)	CH_4 (%)
Average	28.66	3.78	63.57
Min	0.00	0.00	56.04
Max	71.05	9.43	70.35



Contaminants

Selection of the sorbents

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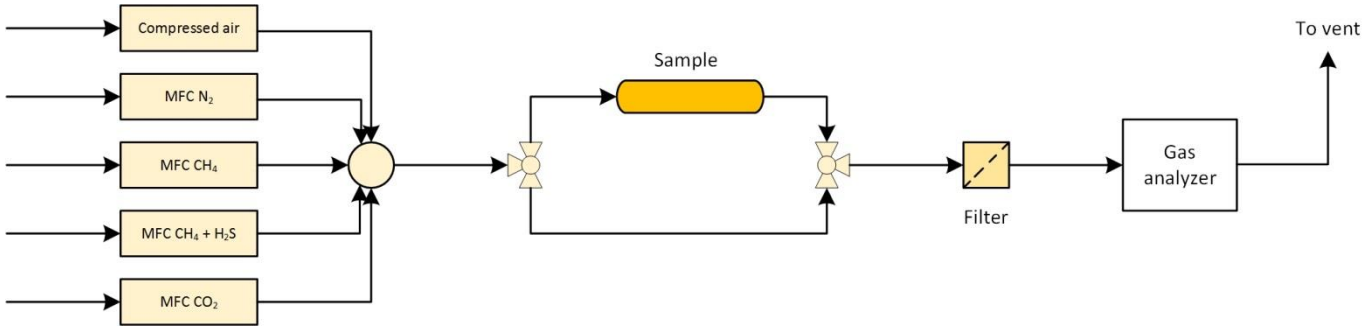
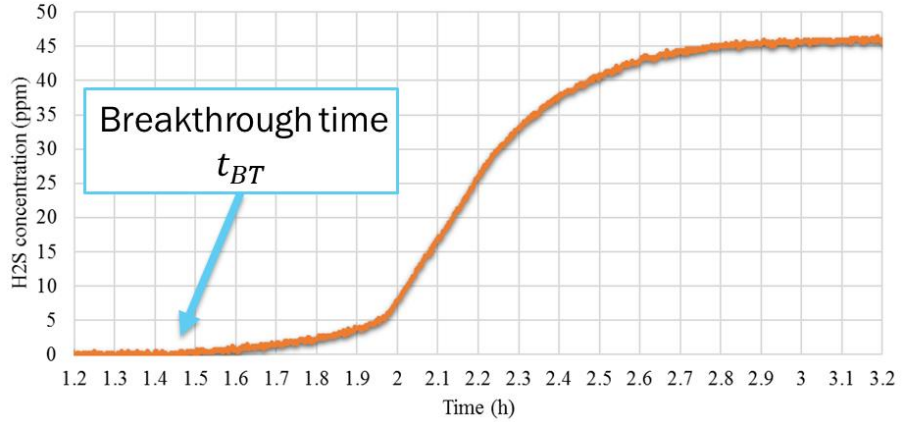
1. Sorbents selection

From:	Producer & Product	Suggested for:	Datasheet performance	Cost	Unit
	SulfaTrap R8G	Siloxanes, large size sulphur compounds and low H_2S levels removal	30-70 mgS/g on biogas @ 2000 ppm(v) H_2S	15.88	€/kg
	AirDep CKC	H_2S removal	> 200 mgS/g on air	2.80	€/kg
	AirDep CKI	H_2S removal	> 200 mgS/g on air	5.00	€/kg
	AirDep C64	Siloxanes removal	600 mgCCl_4/g on air	2.20	€/kg

2. Lab activity



3. Adsorption capacity



Biogas purification system: lead & lag configuration

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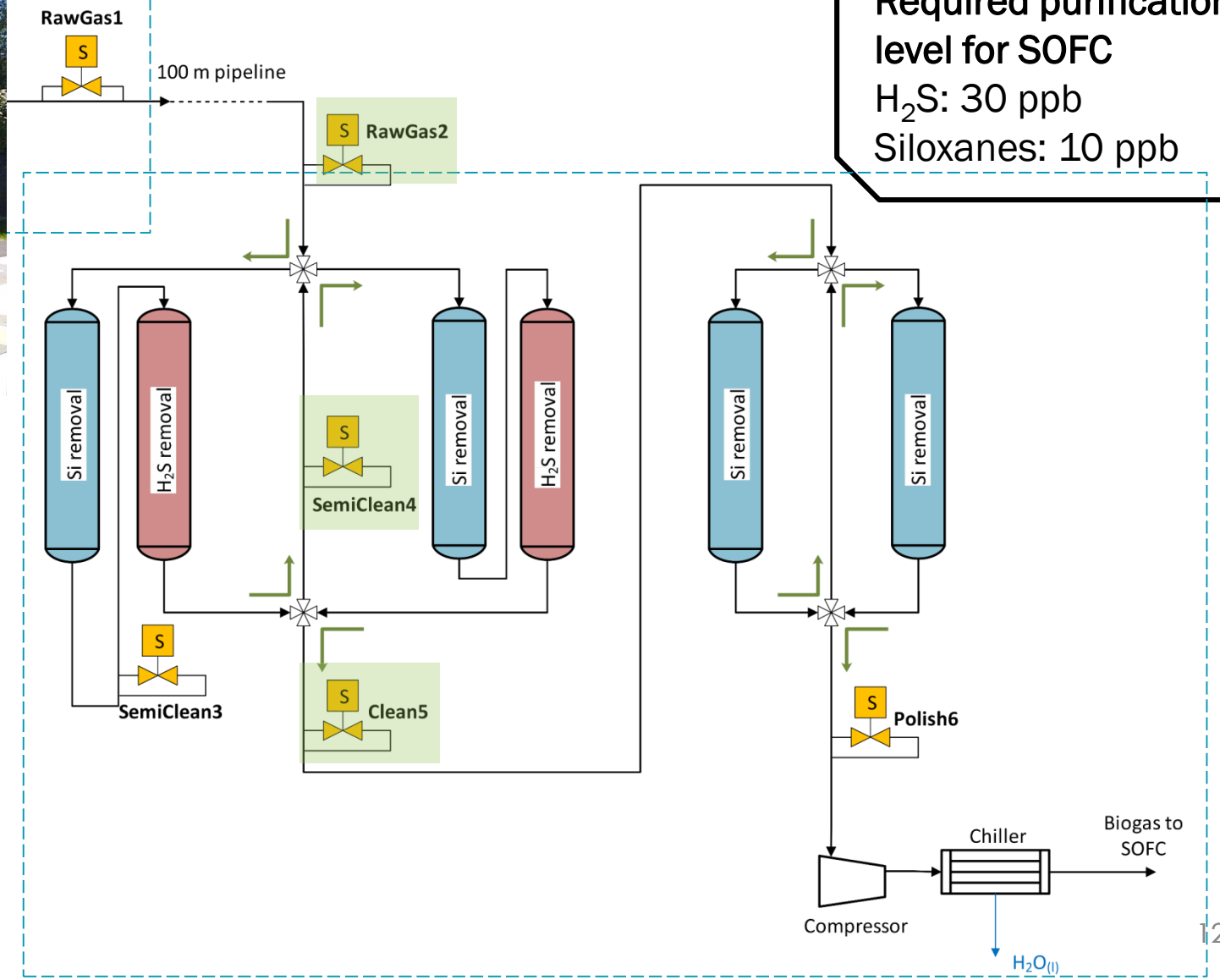
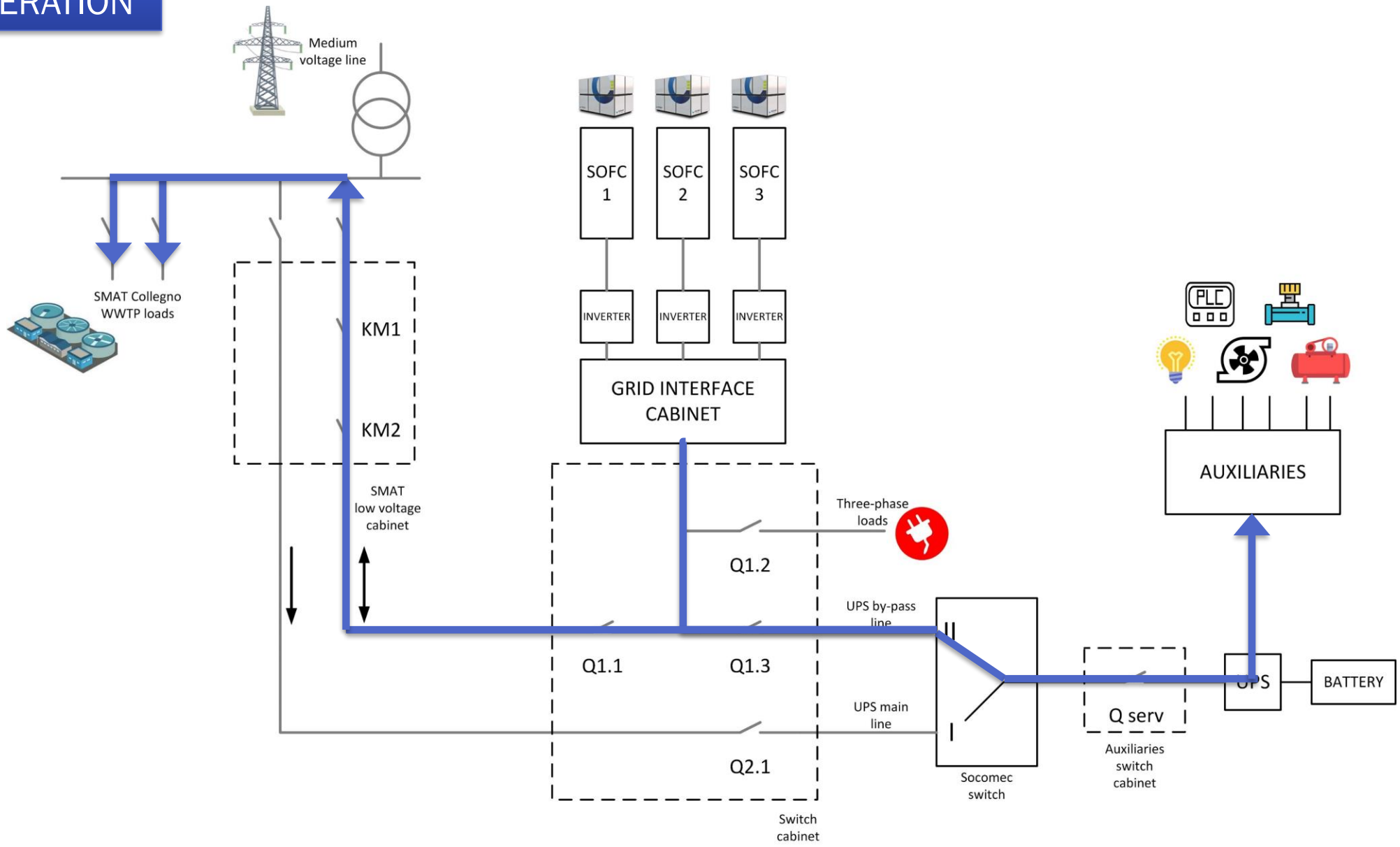
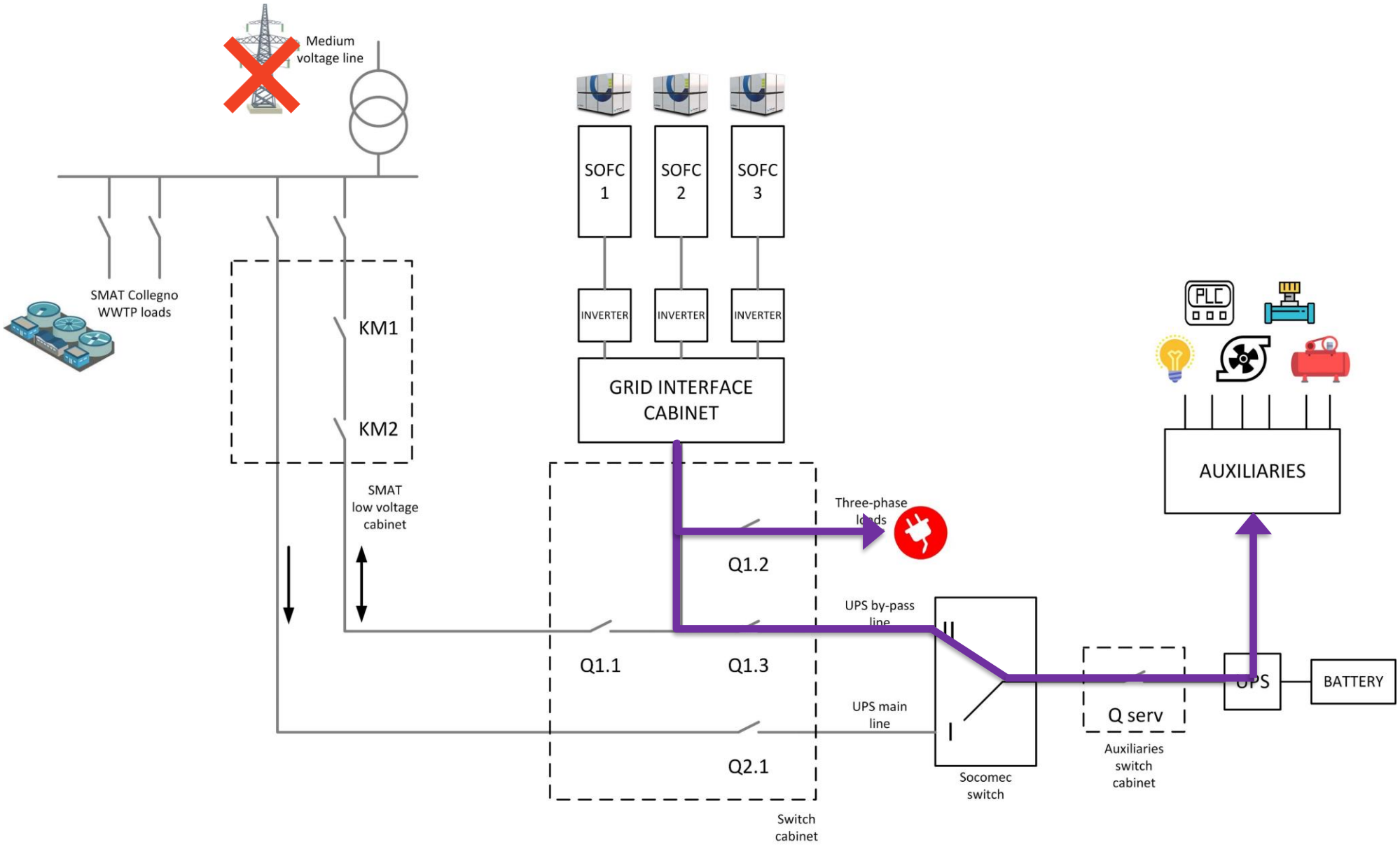
Required purification level for SOFC
H_2S: 30 ppb
Siloxanes: 10 ppb



