

Modular Fuel Cells Providing Resiliency to Data Centers and Other Critical Power Users: Thermodynamic Analysis

23rd Annual Solid Oxide Fuel Cell (SOFC) Project Review Meeting
October 25th-27th, 2022

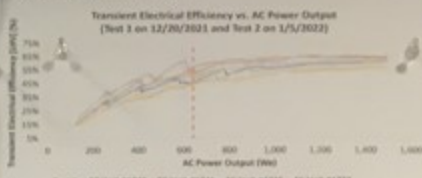
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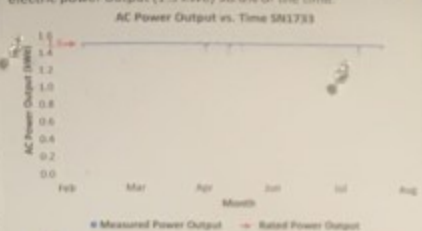
Transient Electrical Efficiency vs. AC Power Output

Transient electrical efficiency remains high even at high electrical power turn-downs.



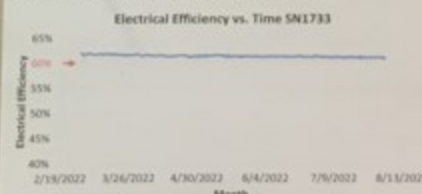
At ~60% turndown (640 W), transient electrical efficiency is $\geq 45\%$ for all four FCs on 2 test dates.

For one FCs, operating over a 5-month time period, measured electric power output meets or exceeds manufacturer-stated electric power output (1.5 kW) 98.6% of the time.



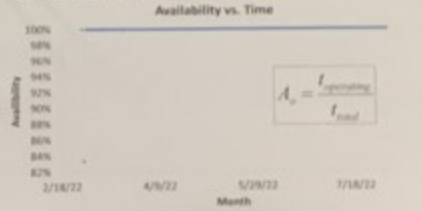
For one FCs, operating over a 5-month time period, measured electric power output meets or exceeds manufacturer-stated electric power output (1.5 kW) 98.6% of the time.

For one FCs, operating over a 5-month time period, measured electrical efficiency meets or exceeds manufacturer-stated electrical efficiency (~60%) 99.5% of the time.



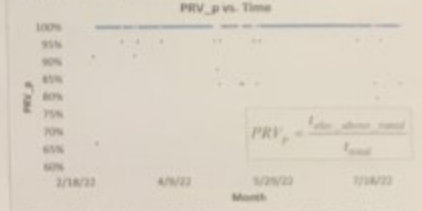
For one FCs, operating over a 5-month time period, measured electrical efficiency meets or exceeds manufacturer-stated electrical efficiency (~60%) 99.5% of the time.

For one FCs, operating over a 5-month time period, the aggregate availability is 99.9%.



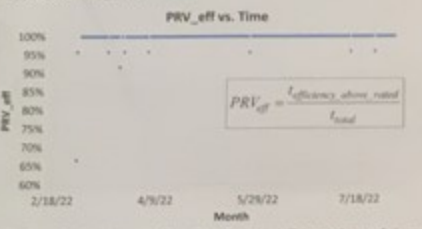
Availability is defined as the amount of time the unit is producing electric power divided by the total time of data collection. Availability is plotted above daily and collected at 1 hour time intervals.

For one FCs, operating over a 5-month time period, the aggregate PRV_p is 98.6%.



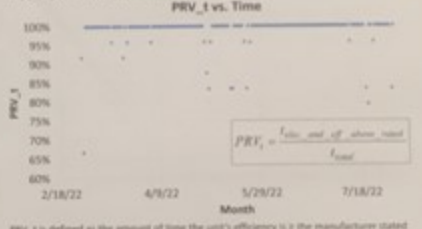
PRV_p is defined as the amount of time the unit's power output is the manufacturer stated power output (1.5kW). PRV_p is plotted above daily and collected at 1 hour time intervals.

For one FCs, operating over a 5-month time period, the aggregate PRV_eff is 99.5%.



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

For one FCs, operating over a 5-month time period, the aggregate PRV_1 is 98.6%.

