Bloomenergy

# Hydrogen Energy Earthshot Summit

# High Temperature Solid Oxide Electrolyzer

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Chief Technology Officer
Executive Vice President of Engineering

August 31 2021

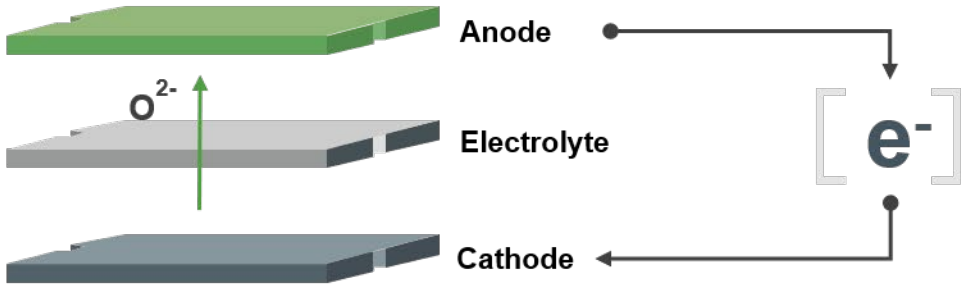
# FUEL CELL OVERVIEW

Be

Methane or Hydrogen

$CH_4 + 4O^{2-} \rightarrow 2H_2O + CO_2 + 8e^-$

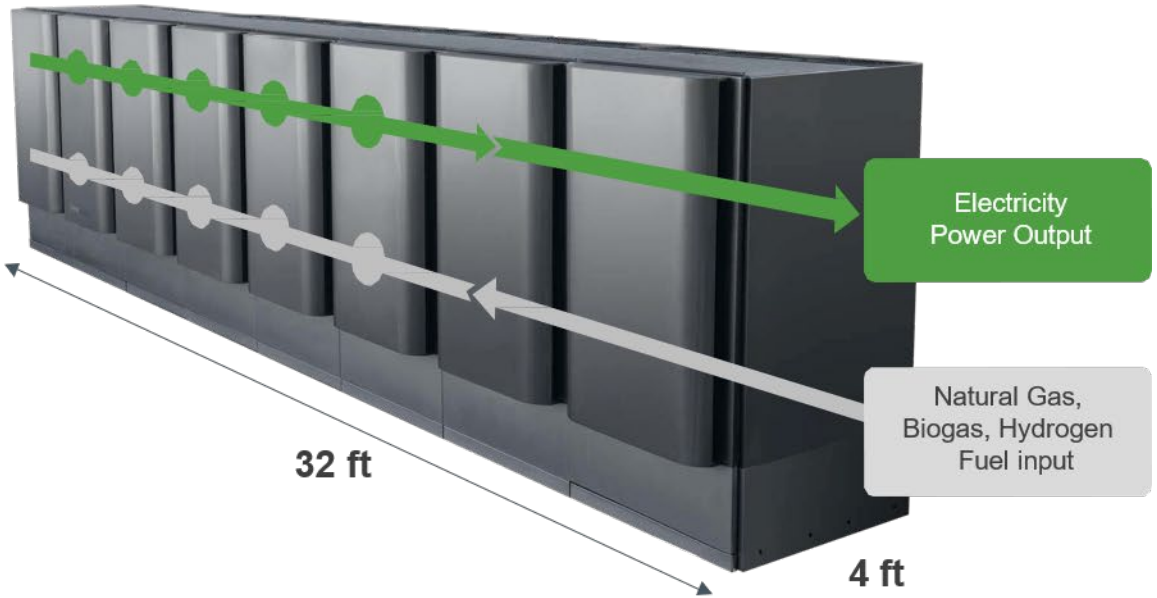
$4H_2 + 4O^{2-} \rightarrow 4H_2O + 8e^-$




