Merchant Hydrogen at Scale: A Technical-Economic Case Study of the Potential for Nuclear Hydrogen

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Overview

Timeline and Budget

- Project Start Date: 09/01/2018
- Project End Date: 09/30/2019
- Total Project Budget: $1,575,000
  - Total Recipient Share: $650,000
  - Total Federal Share: $925,000
  - Total DOE Funds Spent*: TOTAL
    - NE - $137K
    - ANL - $90K
    - NREL- $150K
    - SNL- $23K

Barriers

- Barriers addressed
  - Hybrid operation of nuclear power plants
  - Thermal energy integration with high temperature electrolysis
  - Commercial manufacturing pathway for electrolysis modules

CRADA Partners

- Exelon Corporation
- FuelCell Energy
- Idaho National Laboratory
- National Renewable Energy Laboratory
- Argonne National Laboratory
- Sandia National Laboratory

DOE Sponsors

- DOE-EERE Fuel Cell Technology Office
- DOE-NE Crosscutting Technologies Development, Integrated Energy Systems Program
Nuclear Energy is the only contributor to global clean energy supply that is a carbon-free, scalable energy source that's available 24 hours a day.

Increases in variable wind and solar energy and low-cost natural gas impact baseload nuclear power generation stations; a new operating paradigm is needed for these plants to maintain profitability.

Hydrogen production with nuclear energy may increase plant revenue.

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**The problem**

Could this be the solution?

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**Relevance**

This project aims to evaluate the technical and economic potential for expanding the markets for existing nuclear reactors. This evaluation provides a basis for converting baseload nuclear plants into hybrid plants that produce hydrogen, resulting in commercial investments and industry growth in the United States.
1. Assess hydrogen market in region of **Exelon Nuclear Reactor**

2. Evaluate technical and economic feasibility of integrated nuclear-renewable-hydrogen plant operation

3. Complete preliminary engineering design of thermal and electrical energy integration with **FuelCell Energy’s High Temperature, Steam Electrolysis (SOEC)**

4. Evaluate logistics of dynamic hydrogen production, storage, delivery, and use by industry (e.g., steel manufacturing)

5. Complete investor-grade study with preliminary design

6. Issue DOE project report

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**Approach**

- **Month 1**: Go/No-Go based on Hydrogen Market Evaluation
- **Month 1**: Go/No-Go decision based on Scenario Analysis

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**SCS-Exelon Utility CRADA: Evaluation of Hydrogen Market Potential**

**Exelon and FCE H2@Scale CRADA: Project Planning, Grid Dynamics and Electricity Price Profile Projections; Analysis Tool Development**

**Scenario Analysis Using RAVEN**

**Preliminary Eng. Design & Investment Report**
Roles & Responsibilities

- **NREL/Exelon** - Provide grid pricing (LMP); cost of energy projections
- **ANL** - Determine local hydrogen markets, hydrogen storage & delivery systems & costs
- **INL/Exelon/FuelCell Energy** - Thermal/electrical integration, electrolysis plant design process modeling, economic pro forma calculations
- **SNL/Exelon** - Hydrogen storage, plant safety codes and standards
Accomplishments

- Preliminary Market Assessment Completed
  - Specific nuclear plant site selected
  - Electricity market assessment
  - Thermal integration study completed by Exelon
  - Generic high temperature electrolysis plant developed
  - H2A modeling completed
  - Aspen™ Process Modeling of initial SOEC System
  - Local hydrogen markets identified
  - High Temperature Electrolysis (SOEC) Plant Design Layout and LWR interfaces completed by FuelCell Energy

- Project Progress Meeting January 30, 2019
- Go/No-Go Decision (passed!)
- Project on schedule and budget
Accomplishments

- Hydrogen demand assessment 90% complete
- Hydrogen, production, storage and delivery cost analysis completed using H2A

![Graph showing Annual Hydrogen Demand]

Leverages FCTO Analysis by ANL

“The Technical and Economic Potential of H2@Scale within the United States”
Analysis Approach: Projecting LMPs