NOMINAL OPERATION

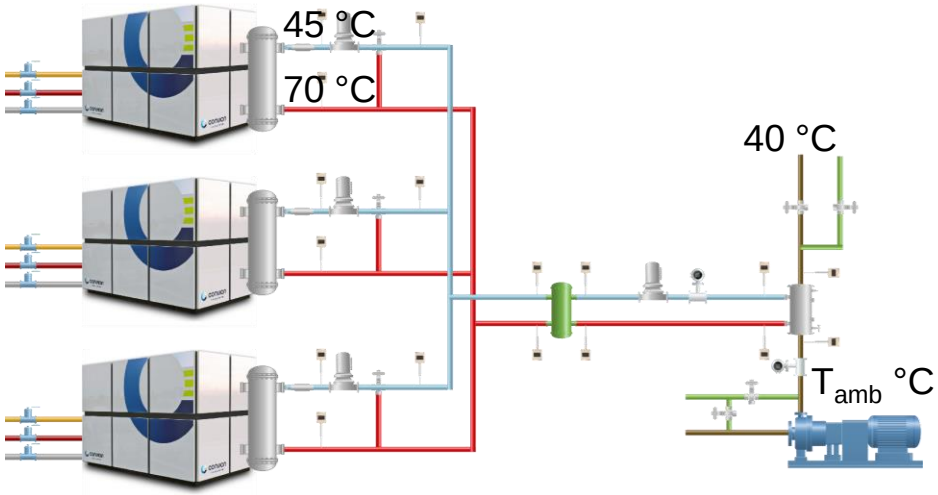


ISLAND MODE

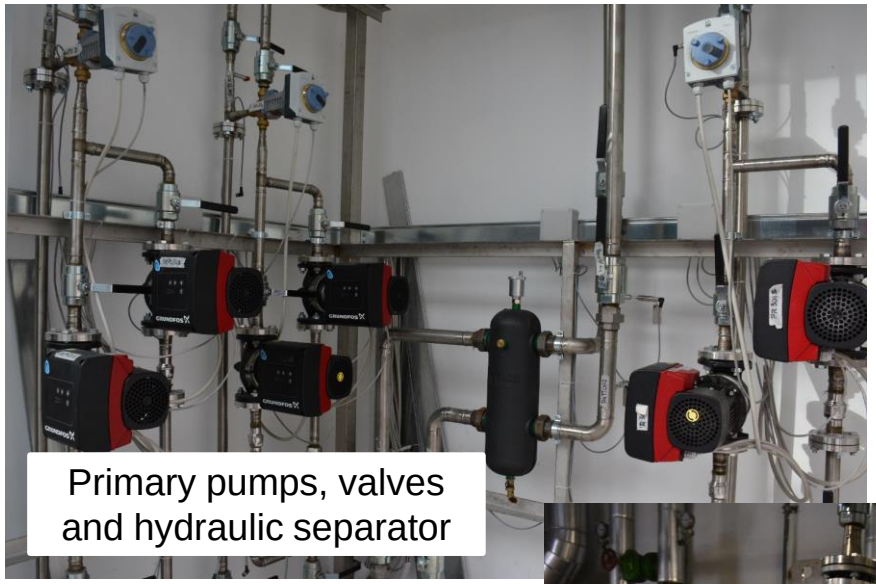

Medium voltage line
SMAT Collegno WWTP loads
KM1
KM2
SMAT low voltage cabinet
SOFC 1
SOFC 2
SOFC 3
INVERTER
INVERTER
INVERTER
GRID INTERFACE CABINET
Three-phase loads
Q1.2
UPS by-pass line
Q1.1
Q1.3
UPS main line
Q2.1
Switch cabinet
Socomec switch
Q serv
Auxiliaries switch cabinet
PLC
AUXILIARIES
UPS
BATTERY

Thermal recovery system and activities

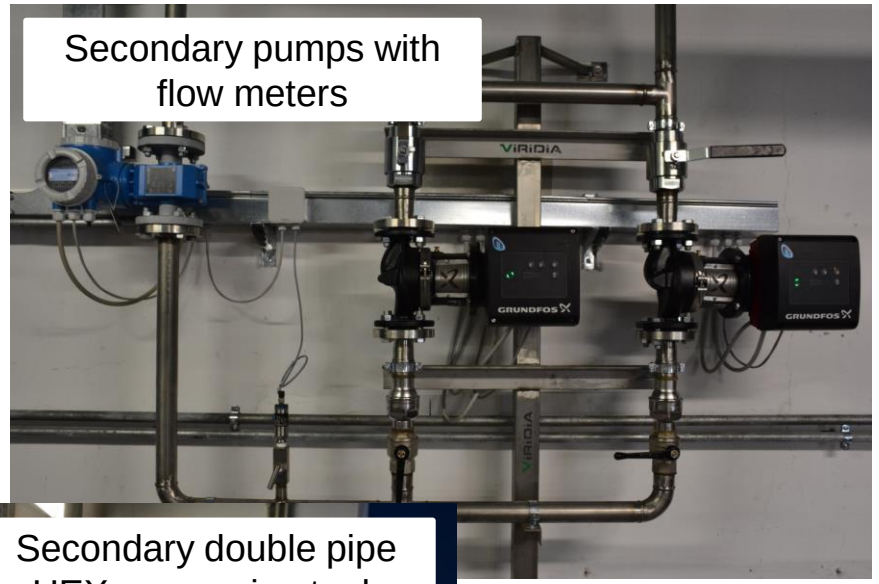
- **Exhaust gases** are found at around **200-250°C** and are cooled down by controlling the water side (dew point is ~ 36 °C at full power but condensation should be avoided)
- **Thermal recovery on SOFC side** is performed by using a mixture of water-glycol (30% glycol) with set-point temperatures of **45°C (inlet) and 70°C (outlet)**. Water flow rate is adjusted by using a dedicated PID controller.
- A mixing valve, controlled by another PID, is used to guarantee 45°C at the HEX inlet and avoid condensation.
- On the **sludge side**, sludge is heated up from ~ ambient temperature **to 40°C** (a PID controller is available to regulate the flow rate in order to guarantee a fixed outlet temperature)



