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15-16 NOVEMBER

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Waste2Watts

'Unlocking unused bio-WASTE resources with loW cost cleAning and Thermal inTegration with Solid Oxide Fuel Cells'

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W2W Waste2Watts

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Project Overview

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- **H2020-JTI-FCH-2018-1**
- FCH-02-7-2018 — **Efficient and cost-optimised biogas-based co-generation by high-temperature FC**
- 1.1.2019 – 30-09.2023
- % stage of implementation 01/11/2023: 75 %
- Total project budget: >2 M€
- Clean Hydrogen Partnership max. contribution: **1.68 M€**
- Other financial contribution: >0.3 M€
- Partners: 10 (CH, D, F, IT)

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Objectives

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Design a biogas-SOFC CHP with gas processing, pollutant removal and thermal integration.
2 cleaning approaches and hardwares were developed:

Site size (kWe)	Bio-source	Cleaning requirement	How	PoC	Where
multi-10 kWe	typically farms	H_2S (1000 ppm) org. S (few ppm)	solid sorbents	SOFC □CHP Identified sorbents Farm site	CH
multi-100 kWe	typically large OFMSW; landfill	idem Si (few ppm)	deep cooling equipment	Cleaning only (no SOFC) implemented on large biowaste site	LIT

- Cost projections for cleaning and SOFC
- >55% electrical efficiency
- Choice of contaminants + gas mixtures
- Testing of sorbents
- Testing of stacks, cells and reformer catalysts
- Biogas sites potential

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KPI's

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Mid-size 5-400 kWe

KPI	FCHJU 2023	CHE 2024	Achieved
SOFC CAPEX	<6500 €/kWe	<5000 €/kWe system	<4000 €/kWe ✅
Stack durability	50'000 h	0.4%/kh (NG)	<0.5%/kh in clean BG ✅
Efficiency elec.	42-55%	58% (CH_4)	55% with BG ✅
LCOE	2 * grid-parity		projections ✅

Project-specific KPI's on pollutants, cleaning, dry reforming

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1. System layout / efficiency

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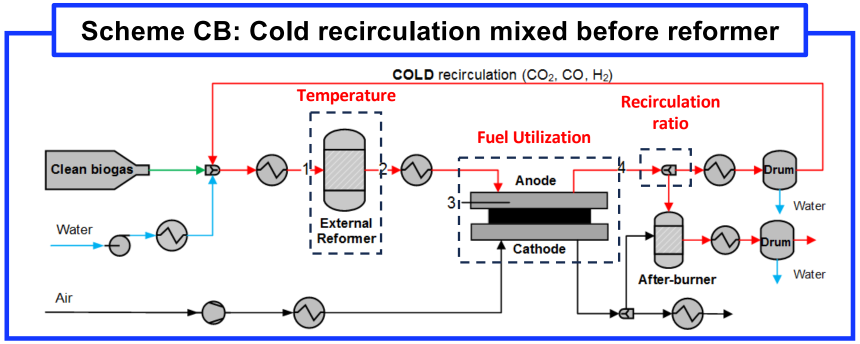
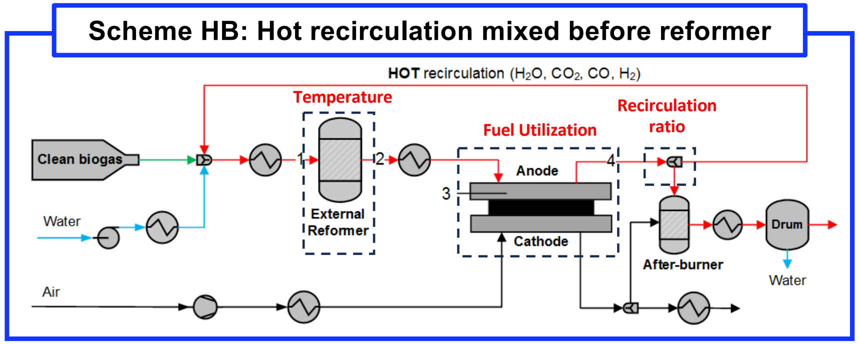
Sensitivity:

