Project ID 2052

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

DOE Sponsors

- DOE-EERE Fuel Cell Technology Office
- DOE-NE Crosscutting Technologies Development, Integrated Energy Systems Program

Barriers

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

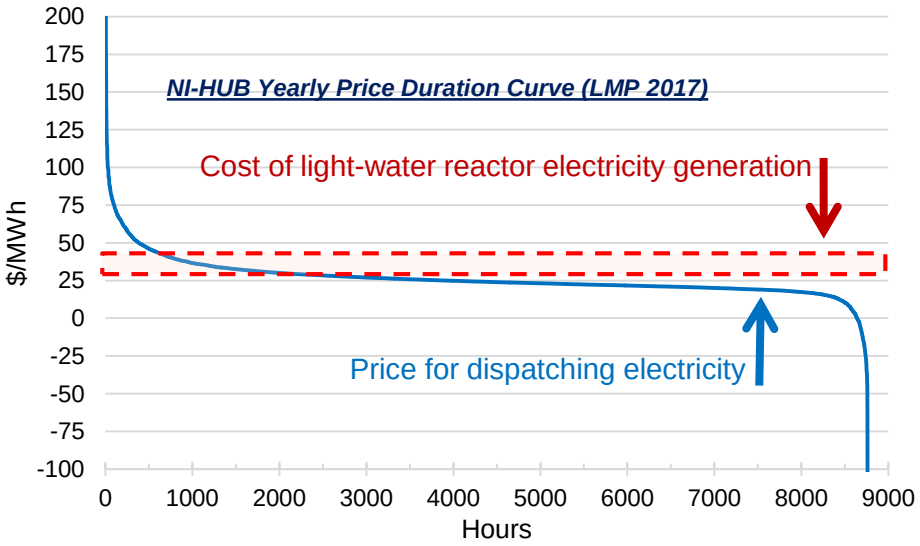
CRADA Partners

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

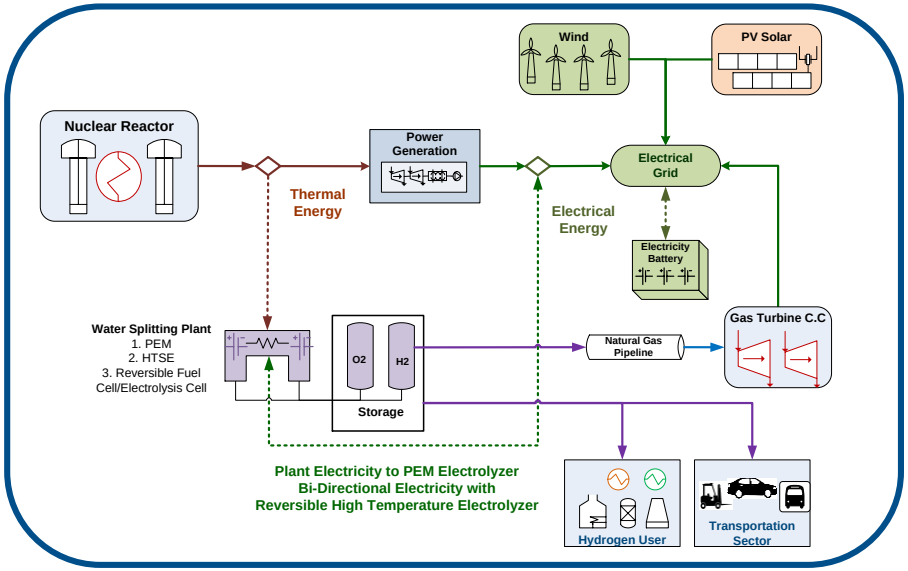
Relevance

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.