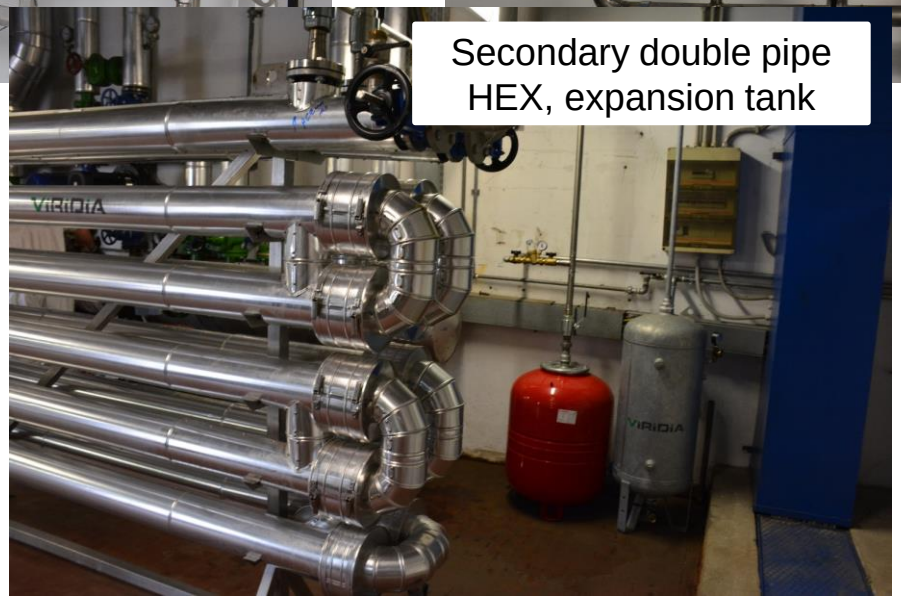
Thermal recovery system and activities



Primary pumps, valves and hydraulic separator



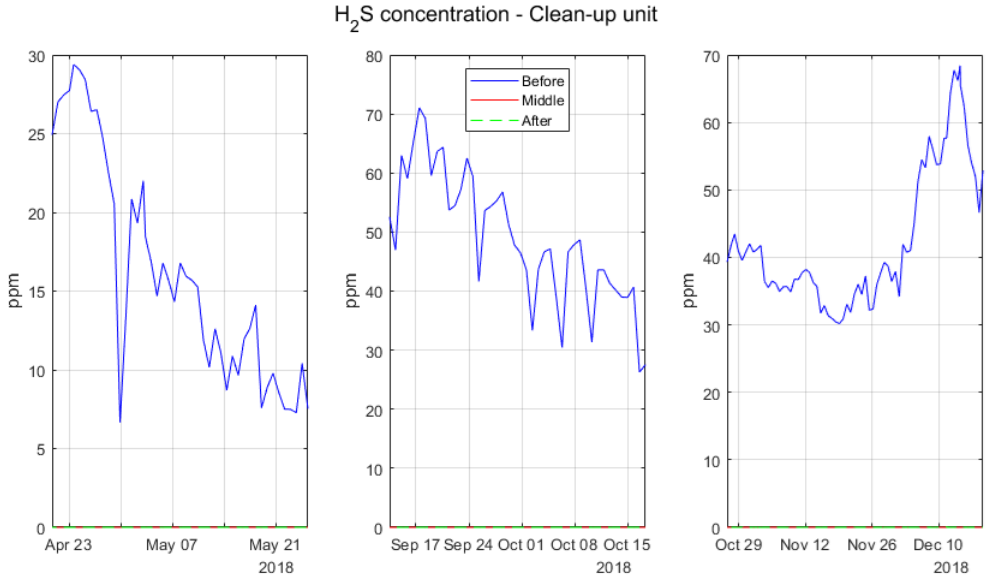
Secondary pumps with flow meters

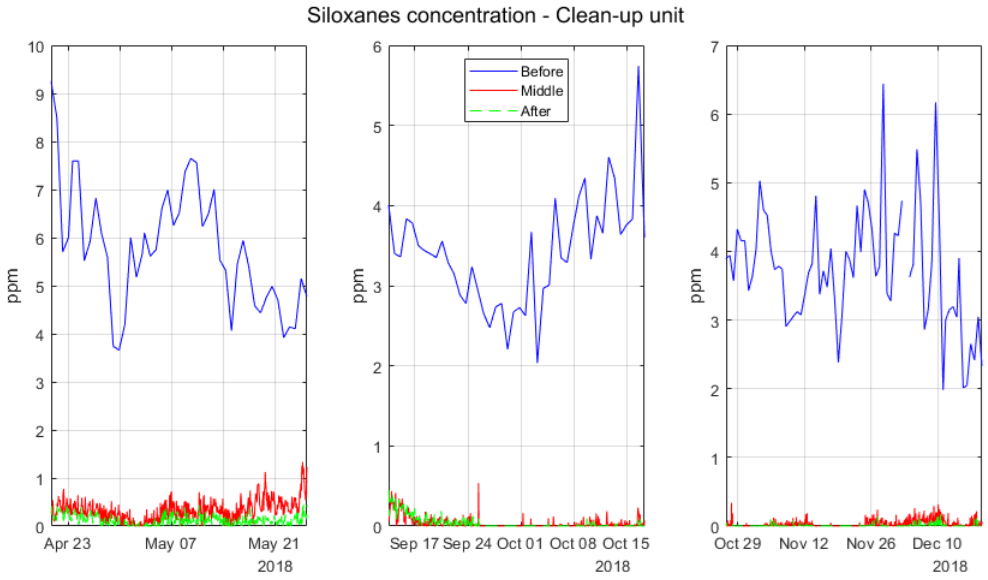


Secondary double pipe HEX, expansion tank

Sludge pump and flow meter

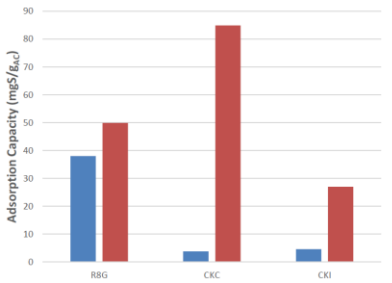
Biogas clean-up



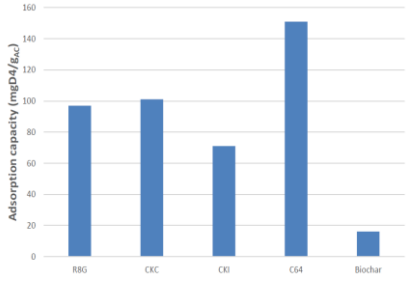


H_2S: 52.62 mg/m^3
Siloxanes: 4.20 mg$_{Si}$/m^3

Ads. capacity 85 (mgS/gAC)

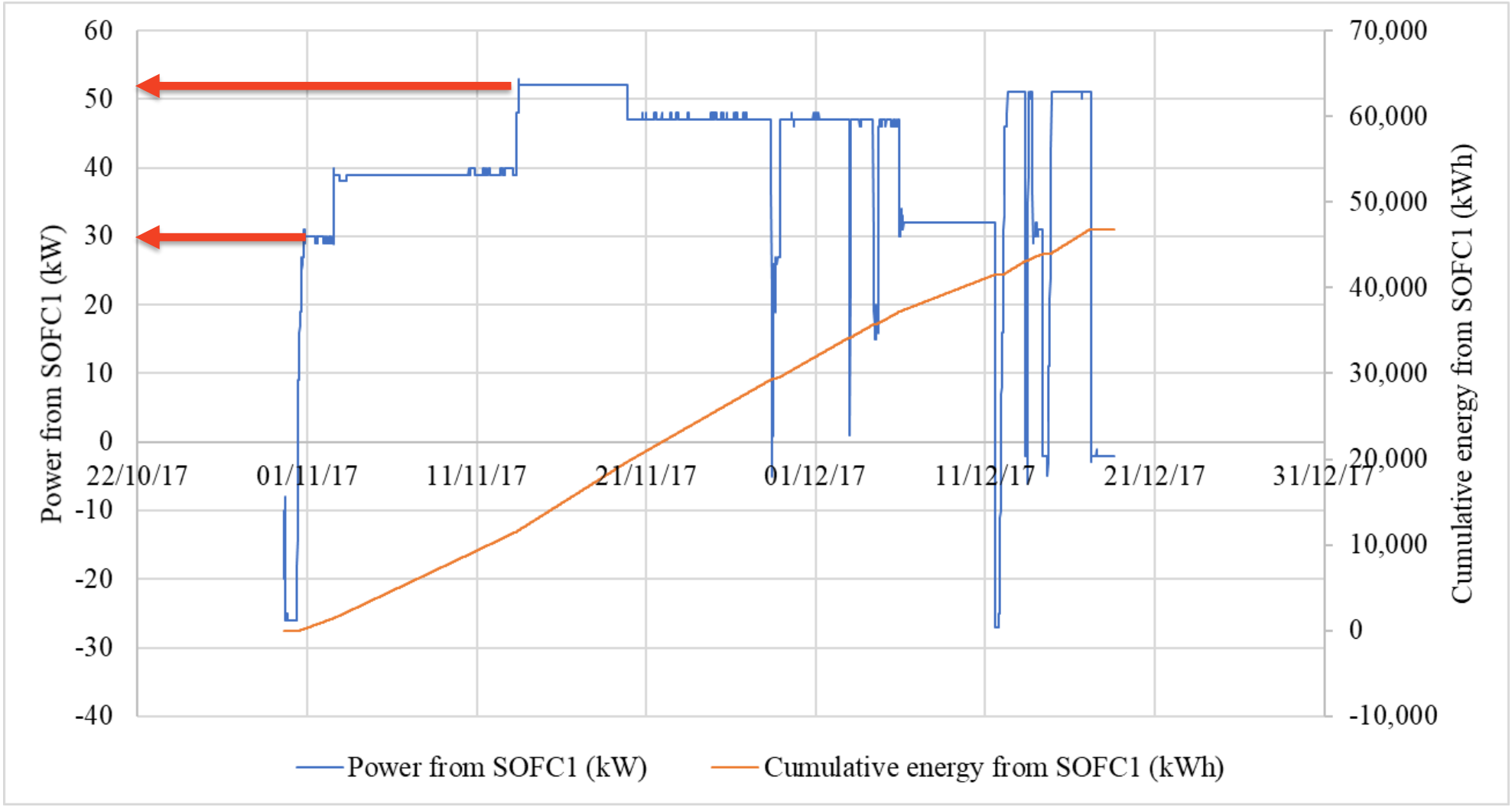


Ads. capacity 150 (mgD4/gAC)