- CH_4 50-70%
- N_2 0-10%
- FU : 65-85%
- Reformer : 300-800°C
- Recirculation: 0-100%

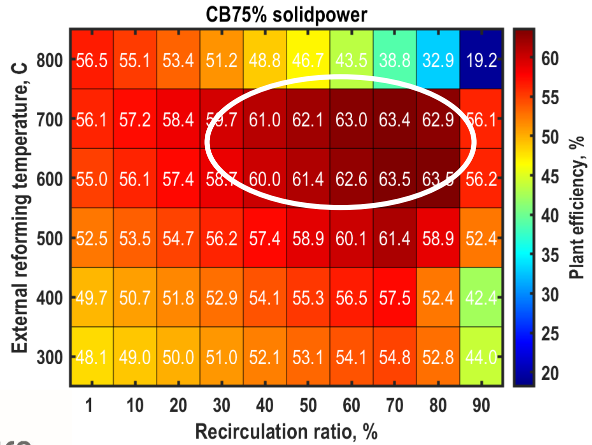
System elec. eff. >55% identified (w.o. ext. H_2O)

Defines 4 gas compositions for testing : dry reforming (CB), mixed reforming (HB) SunFire (ESC), SolydEra (ASC)

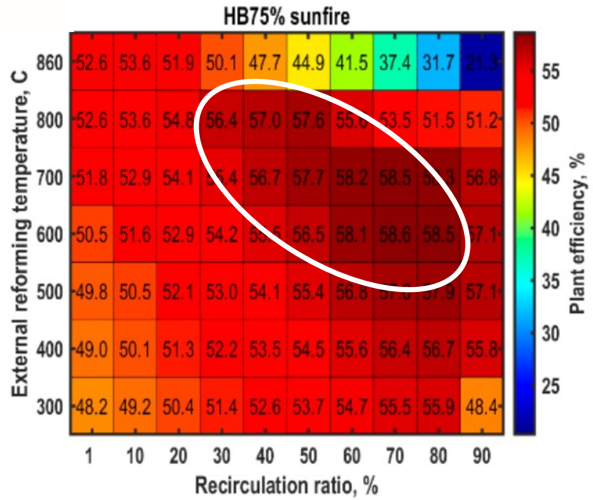




SolydEra



sunfire



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2. Contaminants assessment

Data measured from :
21 sites

=> database available

~200 trace contaminants listed

Published Jan'2022
well cited

=> choice of contaminants for tests
H_2S, CH_3-S-CH_3 (DMS), CH_3SH, COS
in a realistic gas matrix

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journal homepage: www.elsevier.com/locate/renene

Biogas composition from agricultural sources and organic fraction of municipal solid waste

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A R T I C L E I N F O

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Keywords:
Agricultural biogas
Organic sulfur compounds
Dimethylsulfide
Terpenes
Siloxane

A B S T R A C T

This paper presents an overview of biogas compositions originating from agriculture and the organic fraction of municipal solid waste. An intensive data compilation was performed from literature, plant data from an EU project (Waste2Watts) and from sampling campaigns at 5 different anaerobic digesters in Switzerland. Besides reporting the major components of biogas i.e. methane and carbon dioxide, the concentration of minor components such as nitrogen and oxygen, as well as trace amounts of sulfur compounds (H_2S, mercaptans, sulfides, etc.), silicon compounds (siloxanes, silanes), ammonia, halogenated compounds, and other volatile organic compounds (VOCs) are reported. These trace compounds can present a significant challenge to the energetic use of biogas, specifically in the use of novel, high-efficient processes such as high temperature fuel cells or catalytic fuel upgrading units. H_2S and other sulfur compounds are the major concern, as they are abundantly found in agriculture biogas; unlike silicon compounds, which are generally exist in low or undetectable levels.