- *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*



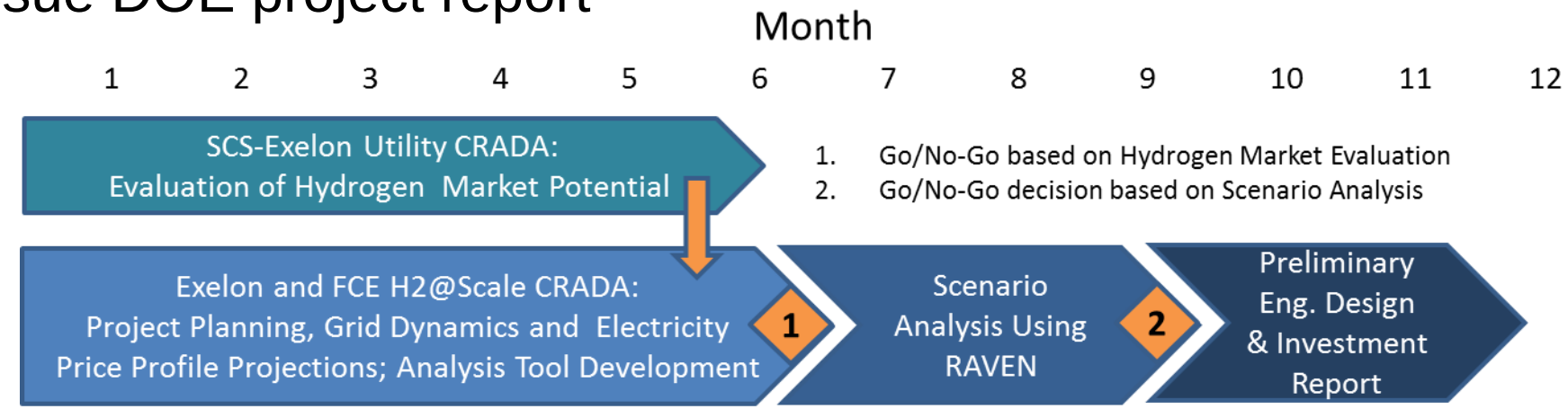
The problem



Could this be the solution?

Approach

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



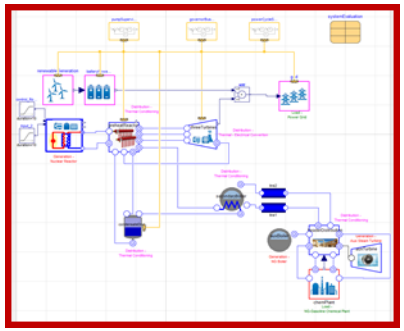
Approach

Resource Potential
- Market size
- Resource availability
- Resource attributes
- Infrastructures requirements

Technology Potential
- Thermodynamics
- Performance
- Systems integration and control

Economic Potential
- Pro forma
- ROI / IRR
- Cash Flow

Market Potential
- Competition
- Policy & Regs



FuelCell Energy Modular Reversible Fuel Cell / Electrolysis Cell, ***SureSource™ Energy Storage*** *Plant Layout*