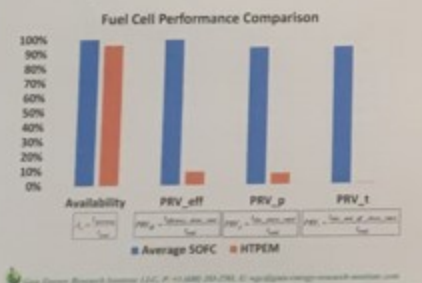


PRV_1 is defined as the amount of time the unit's efficiency is the manufacturer stated electrical efficiency (60%) and power output (1.5kW). PRV_1 is plotted above daily and collected at 1 hour time intervals.

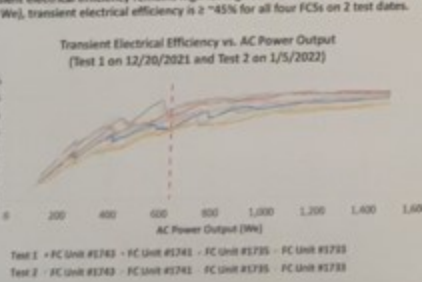
Based on the available data to date, SOFC FCs appear to outperform HTEPM FCs in Availability, Performance at Rated Value and electrical efficiency.

Availability (A _g)	PRV _p	PRV _{eff}	PRV ₁
99.9%	98.6%	99.5%	98.6%

The SOFC FCs appears to outperform HTEPM FCs in (1) Availability (A_g) & (2) Performance at Rated Value (PRV).

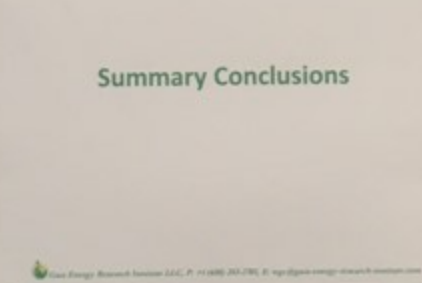


Conclusions
Transient electrical efficiency remains high for high turndowns. At ~60% turndown (640 W), transient electrical efficiency is $\geq 45\%$ for all four FCs on 2 test dates.

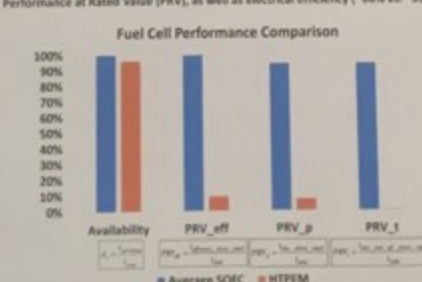


At ~60% turndown (640 W), transient electrical efficiency is $\geq 45\%$ for all four FCs on 2 test dates.

For one FCs, operating over a 5-month time period, the aggregate PRV_1 is 98.6%.



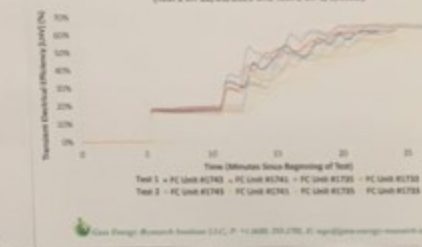
Conclusions
The SOFC FCs appears to outperform HTEPM FCs in (1) Availability (A_g) and (2) Performance at Rated Value (PRV), as well as electrical efficiency (~60% vs. ~33%).



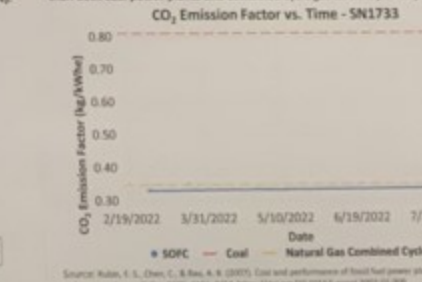
At ~60% turndown (640 W), transient electrical efficiency is $\geq 45\%$ for all four FCs on 2 test dates.

Conclusions
Even under fast ramping conditions, the SOFCs maintain high electrical efficiencies.

For example, within the first 15 minutes of the ramp up period, three of the four FCs achieve a transient electrical efficiency of ~85% or above. After 25 minutes of ramp up, two FCs are at or above ~55% and the other two FCs are at or above ~65%.



Conclusions
Lastly, the SOFC demonstrates a lower CO₂ Emission Factor (~0.33 kg CO₂/kWh) than both coal power plants and combined cycle gas turbine power plants.



Source: Rubin, C. S., Chen, C., & Bao, A. A. (2007). Cost and performance of fossil fuel power plants with CO2 capture and storage. Energy Policy, 33(5), 4884-4914. https://doi.org/10.1016/j.enpol.2007.05.009