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3. Cleaning sorbents testing

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Database on sorbents compiled

- 21 sorbents tested
- 7 different suppliers

Definition of test parameters

Parameter	Value
Temperature	30°C
GHSV	1500 h^{-1}
Sorbent bed height / diameter	3
Gas matrix	CH_4/CO_2 mixture
CH_4/CO_2	50% - 50%
O_2 content	1%
RH	50%
Inlet S (H_2S, DMS, CH_3SH, COS)	30 to 500 ppm

Total of 85 tests (lab + field), ~300 days

=> specific **sorbent per contaminant identified**
=> COS is most difficult to remove

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Waste and Biomass Valorization
https://doi.org/10.1007/s12649-023-02212-6

ORIGINAL PAPER

Check for updates

Hydrogen Sulphide and Carbonyl Sulphide Removal from Biogas for Exploitation in High-Temperature Fuel Cells

F. Santoni[1] · P. Gislon[1] · E. Rozzi[2] · M. Gandiglio[2] · S. McPhail[1] · A. Lanzini[2] · M. Pagani[3] · S. Fiorilli[3]

Received: 13 February 2023 / Accepted: 14 June 2023

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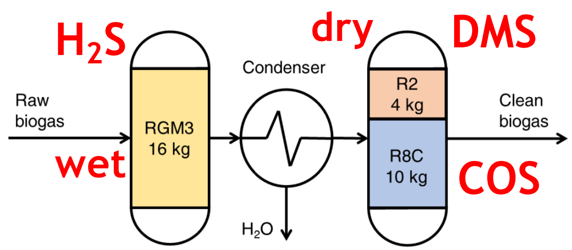
Sorbent-based cleaning designed (small scale)

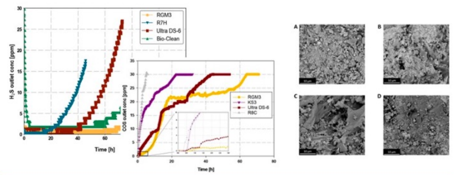
Adsorption-based biogas cleaning system



- Focus on H_2S and COS contaminants
- Analysis of the effect of O_2, humidity and contaminant level

Sorbents tested:
Impregnated activated carbon, functionalized alumina, functionalized zeolite, iron hydroxide

Experimental campaign and sorbents characterization to evaluate the **sorbents performance** under different operating conditions and the **optimal layout of the cleaning system**



	COS			H_2S		
	Dry	Wet		Dry		Wet
	$C_{ads,BT}$	$C_{ads,BT}$	$C_{ads,SAT}$	$C_{ads,BT}$	$C_{ads,SAT}$	$C_{ads,BT}$
Norit RGM3	0.40	0.083	0.69	2.57	4.11	17.71
Airpel Ultra DS-6	1.88	0.031	0.41	0.41	0.73	
Solcarb KS3	0.040	0.016	0.16			
SulfaTrap R8C	2.47	0.023	0.11			
Envirocarb STIX				0.47	1.27	
Bio-Clean				0	2.71	
SulfaTrap R7H				4.58		1.41