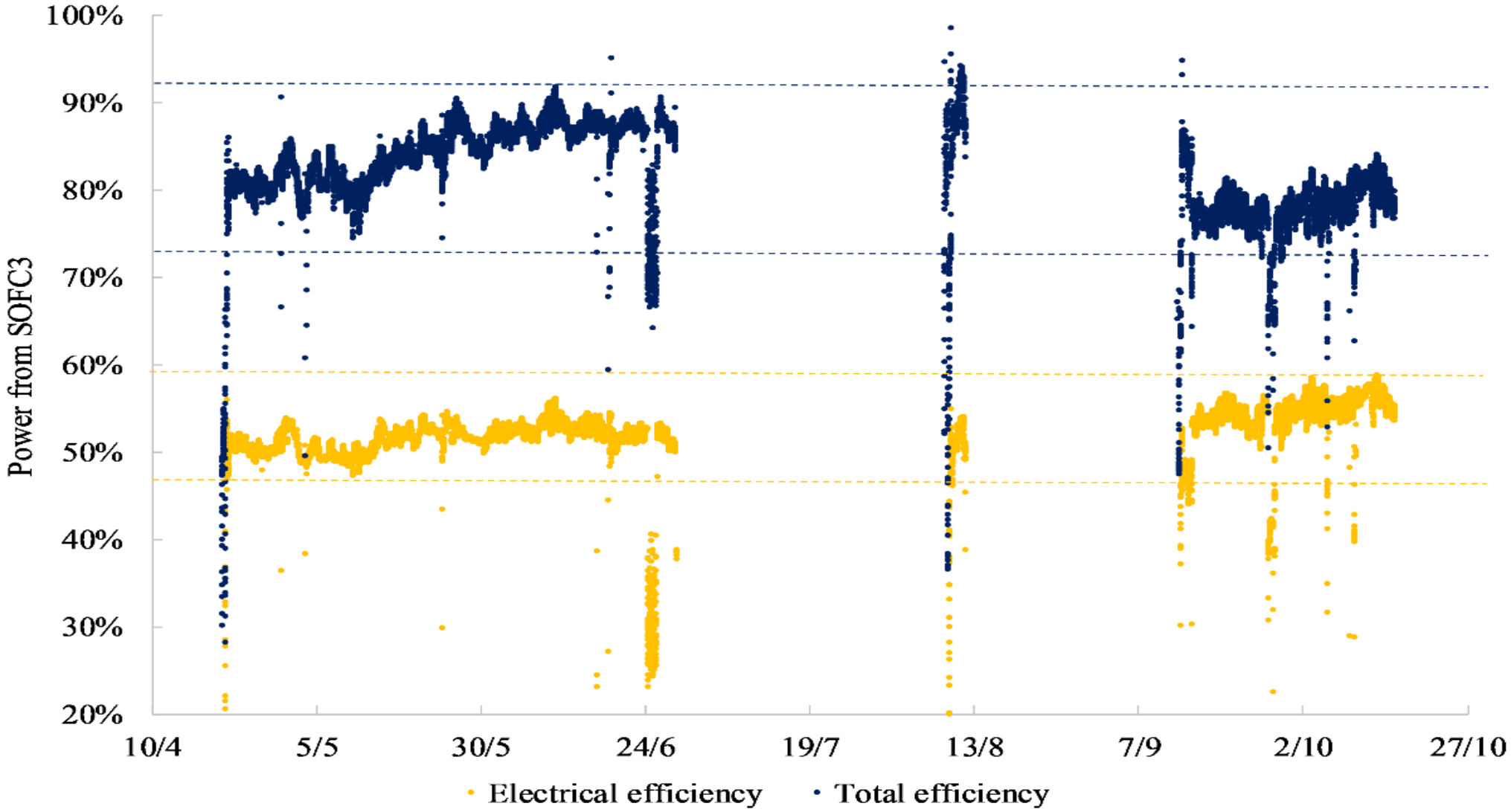


H_2S: 0 mg/m^3
Siloxanes: <0.1 mg$_{Si}$/m^3

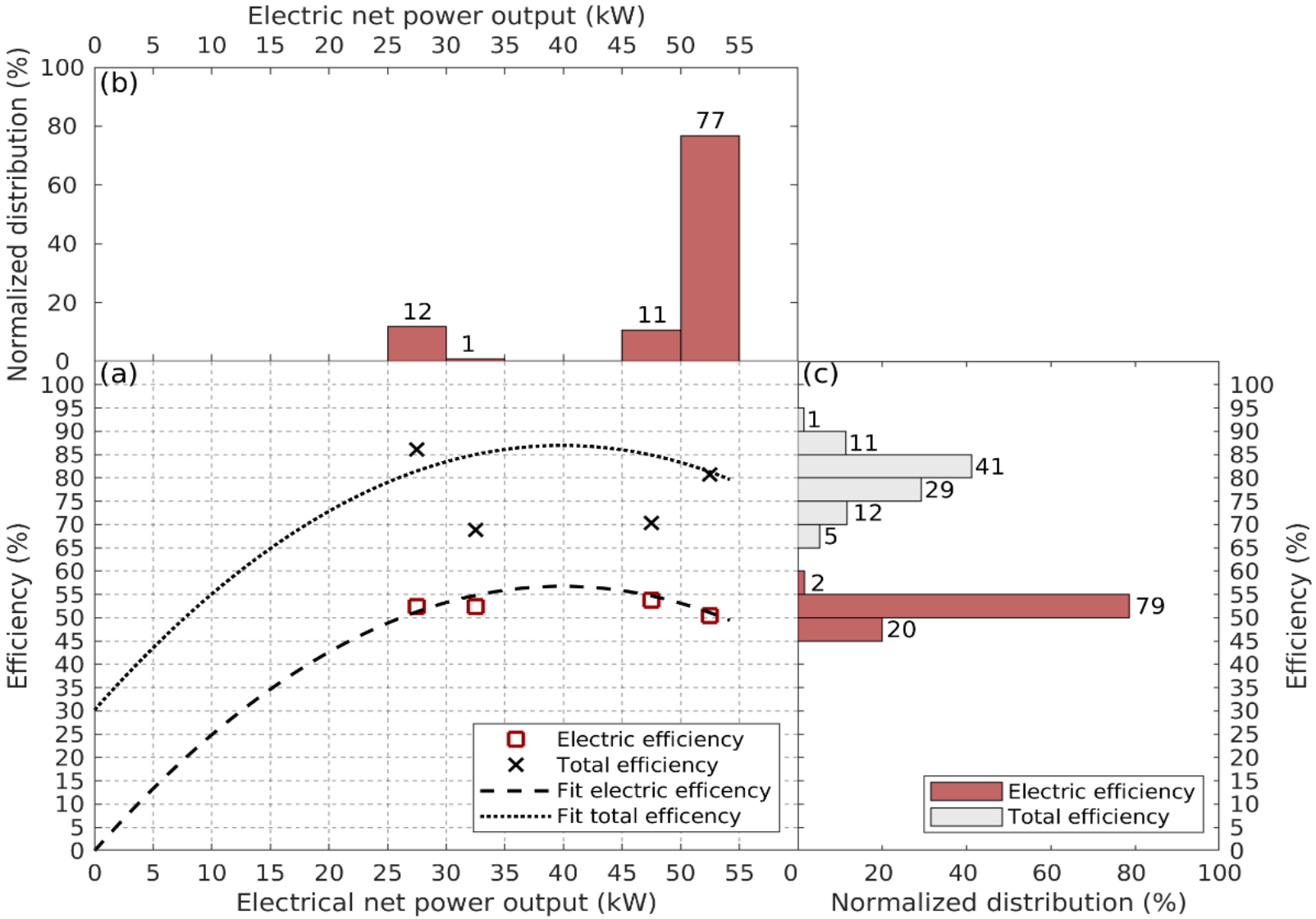
SOFC Electrical Power production – Module 1



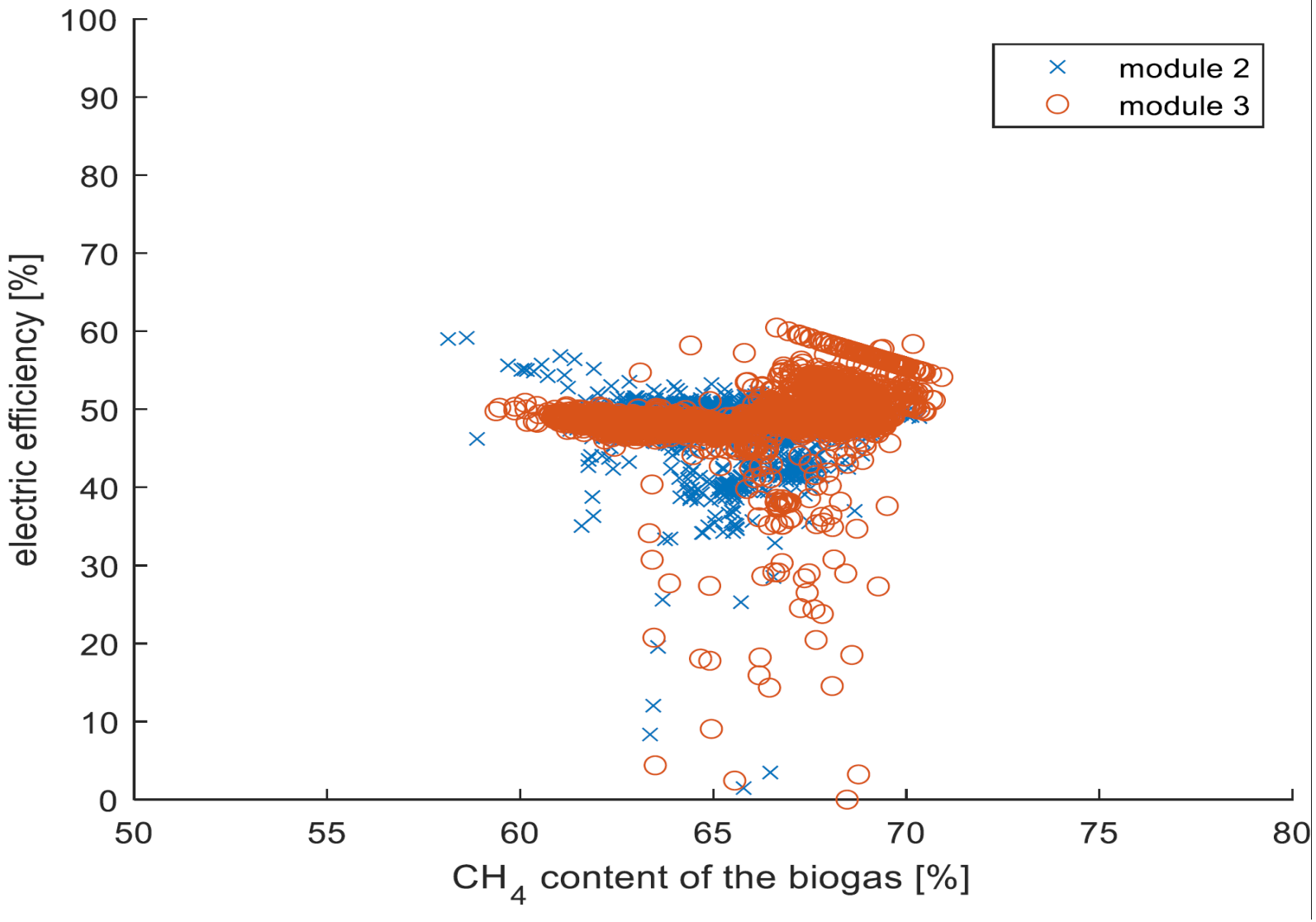
SOFC electrical and global efficiency – Module 1



