

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

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## 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

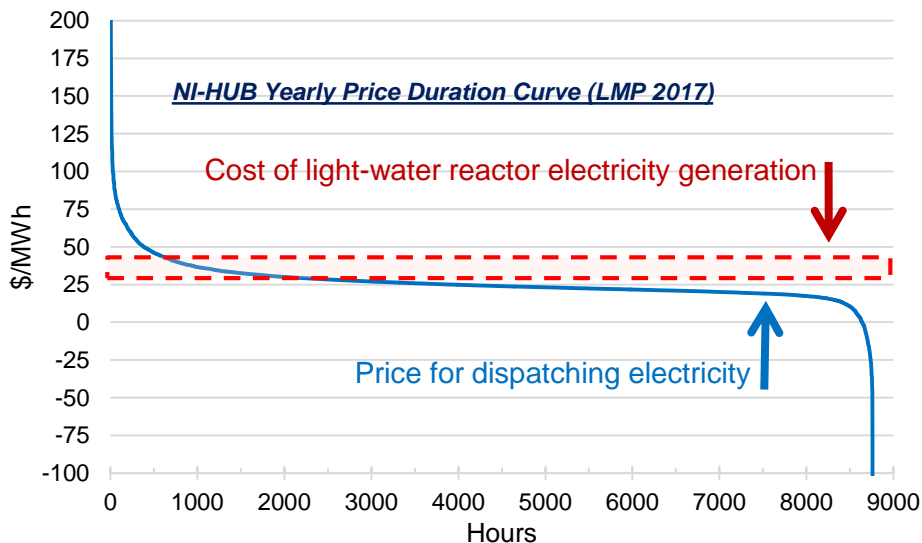
- Barriers addressed
  - Hybrid operation of nuclear power plants
  - Thermal energy integration with high temperature electrolysis
  - Commercial manufacturing pathway for electrolysis modules

## CRADA Partners

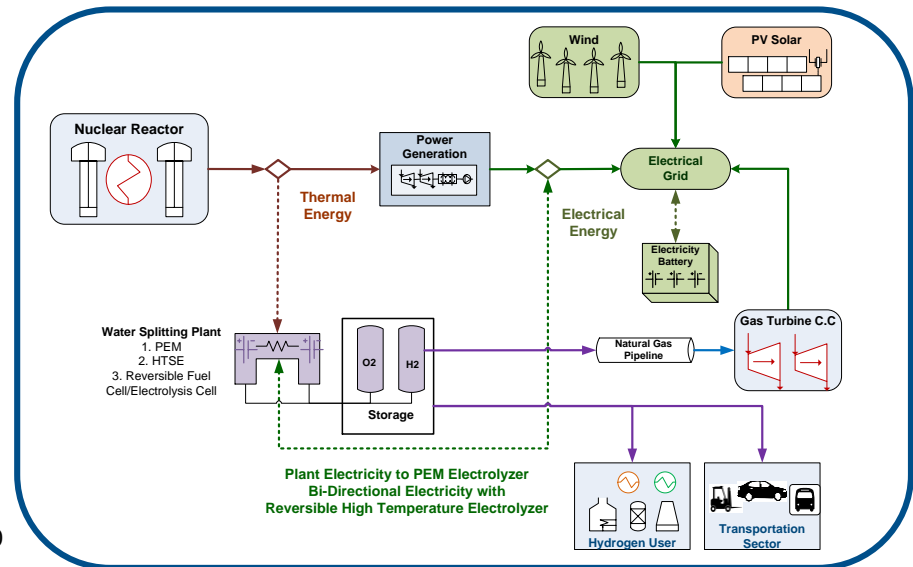
- Exelon Corporation
- FuelCell Energy
- Idaho National Laboratory
- National Renewable Energy Laboratory
- Argonne National Laboratory
- Sandia National Laboratory