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Test campaigns

>7’000 h of sorbents tests

>11’000 h of reformer catalysts tests

~27’000 h of cell testing

>20’000 h of stack testing

4. Stack test example

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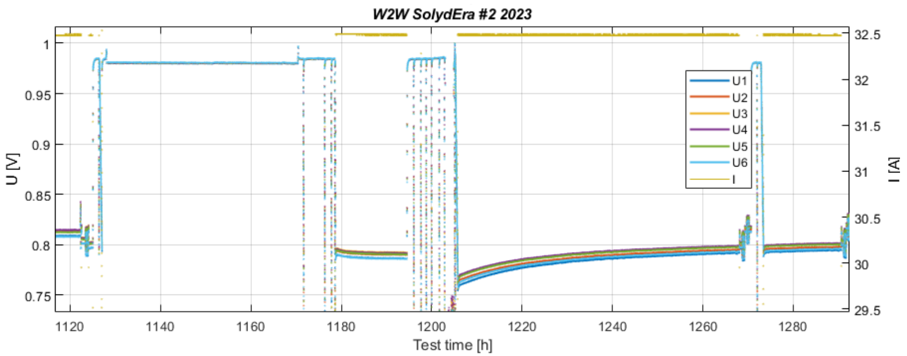
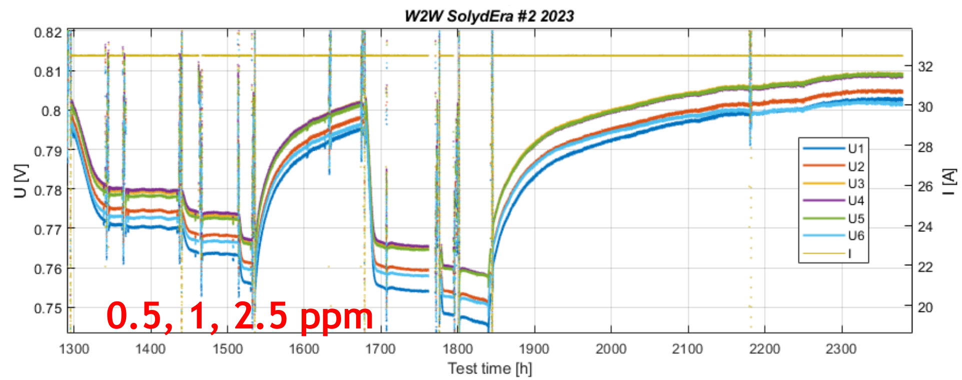
>2500 h (ongoing)

0.5, 1, 2.5, 5 ppm DMS spike tests



recovery



2.5, 5 ppm DMS
tests for >100h

Dry reformed biogas
Poisoned for 100-200 h up to 5 ppm (DMS)
Fully recovered performance

5a. Pilot test 1

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Small scale, farm site.
Commissioning ongoing.
Planned for 2 years test.
Exchangeable sorbents

