

Smart Ways for In-situ Totally Integrated and Continuous Multisource Generation of Hydrogen

D8.10: Annual Data Reporting 2024 WP , T 8.2

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Technical References

| | |
|---------------------|---|
| Project Acronym | SWITCH |
| Project Title | Smart Ways for In-situ Totally Integrated and Continuous Multisource Generation of Hydrogen |
| Project Coordinator | Matteo Testi - FBK testi@fbk.eu |
| Project Duration | January 1, 2020 - March 31, 2024 (51 Months) |

| | |
|----------------------------|------------------------------|
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¹ PU = Public

PP = Restricted to other programme participants (including the Commission Services).

RE = Restricted to a group specified by the consortium (including the Commission Services).

CO = Confidential, only for members of the consortium (including the Commission Services).

Versions

| Revision Version | Date | Changes | Changes made by Partner |
|------------------|---------------|---|-------------------------|
| | 27 March 2024 | PO approval of the research objects | |
| 0.1 | 29 March 2024 | First release | Ilaria Alberti (FBK) |
| 0.2 | 05 April 2024 | Second release with electrolysis and stationary template (missing in the first version) | Ilaria Alberti (FBK) |
| 0.3 | 24 April 2024 | Approval received, submission | Ilaria Alberti (FBK) |

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1 Introduction

The SWITCH project aims to develop an in-situ, fully integrated and continuous multisource hydrogen production system, based on solid oxide cell technology. The core of the system is a reversible Solid Oxide Cell (SOC) operating in two modes: Electrolysis Mode (SOE) and Fuel Cell Mode (SOFC). In electrolysis mode, the SWITCH system will use renewable electricity, water, and heat to produce green hydrogen, with no emissions. In fuel cell mode, the SWITCH system will use natural gas or bio-methane to produce grey or green hydrogen, electricity, and heat when renewable power is not available.

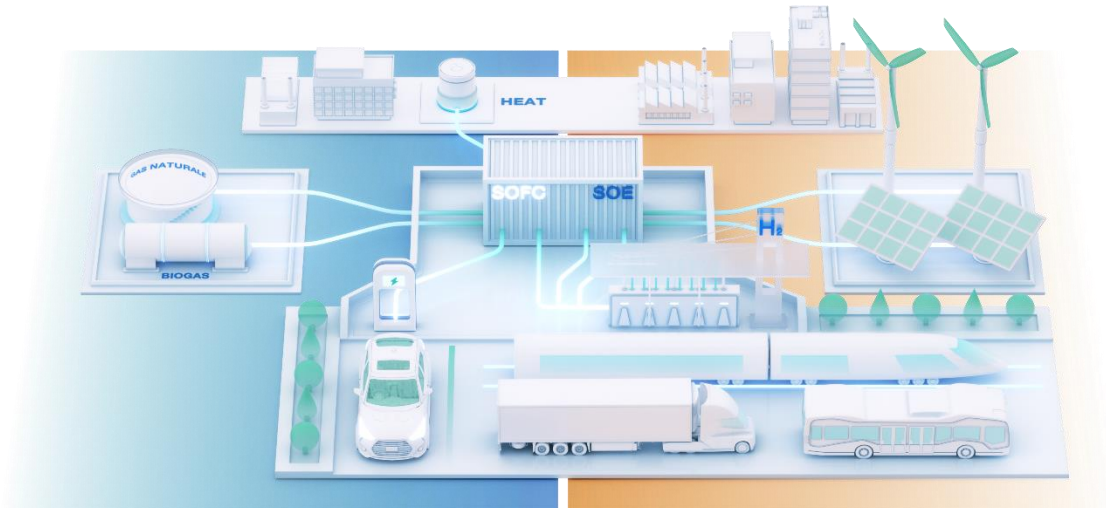


Figure 1. Graphic illustration of the prototype

This deliverable reports the data uploaded in the TRUST (Technology Reporting Using Structured Templates²) platform by the SWITCH partners in February 2024.

TRUST is part of the Annual Data reporting for the Clean Hydrogen JU 2024 that aims to monitor technology progress and identify how each of the projects contributes to the Clean Hydrogen JU targets, objectives and indicators described in the SRIA.³

There are five research objects to be submitted via TRUST:

1. D&E activities.
This object was filled in by the WP7 Leader - FBK
2. Results and Achievements
3. Safety
4. Electrolysis
5. Stationary

The templates were filled in jointly by SolydEra and HyGEAR. The Project Coordinator made the final check and adjustments before submitting the data.