$[e^-]$

Ambient Air

$2O_2 + 8e^- \rightarrow 4O^{2-}$




Fuel Cell | Stack | Server Module | Server | Power Center

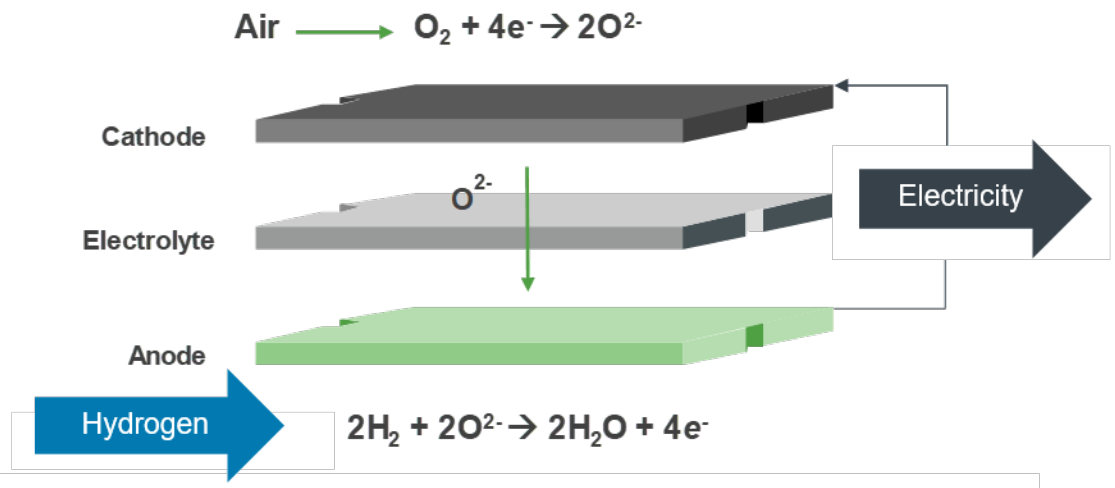
# SOLID OXIDE REVERSIBLE CELL

Be

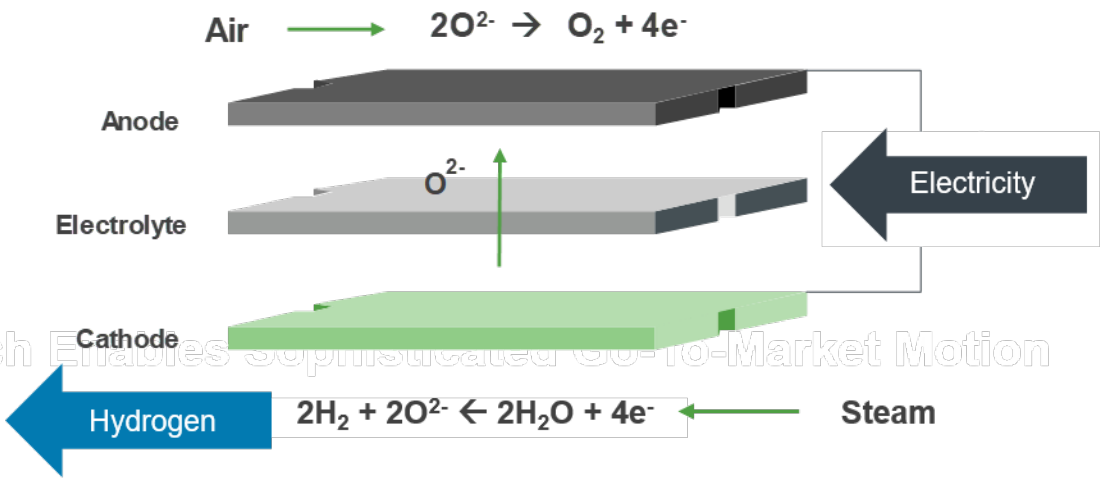
## Fuel Cell Mode


## Electrolyzer Mode

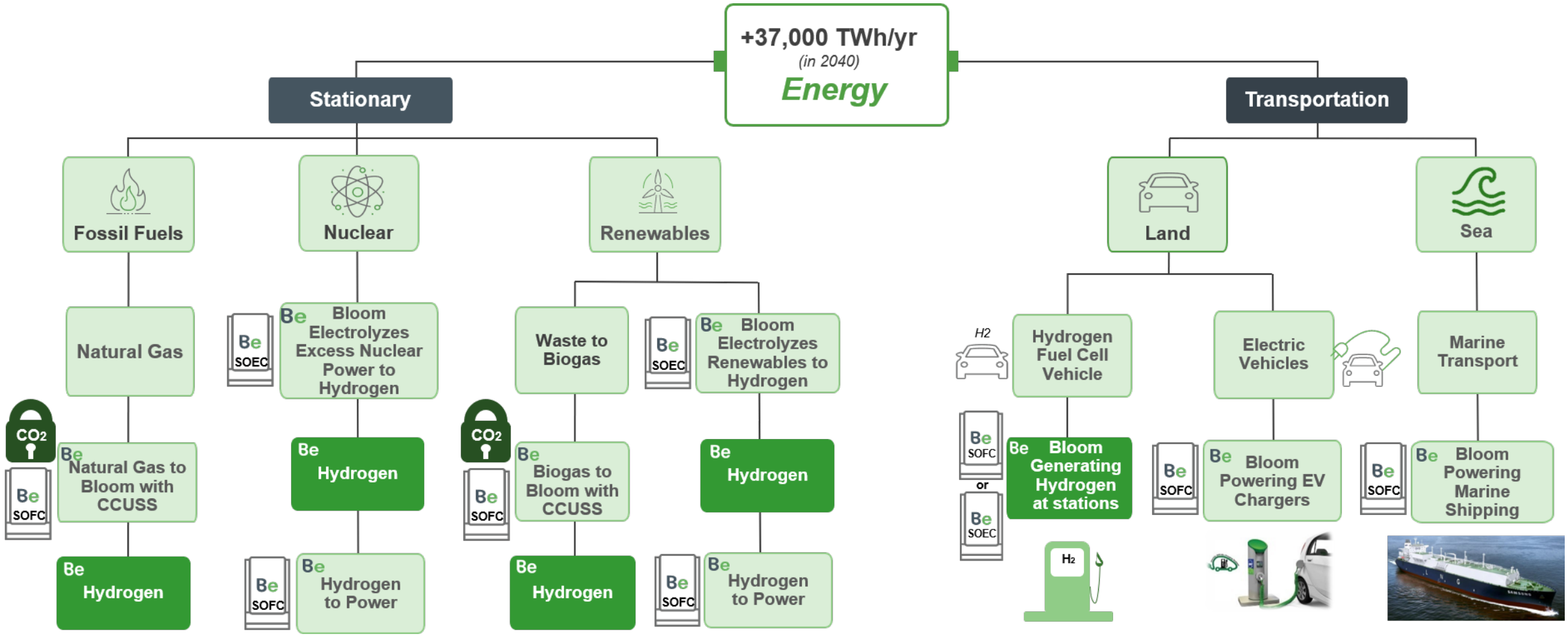

## Fuel Cell Mode




## Electrolyzer Mode



# BLOOM'S VISION ON ENERGY TRANSFORMATION



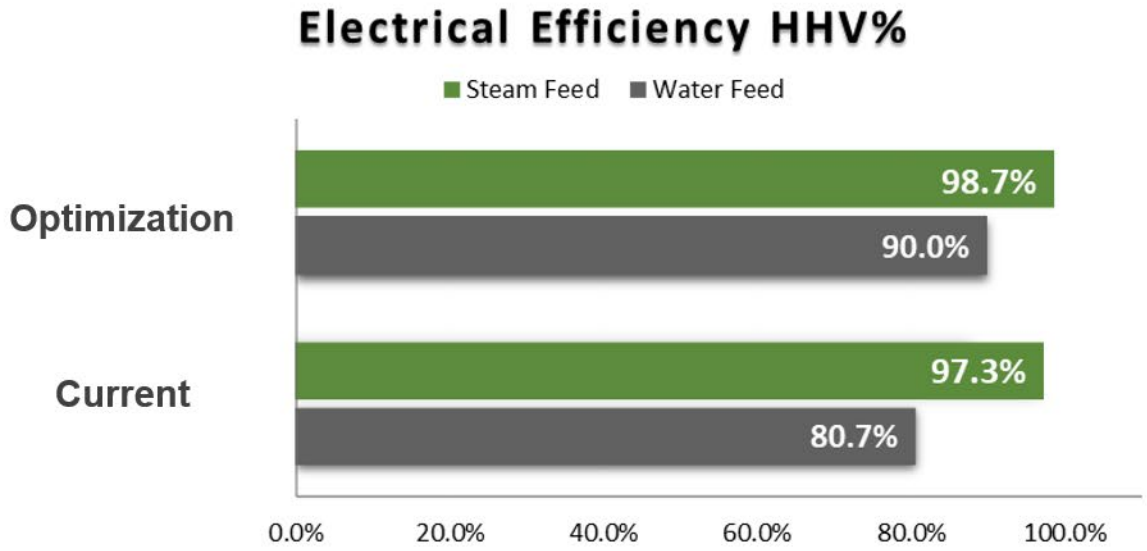
# BLOOM ELECTROLYZER LAUNCH

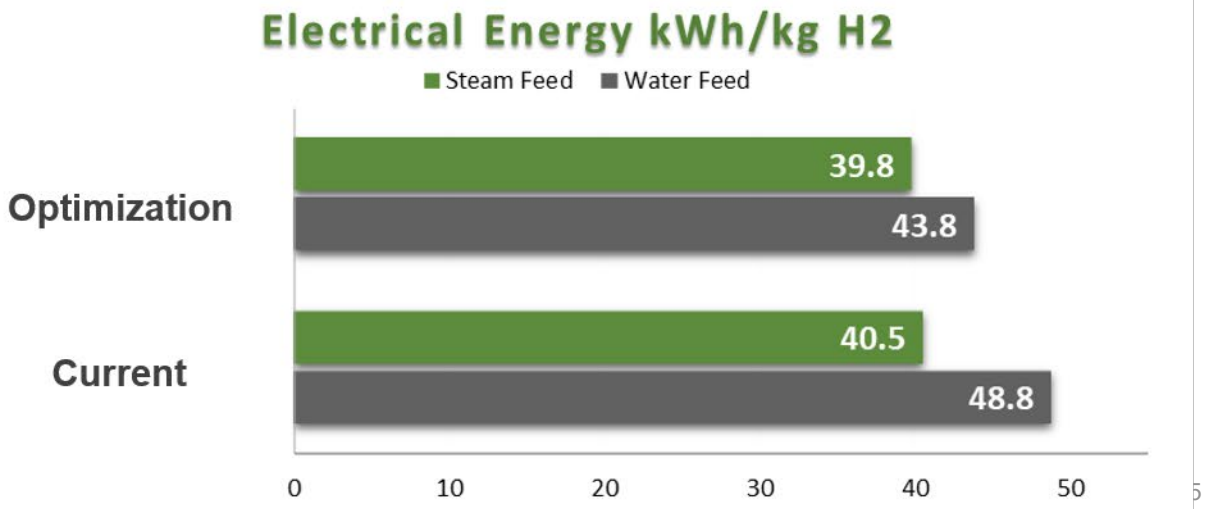
Be

## Bloom Energy Electrolyzer


| Results (Single Module Testing) | Water Feed | Steam Feed |
|---|---|---|
| Hydrogen Production (kg/hr) | 2.54 | 2.69 |
| Electrical Energy (kWh/kg $H_2$) | 48.8 | 40.5 |
| Electrolyzer Efficiency HHV (%) | 80.7 | 97.3 |

(Not including downstream compression)



# HYDROGEN PARTNERSHIP ANNOUNCEMENTS





Bloomenergy®

# FuelCell Energy Overview

## FACILITIES AND FLEET

| | |
|---|---|
| **Danbury, CT** | Headquarters/R&D/Serv. |
| **Torrington, CT** | Manufacturing |
| **Taufkirchen, DE** | Manufacturing/Service |
| **Calgary, AB** | Solid Oxide R&D |
| **~380** | Employees |
| **>255 MW** | Deployed Capacity in Field |