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

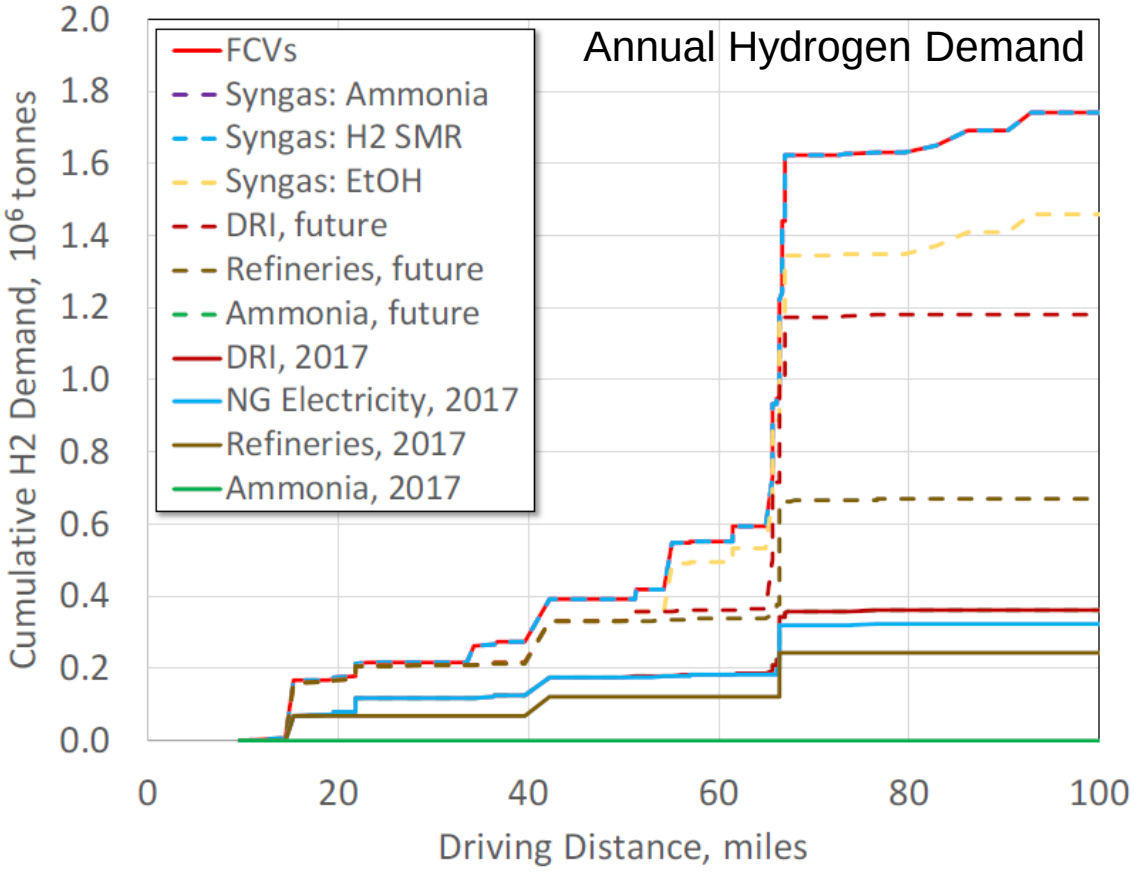
- *Preliminary Market Assessment Completed*
  - ✓ *Specific nuclear plant site selected*
  - ✓ *Electricity market assessment*
  - ✓ *Thermal integration study completed by Exelon*
  - ✓ *Generic high temperature electrolysis plant developed*
  - ✓ *H2A modeling completed*
  - ✓ *Aspen™ Process Modeling 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*

U.S. Light-Water Reactors

Accomplishments

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



Leverages FCTO Analysis by ANL

"The Technical and Economic Potential of H2@Scale within the United States"