SOFC efficiency – Module 1



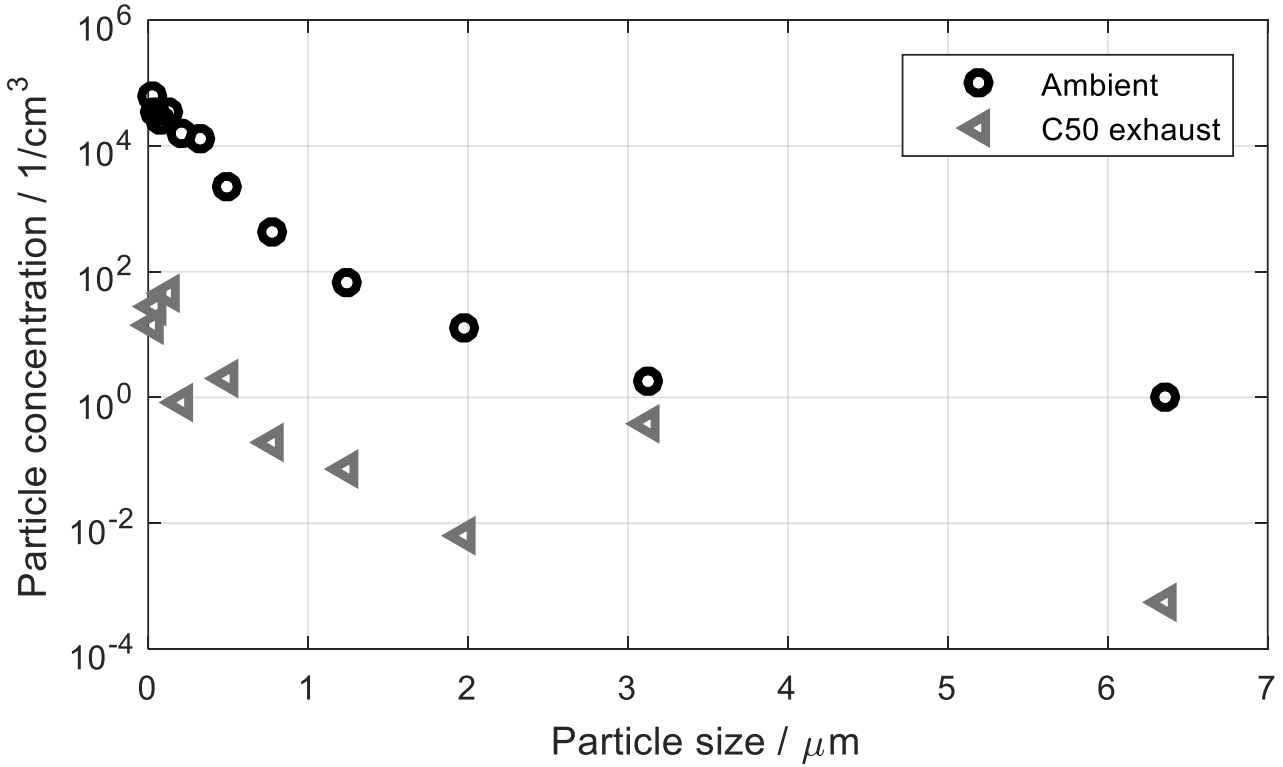
SOFC electrical efficiency vs %CH4



Some results: emissions

Species	Unit	Measured value
H_2O	Vol-%	4.7
CO_2	Vol-%	3.4
CO	mg/m³	<9
CH_4	mg/m³	<2
N_2O	mg/m³	<8
NO	mg/m³	<20
NO_x (as NO_2)	mg/m³	<20
SO_2	mg/m³	<8
C_2H_6	mg/m³	<14
HCHO	mg/m³	<7
HF	mg/m³	<10
HCl	mg/m³	<10
SO_2	mg/m³	<10
O_2	Vol-%	18.3
Particulate	mg/m3	0.01

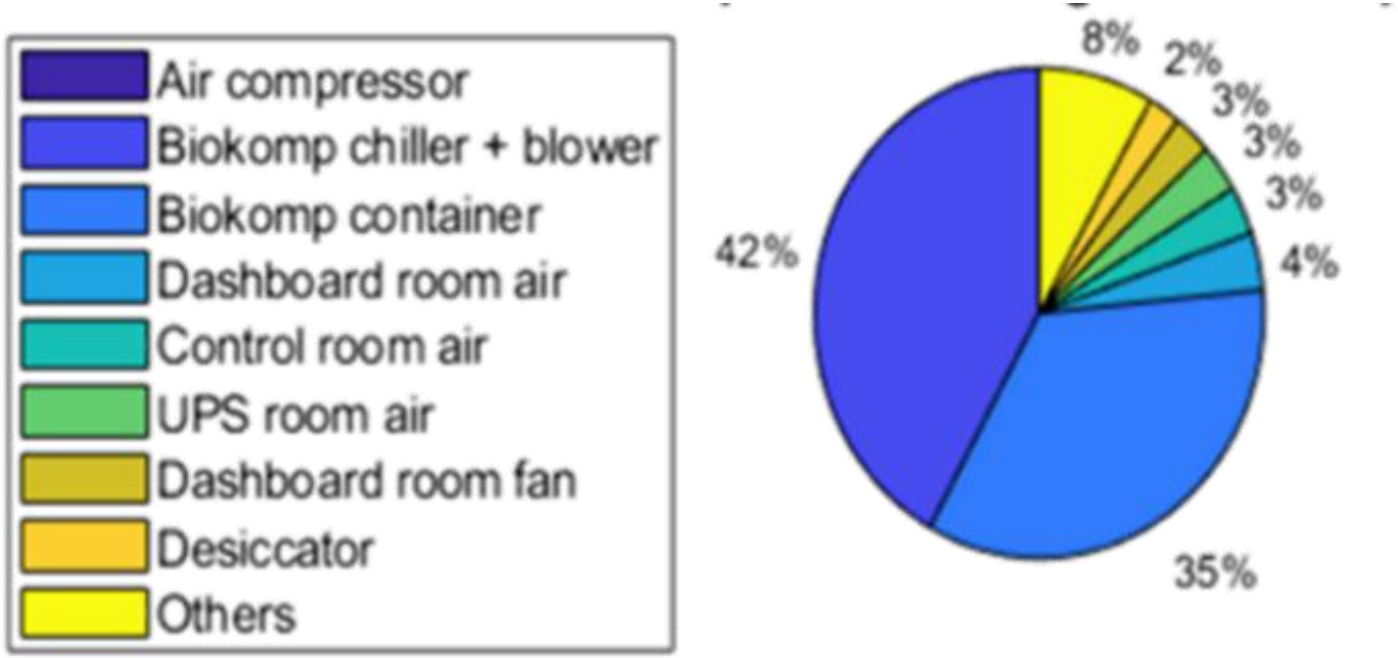
Particulate emission during steady state



Exhausts from biogas-fed SOFC are cleaner than the surrounding air

SOFC auxiliary consumption

OVER A TOTAL PRODUCTION OF AROUND 110 kW



The total auxiliary consumption (including all the biogas treatment section, heat recovery, electrical and control parts, conditioning of the technical building, etc.) is around 11.72 kW.

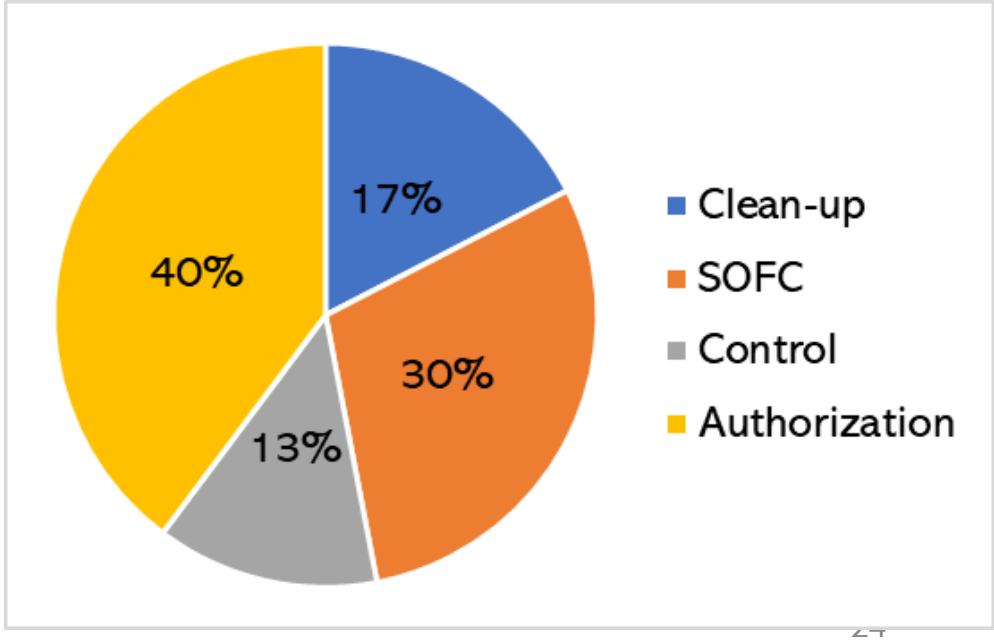
The value is dominated by the biogas treatment section (two chillers, blower, compressor) and all the equipment within the container (especially ventilation and cooling during Summer). The two sections together account for 77% of the consumption.