5b. Pilot test 2: cryocleaning

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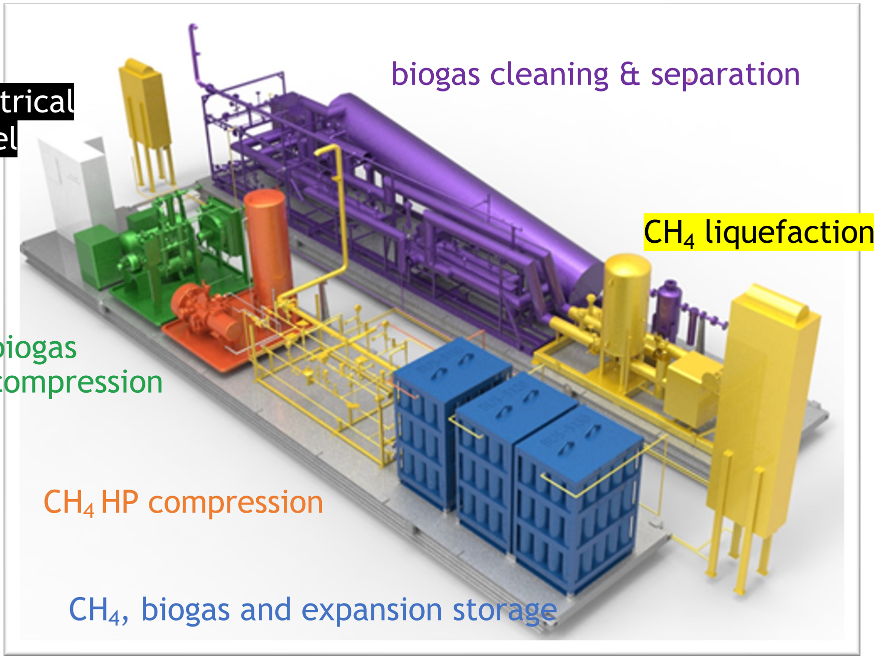
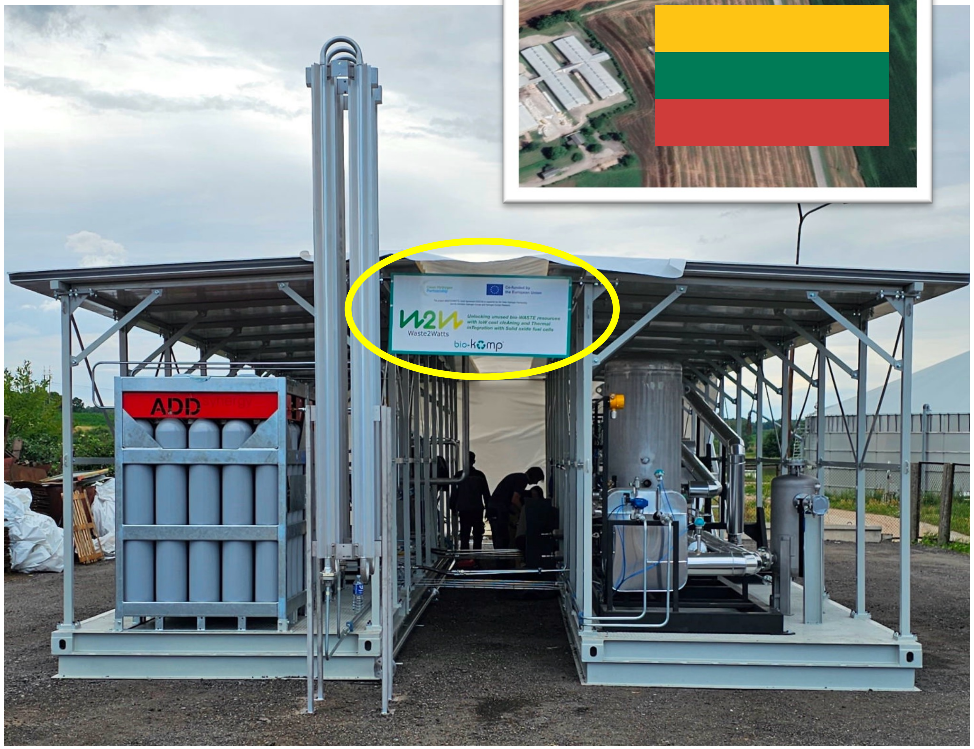
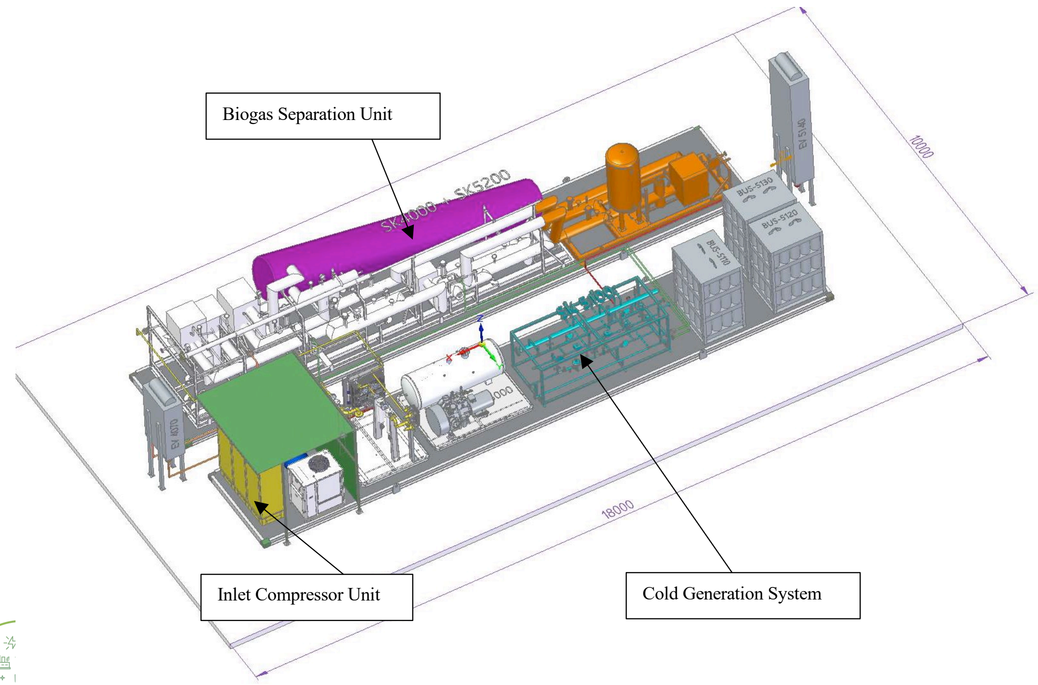


