Hybrid Electrical/Thermal Hydrogen Production Process Integrated with a Molten Salt Reactor Nuclear Power Plant

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Project ID: H2026

PROJECT OVERVIEW

TIMELINE:
Start: July 1, 2018
End: Sept. 30, 2020

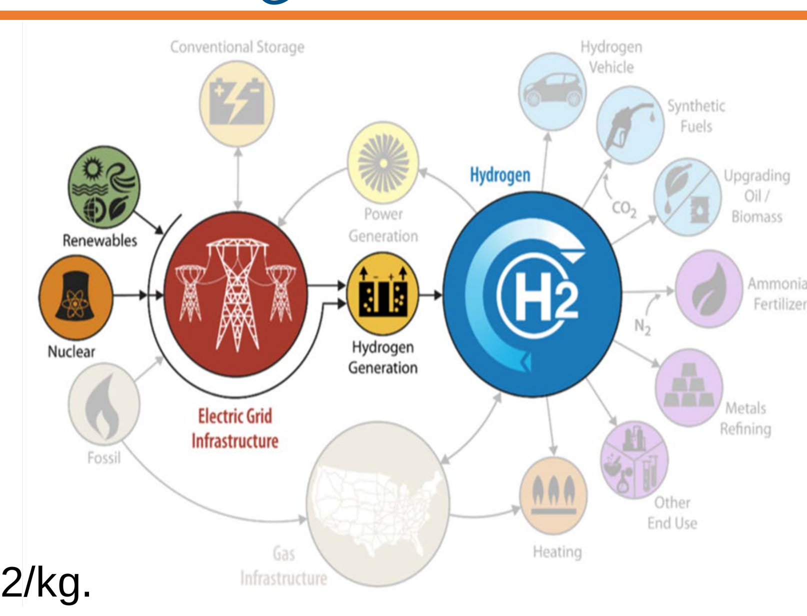
TOTAL CENTER FUNDING:
DOE Share: $600K
Cost Share: $823K
DOE Share Expended: $510K

BARRIERS:
A. Hydrogen Levelized Cost
B. System Energy Efficiency
C. Total Capital Investment

PARTNERS:
SRNL, Sandia National Laboratories, Southern Company

RELEVANCE TO H2@SCALE

- The Hybrid Sulfur (HyS) Hydrogen Generation process has the potential to produce hydrogen gas using both thermal and electrical energy at a cost of <$2/kg.
- HyS can utilize thermal energy from a molten salt reactor (MSR) along with renewable electrical energy from either wind or solar generation to efficiently produce hydrogen.
- The HyS process, being a two step process, can act as a buffer and store thermal energy chemically as liquid SO_2, to be used to generate hydrogen as required to minimize generation and storage costs.



APPROACH

THIS PROGRAM WILL:

- **System Analysis**
  - Develop a plausible path to hydrogen production cost less than $2/kgH$_2$ based on the process design and cost estimation.
  - Develop a conceptual plant design for MSR-HyS
  - Develop a techno-economic analysis of H_2 production via MSR-HyS
- **MEA Development**
  - Develop an SDAPP membrane composition showing better ion conductivity than Nafion®112 in 6 M sulfuric acid.
  - Develop electro-catalyst that show a 20mV performance improvement over Pt/C in 3.5M sulfuric acid solution containing dissolved sulfur dioxide or sodium sulfite
  - Demonstrate performance of at least 100mV lower cell voltage than Nafion® of an MEA using higher temperature membranes and improved catalysts.

HyS CHEMISTRY

- Hybrid Sulfur (HyS) is a two-step thermo-chemical cycle based on sulfur oxidation/reduction
- Key Reaction Step is electro-chemical water splitting using an SO_2 depolarized electrolyzer (SDE).
- All fluid processing minimizes entropic losses due to phase changes
- HyS is "hybrid" cycle requiring both electrical and thermal energy input
- Optimization of the system requires trade-offs between the various components

