SOFC for electricity generation: field operation of EU-funded installations

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AMPS

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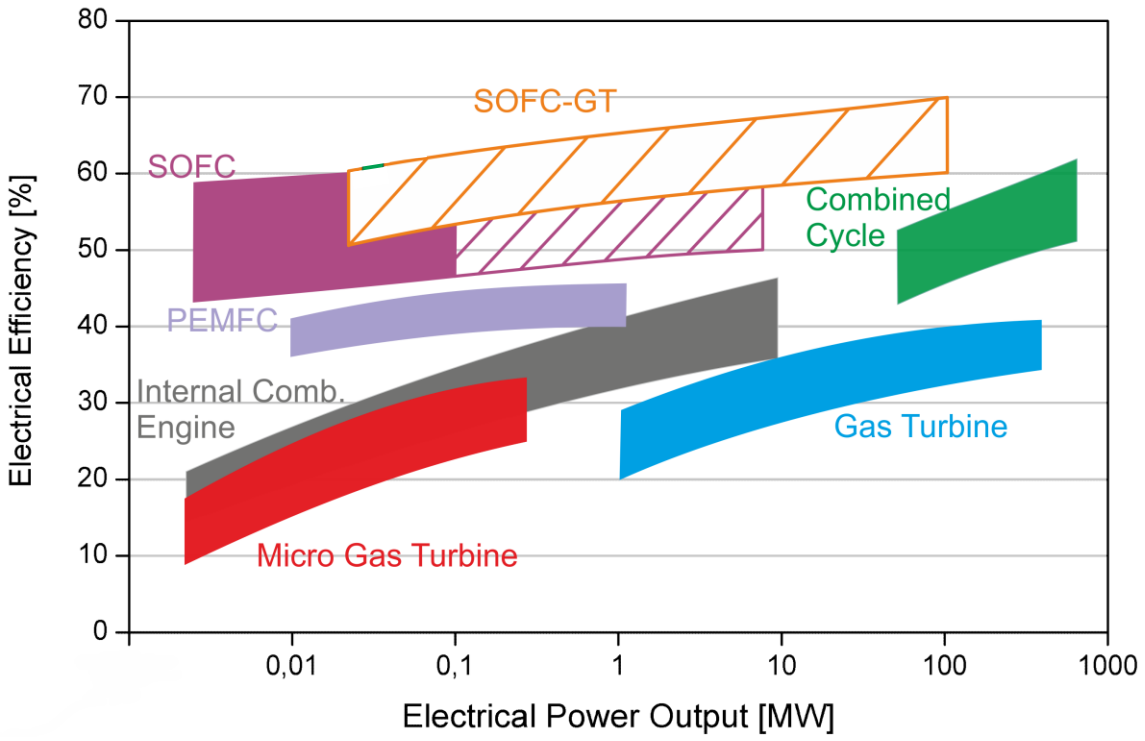
Politecnico di Torino

Why Solid Oxide Fuel Cells?



- **High fuel conversion efficiency**
- **Fuel flexibility**: natural gas, hydrogen, biogas, syngas, ammonia
- **Near-zero pollutant emissions**
- **Combined heat and power** (CHP) operation

Current costs remain high at **3–10 k€/kW** despite recent declines.

EU-funded Comsos project

Country	SOFC units installed	Total power installed
Italy	1	9 kW
Germany	2	18 kW
Austria	1	25 kW
Estonia	1	60 kW
China	6	185 kW
US	1	24 kW