*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



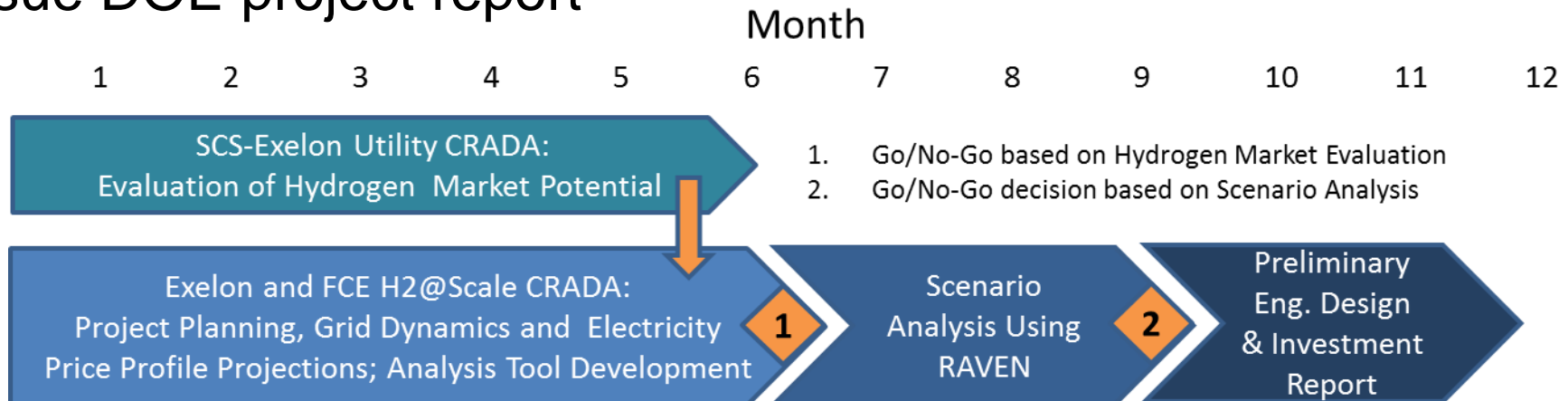
*The problem*



*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



## Resource Potential

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

## Technology Potential

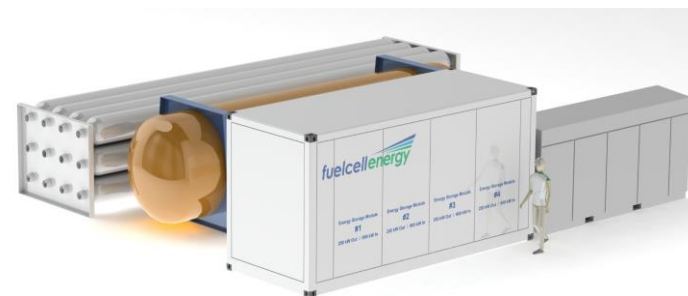
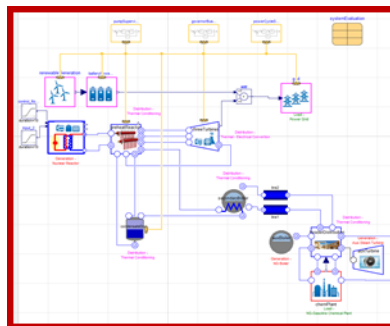
- Thermodynamics
- Performance
- Systems integration and control

## 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

- *Preliminary Market Assessment Completed*
  - ✓ *Specific nuclear plant site selected*
  - ✓ *Electricity market assessment*
  - ✓ *Thermal integration study completed by Exelon*
  - ✓ *Generic high temperature electrolysis plant developed*
  - ✓ *H<sub>2</sub>A 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*



