Objective Evaluation of the Engineering Performance of Stationary Solid Oxide Fuel Cell (SOFC) Systems Based on Measured, Time-Dependent Data

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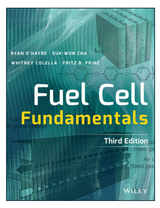


Comparative Performance Data for Solydera (formerly Solidpower Inc.) Solid Oxide Fuel Cell (SOFC) Systems

Summary

Based on the data collected to date, the SOFC fuel cell systems (FCS) evaluated outperform high temperature proton exchange membrane (HTPEM) FCS previously evaluated in terms of (1) Electrical Efficiency & (2) Performance at Rated Value (values include down time).

	Availability (A) Definition	Formula	HTPEM Average Performance of 10 FCS	SOFC Average Performance of 4 FCS over 18 months	SOFC Average Performance of 2 FCS over 24 months
A_o	quantifies the system operating time, power output > 0, when compared to the total time.	$A_o = \frac{t_{operating}}{t_{total}}$	95.9%	86.9%	83.7%
	Performance at Rated Values (PRV) Definition	**Formula**	**HTPEM Average Perform. of 10 FCS**	**SOFC Average Performance of 4 FCS over 18 months**	**SOFC Average Performance of 2 FCS over 24 months**
PRV_{eff}	quantifies the system time operating at or above the rated electric efficiency (η=36% for HTPEM and η=60% for SOFC).	$PRV_{eff} = \frac{t_{efficiency\_above\_rated}}{t_{total}}$	8.9%	82.0%	83.1%
PRV_p	quantifies the system time operating at or above the rated electricity output (5 kWe for HTPEM and 1.5 kWe for SOFC).	$PRV_p = \frac{t_{elec\_above\_rated}}{t_{total}}$	7.4%	73.7%	82.2%
PRV_t	quantifies the system time operating at or above both the rated electricity output (5 kWe HTPEM and 1.5 kWe SOFC) and rated efficiency (η=36% for HTPEM and η=60% for SOFC).	$PRV_t = \frac{t_{elec\_and\_eff\_above\_rated}}{t_{total}}$	0.5%	73.7%	82.2%

Figure compares (1) availability and (2) performance at rated value for efficiency (PRV_{eff}), power (PRV_p), and both efficiency & power (PRV_t) for 4 different SOFC FCSs operated over 18-months with averaged data for 10 HTPEM FCSs. Values include down time.

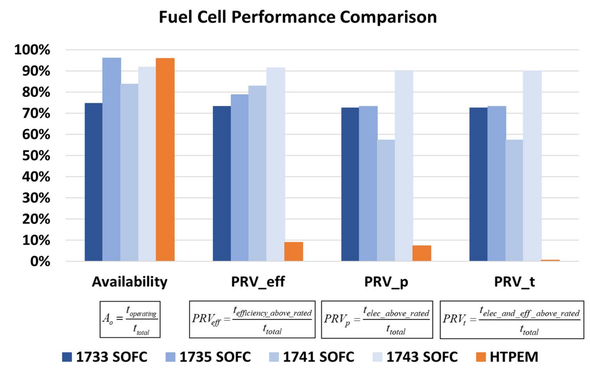
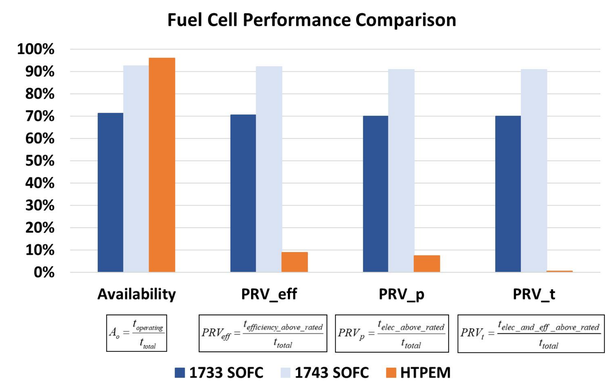
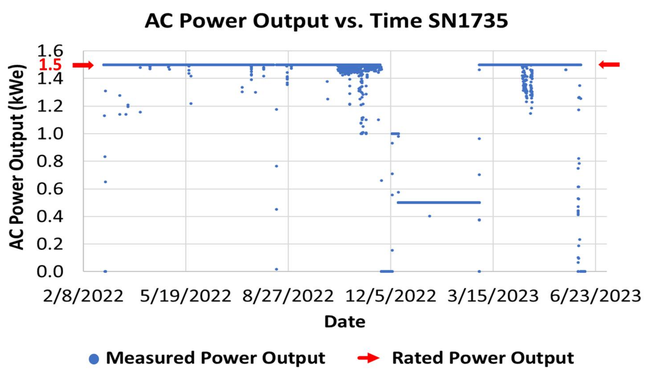


Figure compares (1) availability and (2) performance at rated value for 2 of the original 4 SOFC FCSs operated over 24-months with averaged data for 10 HTPEM FCSs. Values include down time.