12 SOFC units installed worldwide

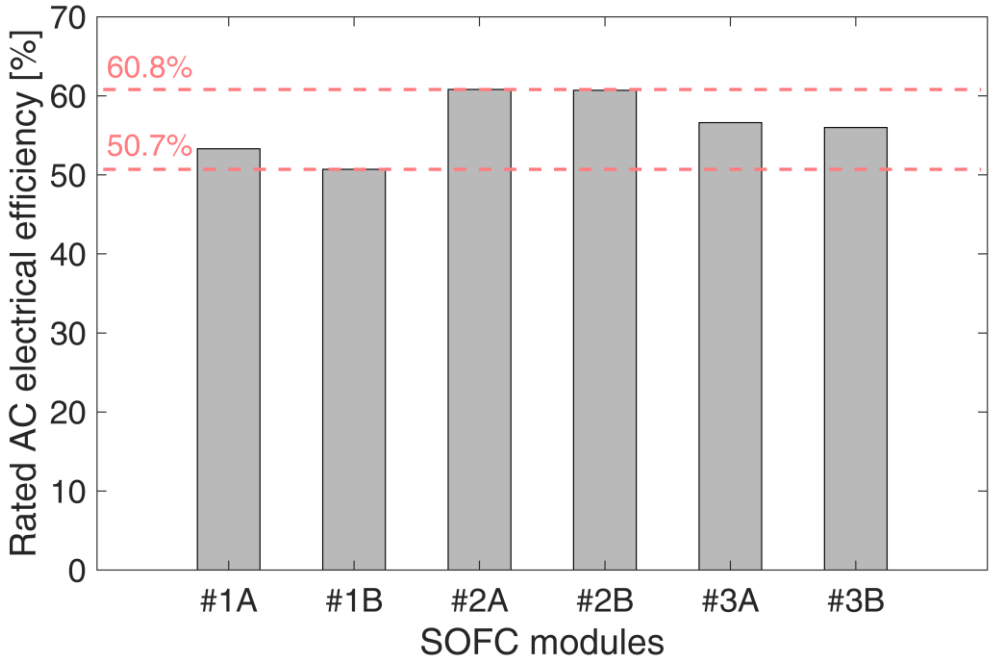
321 kW installed power

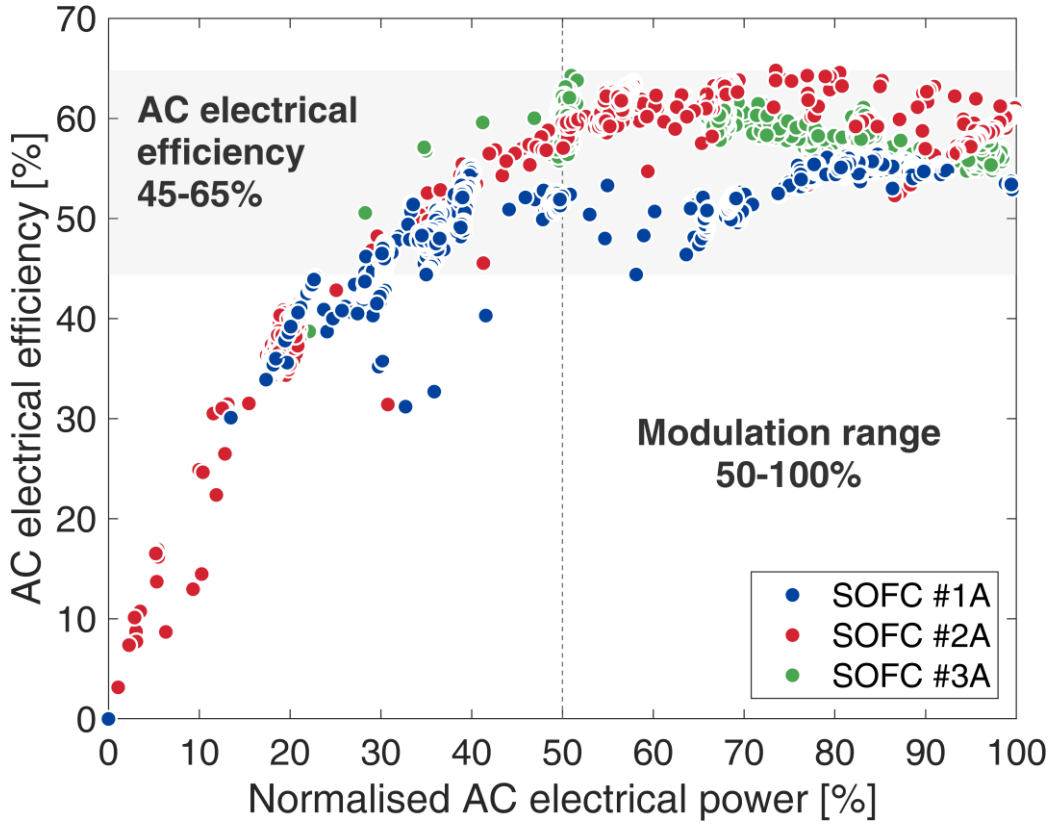
34,000+ hours of operation

P. Marocco, M. Gandiglio, M. Santarelli, When SOFC-based cogeneration systems become convenient? A cost-optimal analysis, Energy Reports. 8 (2022) 8709–8721.