| **12M+ MWh** | Generated Since 2003 |

## ADVANCED FUEL CELL AND ELECTROLYSIS TECHNOLOGIES

**Distributed Generation**

**Distributed Hydrogen**

**Electrolysis & Energy Storage**

**Carbon Capture**


## GLOBAL CUSTOMERS

Pfizer · ExxonMobil · Toyota · City of Tulare · San Diego International Airport · LIPA Long Island Power Authority · Federal Ministry of Education and Research · City of Riverside · American Electric Power · Pepperidge Farm · Radisson Blu · Clearway Energy · Friatec · Pacific Gas and Electric Company · KOSPO · Southern California Edison · e.on · cmeec · Avangrid · Hartford Hospital Connect to healthier.

## OVER 250 MW OPERATING ON 3 CONTINENTS

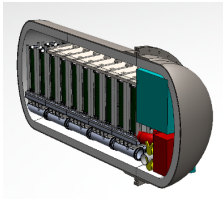



**Enable The World To Live A Life Empowered By Clean Energy**

# Solid Oxide Applications

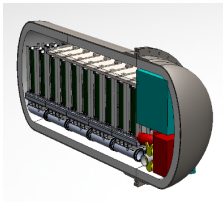
**SOFC Stack**


7 kW DC Power Generation
36 kW DC / 25 kg $H_2$/day electrolysis
350 cells, 17” height

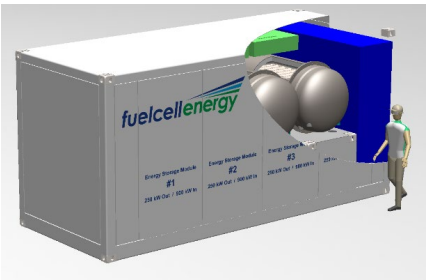


**Power Generation Stack Module – Only runs in power generation mode on a wide range of fuels, including natural gas, biofuels, propane, and hydrogen**

