High Temperature Electrolysis for Efficient Hydrogen Production from Nuclear Energy – INL Research Program Summary

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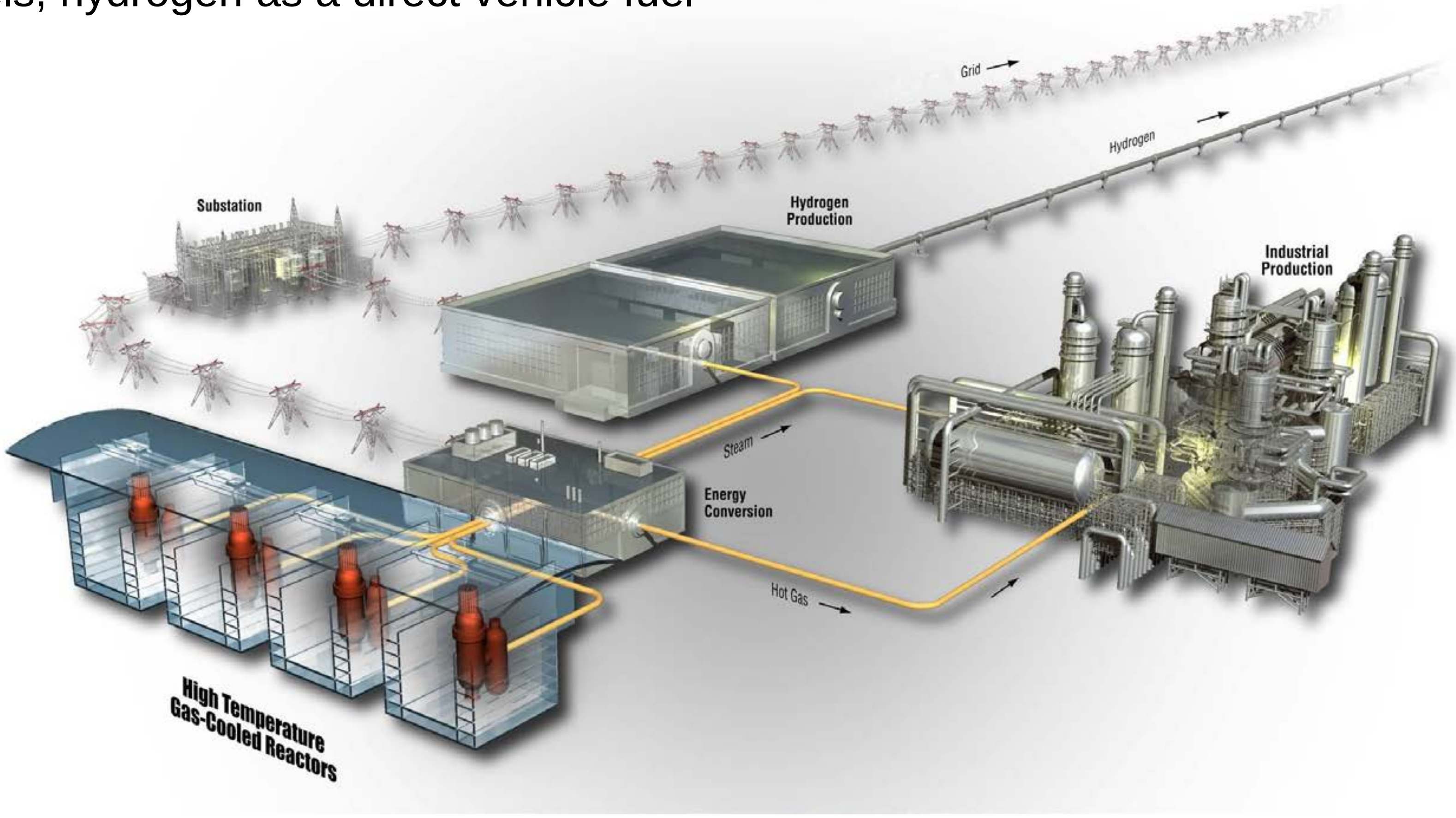
NGNP/VHTR Concept for Large-Scale Centralized Nuclear Hydrogen Production based on High-Temperature Steam Electrolysis