Capacity factor and stops of the plant

	Hours ON - h	Electrical Energy - kWh	Capacity factor - %
Tot. SOFC1	6,537	283,376	46.64%
Tot. SOFC2	7,710	320,115	67.70%
Tot. DEMOSOFC	14,247	603,492	55.00%

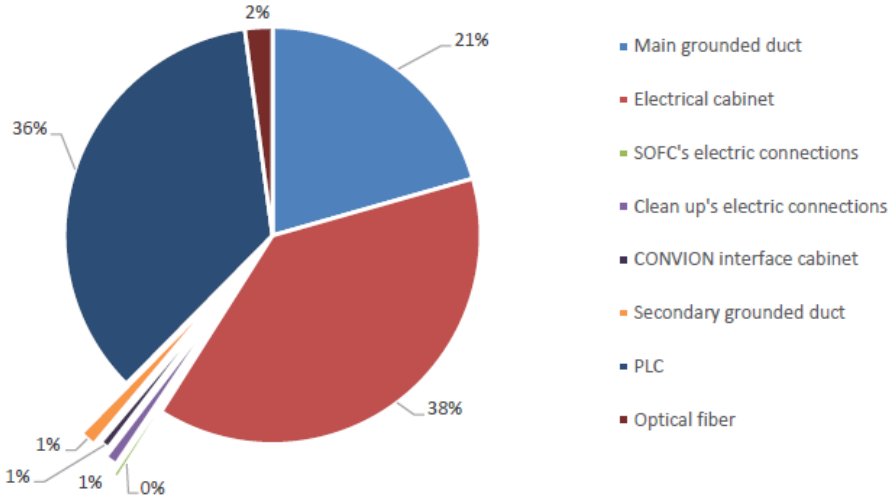
→ **OFF periods were due to:**

- Cleaning system → freezing problem at the beginning (then solved), planned (every 6'000 hours) and unplanned maintenance on the biogas compressor and blower.
- SOFC → air pre-heater maintenance, island mode testing and checking, maintenance on stack module 1.
- Control system → in the first 6-8 months the software was finalized and updated based on the experience gained onsite.
- Authorization → time required to renew the authorization and install the power meter requested

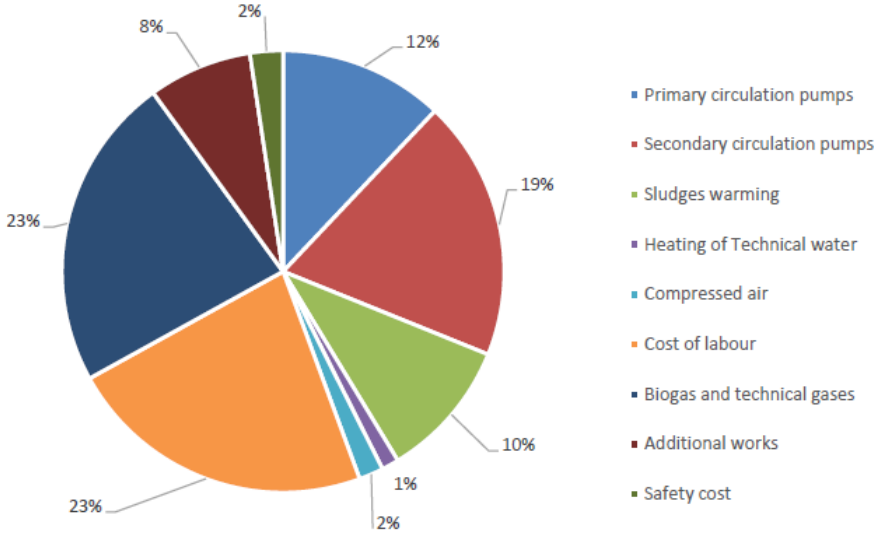


Economics

Electrical works

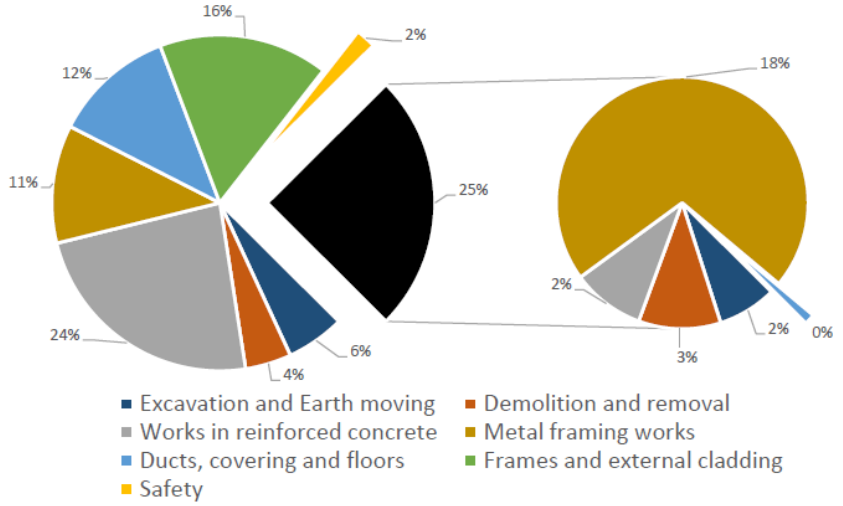


Mechanical works

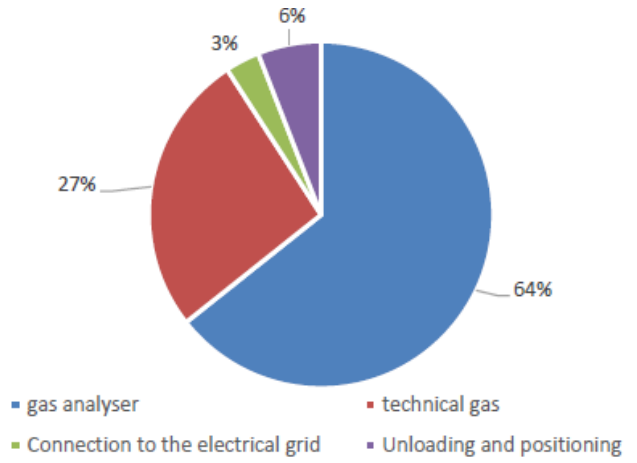


	Actual Cost [€]
Mechanical Works	174.562
Electrical Works	173.913
Civil Works	191.920
Clean-up system	221.087
Auxiliary works	91.677
TOTAL	853.159

Civil works



Auxiliary works



Economics

Plant optimization analysis:

- Moving from underground pipeline to external (covered) pipeline
- Removal of twin pumps
- Reduction of UPS size
- Simplification of the technical building (→ containerized solution)
- Optimization of the cleaning system

	Actual Cost [€]	Estimated Cost [€]	Reduction
Mechanical Works	174.562	65.502	-63%
Electrical Works	173.913	100.819	-42%
Civil Works	191.920	23758	-88%
Clean-up system	221.087	132.652	-40%
Auxiliary works	91.677	54.597	-40%
TOTAL	853.159	377.328	-56%

Future perspectives for SOFC in the WWTP sector and some economic considerations

SOFC energy coverage and cost savings in the WWTP

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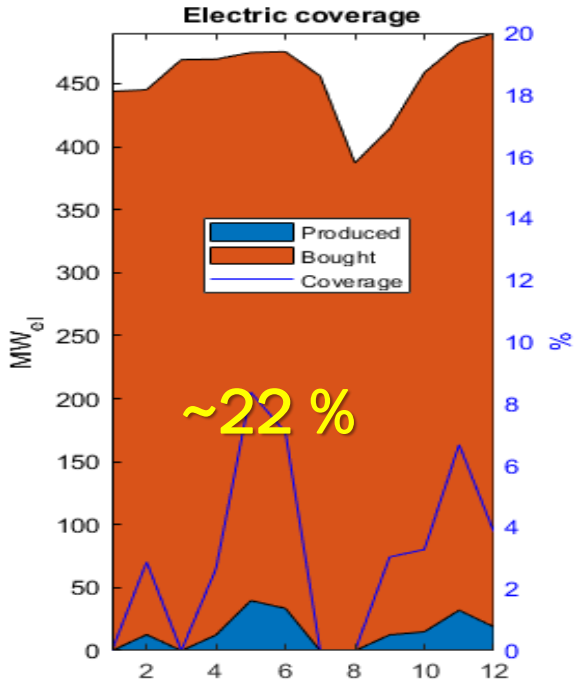
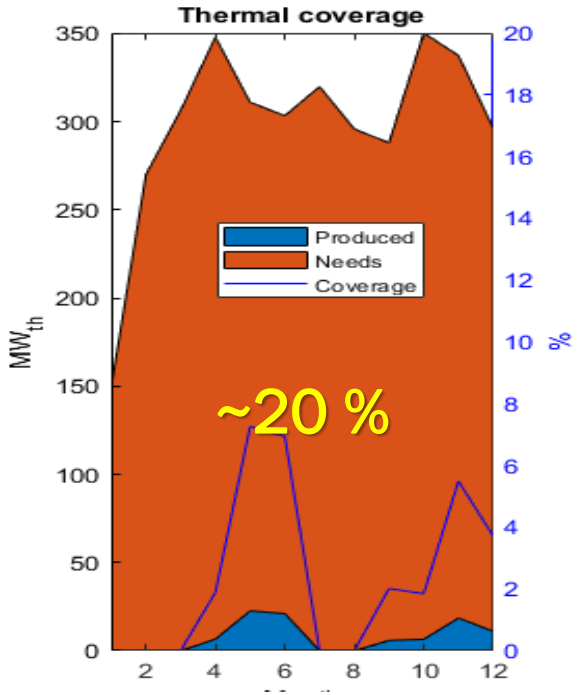
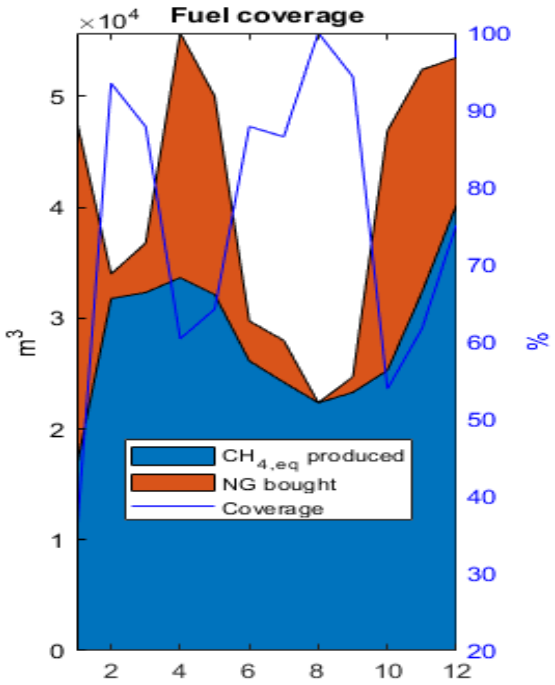
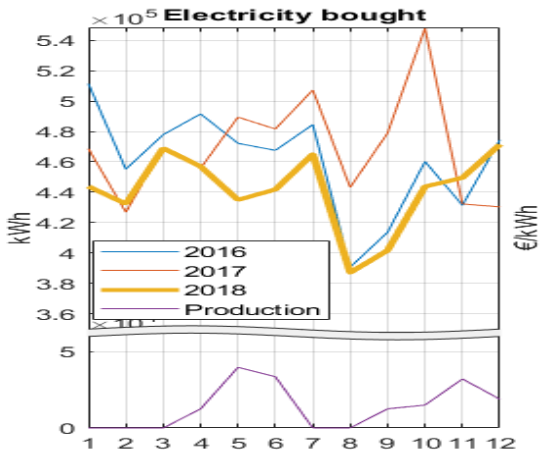
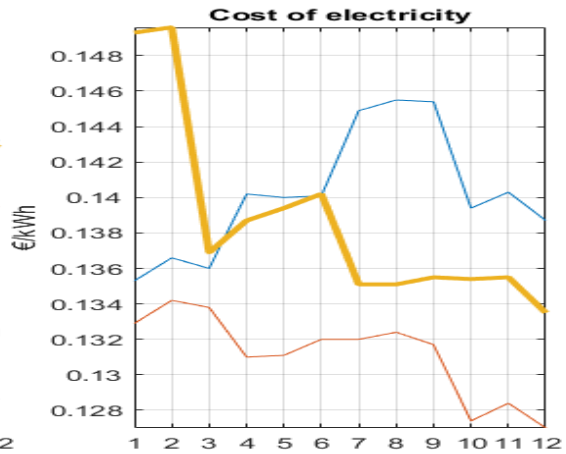
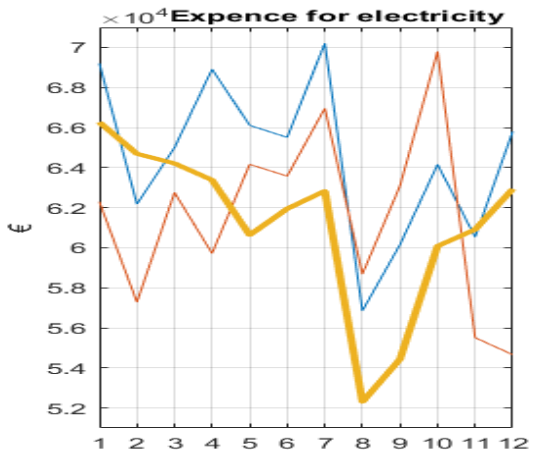