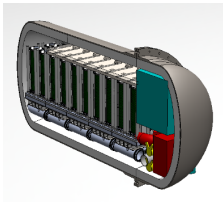
***200kW Power Generation System***



**Electrolysis Stack Module – Produces hydrogen from steam with power input**



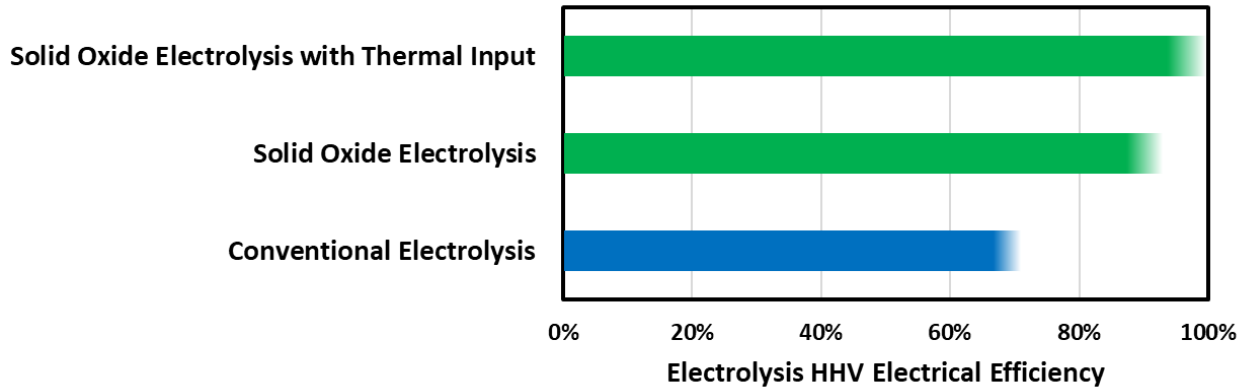

***Electrolysis***
***4,000 kg/day H2 from 7.3 MW***



**Energy Storage Stack Module – Alternates between power generation on hydrogen fuel and electrolysis producing hydrogen from water**


***Energy Storage System***
***1MW 8 MWh***

# Electrolysis Demonstration in Danbury

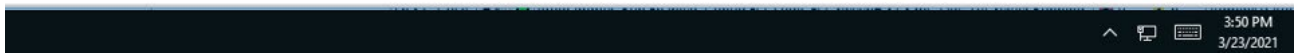



**Efficiency Projection**

| System Performance Parameter | Value |
|---|---|
| Stack Electrical Efficiency (HHV) | 112.9 % |
| System Electrical Efficiency (HHV) | 101.8 % |
| System Total Efficiency (HHV) | 90.7 % |
| Electricity Consumption | 38.7 kWh/kg |
| Thermal Consumption, Simulated | 4.7 kWh/kg |
| Total Energy Consumption | 43.4 kWh/kg |

More Information...

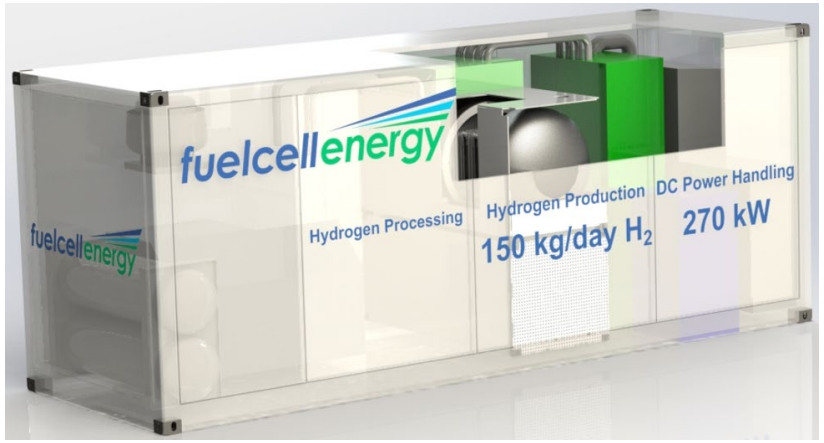
**Actual Performance**

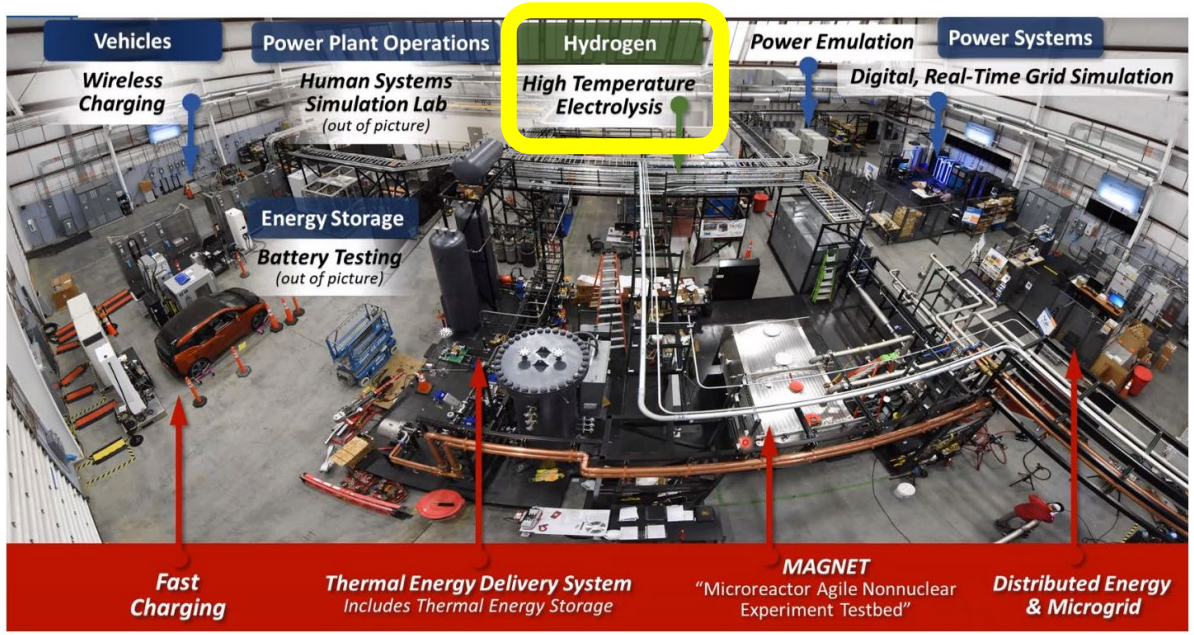



- ***Demonstrating target output and efficiency performance***
- ***Will be converted to energy storage system later this year to develop storage control and system technology ahead of first storage prototype systems***
- ***This demonstration of the technology has developed and optimized control approaches and process improvements which will be used in the 250kW INL Demonstration***