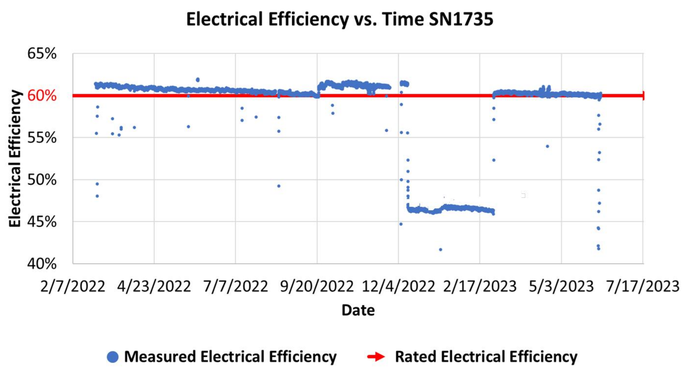


4 SOFC FCSs over 18 months

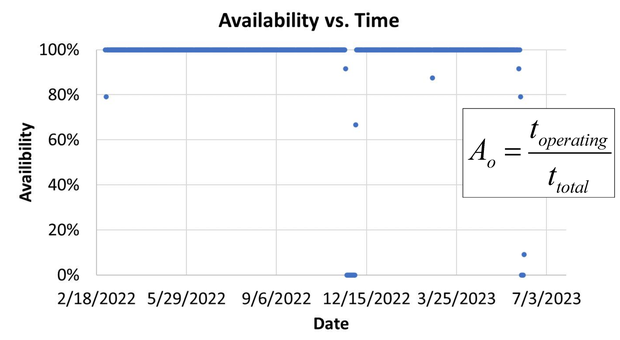
One (1) of the four (4) SOFC systems, referred to as "SN1735," operated over 18-months with measured electric power output meeting or exceeding manufacturer-stated electric power output (1.5 kWe) 74.6% of the time (i.e. the PRV_p including down time).



Over 18 months, SN1735's measured electrical efficiency meets or exceeds manufacturer-stated electrical efficiency (~60%) 80.2% of the time (i.e. the PRV_{eff} including down time).

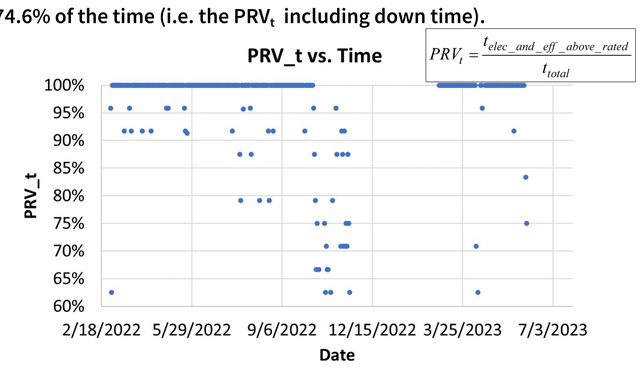


Over 18 months, SN1735 demonstrates an availability of 97.7%.



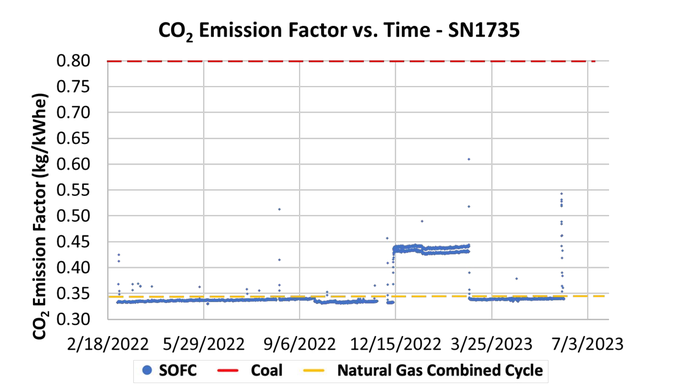
Availability is defined as the amount of time the unit is producing electric power divided by the total time of data collection.
Availability is plotted above daily and collected at 1 hour time intervals.

Over 18 months, SN1735's measured electrical efficiency and power both meet or exceed manufacturer-stated values (i.e. ~60% & 1.5 kWe) 74.6% of the time (i.e. the PRV_t including down time).



PRV_t is defined as the amount of time the unit's efficiency is ≥ the manufacturer stated electrical efficiency (60%) and power output (1.5kWe).
PRV_t is plotted above daily and collected at 1 hour time intervals.