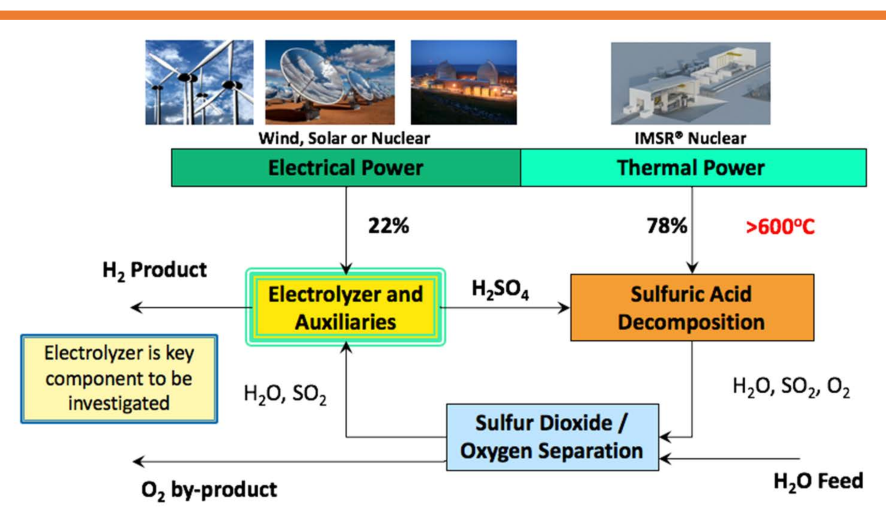
HyS Process

$H_2SO_4 \rightarrow H_2O + SO_2 + {}^1/_2 O_2$	Thermochemical: 600-900°C
$SO_2 + 2 H_2O \leftrightarrow H_2SO_4 + H_2$	Electrochemical: 0.17 v_{th} @ 80-140°C
$H_2O \rightarrow H_2 + {}^1/_2 O_2$	Net Reaction

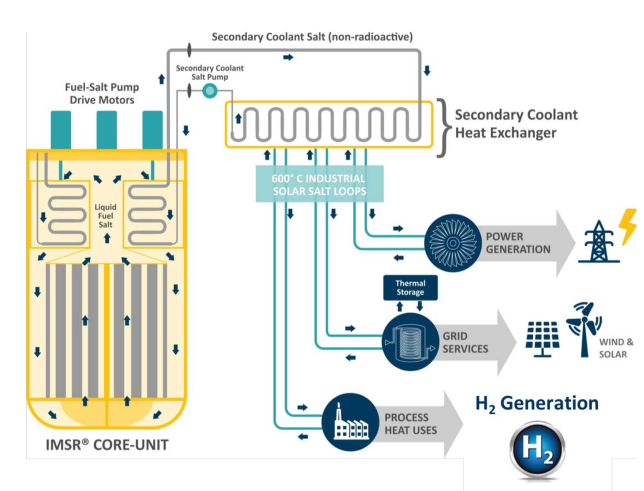
vs. Low Temperature Electrochemical

$H_2O \rightarrow H_2 + {}^1/_2 O_2$ Electrochemical: 1.23 v_{th}

INTEGRATION WITH MOLTON SALT REACTOR



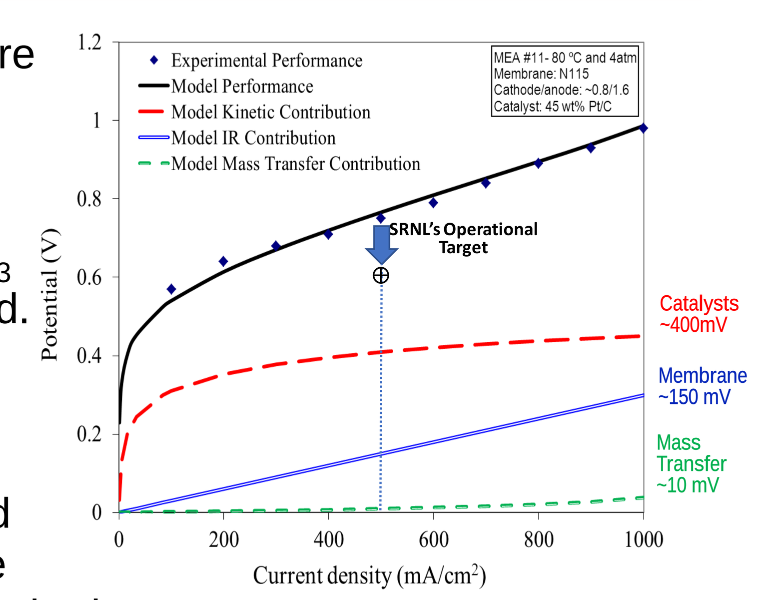
Hydrogen Generation by the Hybrid Sulfur Process



Integration of Hydrogen Generation with an Integral Salt Reactor IMSR®

MEMBRANE ELECTRODE ASSEMBLY (MEA)

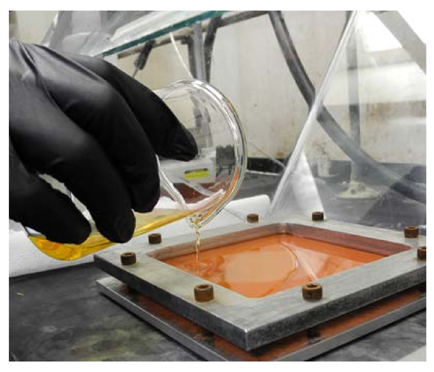
- New high temperature membranes having minimal SO_2 permeability and durability in SO_2/SO_3 environment required.
- New catalysts and supports resulting in 600mV potential at 500mA/cm2 required
- Membrane electrode Assembly (MEA) required having >10% degradation in potential after 700 hrs. operation.