# 250kW Demonstration System

- 150 kg/day Hydrogen production from 270kW (or 250kW with thermal input)
- Demonstration of high efficiency prototype system at Idaho National Laboratory (INL) at nuclear plant operating modes, including thermal energy support for ultra high efficiency electrolysis
- Will demonstrate high efficiency without thermal input, and up to 100% efficiency with thermal input



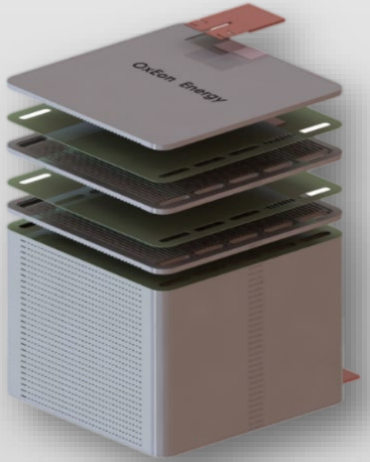




**Idaho National Laboratory Test Facility**

***Packaged prototype of module repeated in larger systems***

# OxEon Energy, LLC

## $H_2$ Shot Summit – Electrolysis Panel Discussions




**J. Hartvigsen**

**August 31, 2021**

**OxEon Energy, LLC**
**North Salt Lake, UT**

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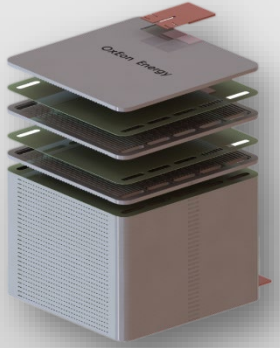
# OxEon Energy, LLC

OxEon energy
Beyond Current Potential

## Utah R&D/Mfg Facility – Founded 2017 after successful 30-year collaboration of founders with their previous affiliation

- New 24,000 ft$^2$ office, laboratory, and manufacturing facility
- NASA, DOE, DOD and Commercial Funding
- Tape casting, cell and stack production, and testing
- End-to-end power to synfuels pilot plant in operation

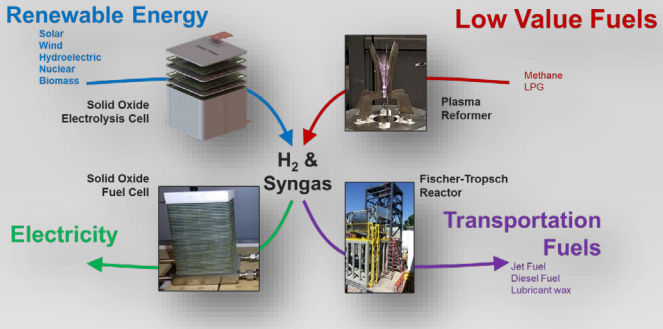



## Solid Oxide Fuel Cell and Electrolysis Stacks

- Longest running solid oxide fuel cell & electrolysis group in world
- Only flight qualified, TRL 9 SOEC unit in history
- 30kW/10kW reversible system test program in process

## Fuel Reformation and Generation

- Plasma Reformer – $H_2$ and Syngas for flare curtailment
- Fischer-Tropsch Reactors – Modular design for transportation fuel production from $H_2$ and Syngas



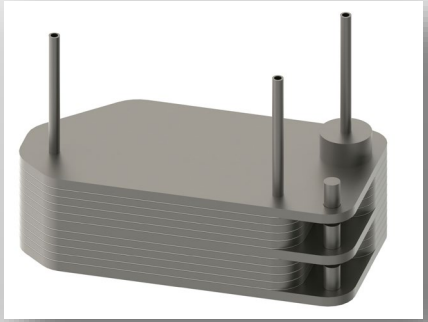
# Solid Oxide Fueled Space Exploration

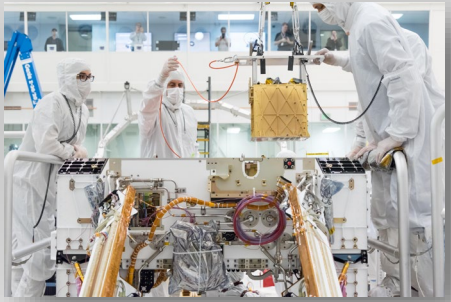

**NASA funded flight program**

- Only flight qualified SOEC in history
- Only TRL9 SOEC device in history
- First production of oxygen from the Mars Atmosphere

**MOXIE SOXE TEAM:**

- **MIT:** Program Prime and Science Team Lead
- **JPL:** Systems integration
- **OxEon:** Stack development and production
  - **TRL 3 to 6 in 18 months!!**
  - Hermetically sealed, ruggedized stack capable of withstanding launch, entry, descent and landing





**Active OxEon Projects with NASA for Next Generation**

- **Mars:** Liquid Hydrocarbon Fuels from Methane and $CO_2$
- **Lunar:** Liquid Propellants for $LH_2$/LOx-Fueled Cislunar Transport
- **SBIR**: Cathode Development for Redox Tolerance