Accomplishments

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

LOW NG + LOW RE PRICES –

80 YEAR NUCLEAR LIFETIME –

LOW DEMAND GROWTH –

ALL OTHER INPUTS USE THE MID-CASE VALUES

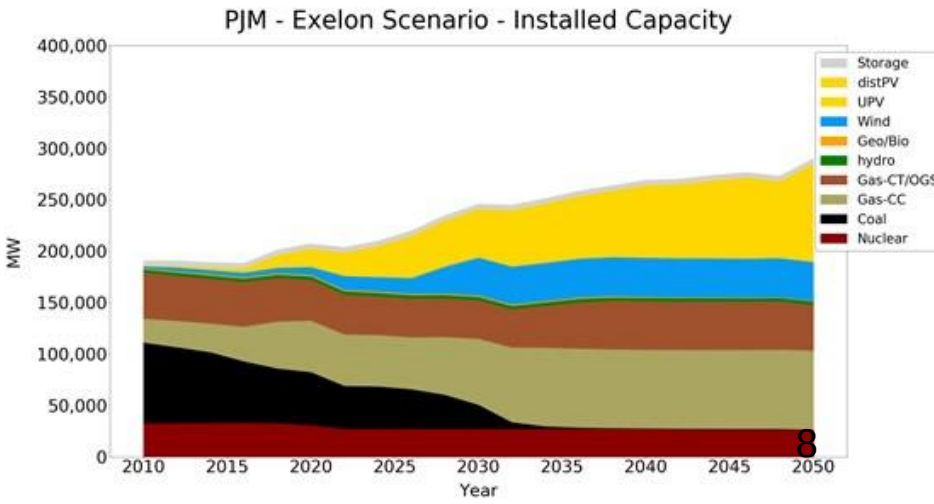
Analysis Approach: Projecting LMPs

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**

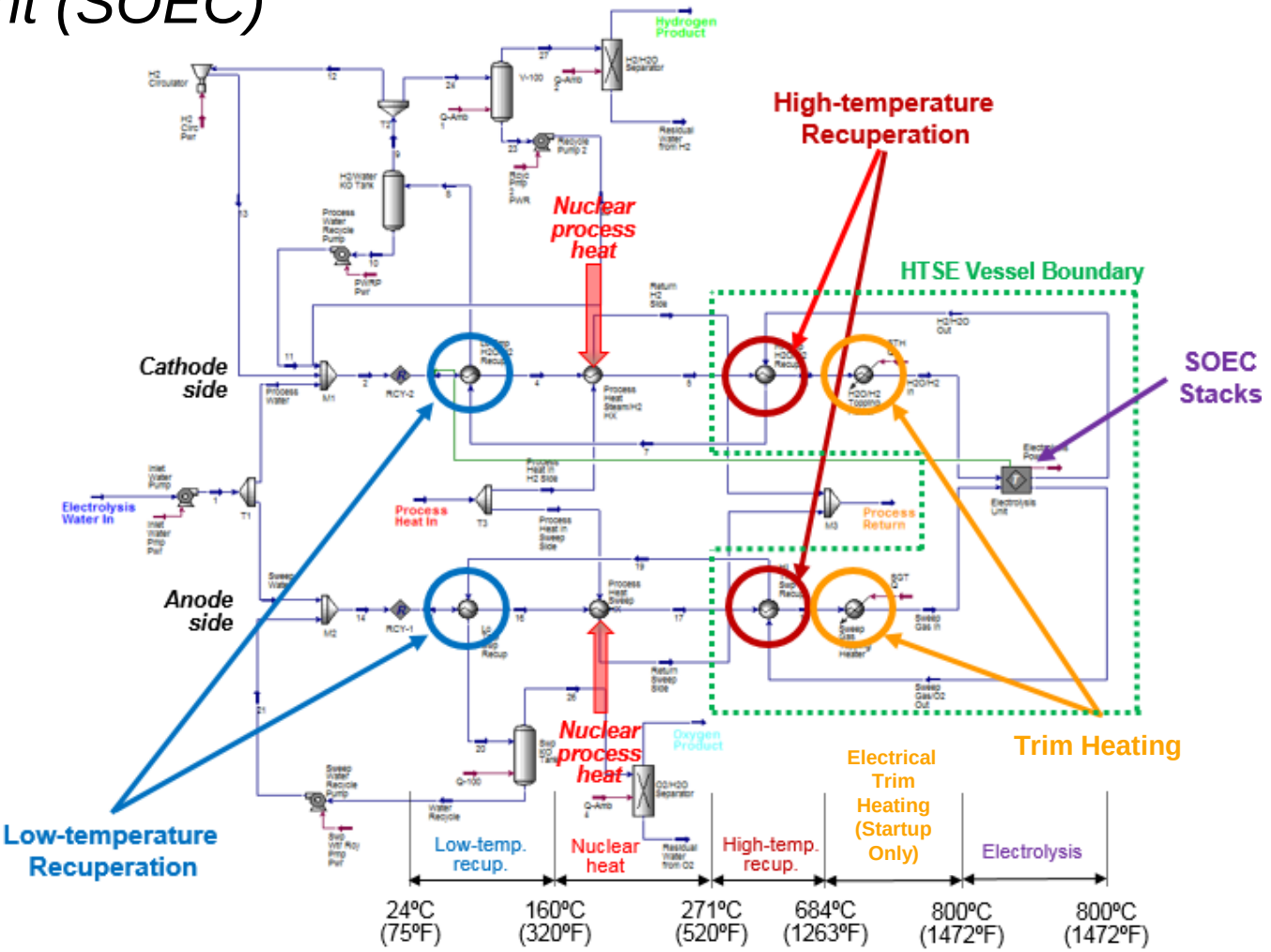


Accomplishments

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

Aspen Process Economic Analyzer (APEA)