² TRUST - Technology Reporting Using Structured Templates platform: <https://trust.fch.europa.eu>

³ Clean Hydrogen Partnership: https://www.clean-hydrogen.europa.eu/knowledge-management/annual-data-collection_en

2 TRUST Research Object: Results

In the research object “Results”, SolydEra and HyGEAR individuated 3 main results achieved in 2023.

For each result, the following information were requested:

- What is the achievement / result accomplished?
- What kind of results is it?
- When did you achieved the results?
- What is the market maturity level?
- What is the time to impact?
- Is the result included in the Innovation Radar (IR) platform?
- Is the result included in the Horizon Result Platform (HRP)?
- What are / have been the major difficulties or shortcomings?

2.1 Result 1: SWITCH Prototype

| N. | Title/Display Name | Value | Data Provider Comment |
|----|-------------------------------------|--|---|
| 1 | Achievement/ Result accomplished | SWITCH prototype | A prototype with a production capacity as expected within Switch project has been realized. |
| 2 | Achievement / Result Type | Product | The prototype can operate in reversible EC/FC mode and supply H2 up to 100 kg/day. |
| 3 | Year Accomplished | 2023 | TRL6 is the final objective of the project pursued through the prototype testing in HYGEAR. Testing to be finalized on first quarter of 2024. |
| 4 | Market Maturity | Market creating potential | Hydrogen market for reversible systems is highly promising, but still at the emerging phase, with an outlook to be more mature in the coming 4 to 5 years. Of particular interest are the hydrogen valleys, hydrogen infrastructures in the TEN-t corridors and small to medium industrial sites. |
| 5 | Time to impact | 1-5 Years | See comment above. |
| 6 | IR | Yes | SWITCH is included in the innovation radar platform. |
| 7 | HRP | No | SWITCH will be included in the last project phase in the HRP. |
| 8 | Major difficulties or shortcomings | Delays in the prototype assembly and integration | Most of delays are subsequent to the delays in CH2P project. Some delays on LSM testing were due to upgrading of research facilities by the involved partners. |

2.2 Result 2: Hot and Cold BoPs

| N. | Title/Display Name | Value | Data Provider Comment |
|----|------------------------------------|---|---|
| 1 | Achievement/ Result accomplished | Hot and Cold BoPs | Second Hot BoP manufactured, assembled, and tested in both SOFC /SOE modes at SolydEra facility, using a single stack. After unit qualification, the hot BoP has been delivery to HyGEAR for its integration into the overall system. Manufacturing and assembly of the Cold BoP units have been completed. |
| 2 | Achievement / Result Type | Product | The Hot and Cold BoP are a complex set of technologies including heat exchangers, steamer, purification unit (PSA) and compressor stage. They can be adapted and applied to several applications with a vast engineering competence developed. |
| 3 | Year Accomplished | 2023 | HOT and COLD BoP have been qualified in laboratory environment by SOLYDERA and HYGEAR. The final versions of the hot BoP have been manufactured and delivered to HyGEAR. The cold BoP components, including PSA unit and compressors, have been finalized. |
| 4 | Market Maturity | Market creating potential | Hydrogen market for high temperature systems is highly promising, but still at the emerging phase, with an outlook to be more mature in the coming 4 to 5 years. the specific modules and components can meet requirements of several application fields. |
| 5 | Time to impact | 1-5 Years | See comment above. |
| 6 | IR | Yes | SWITCH is included in the innovation radar platform. |
| 7 | HRP | No | SWITCH will be included in the last project phase in the HRP. |
| 8 | Major difficulties or shortcomings | Delays on BoP components assembly and integration | Cold BOP and Hot BOP required more time than expected to redesign parts and components to comply with the final engineering, safety requirements and optimization of performances at expected values. |