SOFC performance: Electrical efficiency

Data analysis of **six SOFC modules**: two for each SOFC manufactures

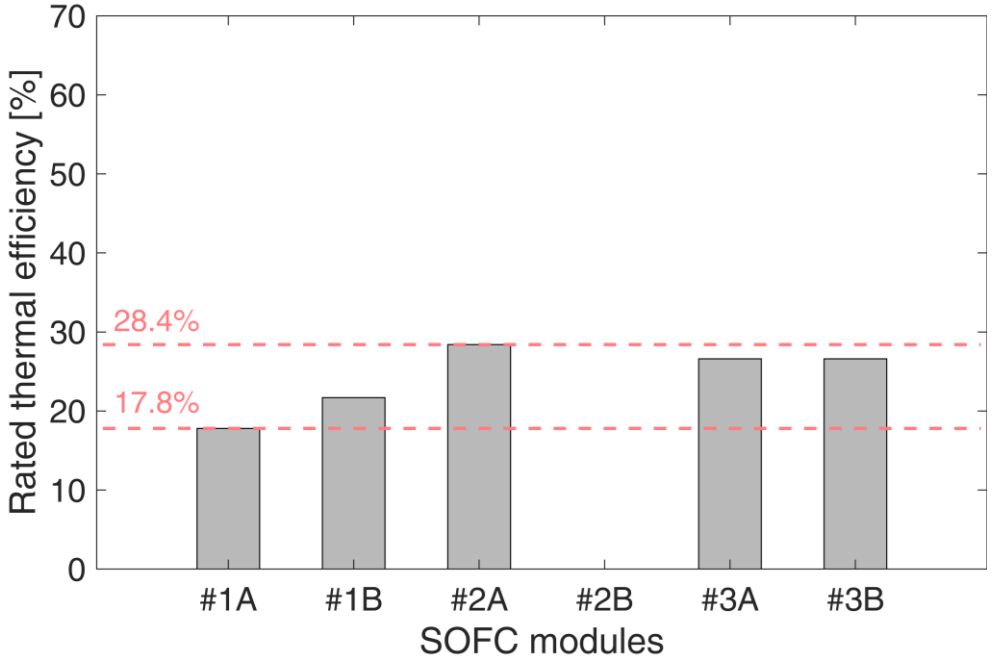


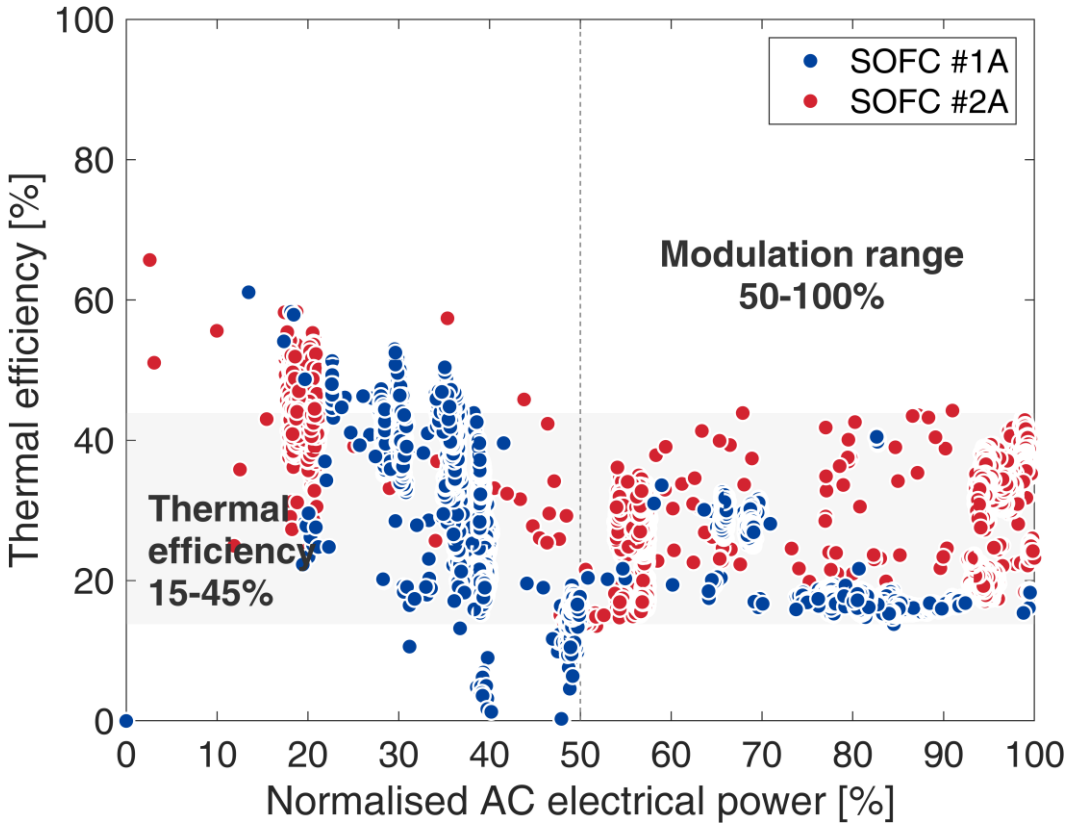


M. Gandiglio, P. Marocco, A. Nieminen, M. Santarelli, J. Kiviaho, Energy and environmental performance from field operation of commercial-scale SOFC systems, Int. J. Hydrogen Energy. 85 (2024) 997–1009.

