ComSos

Project n° 779481

"Commercial-scale SOFC systems"

Deliverable number 5.2

Techno-economic models of the considered SOFC-based CHP systems

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Abstract:

The following deliverable is presenting the technical and economical details of the 3 SOFC systems installed in the framework of the COMSOS project. Because of the system-level nature of the project, the systems will be modelled with a 'black box' approach and input-output streams will be listed for each system, together with its performance and lifetime. Economic data have been also collected in terms of investment (stack and Balance of Plant -BoP) and operating costs but won't be shown in this report because of confidentiality issues.

The techno-economic model of the considered SOFC-based CHP systems will be then used for the business analysis to evaluate the affinity (both technical and economical) between the considered SOFC-CHP systems and the different market segments.

This is the **public version** of the D5.2 report.

Keyword list:

Techno-economic, performance, efficiency, SOFC systems, costs

Summary

1. Introduction

The work is divided into four chapters: three sections dedicated to each single SOFC-CHP system and a final comparison of the three units. The analysis includes both technical and economical information, collected by POLITO from SUNFIRE, SOLIDPOWER and CONVION.

Because of confidentiality, not all the data collected will be reported in this public report. Anyway, to show the work performed, the total list of collected data is presented in the table below.

Table 1. Collected data for techno-economic modelling.

Technical information
SOFC system nominal size
Electrical efficiency @ nominal size
Thermal efficiency @ 70C return temp
Modulation range (min-max)
Ramp-up rate
Ramp-down rate
Electrical efficiency curve (load% vs. efficiency)
Average system availability
Current stack technical lifetime
Duration of maintenance per year
Start-up time
Shut-down time
Black start capability
Degradation rate
Thermal cycle allowance
NOx emission
Streams required onsite (compressed air, water, nitrogen)
Economic information
Manufacturing cost stack
Manufacturing cost Balance of Plant
Operational cost
Startup/shutdown cost
Commissioning and installation cost (if the investment cost is not a turnkey solution)

2. SUNFIRE SOFC module

The SUNFIRE SOFC-CHP system is a 20 kWe SOFC module with an electrical efficiency higher than 50% and a total efficiency (electrical + thermal) higher than 80%. Electrical efficiency is ranging from approx. 55% to 45% during lifetime of the system. An average value of 50% over the lifetime of stacks has been mentioned as a good approximation. Thermal efficiency value (30%) is also an average value during lifetime, even if – because of electrical efficiency reduction during lifetime – the producer is expecting a shift to thermal efficiency towards End of Life (EoL).

Modulation is feasible within the module in a range 50-100% (of electrical power output) with ramp-up and down rates of 200 W/min (from 0 to 20 kWe: 100 minutes). The producer does not provide an efficiency-power plot but specific information which are useful to understand the behaviour of the system. In particular, electrical efficiency shows:

- Increase of + 3% points between 50 and 80% of nominal power
- Increase of +1% point @ 90 % of nominal power

A more general description of the same concept is shown in Table 2.

Target system lifetime is 45’000 hours with less than 8 hours maintenance per year. Target lifetime estimation is based on current experience developed with Sunfire installation. Lifetime is express with EoL at 70 % of nominal power.

Start-up time is 10 hours and shut down time less than half an hour. As will be confirmed by the other producers, SOFC system are not capable of black start, thus excluding on-off modulation of the system.

NOx emissions are lower than 10 mg/kWh and this will be verified during the COMSOS project field test phase. No auxiliary streams are required on site except natural gas and electrical power connection.

Table 2. Technical information and performance of the SUNFIRE SOFC module (20 kWe).