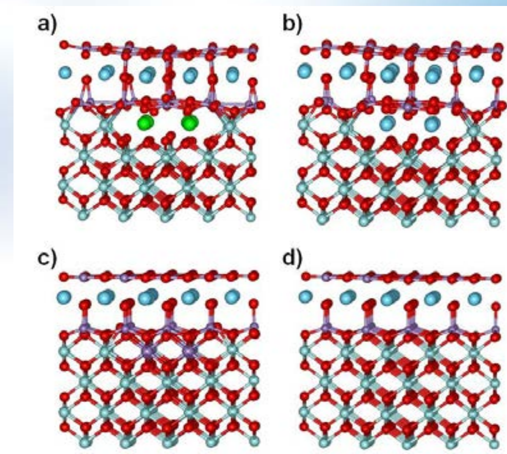
- Directly coupled to high-temperature gas-cooled reactor for electrical power and process heat
- 600 MWth reactor could produce ~85 million SCFD (2.5 kg/s) hydrogen (similar to a large steam methane reforming plant) and 42 million SCFD oxygen
- Potential applications include petroleum refining, ammonia production, synthetic liquid fuels, hydrogen as a direct vehicle fuel



The INL High Temperature Electrolysis Project History and Background

- INL served as the lead laboratory for High-Temperature Electrolysis (HTE) research and development from 2003 – 2009, under the DOE Nuclear Hydrogen Initiative (NHI)
- During FY09, HTE was selected by DOE as the primary nuclear hydrogen production technology for continued development toward early deployment (based on the recommendation of an external independent review team)
- HTE activities were funded under the Next Generation Nuclear Plant (NGNP) Program from FY10 - FY12
- Industry Collaborators:
  - Ceramatec (co-authored initial NERI proposal with INL)
  - MSRI
  - Versa Power

INL HTE Research Scope



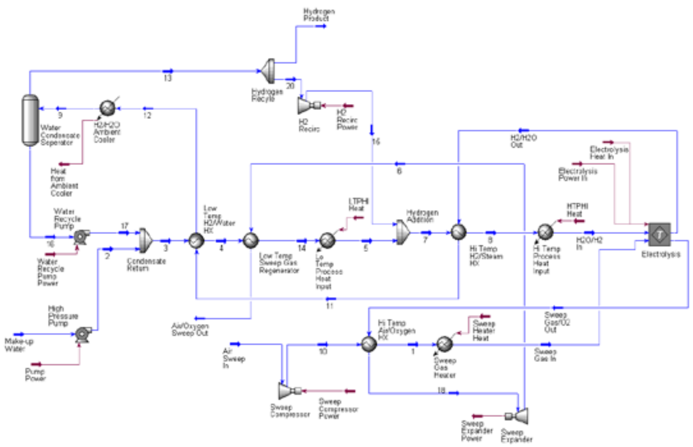
Fundamentals

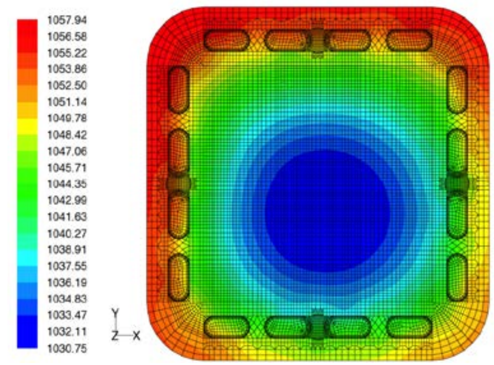
Small-Scale Experiments

CFD Simulation

System Modeling

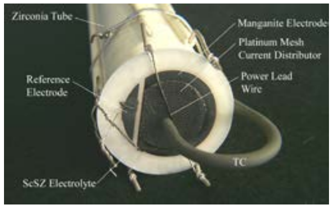
Technology Demonstration

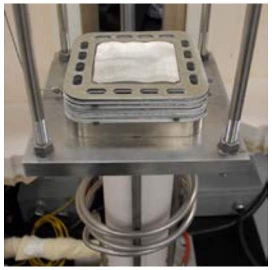


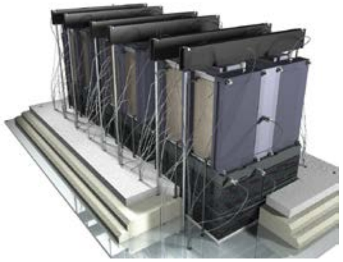


Scale of INL HTSE Test Activities

Test configuration	Electrolysis Power at Design Condition (1.2 V, 0.5 A/cm^2)
Button cell (2.5 cm^2)	1.5 W
Single cell (16 cm^2)	9.6 W
Small stack (100 cm^2,10 cells)	600 W
Large Stack (100 cm^2, 50 cells)	3 kW
Multiple-stack module (4 large stacks)	12 kW