SOFC performance: Thermal efficiency

Data analysis of **six SOFC modules**: two for each SOFC manufactures





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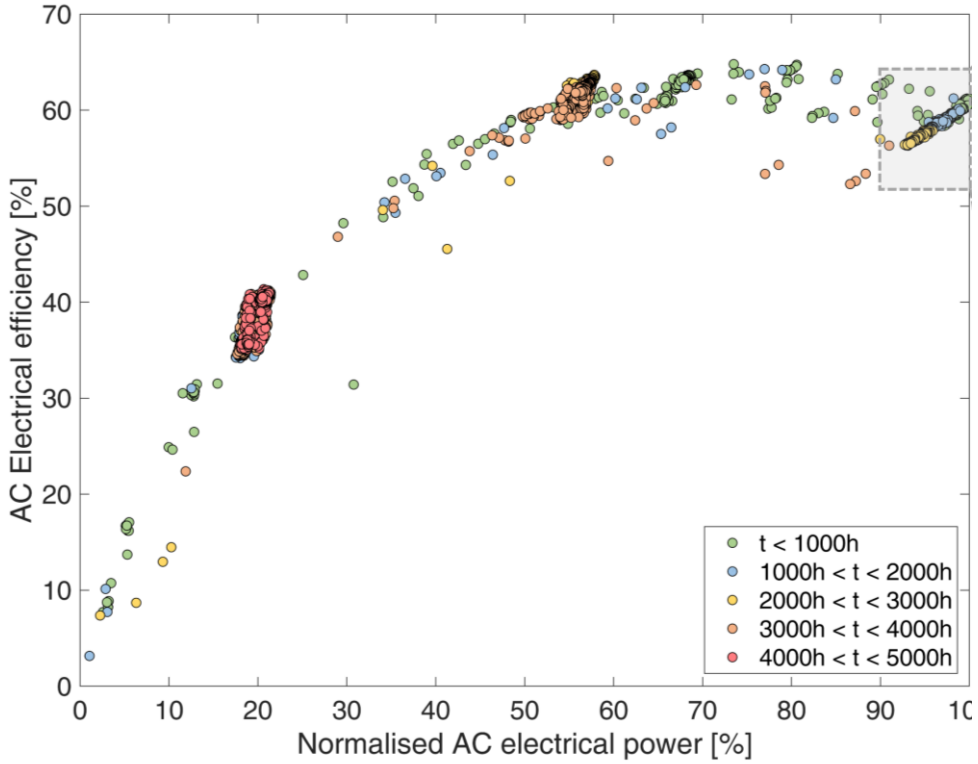
SOFC durability: Electrical efficiency

Average degradation rates
for the six SOFC modules
(in the 70-100% modulation range)

SOFC	Degradation rate [%/1000h]
#1A	n.a.
#1B	0.7
#2A	1.3
#2B	3.2
#3A	n.a.
#3B	0.7

Impact of degradation phenomena on SOFC #2A
(operated for 4129 h).



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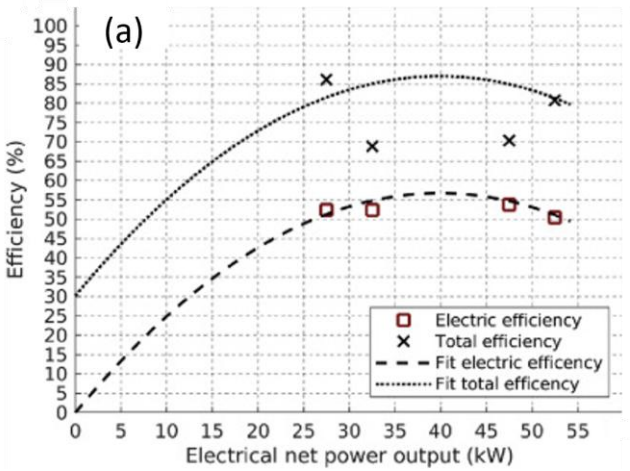
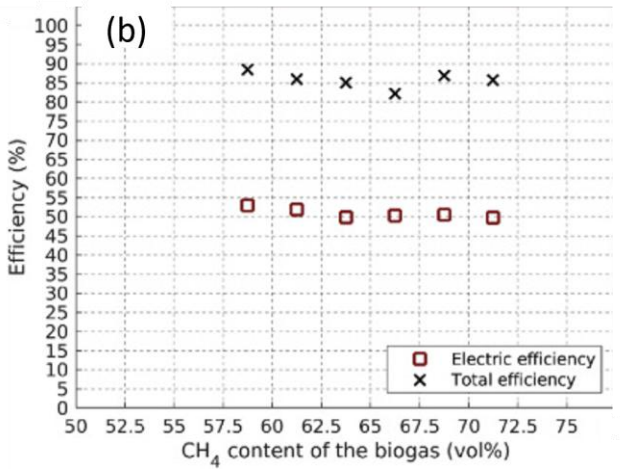
DEMOSOFC project

DEMOSOFC project: First industrial-sized SOFC fueled with biogas from waste water

Two 55 kWe modules

- Two **55-kWe SOFC modules** powered by biogas from wastewater
- **High electrical efficiency**: 50-55%
- **High total system efficiency**: 80-90%
- **High and stable performance** at varying electric net power output
- **Efficiency is uneffected by CH_4 content** in biogas