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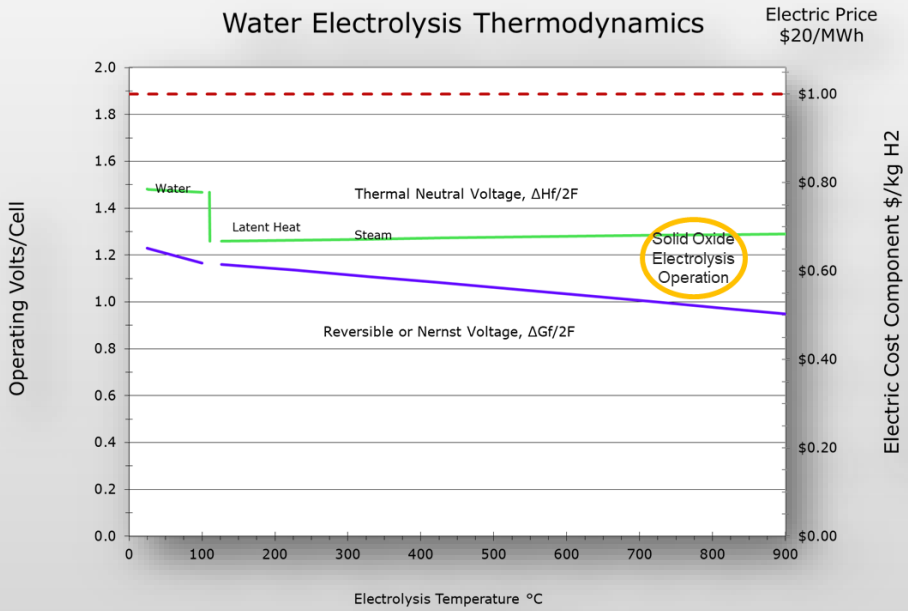
# Why Solid Oxide Electrolysis?




- Solid Oxide nominal operating point 1.28V
  - LHV Thermal Neutral Voltage (100% stack efficiency)
- Synthesis process integration to raise steam
  - Low temperature heat (~200°C) saves 0.2V or $0.10/kg
  - 50% more hydrogen per MWh at 1.28V vs 1.91V

- Electrochemistry Deployment
  - Onboard, on demand
    - Fuel cells & batteries
    - Low capital utilization factor
    - New distribution & fueling infrastructure
  - Stationary, storable & dispatchable
    - Electrolysis: $H_2$ to synfuels
    - High capital utilization factor
    - Use of existing infrastructure & fleet
    - Industrial, Residential & Commercial
      - SNG, Hythane, Hydrogen

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# Approach to 1:1:1 Success

$0.32/kg $H_2$ remaining in current operation for CapEx – **BREAKTHROUGH OPPORTUNITY**

- **Technical Focus:**
  - **Performance:** Power density improvements for CAPEX reduction. Lifetime enhancement.
  - **Design and BOP**: Number of stacks required to displace fossil a driver for footprint and power density
- **Grant/Loan Funding**
  - **Stack Manufacturing**: Production capacity & costs
  - **Demonstrations at scale** to drive manufacturing and create industrial acceptance establishing supply chain
- **Policy:**
  - Incentives to level competitive markets with last century incumbents (fossil resources)

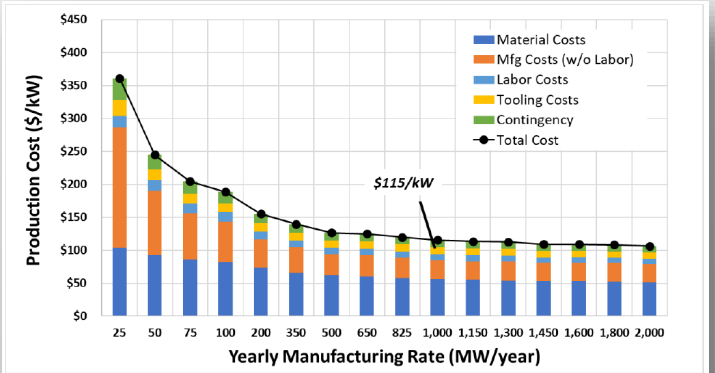


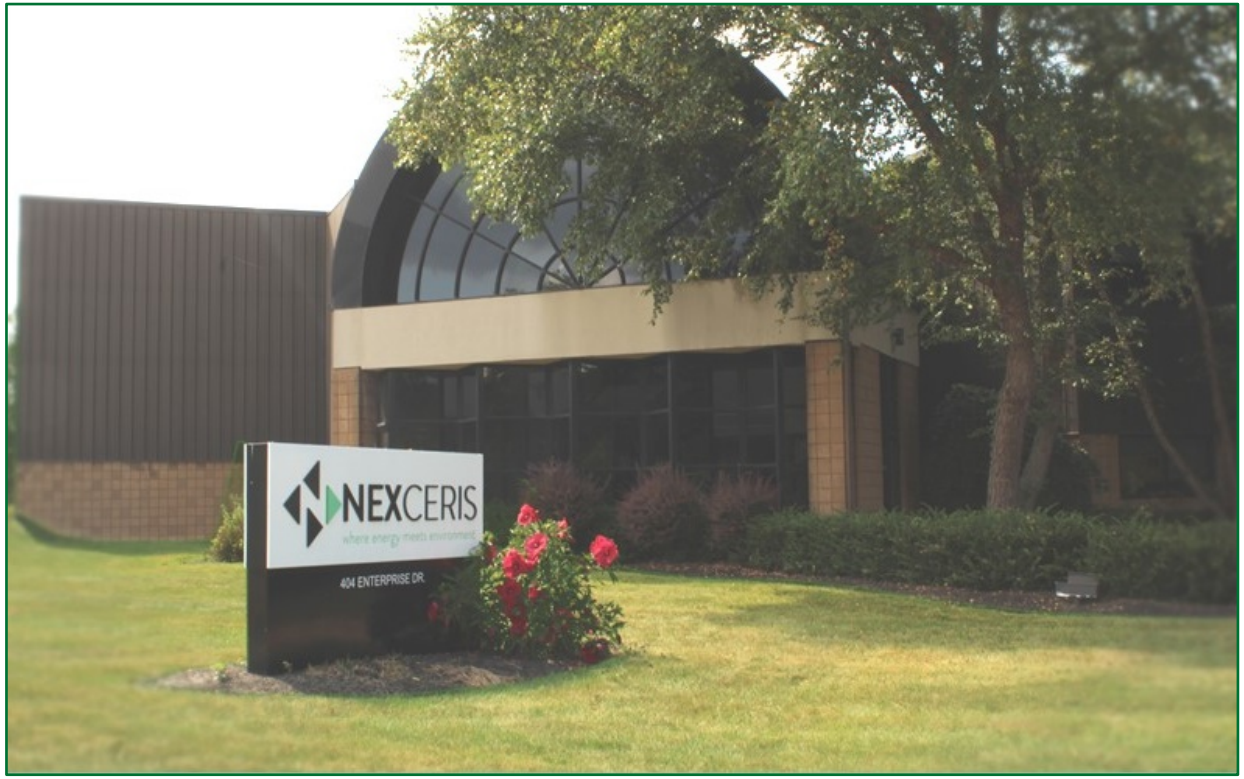

**Figure 1.** Total manufacturing cost of solid oxide electrolysis stack using **electrolyte-supported cells**. The text box highlights the estimated cost at the 1,000 MW/year manufacturing rate. See