2.3 Result 3: System control finalization and safety analysis

| N. | Title/Display Name | Value | Data Provider Comment |
|----|------------------------------------|--|---|
| 1 | Achievement/ Result accomplished | system control finalization and safety analysis | The overall system control logic has been validated and tested at HyGEAR facilities based on activity performed by HYGEAR, SOLYDERA and FBK. The safety analysis, based on Hazop methodology, has been performed by HyGear in collaboration with SolydEra. |
| 2 | Achievement / Result Type | Design | HAZOP analysis was performed on the final system PI&D. The risk index related to each system component was quantified, and safety reduction measurements were integrated into the P&ID. The con and safety system (SPLC) has been validated, including I/O test and communication with main PLC |
| 3 | Year Accomplished | 2023 | Activity finalized along 2023. |
| 4 | Market Maturity | Emerging | Same considerations as above. Hazop is indeed applied to the engineering of the full SWITCH system, so the considerations are related to the final product. |
| 5 | Time to impact | 1-5 Years | Same considerations as above. Hazop is indeed applied to the engineering of the full SWITCH system, so the considerations are related to the final product. |
| 6 | IR | Yes | SWITCH is included in the innovation radar platform. |
| 7 | HRP | No | SWITCH will be included in the last project phase in the HRP. |
| 8 | Major difficulties or shortcomings | Delays in the control hardware supply and safety analysis finalization | The system safety analysis needed more time than expected due to the complex finalization of the first layout of the P&ID after several loops of optimization of the layout due to components testing in the laboratory. |

3 TRUST Research Object: Safety

The research object "Safety" was divided in descriptive and operation parameters.

TRUST Manual explains the difference among the two parameters:

"Descriptive parameters define the item addressed in the questionnaire and allow to set the scene for which actual results are reported as **operational parameters**.

*In principle, descriptive parameters do not change during the project lifetime, while operational parameters evolve and will be different from one annual data collection exercise to the next according to progress in the reference period."*⁴

3.1 Descriptive parameters

The descriptive practices in this research objects were only three and focused on the start and end date for reporting and on the presence of a Safety Management Plan, which is not available.

3.2 Operational parameters

| N. | Title/Display Name | Value | Data Provider Comment |
|----|---|---|-----------------------|
| 1 | Incident / Event | NO events | |
| 2 | HELLEN or HIAD database event | NO | |
| 3 | Number of incidents / events | 0 | |
| 4 | Maximum Stored Hydrogen Inventory Mass | <1 g | No H2 storage |
| 5 | Hydrogen Storage State | <100 bar litre | |
| 6 | Average Hydrogen Consumption (or Production) Rate | <i>*Confidential information</i> | |
| 7 | Type of project, "location" | Research in industry lab | |
| 8 | Public visibility, impact of a potential accident | None | |
| 9 | Available safety expertise in consortium | HyGear is an experienced hydrogen producer and manufacturer of SMR systems | |
| 10 | KPI - Safety Workshops | 4 | |
| 11 | Management capabilities and pro-active attitude | HyGear has safety officers to check the HAZOP analysis and to execute a safety check and to release the system for operation. | |

⁴ Clean Hydrogen Partnership, TRUST Manual: <https://www.clean-hydrogen.europa.eu/system/files/2022-02/TRUST%20user%20manual.pdf>

4 TRUST Research Object: D&E Activities

4.1 Descriptive parameters

| N. | Title/Display Name | Value | Data Provider Comment |
|----|--|-------|---|
| 1 | Updated/revised D&E plan | No | The initial D&E Plan has been released in 2020 and the WP7 Leader regularly asks for information on activities done and planned. A final plan will be delivered by the end of the project, in March 2025. |
| 2 | Dissemination Activities in total | 150 | Partners participated in events and won awards; a factsheet campaign gave visibility to the project. Numerous and different kind of activities have been done to disseminate the project. |
| 3 | Dissemination Activities within the timeframe of this data collection exercise | 70 | In 2023, partners participated in 2 scientific conferences and attended 2 crucial events. 2 video interviews were recorded, and 2 awards won. 10 news were published and posted on social media. The two awards received had a great echo on newspapers: more than 25 articles were published |
| 4 | Presentation of results in conferences, events, and workshops | 3 | EPFL participated in ECOS2023 and ECS Meeting. SE participated in Hannover Messe with a booth and poster about SWITCH |
| 5 | Peer-Reviewed Scientific Publications | 0 | Partners focused on achieving results. In 2024, at least 2 publications are expected. |
| 6 | Peer-Reviewed Scientific Publications in Open Research Europe | 0 | Publications will be included in Zenodo and SWITCH Website |
| 7 | Education & Training Activities | 0 | |
| 8 | Meetings with stakeholders | 1 | All the events should be considered meetings with stakeholders, but here is indicated the participation of SWITCH to the European Hydrogen Week |
| 9 | Other Dissemination Activities | 12 | 2 videos, 2 awards, 6 factsheets, 2 press release. The articles published in online magazines and newspapers as echoes of the two press releases are not included in this amount. |
| 10 | Scientific/Research Communities | 2000 | This is an estimated number including participants in conferences, events, views on website and social media. It is not possible to estimate the views of the magazines and newspapers. |
| 11 | Industry/Business Partners | 1000 | This is an estimated number including participants in conferences, events, views on website and social media. It is not possible to estimate the views of the magazines and newspapers. |
| 12 | EU Institutions / Policy Makers | 0 | |
| 13 | Standardisation Bodies | 0 | |