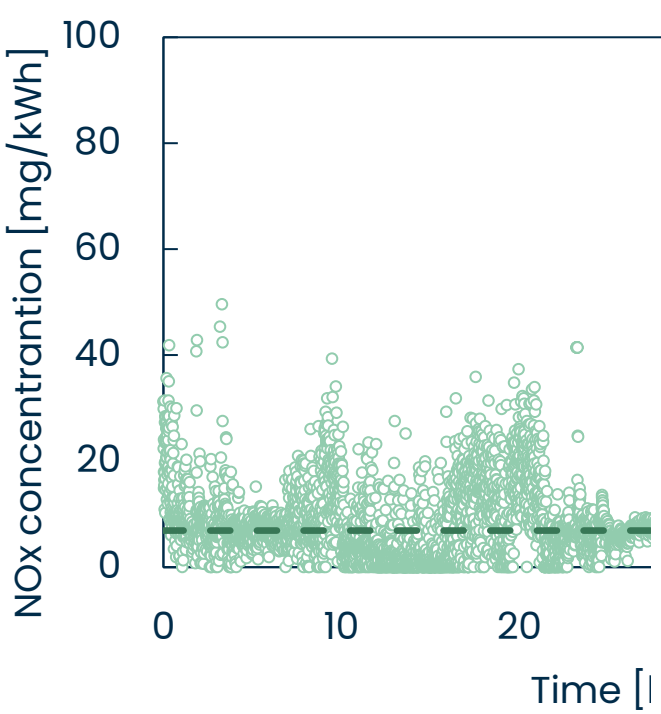


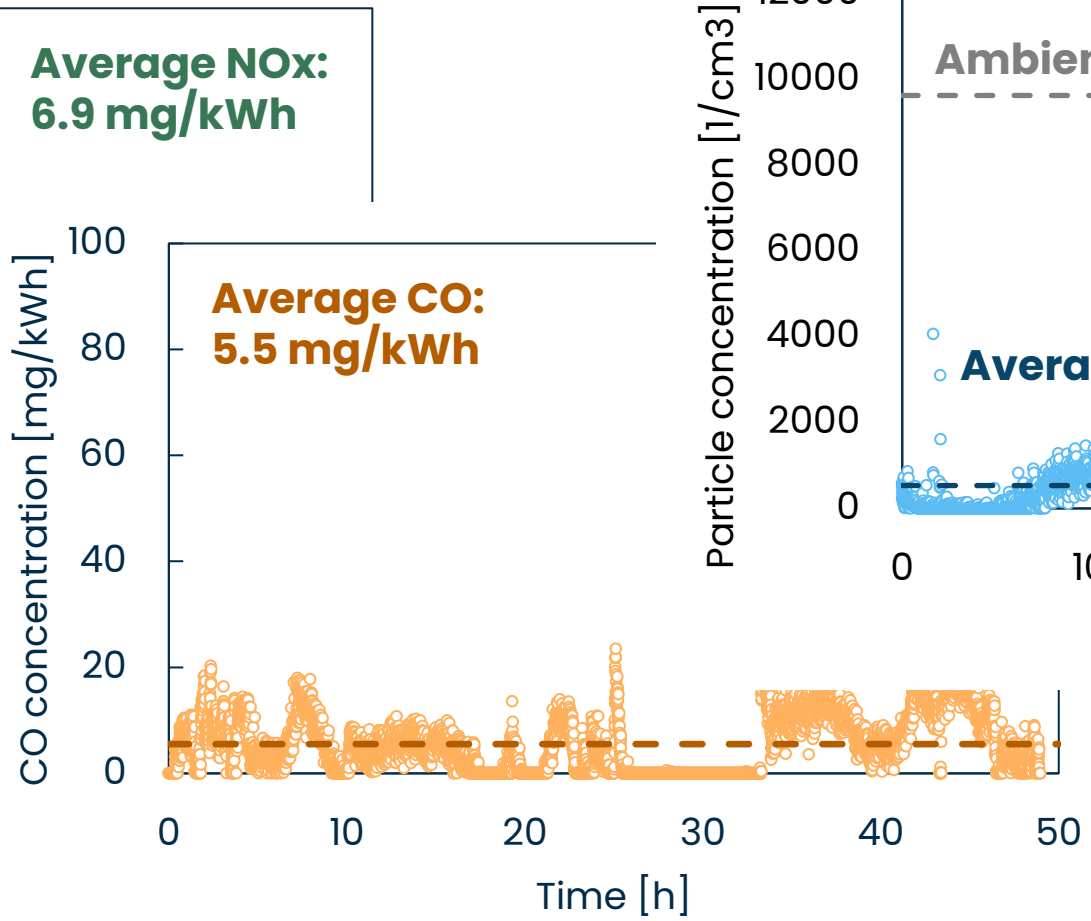


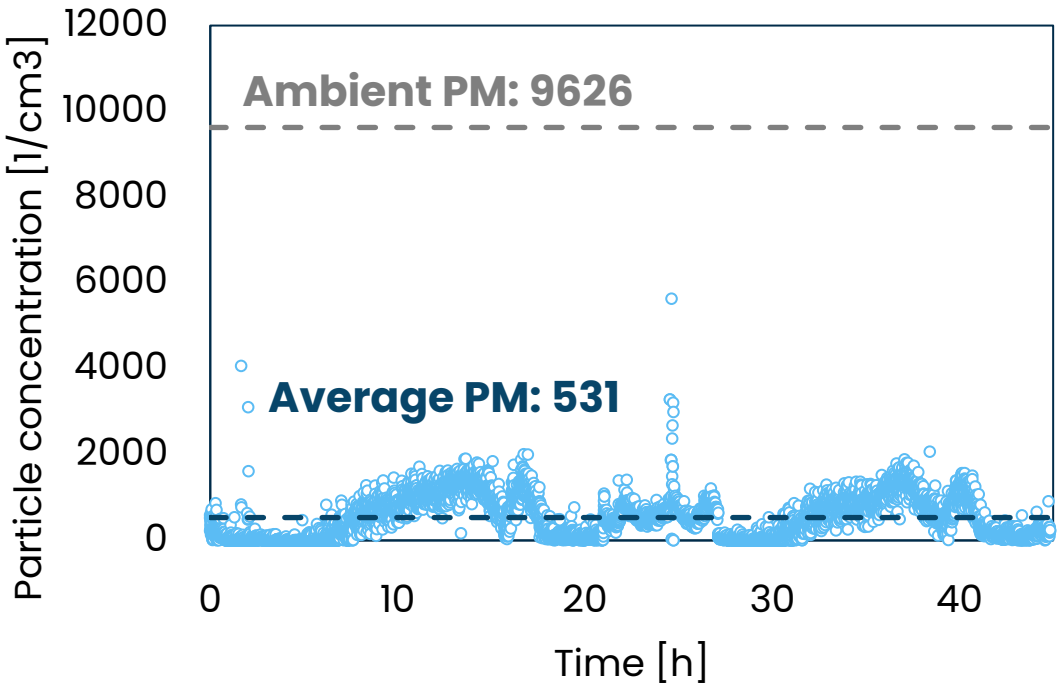
H. Langnickel, M. Rautanen, M. Gandiglio, M. Santarelli, T. Hakala, M. Acri, J. Kiviaho, Efficiency analysis of 50 kWe SOFC systems fueled with biogas from waste water, J. Power Sources Adv. 2 (2020) 100009.

Pollutant emissions

- Pollutants emissions **at constant power output (SOFC #1)**
- Measurement techniques: FTIR and ELPI