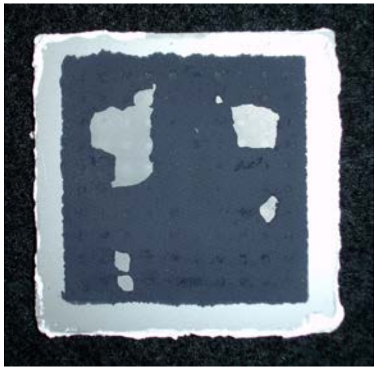


Technical Challenge: SOEC Performance Degradation

Degradation is more severe in the electrolysis mode compared to the fuel cell mode

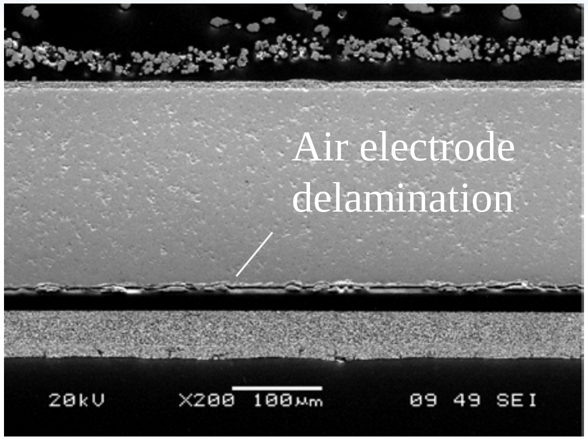
Possible degradation mechanisms include:

- chromium migration
- corrosion of metallic components
- morphology change (coarsening) in electrochemically active layers
- electrode delamination…

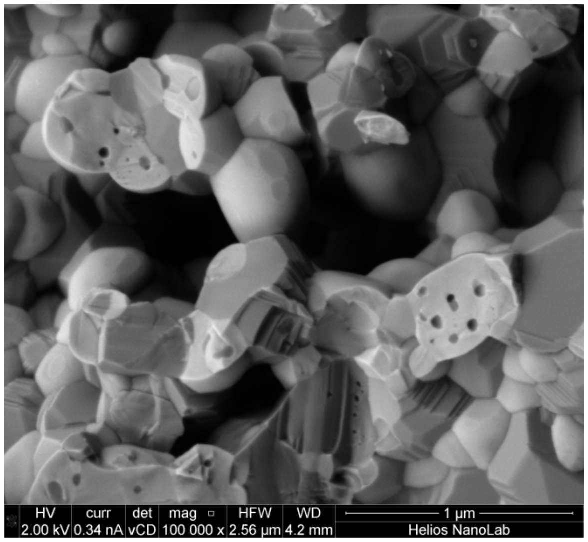


Delamination of air electrode, single cell tested at INL

Status: Working with industry, significant progress was made over the duration of the INL HTE program in reducing degradation rates from ~50%/khr to <2%/khr



Initial H_2 electrode microstructure



Suggestions for Additional Research

(Current technology readiness level is ~TRL5)

- Continued support of basic research into cell and stack materials and fabrication techniques for improved initial and long-term performance
- Associated small-scale testing
- Pilot-scale demonstration

HTSE Hydrogen Production Cost Estimates

$/kg H2 (baseline case)	Electrolyzer Capital cost basis	Reactor Thermal Power (MW)	Reactor Tout/power cycle	electricity cost ($/MWh)	H2 Production rate (kg/day)	installed cost (Lang) factor	IRR (%)	H2A?	Organization	Year
Nuclear/Large-Scale										
$3.67	SECA (2007)/2; $100/kW	600	750/Rankine	n/a	151200	4.74	12	N	INL	2010
$3.03	SECA (2007)/2; $100/kW	600 MW	750/Rankine	n/a	159840	4.74	10	N	INL	2010
$3.85	SECA (2007)/2; $100/kW	600	750/Rankine	n/a	170400	4.74	15	N	INL	2010
$3.23	$200/kW	600	900/Direct He Brayton	n/a	203558	4.74	10%	Y	INL	2008
$2.56	$30/kW	600 MW	n/a	$60/MWh	159840	range: 1 - 4.2	?	N	Dominion Engineering	2012
1.87 – 1.93 €	$170/kW	range	range	40 €/MWh	129600	?	6%	N	MINES/CEA	2010
Distributed										
$3.12	SECA(2012)/2; $50/kW	n/a - distributed production	n/a - distributed production	$55.40	1500	4.1 for most components	10%	Y	INL	2012
$2.68	SECA(2012)/2; $50/kW	n/a - distributed production	n/a - distributed production	$55.40	50,000	4.1 for most components	10%	Y	INL	2012

Thank you!