Reverse Stirling engine for deep biogas cooling (-100°C)
Liquefied CH_4 for cooling
100 m^3/h BG flowrate (=> 65% CH_4 => 650 kW gas)
Cycle power consumption (prototype): 31 kWe
Cost: 280’000 € (<1000 €/kWe ✅)

Site : Vilnius, Lithuania
1993, large site (hog farm + wastes), **400 m^3/h**
Contaminants: 1300 ppm S; traces of Si
Now sorbents are used => huge OPEX
OPEX of scalable cryocleaning expected to be lower

Commissioning ongoing – planned for 1 yr test phase





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Exploitation Plan / Expected Impact

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Pilot site 2 = business case for BioKomp.
International patent will be filed.

Pilot site 1 will run for 2 years, testing different (cheaper) sorbents.
Low OPEX/CAPEX, easy to dismantle.

SolydEra + digester company for complete biogas solution in multi-10 kWe scale.

Cryocleaning as new solution for large biogas flows (S, Si, VOC).

Sulfur cleaning defined more accurately.
Voltage drop is an indicator for S-poisoning.

Solutions apply also to CH_4 injection, ICE, catalysis.

Market potential evaluated :
50 kWe CHP make a good case
= 100’000 units in CH, D, F, IT

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Risks, Challenges and Lessons Learned

New cryocleaning approach = high risk, high potential reward

Low funding for small scale demo => hardware cost minimised

Sulfur cleaning still tedious, <1 ppm needed => explore alternative methods

Regulations needed, simplification, support for farmers

Project target rows against mainstream thinking (=biomethane injection, large scale), separating CH_4 from CO_2, to burn it later to **heat**…🤔
=> leaves most of the biogas potential unused (farms, smaller scale)
=> 50 kWe units make sense, if small digesters and SOFC systems become cheap enough
=> to deliver winter electricity base load

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Thank you

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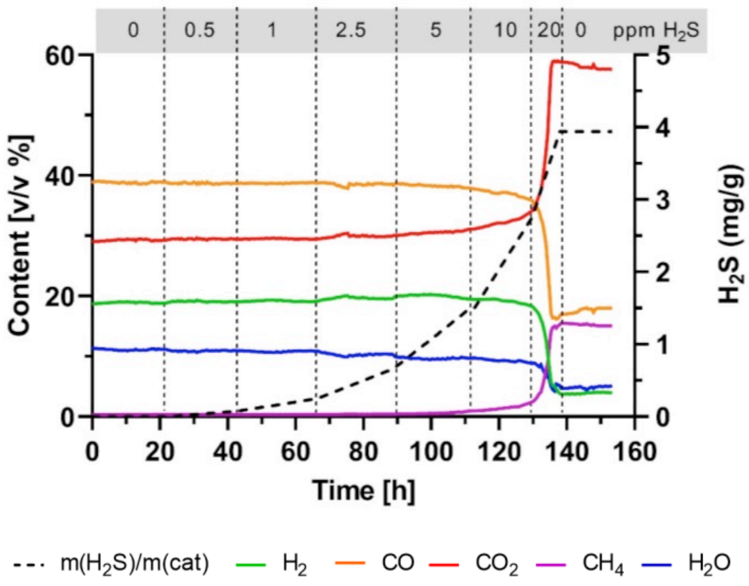
4a. Reforming catalysts tests