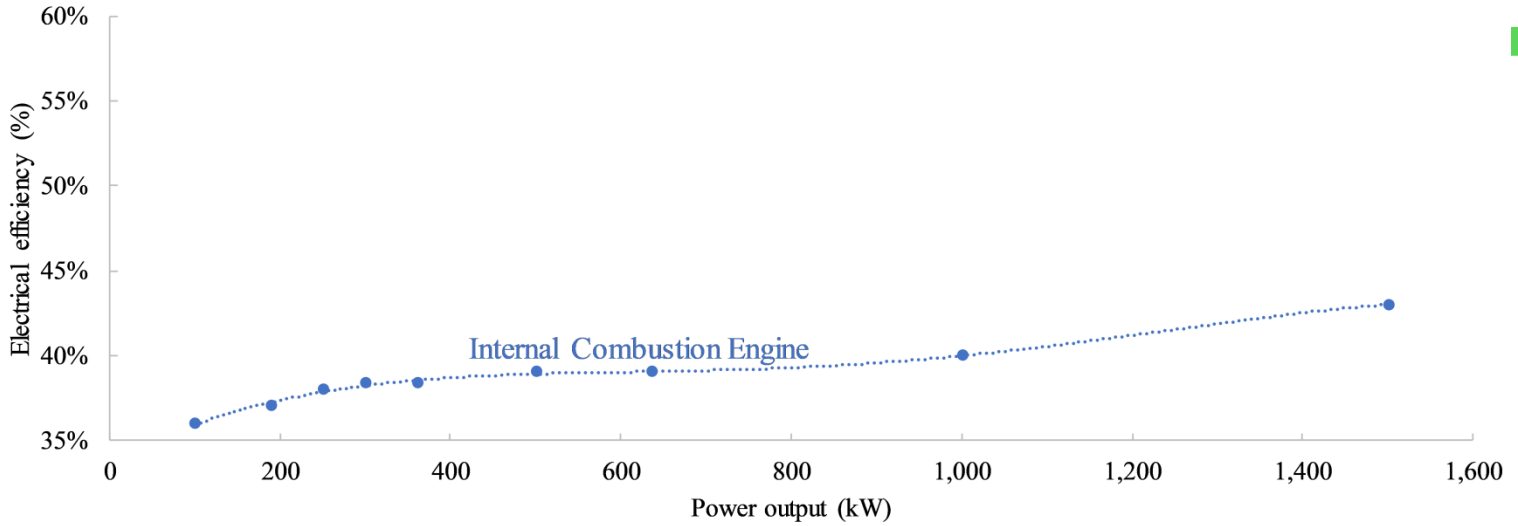


Savings per year so far:

EL 59'633 €/yr
TH 17'004 €/yr

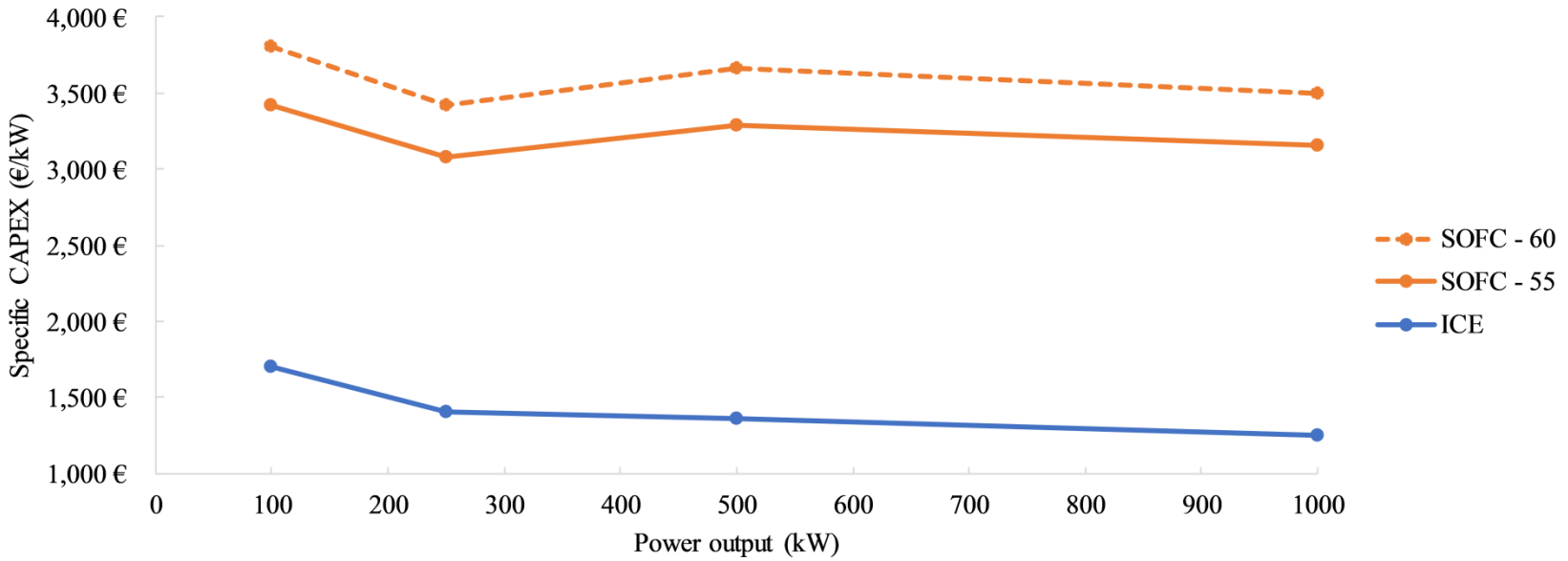
TOT 76'637 €/yr

Which should be the price of an SOFC system in a WWTP?



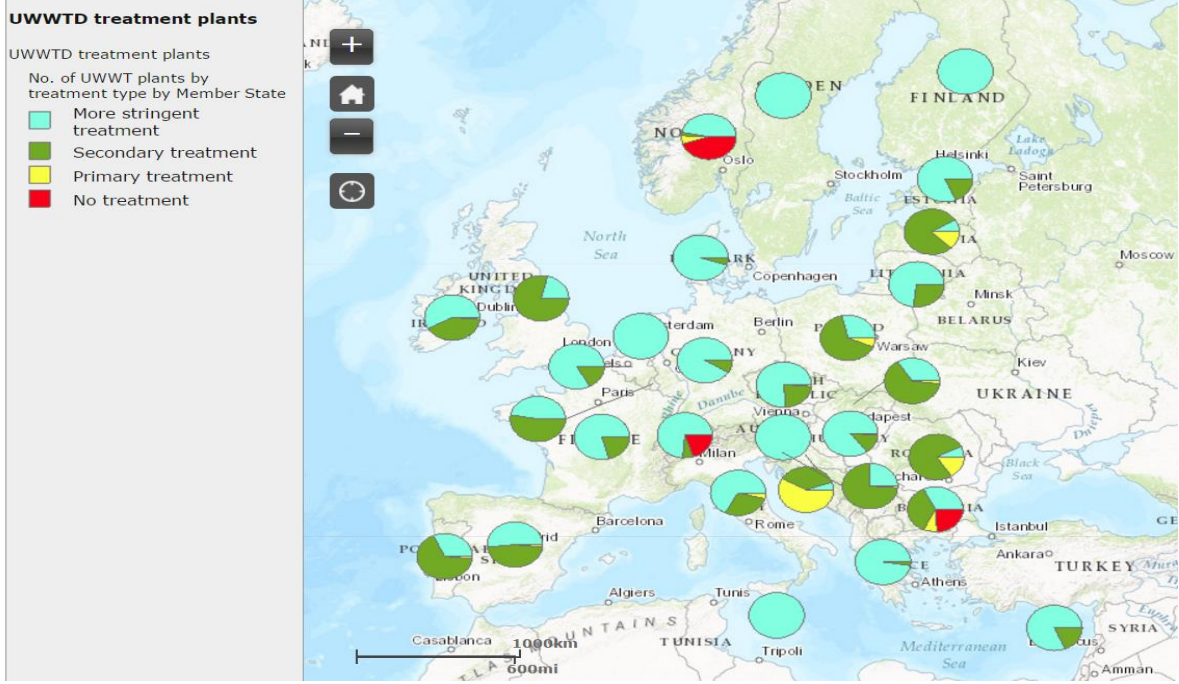
Power output (kW)	100	250	500	1000
Cost of electricity (€/kWh)	0.123 €	0.102 €	0.099 €	0.094 €