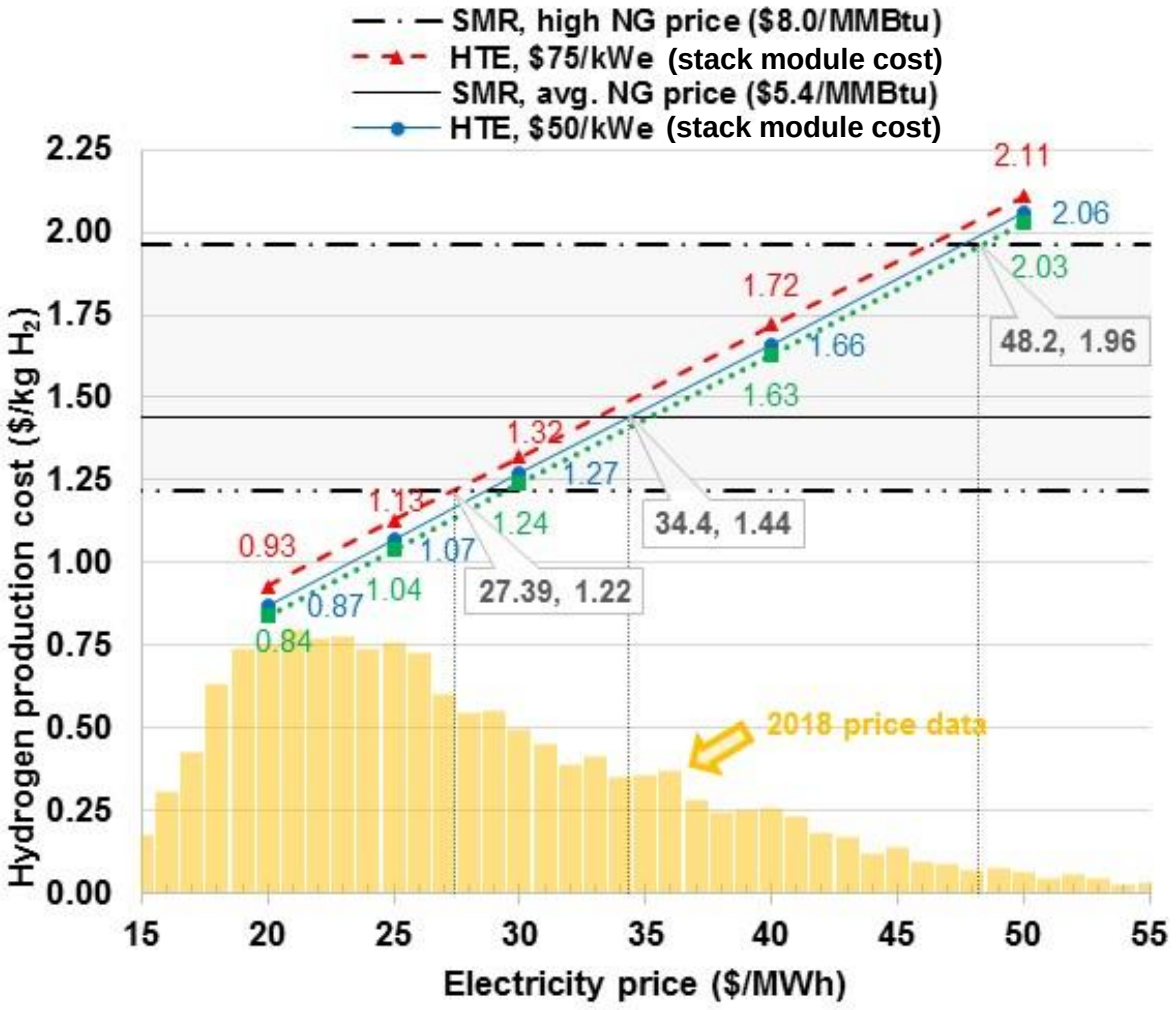
- Cost estimating software that provide CAPEX estimates and OPEX estimates for comparing and screening multiple process schemes.
- Integrated with process simulators ASPEN HYSYS and Aspen Plus.
- Map the simulator unit operations to APEA, e.g.,



Heat Recuperation Improves efficiency

Accomplishments

- *H2A model prediction and sensitivity studies completed*



- **LWR/HTE (SOEC)**
  - 1191 MWe
  - 755 tons/day H_2 (639 tons/day H_2 with an operating capacity efficiency of 84.7%)
  - $403/kWe (DC power input)
  - TCI of $434 M
- **SMR**
  - 639 tons/day H_2 with an OCF of 90%
  - TCI of $292 M