Source: SOEC Stack Mfg Cost Analysis, Strategic Analysis, Apr21

# About Nexceris

## Nexceris, LLC

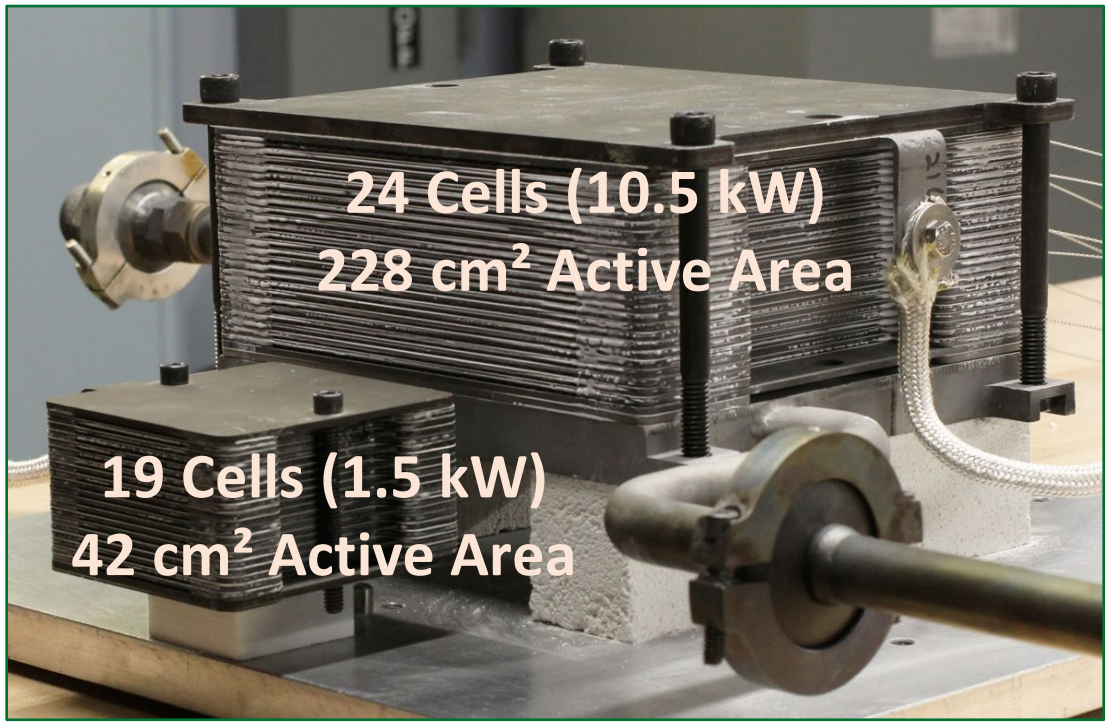
- Founded in 1994, privately held, located in Lewis Center, Ohio.
- 25+ years of experience in the solid oxide fuel cell and electrolysis space.
- Vertically integrated manufacturer of solid oxide materials, cells, coatings and stacks.

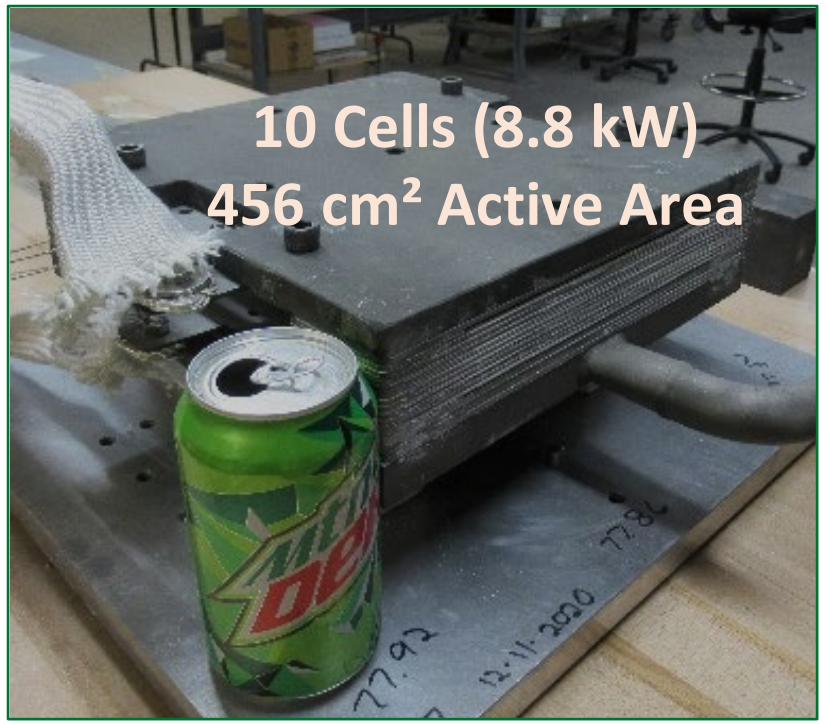



**Proven solid oxide technology provider and stack manufacturer with state-of-the-art high temperature electrolysis capability.**

NEXCERIS
where energy meets environment

# HTE Stack Platforms




**Stack power levels based on DOE 2030 target (1.28 V/cell @ -1.5A/cm²).**
**This corresponds to 40-50 kW for full-scale (456-cm²) stack (50-60 cells).**