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|----|---|------|---|
| 14 | Society / Specific End-Users Communities | 3000 | Estimated number of readers of press release and online magazines, newspapers |
| 15 | Other Target Audiences | 0 | |
| 16 | Delivered Dissemination Activities | 70 | all dissemination activities mentioned above were delivered |
| 17 | On-going Dissemination Activities | 8 | Participation in conferences and at least 2 publications are being planned for 2024. Other dissemination materials will be created. |
| 18 | Postponed or Cancelled Dissemination Activities | 0 | |
| 19 | OpenAIRE platform | No | |
| 20 | Exploitation Activities performed within the timeframe of this data collection exercise | 2 | Workshop with HRB Service 2 (Business Development Plan) and IPR Agreement |
| 21 | IPR Activities within the timeframe of this data collection exercise | Yes | Following a survey, SWECO prepared and submitted a deliverable with regards on IPR |
| 22 | Business Model / Plan - Market Survey | No | SWECO is working on the Market Deployment Plan. The HRB Service 2 was related to Business Development Plan |
| 23 | Potential Investors / Users | No | |
| 24 | Steps towards standardisation | No | |
| 25 | Patent Application | No | |
| 26 | Other Exploitation Activities | No | |
| 27 | Other Exploitation Activities_ | 0 | |
| 28 | Industry/Business Partners | No | HyGEAR, SolydEra and Shell are business partner of the project |
| 29 | Research Communities | No | |
| 30 | Standardisation Bodies | No | |
| 31 | Innovators | No | |
| 32 | End Users | No | Business partners of the project can be also potential end-users |
| 33 | Other Audience | No | |
| 34 | Other Audience_ | 0 | |
| 35 | Lack of Regulation, Codes or Standards | No | |

| | | | |
|----|--------------------------|-----|--|
| 36 | Lack of Financing | Yes | Following the change of demo site, an amendment has been submitted in order to transfer the transfer among partners. |
| 37 | Lack of Labor Skills | No | |
| 38 | Trade Issues | No | |
| 39 | IPR-related Issues | No | SWECO submitted a deliverable with regards on IPR and, by the end of the project, the Consortium should start thinking of an Ownership Agreement related to the main KER of the project, the SWITCH Prototype. |
| 40 | Other | No | |
| 41 | Innovation Radar | No | |
| 42 | Horizon Results Platform | No | The Consortium is planning to make a video by the end of the project and might decide to use it for the Horizon Results Platform. |
| 43 | Horizon Results Booster | Yes | SWITCH benefitted of Service 1 Module A and C of the HRB in 2021. In 2023, the Consortium participated in HRB Service 2 (BDP). |
| 44 | Standardisation Booster | No | The initiative has been presented to the Consortium, but it has been decided not to use the service before the end of the project. The Consortium might consider applying after the end of the project. |
| 45 | Dealflow | No | |
| 46 | Other | No | |

5 TRUST Research Object: Electrolysis

5.1 Descriptive parameters

| N. | Title/Display Name | Value | Data Provider Comment |
|----|---|---------------------------|--|
| 1 | Start date for reporting | 01/01/2023 | |
| 2 | End date for reporting | 31/12/2023 | |
| 3 | Deployment date | 24/03/2024 | FAT and debugging activities to start the testing phase |
| 4 | Country | Netherlands | |
| 5 | Town | Arnhem | The change of the demo has been officially accepted by amendment |
| 6 | Technology | SOEL | Solid oxide electrolysis |
| 7 | Electrolyser manufacturer | SolydEra | |
| 8 | Stack manufacturer | SolydEra | |
| 9 | Stack nominal capacity | 18.75 kW | The power of each stack included in the 75 kW SOE module |
| 10 | Number of stacks | 8 | 4 stacks arranged in each 75 kW SOE module, hence 8 stacks for two 75kW SOE modules installed |
| 11 | Nominal system electrical power | 150 kW | Power absorbed by two developed SOE modules |
| 12 | Overload capacity | 10% | Confirmed by Solydera |
| 13 | System minimum power | 50% | Confirmed by Solydera |
| 14 | Hydrogen production capacity | 4.2 kg/h | Each SOE module can produce up to 50 kg/day (2.1 kg/h) at full capacity |
| 15 | Operating pressure | 1.05 bar | Absolute pressure |
| 16 | Operating temperature | 750 °C | Range of temperature: 700-790°C |
| 17 | Power usage of BoP | <i>*confidential data</i> | |
| 18 | Area occupied by unit | 396 m ² /MW | Based on two 40' containers footprint. Two SOE modules of 75 kW each plus hot BoPs, steam generator, power electronics and gas pre-processing arranged in one 40' container and all gas post-processing plant, automation and H2 compressors arranged in a second 40' container. |
| 19 | KPI- Electricity consumption @ nominal capacity | 35.7 kWh/kg | Electricity consumption of the SOE units considering free-steam and major BoP components. |