Technical information	Value	Unit
SOFC system nominal size	20	*kW*
Electrical efficiency @ nominal size	> 50	*%*
Thermal efficiency @ 70C return temp	> 30	*%*
Modulation range (min-max)	50…100	*% (range)*
Ramp-up rate	200	*W/min*
Ramp-down rate	200	*W/min*
Electrical efficiency curve (load% vs. efficiency)	> 53 % @ 50…80 %	*plot-table*
Current stack technical lifetime	> 45,000 h target	*hrs*
Duration of maintenance per year	< 8 h	*hrs*
Start-up time	10	*hrs*
Shut-down time	< 0,5 h	*hrs*
Black start capability	No	*Yes/No*
Thermal cycle allowance	30 in total during stack lifetime	*#/year*
NOx emission	< 10 mg/kWh	*mg/m3*
Streams required onsite (compressed air, water, nitrogen)	None	-

3. SOLIDPOWER SOFC module

This section is related to the SOLIDPOWER SOFC module, which nominal size is 12 kWe. Before analyzing the data, it should be stated that the 12 kWe SOFC-CHP system is a new product under commercialization at SOLIDPOWER and thus not all the data requested were available. For this reason some data, and it will be specified in the text, are referred to the 1.5 kWe Bluegen module currently commercialized by SOLIDPOWER. If new data will be available during the next months from laboratory testing, the technical model here presented will be updated accordingly.

Electrical efficiency of the new 12 kWe SOFC module will be 60% while total efficiency up to 90%. Thermal efficiency is here expressed at 30 °C return temperature (different respect to other producers). The detailed analysis and comparison in terms of thermal efficiency will be done during the COMSOS project installations phase, with real data from onsite operation (WP4 activity).

The SOFC module also requires water as auxiliary service.

Table 3. Technical information and performance of the SOLIDPOWER SOFC module (12 kWe).

Technical information	Value	Unit
SOFC system nominal size	12	*kW*
Electrical efficiency @ nominal size	60	*%*
Thermal efficiency @ 30C return temp	30	*%*
Streams required onsite (compressed air, water, nitrogen)	Water	-

4. CONVION SOFC module

This section is devoted to the analysis of the CONVION SOFC module. The SOFC-CHP system is the largest in terms of size, with a nominal power production of 60 kWe. Electrical efficiency at nominal size is 60% (at Beginning of Life – BOL), while total efficiency is 81%. Thermal efficiency is currently estimated in this model (21%) and could reach 24% if exhaust gases are cooled down until 40 °C.

Theoretical modulation range is 0-100% with the possibility of keeping the system also in standby at 0% power (but consuming fuel). Continuous feasible modulation is indeed 30-100%.

The average system availability is in the range of 96-98%, while system lifetime is currently 40'000 hours with a target value of more than 60'000 hours.

Start-up and shut-down time are respectively 10 and 12 hours. Again, as happened for the previous SOFC modules, black start is not feasible.

NOx emissions are lower than 2 mg/m^3 and no stream is required on site for the operation of the system.

Table 4. Technical information and performance of the CONVION SOFC module (60 kWe).

Technical information	Value	Unit
SOFC system nominal size	60	*kW*
Electrical efficiency @ nominal size	60	*%*
Thermal efficiency @ 70C return temp	21	*%*
Modulation range (min-max)	0-100	*% (range)*
Average system availability	96 - 98	*%*
Current stack technical lifetime	Current 40'000 Target > 60'000	*hrs*
Start-up time	10	*hrs*
Shut-down time	12	*hrs*
Black start capability	NO	*Yes/No*
NOx emission	< 2	*mg/m^3*
Streams required onsite (compressed air, water, nitrogen)	None	-

5. Comparison and discussion

This chapter will try to analyze and compare the technical and economic data collected from the 3 SOFC producers.

Looking at the technical performance (shown in Table 5) some comparisons have been performed.