SOFC-CHP system investment cost to have the same Cost of Electricity of the ICE case study

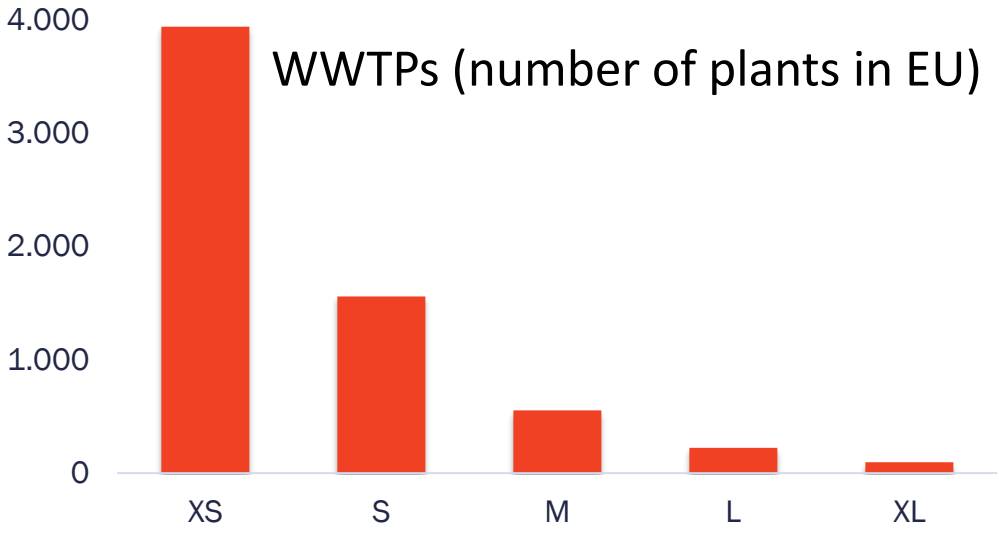


Potential markets analysis

- Minimum entering load for WWTP with anaerobic digestion: 20’000 P.E. (20’000 P.E. ~ 40 kW SOFC)
- Biogas specific production: 10-29 l/P.E./day) (value for conservative calculation: 10 l biogas/P.E./day)
- Methane content: 60%
- Capacity factor: 95%
- SOFC electrical efficiency: 53%



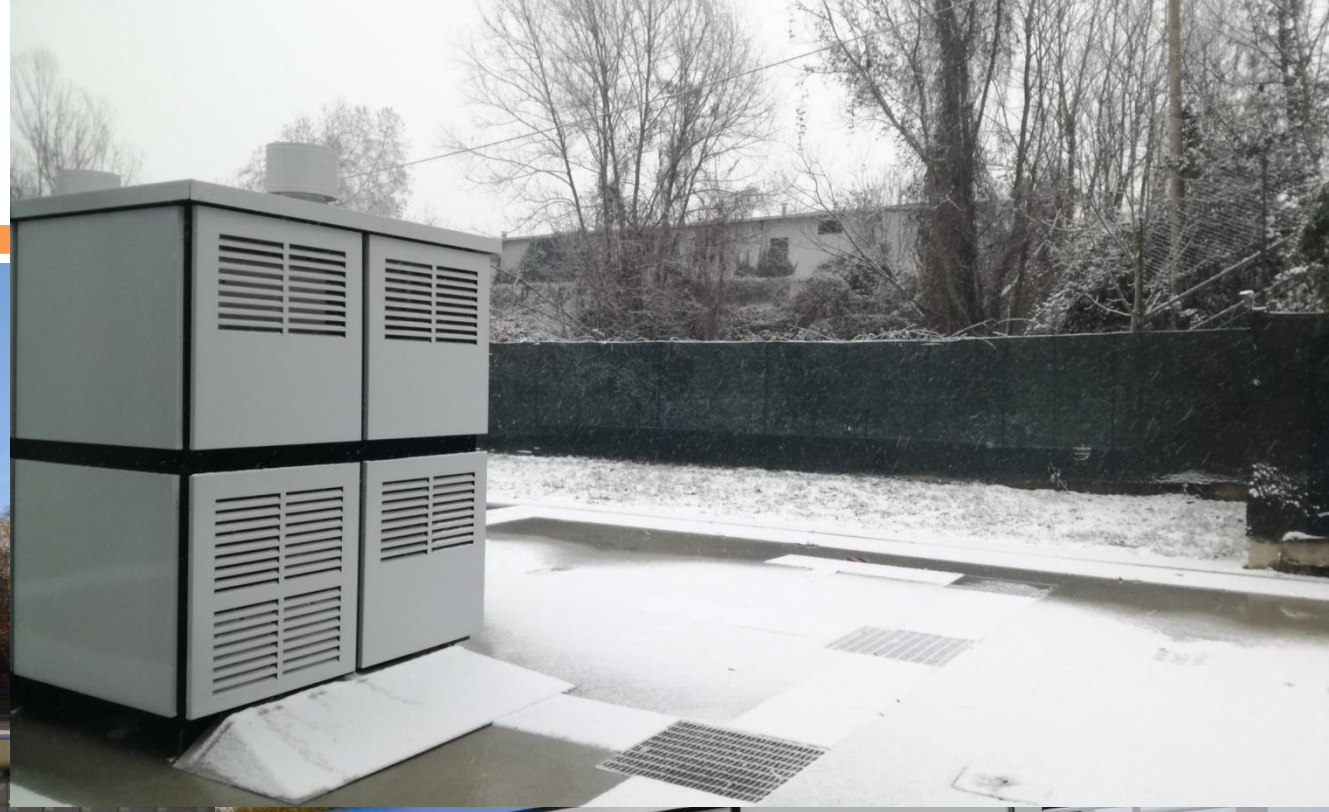
XS	20-60 kP.E.	25 – 80 kW
S	60-150 kP.E	80 – 200 kW
M	150-350 kP.E.	200 – 500 kW
L	350-750 kP.E.	500 - 1000 kW
XL	>750 kP.E.	1000 - 1500 kW

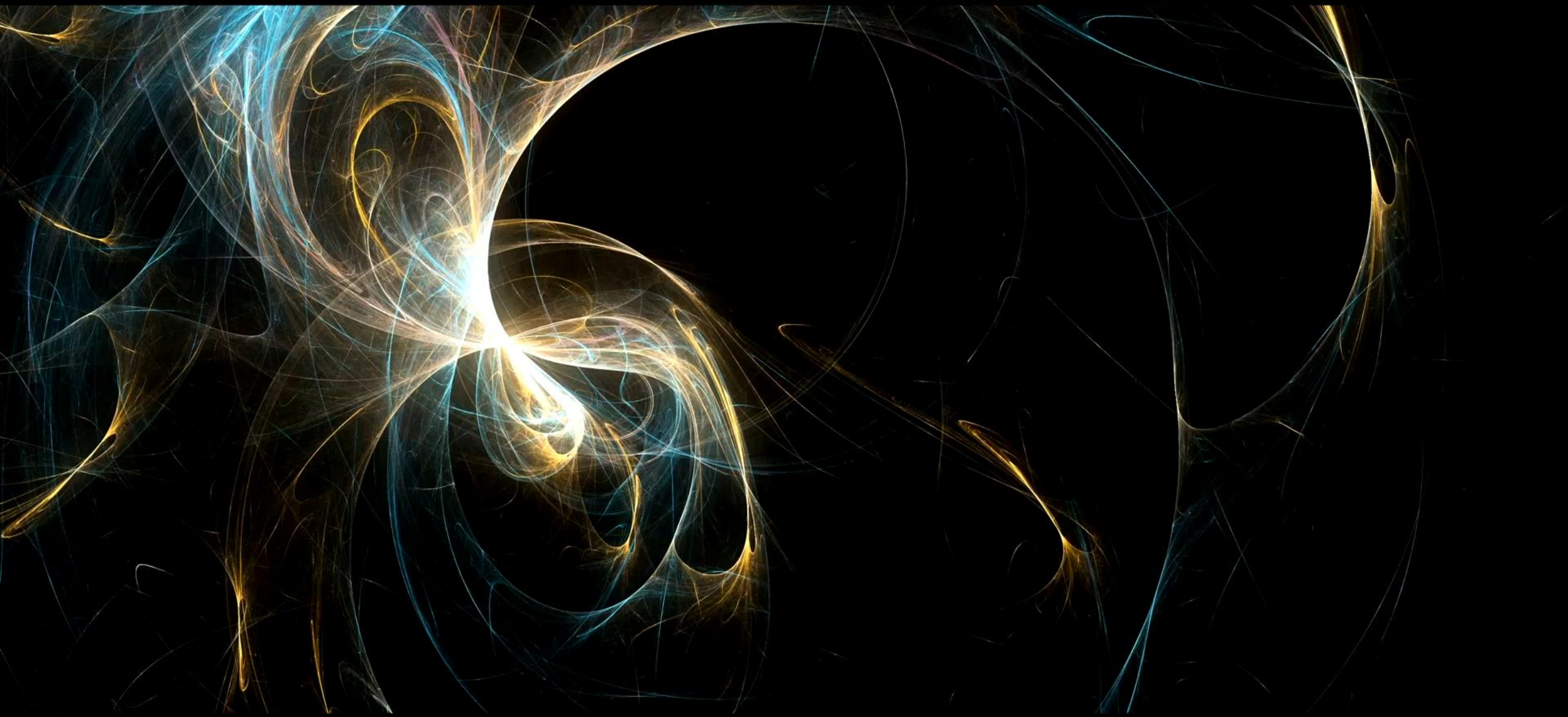


Potential biogas production in EU
1.86 - 5.44 billion m^3/y

Potential SOFC installations in EU
930 - 2550 MW_{el}

Pictures





Thank you!

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