| | | | |
|----|--|---------------------------|--|
| 20 | KPI - Capital cost €/((kg/d) | <i>*confidential data</i> | |
| 21 | KPI - Capital cost €/kW | <i>*confidential data</i> | |
| 22 | KPI - O&M cost | <i>*confidential data</i> | |
| 23 | KPI - Heat demand @ nominal capacity (only SOEL) | 15.2 kWh/kg | Heat demand for steam at 90% of steam utilisation and 5% of steam train heat losses |
| 24 | KPI - Reversible capacity (only for SOEL) | 33% | 150 kW in SOEL and 50 kW on SOFC mode |

5.2 Operational parameters

| N. | Title/Display Name | Value | Data Provider Comment |
|----|---|-------|--|
| 1 | KPI - Hot idle ramp time | | Data is not available because the test did not start in 2023 |
| 2 | KPI - Cold start ramp time | | Data is not available because the test did not start in 2023 |
| 3 | KPI - Degradation | | Data is not available because the test did not start in 2023 |
| 4 | KPI - Current Density | | Data is not available because the test did not start in 2023 |
| 5 | KPI - Use of critical raw materials as catalysts | | Data is not available because the test did not start in 2023 |
| 6 | KPI - Roundtrip electrical efficiency (only for SOEL) | | Data is not available because the test did not start in 2023 |
| 7 | KPI - Ramp Duration | | Data is not available because the test did not start in 2023 |
| 8 | KPI - Stability | | Data is not available because the test did not start in 2023 |
| 9 | KPI - Ramp Precision | | Data is not available because the test did not start in 2023 |
| 10 | KPI - Reliability | | Data is not available because the test did not start in 2023 |
| 11 | Fraction of renewable energy input | | Data is not available because the test did not start in 2023 |
| 12 | Hours of operation | | Data is not available because the test did not start in 2023 |
| 13 | Quantity of hydrogen produced | | Data is not available because the test did not start in 2023 |
| 14 | Cost of the hydrogen produced | | Data is not available because the test did not start in 2023 |
| 15 | Stack electrical efficiency (HHV, DC current) | | Data is not available because the test did not start in 2023 |
| 16 | System electrical efficiency (HHV, AC current) | | Data is not available because the test did not start in 2023 |
| 17 | System availability | | Data is not available because the test did not start in 2023 |

6 TRUST Research Object: Stationary (Fuel Cell)

6.1 Descriptive parameters

| N. | Title/Display Name | Value | Data Provider Comment |
|----|--|-----------------------------------|--|
| 1 | Start date for reporting | 01/01/2023 | |
| 2 | End date for reporting | 31/12/2023 | |
| 3 | Country | Netherlands | |
| 4 | Town or region | Arnhem | The change of the demo is officially accepted by the amendment. |
| 5 | End user | Shell Technology Centre Amsterdam | |
| 6 | Deployment date | 24/03/2024 | Indicative date |
| 7 | Manufacturer | SolydEra/HyGear | |
| 8 | Model | LSM-25 | Solydera confirmed the use of the models with 25 kW SOFC and 75 kW SOE (LSM was developed in two versions 32/100 SOFC/SOE power and 25/75 kW) |
| 9 | Stack manufacturer | SolydEra | |
| 10 | Technology | SOFC - Solid oxide fuel cell | |
| 11 | Stationary application | Off-grid power | System will produce both electrical power and hydrogen simultaneously |
| 12 | Fuel | Natural gas Biogas Hydrogen | |
| 13 | Does the fuel cell system include a fuel reformer? | yes | |
| 14 | Number of stacks | 8 | The stacks are integrated in a large stack module (LSM) in bundles of 4 stacks. Two LSM installed, each of them is rated 25 kW in SOFC mode and -75 kW in SOE mode |
| 15 | Electrical power of stacks | 6.25 kW | in SOFC mode |
| 16 | Rated system electrical capacity | 50 kW | Two LSM modules in SOFC mode |
| 17 | Rated system thermal capacity | 43 kW | This is the thermal power available for two LSM modules at the cathode and anode gas outlets. Most of this thermal power may be reused in the process |