Catalysts tested (>11’000 h of tests) :

- $Sm_2Ru_{0.2}Ce_{1.8}O_7$
- Ni_4Fe on$Mg_xAl_yO_z$
- 3 wt % Ru/$CaZr_{0.85}Sm_{0.15}O_{3-d}$

Better performance with dry reforming
No carbon deposition detected

~100 h of exposure to 5 ppm S before full deactivation

Ni_4Fe activity partially regenerated

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4b. Cell tests

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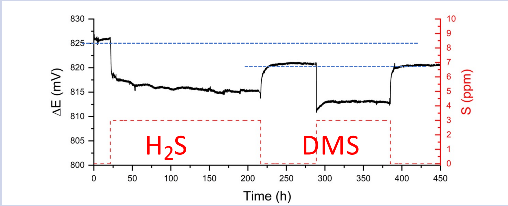
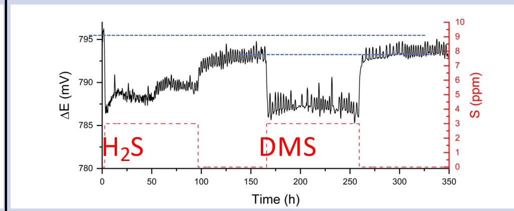
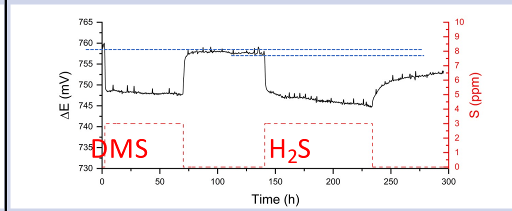
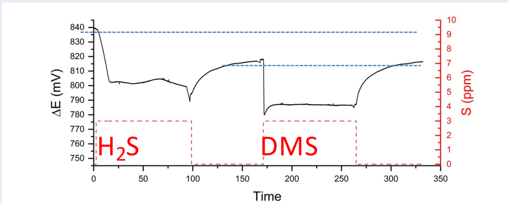
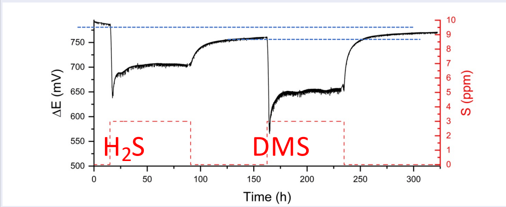
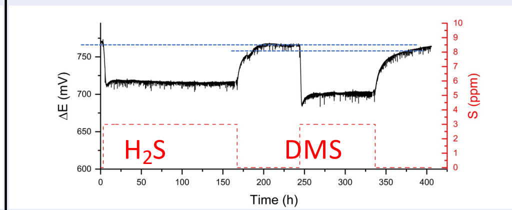
3 ppm H_2S/ 3 ppm DMS	Dry H_2	Dry reformed biogas	Steam reformed biogas
sunfire			
SolydEra			

Total 26’700 h of testing (25 cells) with biogas matrix and H_2S, DMS, COS, 0.5 to 5 ppm

ESC cells more **tolerant** to sulfur (850 °C) than **ASC** cells (750 °C)

Higher voltage losses in **dry reformed** biogas (WGS affected)

DMS leads to **stronger** deactivation but is **reversible**

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