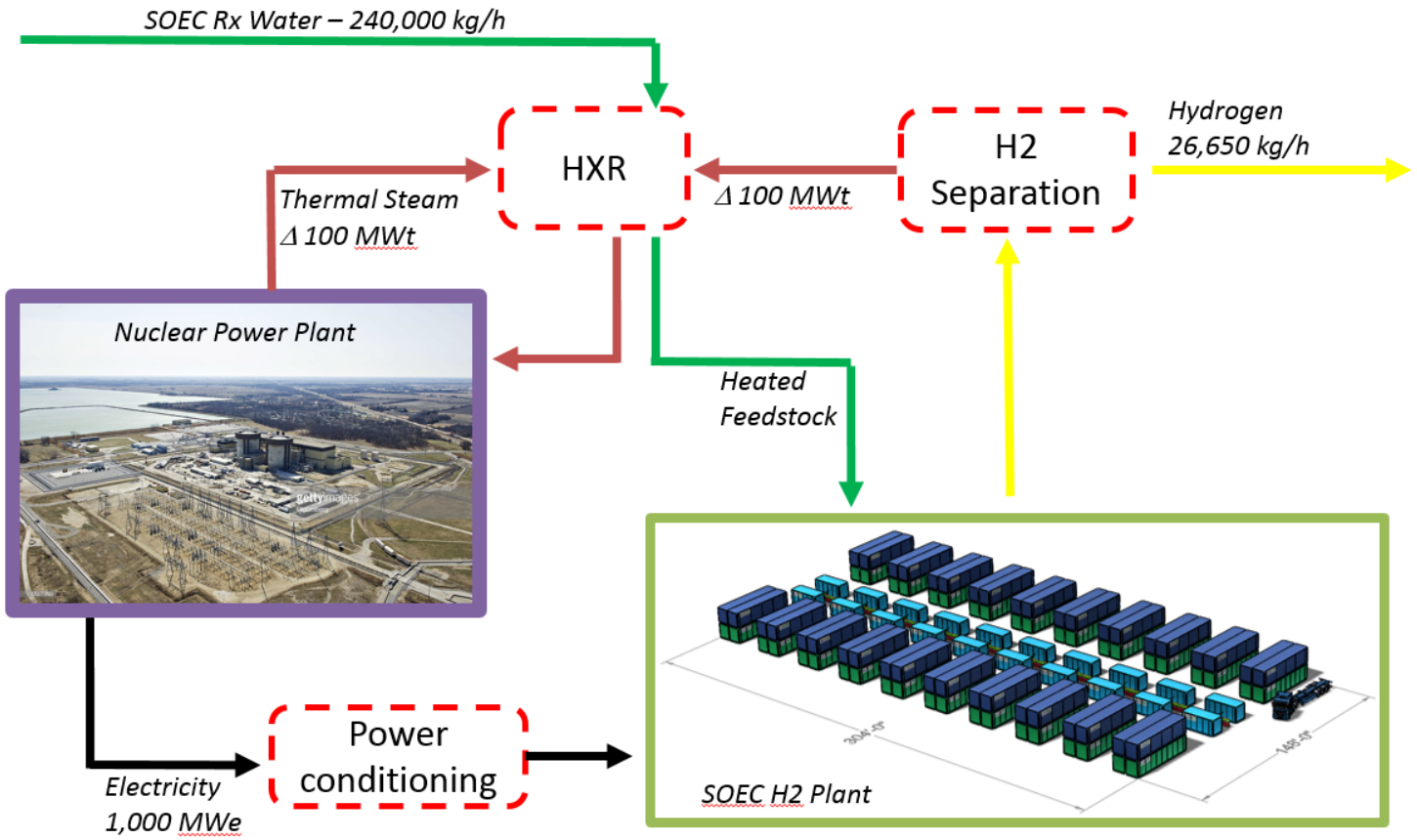
H_2 Production Cost Results Summary (2019$)
Large-Scale Scenarios – LWR/HTE vs. Natural Gas SMR