- Establish fleet buildout using ReEDS capacity expansion model
- Translate each ReEDS buildout year into a PLEXOS production cost model database
- Run each PLEXOS model to obtain the resulting LMPs for our region of interest
- Transfer LMPs to INL for techno-economic analysis

Accomplishments

- NREL Coordinated with Exelon and Constellation to select key parameters
- Approach to project in the future Local Marginal Price established
Accomplishments

Initial Aspen™ modeling for generic high temperature electrolysis plant (SOEC)

Aspen Process Economic Analyzer (APEA)

- Cost estimating software that provide CAPEX estimates and OPEX estimates for comparing and screening multiple process schemes.
- Integrated with process simulators ASPEN HYSYS and Aspen Plus.
- Map the simulator unit operations to APEA, e.g.,

Heat Recuperation Improves efficiency
Accomplishments

- **H2A model prediction and sensitivity studies completed**

**LWR/HTE (SOEC)**
- 1191 MWe
- 755 tons/day \( \text{H}_2 \) (639 tons/day \( \text{H}_2 \) with an operating capacity efficiency of 84.7%)
- $403/kWe (DC power input)
- TCI of $434 M

**SMR**
- 639 tons/day \( \text{H}_2 \) with an OCF of 90%
- TCI of $292 M
Accomplishments

High Temperature Electrolysis Plant Design Layout

Nuclear Plant to SOEC H2 Plant System Architecture

- SOEC Rx Water – 240,000 kg/h
- Thermal Steam ∆100 MWe
- Δ100 MWe
- HX System
- H2 Separation
- Hydrogen 26,650 kg/h
- Heated Feedstock
- Nuclear Power Plant
- Power conditioning
- Electricity 1,000 MWe
- SOEC H2 Plant
Collaboration & Coordination

- CRADA Project involves 2 Industries, 4 National Labs
  - Subcontractors to Exelon: Constellation
  - DOE NE-EERE Partnership
  - DOE-EERE / Fuel Cell Technology Office
  - DOE-NE / Crosscutting Technologies Development, Integrated Energy Systems Program

- Bi-weekly project meetings; Regular offline meetings

- Intellectual property protection managed under CRADA

- Proprietary / Business Sensitive material managed

Exelon and FuelCell Energy are supportive of H2@Scale and DOE-NE activities
- Exelon and FCE participation: January NE-LWRS Stakeholder Engagement
- Exelon Presentation: February FCTO “Make” Webinar

Cooperation and confidentiality underscores this CRADA

The team is focused on the outcomes that will accelerate business success

Remaining Barriers & Challenges

- The project is set to engage industrial users of hydrogen
- Aspen™ modeling for the investor grade report is a significant undertaking
- INL RAVEN system optimization modeling is dependent on and requires timely completion of Phase 2 grid LMP projections
Proposed Future Work

- The project has entered Phase 2
- NREL grid modeling is underway with input from Exelon & Constellation
- INL Aspen™ Modeling has commenced with input from FCE

Analysis Approach: Projecting LMPs

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4. Transfer LMPs to INL for techno-economic analysis
Proposed Future Work

- RAVEN “system scale and operating optimization” will be completed in FY19-Q4 and FY20-Q1
- SNL will conduct safety assessment and provide guidance relative to siting a hydrogen plant near a nuclear plant
- Project team will begin discussion with hydrogen off-takers
- Investor report due to Exelon and FuelCell Energy FY19-Q4

**Example RAVEN Optimization of Nuclear, Wind, Natural Gas, Battery, Hydrogen Plant integrated system**
Summary

- This CRADA addresses new market opportunities for nuclear energy at a time when existing reactors are experiencing diminishing revenues.
- Preliminary results indicate a light-water reactor hybrid producing electricity and hydrogen can be profitable and may spur commercialization of H2@Scale.
- This work is an example of a successful DOE cross-cutting effort.

- **This project is on schedule and on budget**
- **CRADA partners are working well together**
- **Technology transfer includes model sharing with the industrial partners**
- **The investor-grade report will help to accelerate technology commercialization and capital investment in real projects**
- **The DOE goal of $2.00/kg H₂ appears to be possible with technology acceleration**
- **Clean hydrogen will be a game changer**

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Yes, LWR Hydrogen hybrids could this be the solution!