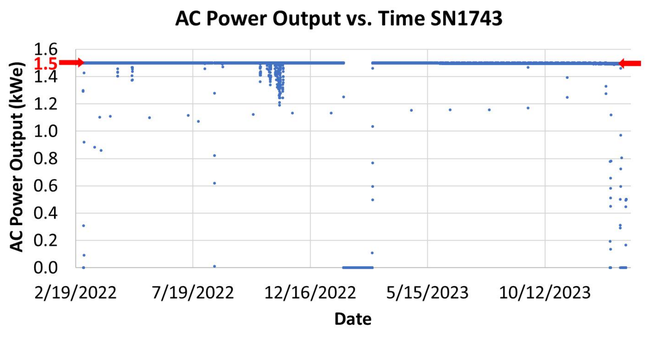
The SOFC demonstrates a lower CO_2 Emission Factor (~0.33 kg CO_2/kWhe) than both coal power plants and combined cycle gas turbine power plants.



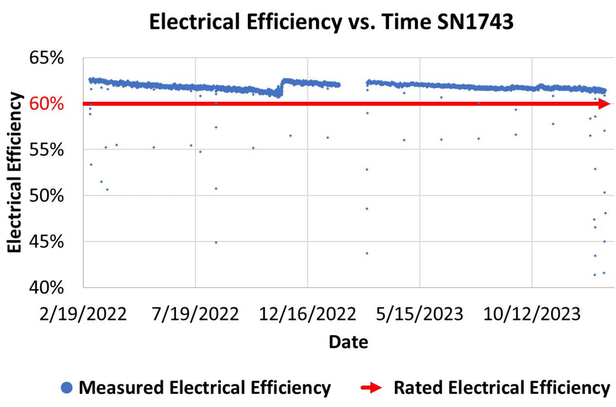
Source: Rubin, E. S., Chen, C., & Rao, A. B. (2007). Cost and performance of fossil fuel power plants with CO2 capture and storage. Energy Policy, 35(9), 4444–4454. https://doi.org/10.1016/j.enpol.2007.03.009

2 SOFC FCSs over 24 months

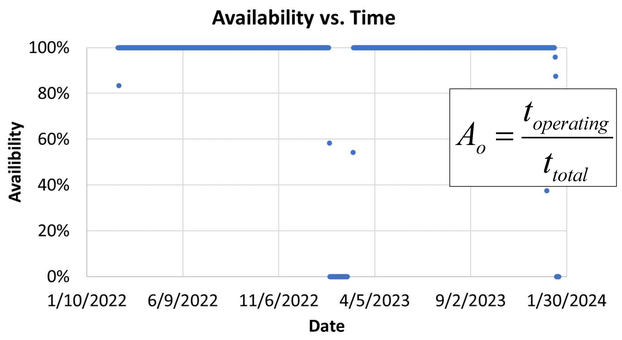
One (1) of the four (4) SOFC systems, referred to as "SN1743," operated over 24-months with measured electric power output meeting or exceeding manufacturer-stated electric power output (1.5 kWe) 92.4% of the time (i.e. the PRV_p including down time).



Over 24 months, SN1743's measured electrical efficiency meets or exceeds manufacturer-stated electrical efficiency (~60%) 93.4% of the time (i.e. the PRV_{eff} including down time).

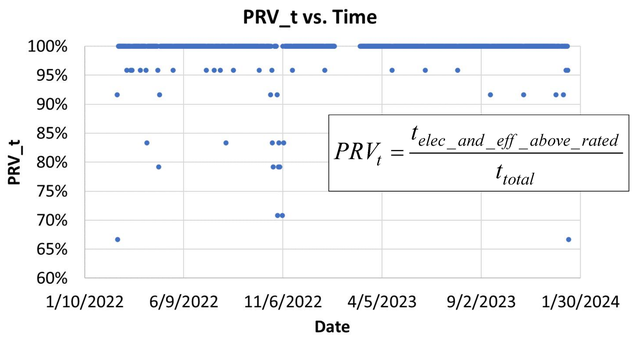


Over 24 months, SN1743 demonstrates an availability of 93.7%.



Availability is defined as the amount of time the unit is producing electric power divided by the total time of data collection.
Availability is plotted above daily and collected at 1 hour time intervals.

Over 24 months, SN1743's measured electrical efficiency and power both meet or exceed manufacturer-stated values (i.e. ~60% & 1.5 kWe) 92.4% of the time (i.e. the PRV_t including down time).



PRV_t is defined as the amount of time the unit's efficiency is ≥ the manufacturer stated electrical efficiency (60%) and power output (1.5kWe).
PRV_t is plotted above daily and collected at 1 hour time intervals.

Dr. Whitney G. Colella

Dr. Colella serves as Founder, President & Principal Research Engineer of Gaia Energy Research Institute.
Dr. Colella has over ~25 years of R&D experience in academia, government, & private industry in the areas of advanced energy conversion system design, operation, & control. Her areas of expertise include the thermodynamics, chemical engineering process plant design, heat transfer, economics, computer modeling, techno-economic analysis (TEA), life cycle assessment (LCA), emissions monitoring, design for manufacture & assembly analysis (DFMA), energy systems analysis, independent testing, & resiliency of advanced energy systems.

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