Accomplishments

- *High Temperature Electrolysis Plant Design Layout*

fuelcellenergy

Nuclear Plant to SOEC H2 Plant System Architecture



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

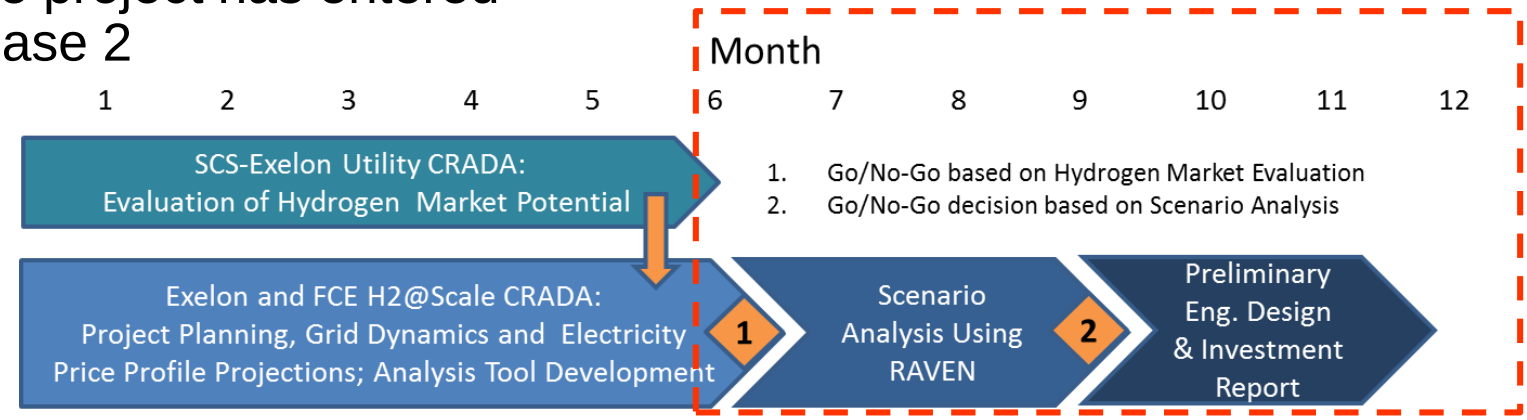
The team is focused on the outcomes that will accelerate business success

Remaining Barriers & Challenges

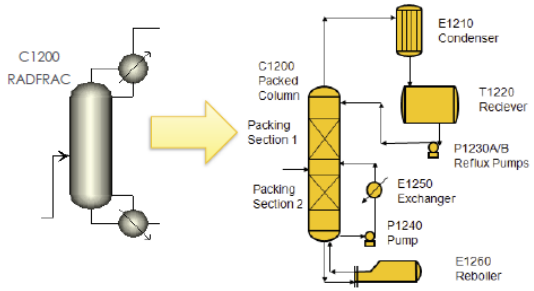
- The project is set to engage industrial users of hydrogen
- Aspen™ modeling for the investor grade report is a significant undertaking
- INL RAVEN system optimization modeling is dependent on and requires timely completion of Phase 2 grid LMP projections