- Electrical efficiency is always higher than 50% in all cases. SP and CO units seem to show higher performance compared to SF; WP4 field data analysis on the COMSOS demonstration will be devoted to the verification of the presented data and values will be updated in case of different site activity results. Electrical efficiency is here expressed from NG from the grid to AC power but details on the limits of control volume will be further discussed with the producers.
- Thermal efficiency cannot be compared in detail among the three producers since data are referred to different return temperature. SP, for example, provided the data on 30 °C return temperature while the others on 70 °C (estimation for models). As explained before, the experimental activity onsite will help to refine these data. Thermal efficiency is indeed strongly related to the end user thermal needs and thus cannot be define 'a priori'.
- The modulation range is also quite similar among the producers with a more limited lower bound in case of SF stacks. Operation of the system under modulation will anyway be avoided as much as possible since the systems prefer to work in stable conditions.
- Ramp-up and down rates are varying a lot among the three producers. Start-up time is anyway acceptable for the three modules, given the fact that black start capability and on-off operation are not feasible.
- For what concerning stack lifetime, collected data seem to be not fully in line among the producers and a better definition of 'current' and 'target' scenarios will be done before developing the business scenarios analysis. Current stack lifetime seems to be quite close (or sometimes higher) to 40'000 hours (around 4.5 years) while targets are close to 60'000 (6.8 years, at least + 2 years compared to current values).
- Maintenance time per year is variable among the three systems but always lower than one working week (40 hours).
- NOx emissions always seems to be lower than the instrument detection limit, while auxiliary streams required on site are water from SP system and nothing else (except power and NG) for the other two modules.

Table 5. Technical comparison table for the 3 SOFC-CHP modules. Numbers and rows in bold style are representing values calculated from the initial producers data.

Technical information	Sunfire	Solidpower	Convion	Unit
SOFC system nominal size	20	12	60	*kW*
Electrical efficiency @ nominal size	>50	60	60	*%*
Thermal efficiency	30	30	21	*%*
Total efficiency	**80**	**90**	**81**	***%***
Modulation range (min-max)	50-100		30-100	*% (range)*
Ramp-up rate	200			*W/min*
Ramp-down rate	200			*W/min*
Time from 0 to full power	**100.00**		**33.33**	***min***
Stack technical lifetime - current			**40,000**	***hrs***
Stack technical lifetime - target	**45,000**		**60,000**	
Duration of maintenance per year	< 8			*hrs*
Start-up time	10		10	*hrs*
Shut-down time	< 0.5		12	*hrs*
Black start capability	No		No	*Yes/No*
NOx emission	<10 mg/kWh		<2	*mg/m^3*
Streams required onsite (compressed air, water, nitrogen)	None	Water	None	-

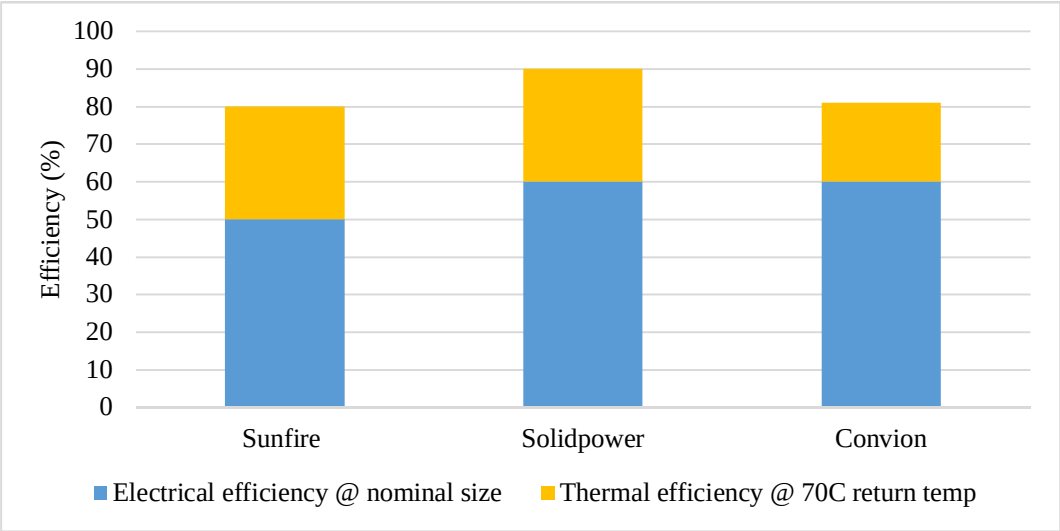

Figure 1. Electrical and thermal efficiency comparison.

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