| | | | |
|----|---|---------------------------|---|
| 18 | Start-up time | 72000 s | About 20 hours are required for heat up the system from room temperature to hot stand-by, when the stacks are ready to be polarised |
| 19 | Transient response time | 1500 s | Indicative value |
| 20 | Part load operation electrical efficiency - 30% | <i>*confidential data</i> | |
| 21 | Part load operation electrical efficiency - 50% | 55% | Referred to the qualification test of a LSM module at 64% load. No data available at 50% load. |
| 22 | CO emissions at rated conditions | | No data available (not measured yet) |
| 23 | NOx emissions at rated conditions | | No data available (not measured yet) |
| 24 | SOx emissions at rated conditions | | No data available yet (not measured yet) |
| 25 | System installation costs | <i>*confidential data</i> | |
| 26 | Estimated Cost of spare parts | <i>*confidential data</i> | |
| 27 | KPI - Hydrogen tolerance | 100 % (volume) | Basically the FC system can operate with partially reformat natural gas, Syngas, Biogas, LNG and Hydrogen |
| 28 | KPI - Land use / footprint | 0.057 m ² /kW | Referred to an LSM module, excluding BoP and auxiliary equipments. |
| 29 | KPI - Rated system electrical efficiency (LHV) | 54% | It is expected the rated electrical efficiency of the SolydEra commercial system Bluegen, which is 54% net AC |
| 30 | KPI - Rated system electrical efficiency (LHV) | | No data available. Most of the produced heat is recycled into the process |
| 31 | KPI - Rated system thermal efficiency (LHV) | 10y | Expected lifetime including one stack replacement. The system is considered at the end of life when the voltage drop of the replaced stack is more than 10% |
| 32 | KPI - Lifetime of the fuel cell system | 40000h | With a measured relative voltage drop of 0.25% / 1000 h, the expected life of the tack is 40'000 hours, when the total voltage drop is about 10% |
| 33 | KPI - Stack durability | <i>*confidential data</i> | |

6.2 Operational parameters

| N. | Title/Display Name | Value | Data Provider Comment |
|----|--|-------|---|
| 1 | Est. system CAPEX (per kW) @ mass production | | Data is not available because the test has not yet been performed in 2023 |
| 2 | KPI - Stack Production cost | | Data is not available because the test has not yet been performed in 2023 |
| 3 | KPI - Degradation @ CI & FU=75%, if SOFC | | Data is not available because the test has not yet been performed in 2023 |

| | | |
|----|--|---|
| 4 | KPI - Degradation @ CI, if PEMFC | Data is not available because the test has not yet been performed in 2023 |
| 5 | KPI - Reliability | Data is not available because the test has not yet been performed in 2023 |
| 6 | KPI - Warm start time | Data is not available because the test has not yet been performed in 2023 |
| 7 | KPI - Availability | Data is not available because the test has not yet been performed in 2023 |
| 8 | KPI - Operational and maintenance costs (OPEX) | Data is not available because the test has not yet been performed in 2023 |
| 9 | KPI - Number of stack replacements | Data is not available because the test has not yet been performed in 2023 |
| 10 | Hours of operation | Data is not available because the test has not yet been performed in 2023 |
| 11 | Days of operation | Data is not available because the test has not yet been performed in 2023 |
| 12 | Hours of operation - cumulative | Data is not available because the test has not yet been performed in 2023 |
| 13 | Number of safety incidents | Data is not available because the test has not yet been performed in 2023 |
| 14 | Energy input from fuel | Data is not available because the test has not yet been performed in 2023 |
| 15 | Electricity produced | Data is not available because the test has not yet been performed in 2023 |
| 16 | Useful heat output | Data is not available because the test has not yet been performed in 2023 |
| 17 | Efficiency degradation rate | Data is not available because the test has not yet been performed in 2023 |
| 18 | Power degradation rate | Data is not available because the test has not yet been performed in 2023 |
| 19 | Fuel price | Data is not available because the test has not yet been performed in 2023 |