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Leveraging Geothermal stability to mitigate load-induced degradation in solid oxide electrolysis systems

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INTRODUCTION

Global energy transition demands large-scale, flexible conversion of electricity to fuels. SOEC's offer high efficiency : 65 – 90% system efficiency (HHV basis) depending on heat integration. However, load – induced degradation from renewable energy intermittency remains a critical barrier.

Parameter	Solar / wind	Impact on SOEC's
Capacity Factor	25 — 45 %	Thermal cycling stress
Ramp rate	10 — 50 %/min	Electrochemical Transients
Cycling Frequency	Multiple load cycles /Day	Compositional Fluctuations
Predictability	Hours ahead	Accelerated Degradation

Key degradation mechanisms oxygen electrode delamination (≈ 40& of observed failures), interconnect oxidation (≈ 30& of failures), microstructural coarsening (reduced active area), thermal stress cracking and reaction site blocking.

The Geothermal Solution - Baseload Stability: >90% capacity factor, low cycling , Predictable operation , Low ramp rates.

METHODS

This study evaluates the impact of geothermal baseload stability on SOEC degradation risk relative to wind and solar-driven operations.

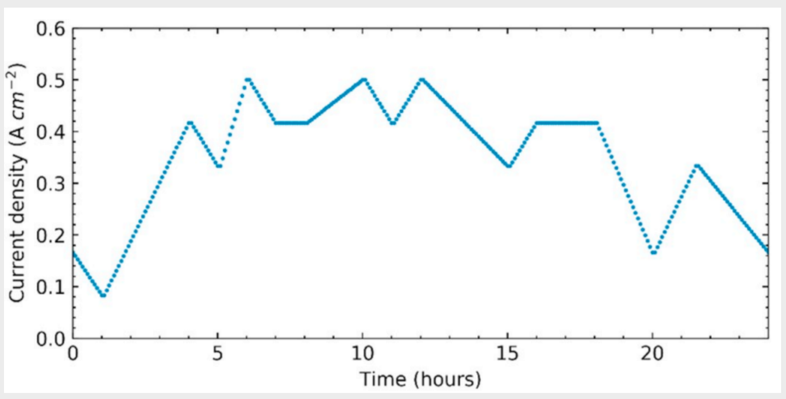
Data & Inputs

- Geothermal operating data (2020–2025) **:** Olkaria V powerplant
- SOEC simulated cycling profile: representative daily wind-driven load fluctuation
- Normalized RES generation curves: literature-derived solar diurnal and wind stochastic output profiles

Approach

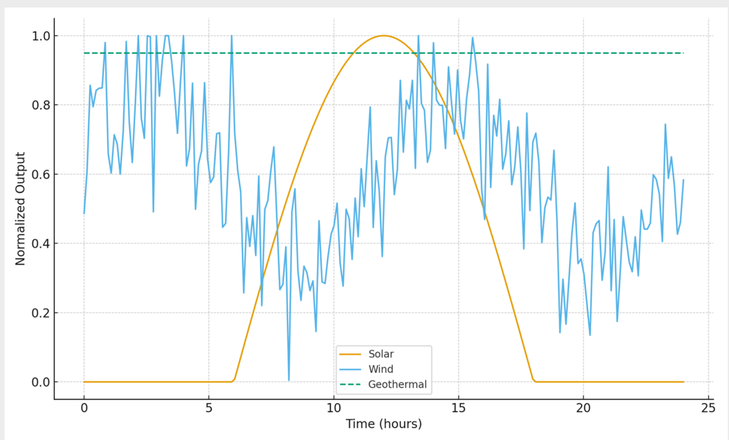
Parameter	Solar / wind
Quantify operational stability	Variance, ramp frequency, load events
Relate operational signatures to known SOEC degradation modes	Temperature (700 – 850°C), gradients, thermal stress cycling
Performance benchmark	Geothermal baseload profile against RES variability