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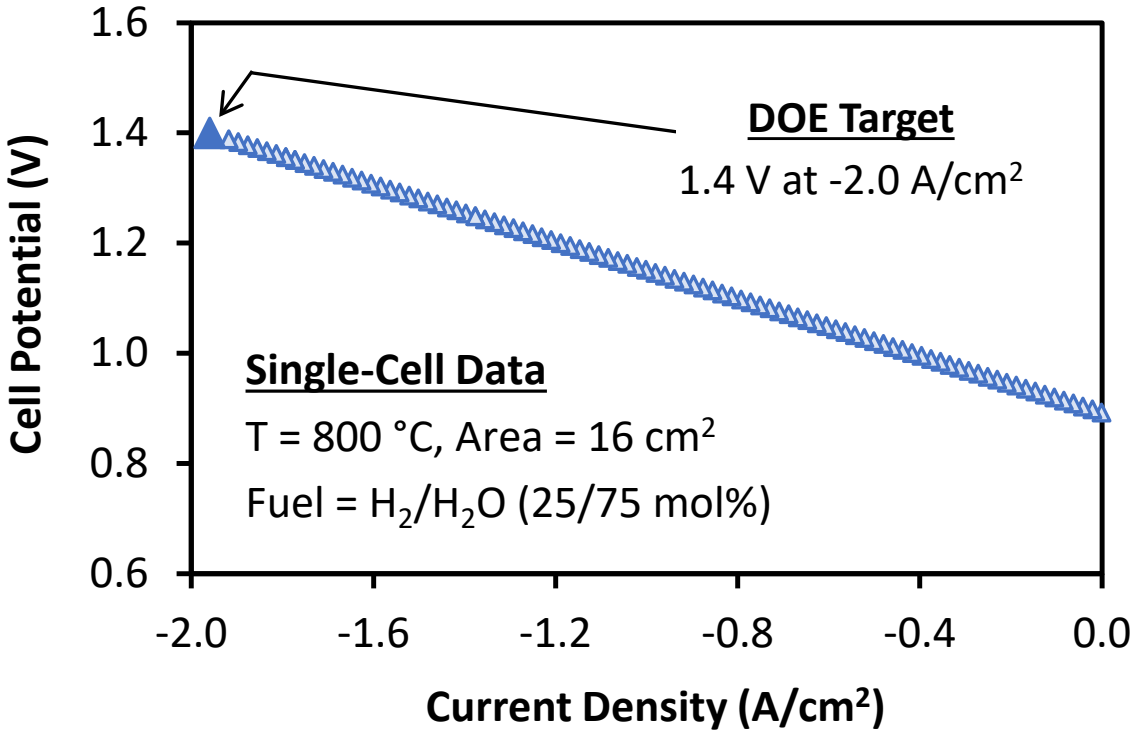
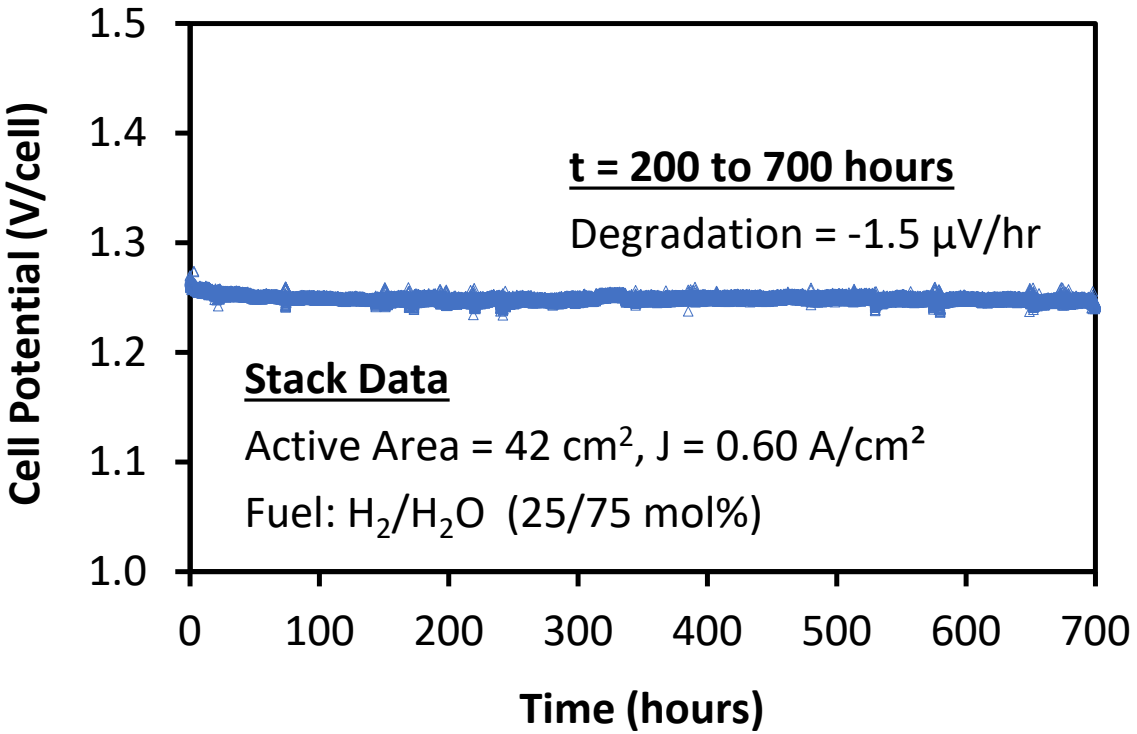
# HTE Cell and Stack Testing




**New HTE electrode materials enable state-of-the-art performance and stability!**

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# Status and Path Forward

## Current Nexceris Activities

- Validation of large-area HTE stack with pressurization capability.
- Implementation of high-performance electrodes and coating technologies in HTE stacks.
- Long-term stack durability testing
- Third-part evaluations of HTE stacks (at INL and other partner sites).

## What's Next

- Development and implementation of HTE stack manufacturing technology.
- Long-term stack durability testing
- Pilot-scale HTE stack manufacturing.
- System level demonstrations at progressively larger scales.
- Scale up and full-scale HTE stack manufacturing.

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