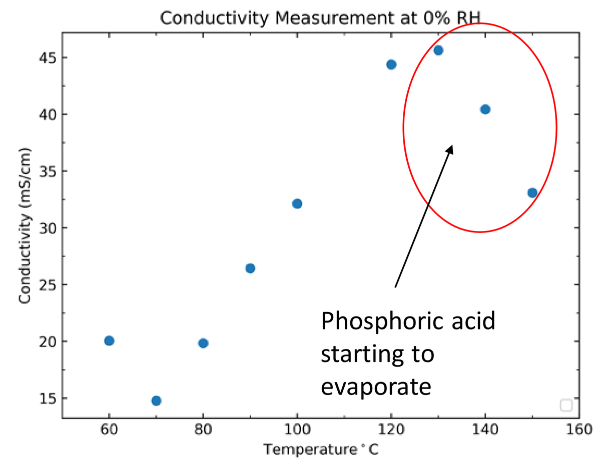


Kinetics (catalyst)	Cell resistance (membrane)
↑ Operating temperature	↑ Operating temperature
↑ Intrinsic higher activity	↑ ionic conductivity

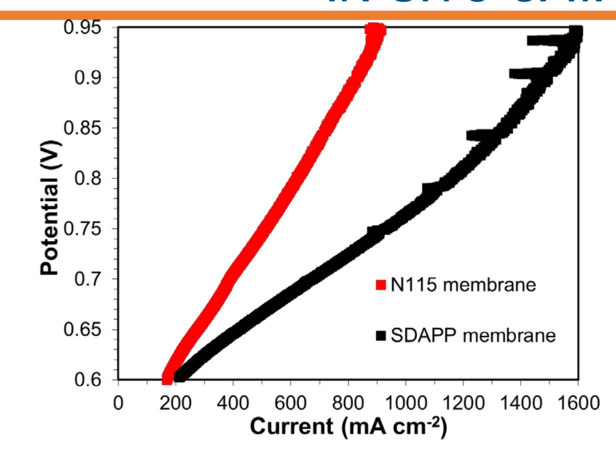
MEMBRANE DEVELOPMENT

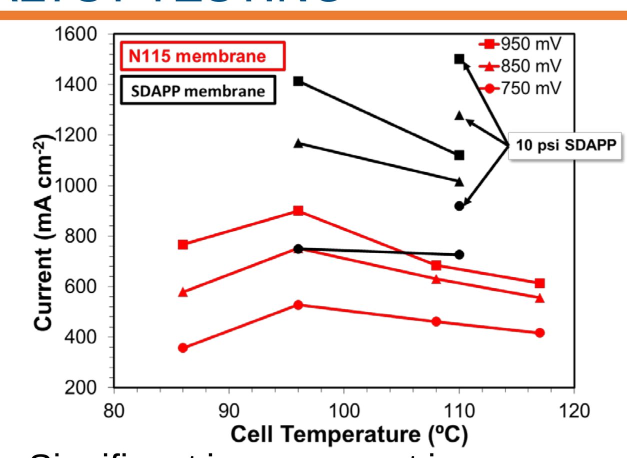
- Improve ionic conductivity and stability at high acid concentrations and temperatures
- Prevent sulfur formation at the cathode
  - Limit or eliminate formation H_2S and SO_2 reactants*
- Utilize membranes with low SO_2 permeability
- Developed SDAPP membranes with alternate acid concentrations to optimize MEA performance