RESULTS



Simulated wind profile for stack testing (Rao, 2020**)**

Normalized Renewable output profiles



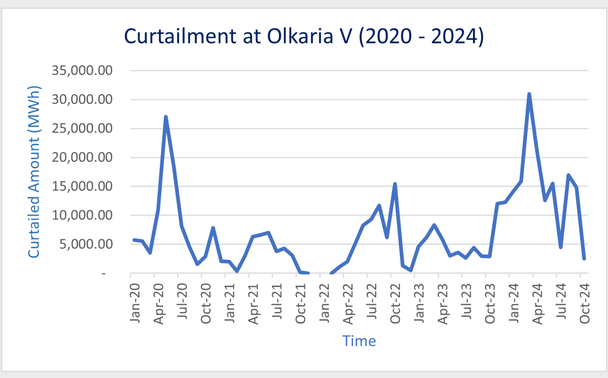
Geothermal Performance Stability

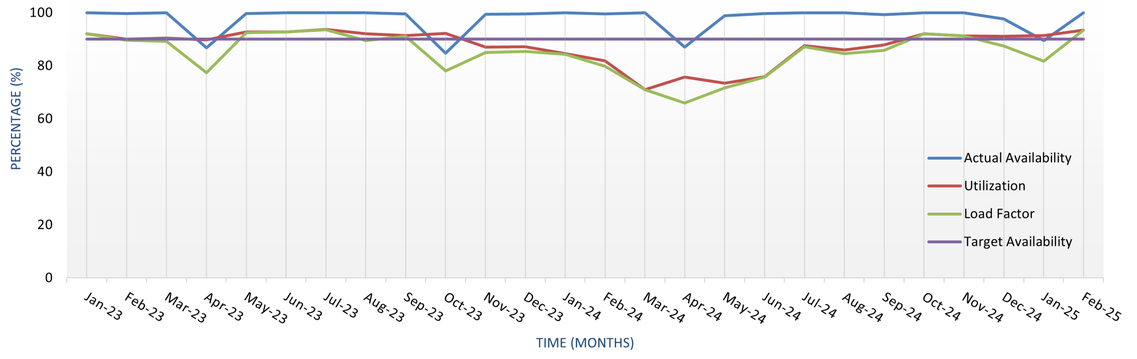
Availability consistently >95%

Load factor frequently >90%

Curtailment minimal → near-continuous, steady load supply

No deep turn-down events unlike RES profiles





KenGen internal performance dataset (2020–2025)

DISCUSSION

SOEC Degradation Risk Map

Degradation Mechanism	Exacerbated by Power Variability?	Geothermal	Wind	Solar
Thermal Cycling	Yes	Low	High	High
Current Density Fluctuations	Yes	Low	High	Moderate
Current Reversals	Yes	Low	High	Moderate
Thermal Gradients	Yes	Low	High	High
Redox Cycling	Yes	Low	Moderate	Moderate
Interconnect Oxidation Stress	Yes	Low	High	High
Mechanical Fatigue	Yes	Low	High	High
Microstructural Coarsening	Indirect	Low	Moderate	Moderate

Low High Moderate

Geothermal power minimizes major SOEC degradation triggers, allowing significantly longer stack life and more stable hydrogen output compared with wind/solar-driven electrolysis.

CONCLUSION

Synergy between geothermal baseload power and high-temperature electrolysis offers a robust pathway for efficient and durable renewable hydrogen generation.

Geothermal stability provides a structural advantage for SOEC deployment through:

- Ultra-low cycling frequency → reduced thermal & electrochemical stress
- High load factor (> 90%) → maximized hydrogen output and system utilization
- Minimal curtailment → continuous, uninterrupted delivery of both power and thermal energy
- Predictable operating profile → Leads to an extended stack lifetime

As a result, geothermal-integrated SOEC systems can achieve longer operational lifetimes, lower lifecycle OPEX, and more reliable large-scale green hydrogen production .

NEXT STEPS

- Simulate real geothermal steam - SOEC coupling
- Simulate long term SOEC degradation testing under geothermal profiles
- Techno-economic comparisons: geothermal vs RES & hybrid systems

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