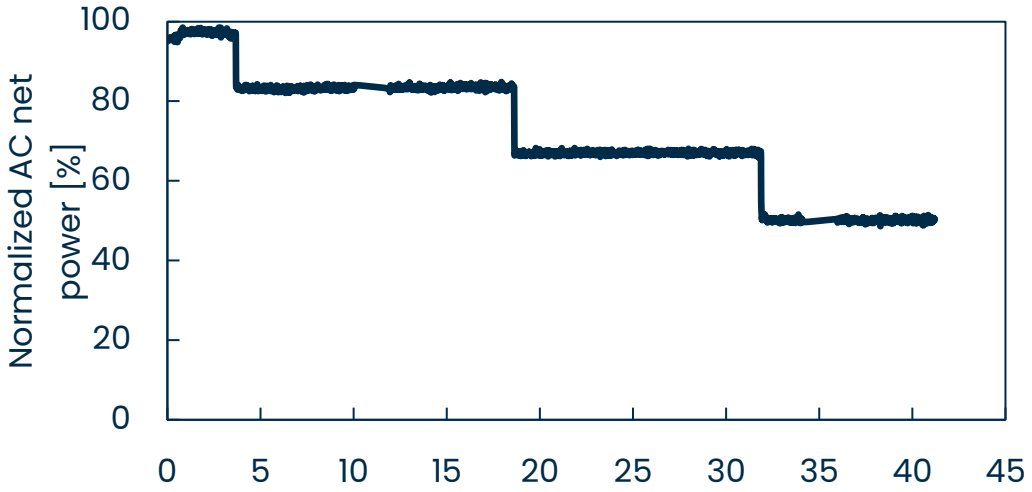




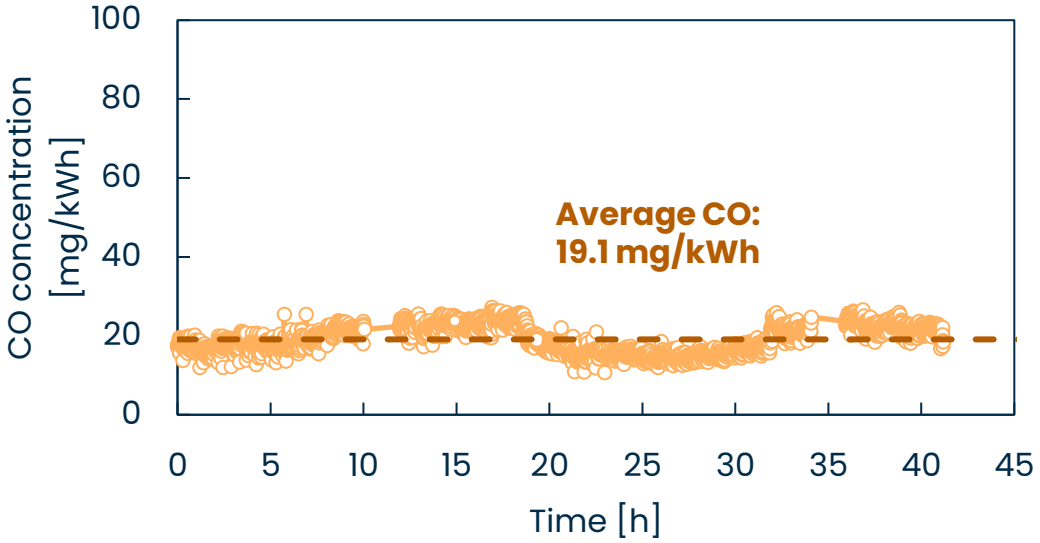


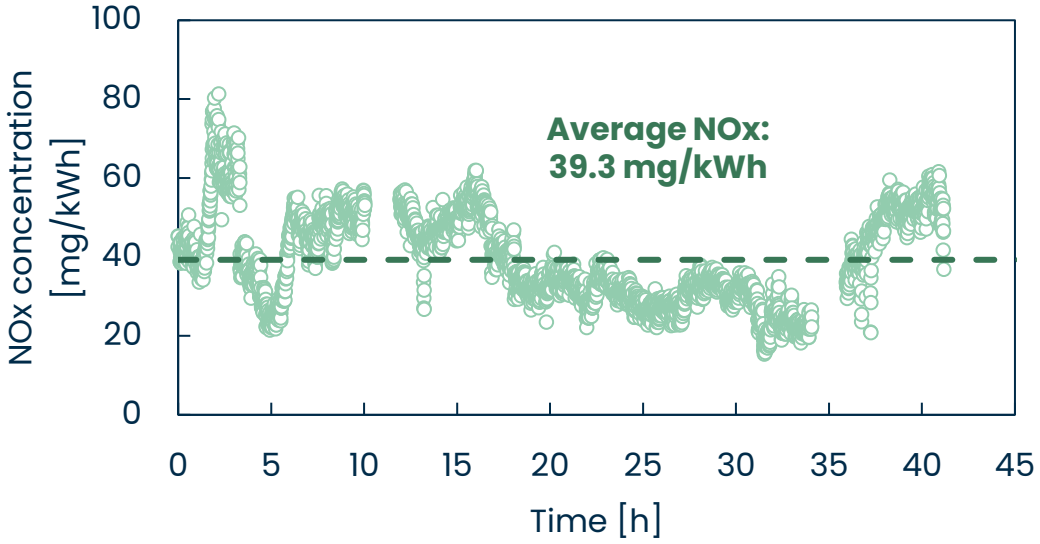
Pollutant emissions

- Pollutants emissions **at variable power output (SOFC #3)**
- Measurement techniques: FTIR and ELPI



- **Pollutants emissions** are kept **low even at partial power**
- **ICE emissions are 1 order of magnitude highers**: 280-520 mg/kWh for NOx and 620 mg/kWh for CO





Outlook

To sum up, given the key advantages of **SOFC technology**, they could play a role in the following applications:

1. CHP systems for **commercial and public buildings**[1] (e.g. data centers, hotels, hospitals)
2. CHP applications in the **biogas sector**[2]
3. **Heavy-duty transport** (e.g. maritime[3], aviation[4])