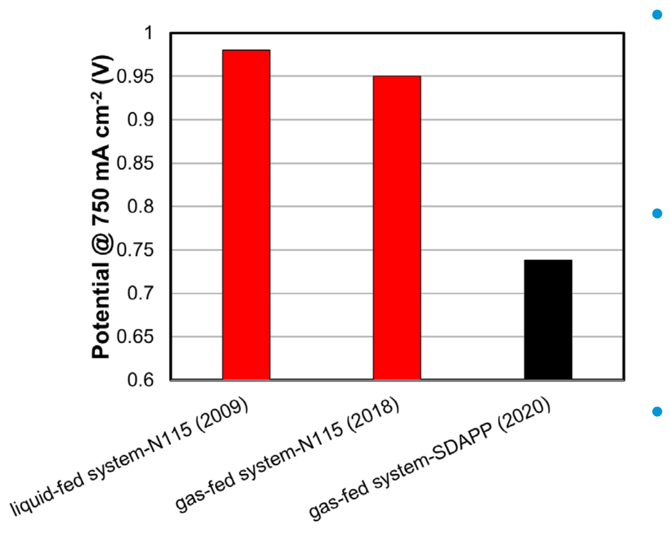




IN-SITU CATALYST TESTING

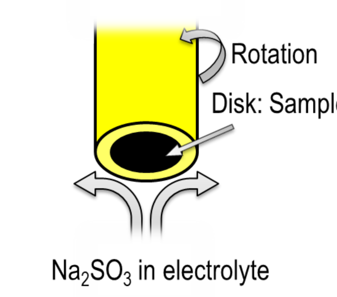




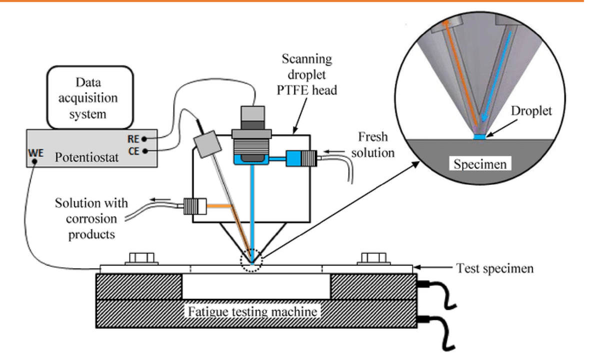


- Significant improvement in electrolyzer performance is observed with the use of SDAPP membrane vs state-of-the-art Nafion® membrane
- SDAPP based MEA operated with 10 psig shows ~1.5 x increased current under same operation potential vs Nafion®
- A drop in operation potential of more than 200 mV can be observed vs previous electrolyzer runs

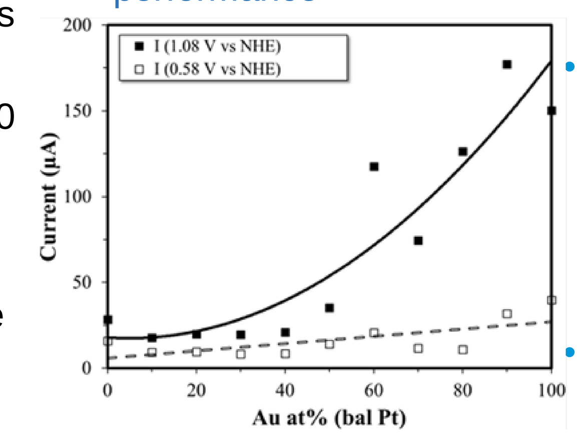
EX-SITU CATALYST TESTING



Rotating disk electrode with Na_2SO_3 dissolved in sulfuric acid was used to evaluate the catalyst performance



Scanning droplet system (SDS) probe for irreversible redox reactions



- Cyclic voltammetry studies on SDS show trends in activity:
  - Au>>Pt at high potential (kinetic region)
  - Au>~ Pt at low potential (activation region)
- Consistent with linear sweep voltammetry results

TECHNOECONOMIC ANALYSIS

- Given projected performance of IMSR® and HyS process, production cost estimated to be 2.55 $/kg H_2.
  - 650°C upper limit major hurdle
  - Path to 1.93/kg H_2 identified
    - Requires 25% reduction in heat, power cost
- Conceptual plant design based on s-PBI MEA SDE
  - Being updated for SDAPP MEA
    - Wet cathode for SDAPP MEA alters flowsheet, energy balance
- TEA for H_2 production via MSR-HyS
  - Previous TEA being updated for SDAPP MEA
  - More flexible SDE performance targets

PROPOSED FUTURE WORK

- Evaluate electrolyzer performance at process relevant conditions
- Evaluate electrolyzer performance under pressure
- Incorporate Au based catalyst into catalyst layer
- Explore ternary alloys of PtAuM (M = transition metal) via combinatorial sputter deposition
  - e.g. V used industrially in H_2SO_4 production
- Identify combinations of cell potential, current density, and acid concentration that will achieve specific production cost targets

SUMMARY

The HyS process could add value to nuclear generation and serve as an energy storage mechanism for concentrating solar

- Thermal energy can be used most effectively through hybrid thermo-chemical/electro-chemical process.
- HyS process utilizes 78% thermal energy and 22% electrical energy with ability to store SO_2 or H_2SO_4 indefinitely as required.

Electro-chemical step key to efficient SO_2 oxidation

- Potential high temperature membrane with minimal SO_2 permeation identified as SPP which needs to be optimized for SO_2/SO_3 environment.
- Potential $Pt_xAu_yV_z$ alloy catalyst identified to greatly reduce required cell potential and needs further investigation.