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



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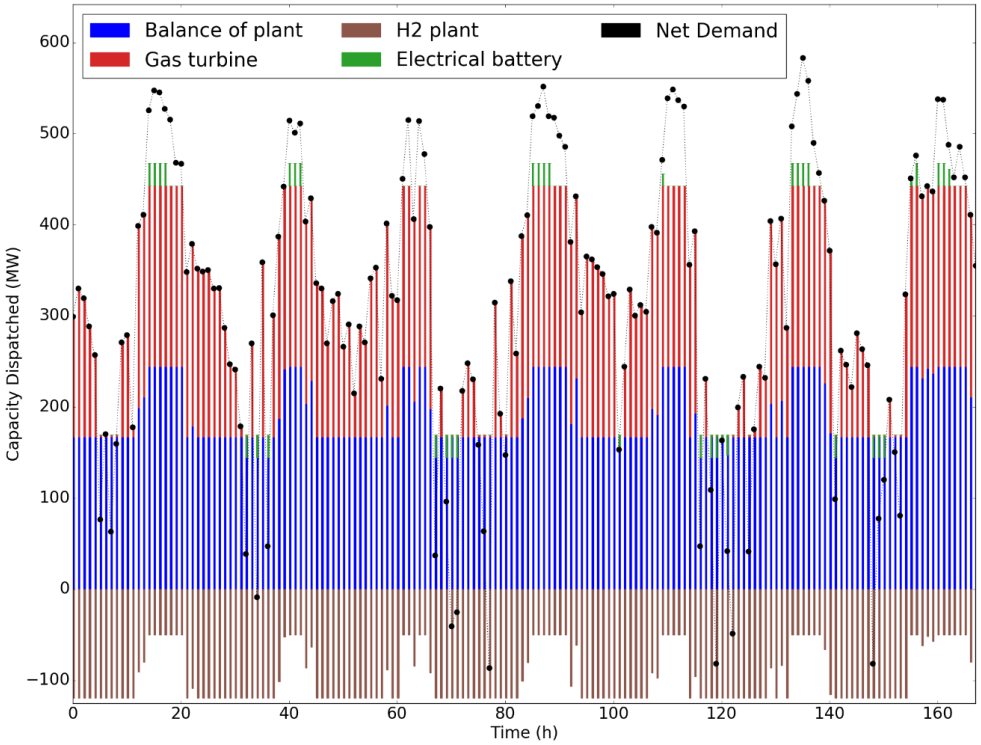
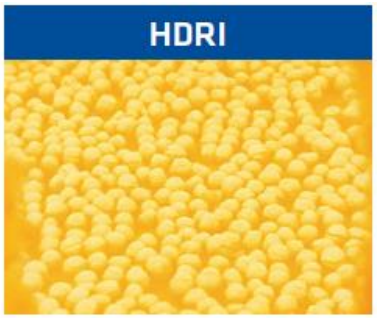
Proposed Future Work

- 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

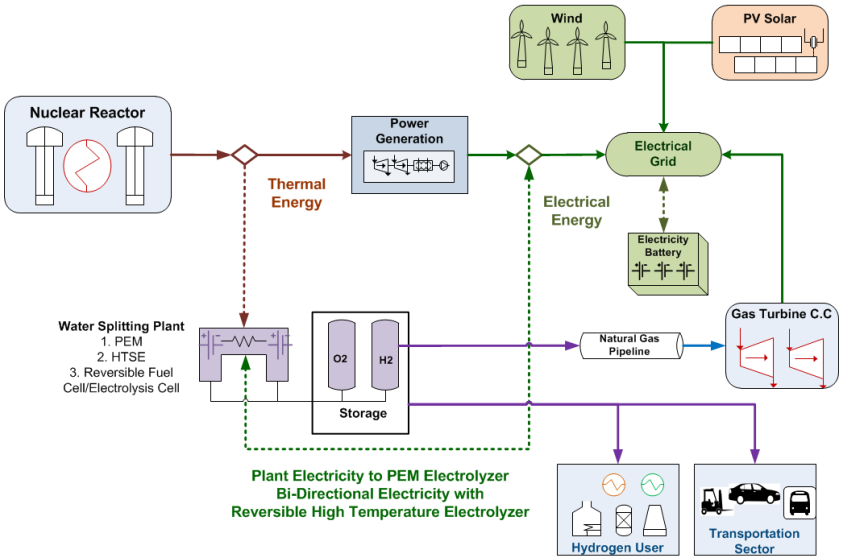
MIDREX® Direct-Reduced Iron Products



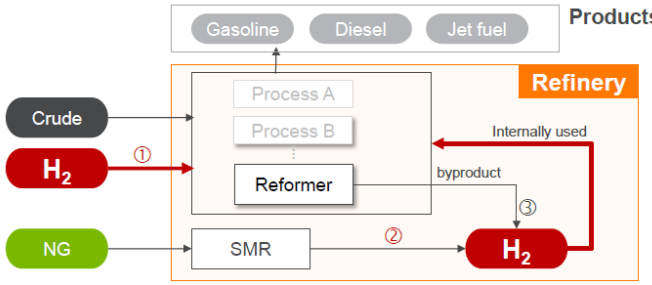
Summary

- 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 H_2 appears to be possible with technology acceleration*
- *Clean hydrogen will be a game changer*



Yes, LWR Hydrogen hybrids could this be the solution!