[1] *F. Accurso, et al., Installation of fuel cell-based cogeneration systems in the commercial and retail sector. Assessment in the framework of the COMSOS project, Energy Convers. Manag. 239 (2021).*

[2] *M. Gandiglio, et al., Results from an industrial size biogas-fed SOFC plant (the DEMOSOFC project), Int. J. Hydrogen Energy. 45 (2020) 5449–5464.*

[3] *https://www.linkedin.com/showcase/soffhice-project/*

[4] *G. Peyrani, et al, Solid oxide fuel cells for aviation: A comparative evaluation against alternative propulsion technologies, ETransportation. 24 (2025) 100408. https://doi.org/https://doi.org/10.1016/j.etran.2025.100408.*

Thank you!

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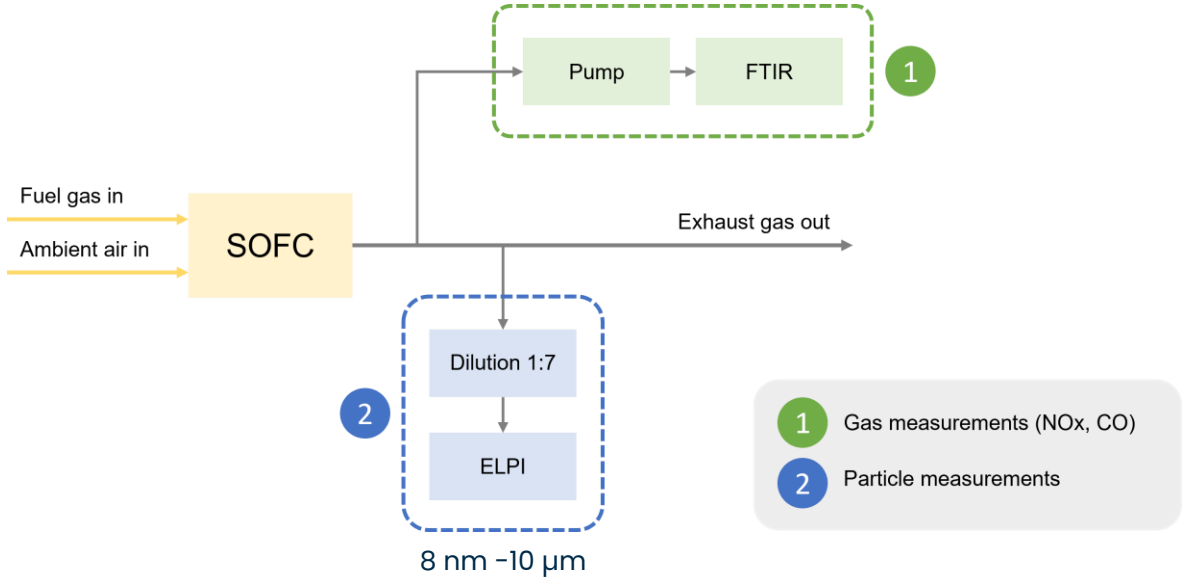
Emissions measurement setup

On-site emission measurements done using a **laboratory-in-a-van approach from VTT**

Measurements techniques

- Gaseous species: **FTIR** (Fourier-Transform Infrared Spectroscopy)
- Particulate matter: **ELPI** (Electrical Low Pressure Impactor)



Techno-economic analysis

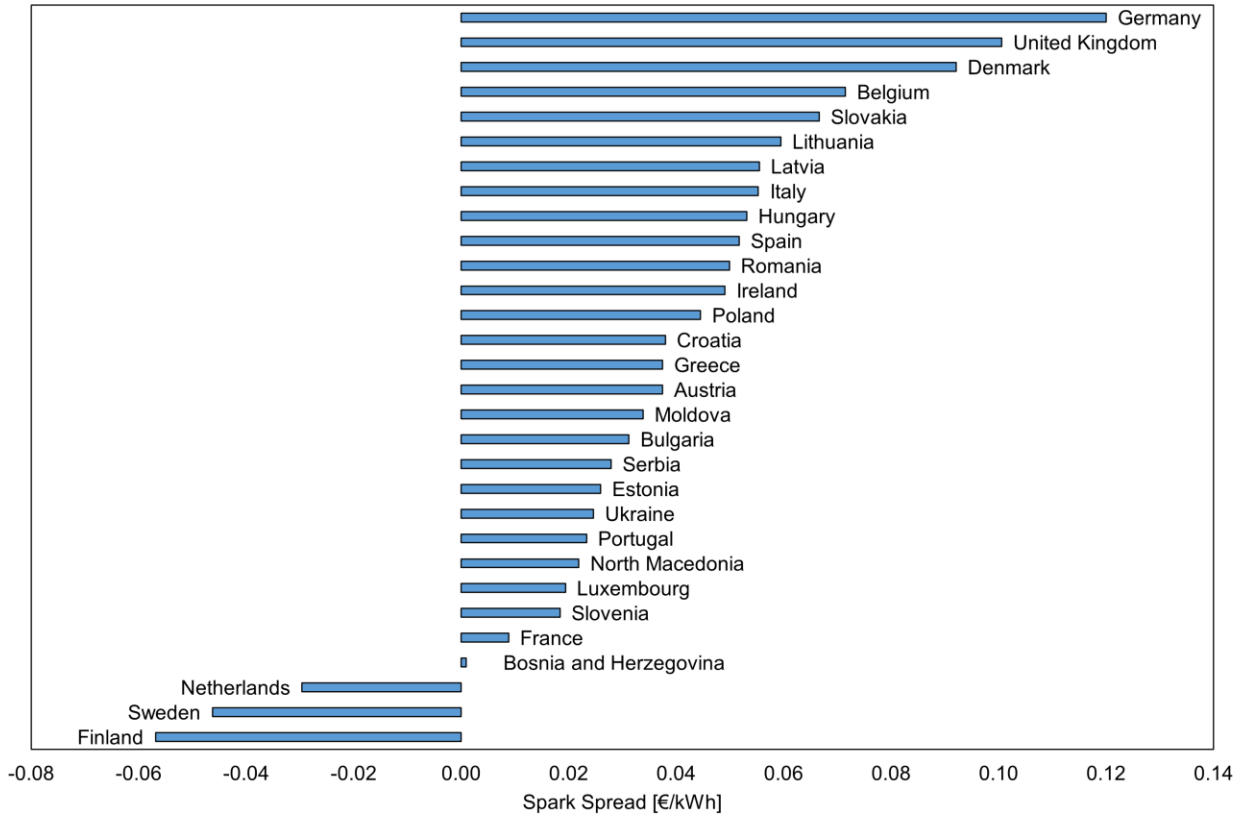
The **Spark Spread** (SS) gives an indication of the discrepancy between the electricity price and the gas price:

$$SS = c_{el} - \frac{c_{gas}}{0.5}$$

High variation across EU Countries:

- $SS_{max} = +0.12$ → Germany
- $SS_{min} = -0.06$ → Finland
- $SS_{avg} = +0.04$ → Average EU

Spark Spread (SS) for European countries (evaluated from Eurostat database for non-household consumers over the last three years)



__P. Marocco__, M. Gandiglio, and M. Santarelli, "When SOFC-based cogeneration systems become convenient? A cost-optimal analysis," Energy Reports, vol. 8, pp. 8709–8721, 2022

Techno-economic analysis

Sensitivity analysis on:

- **Spark spread**: -0.05 to 0.1 €/kWh
- **Stack lifetime**: 5 to 10 years
- **SOFC CAPEX**: **1.2** to **12** k€/kW

Target cost

Comsos cost at the beginning of the project (2018)

Case study (**supermarket**):

- Base load: ~85 kW
- Maximum load: ~400 kW