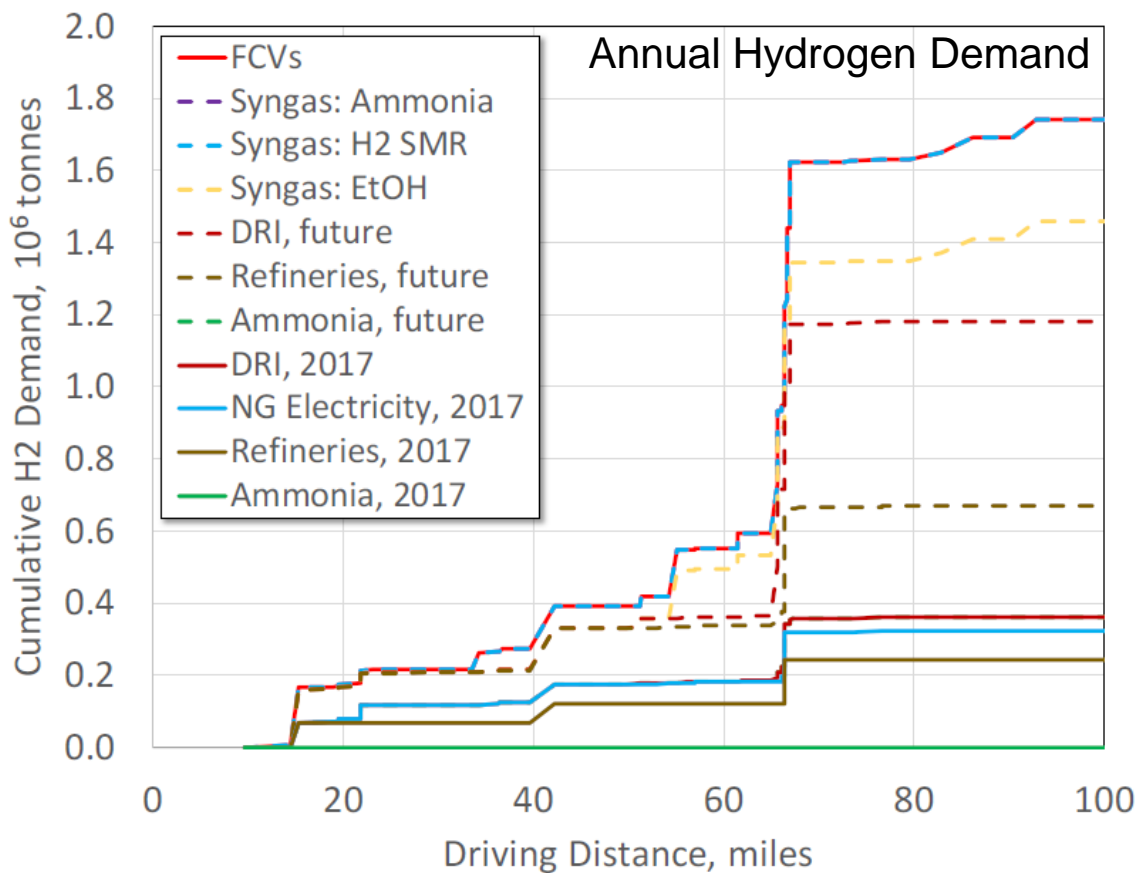
*U.S. Light-Water Reactors*





# 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



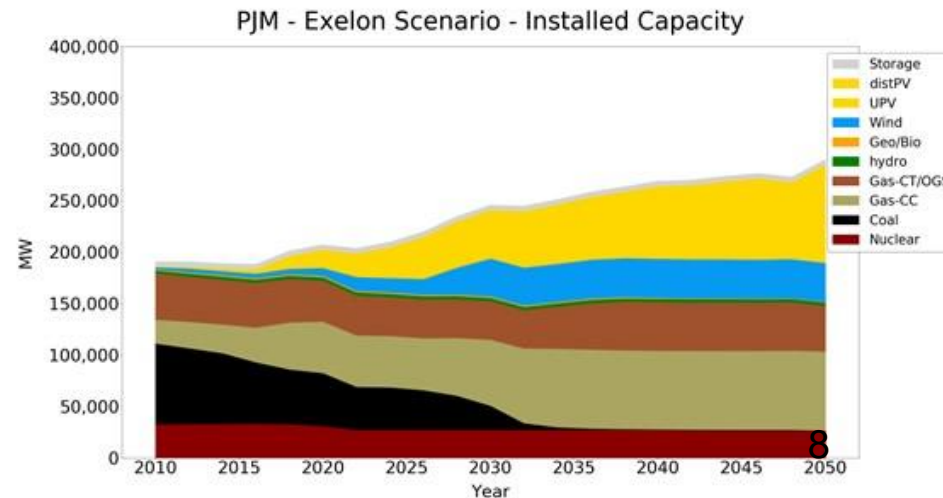
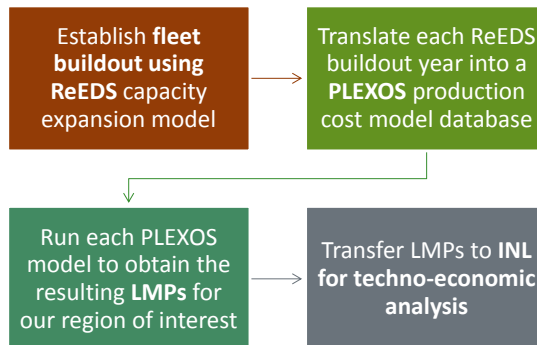
LOW NG + LOW RE PRICES –

80 YEAR NUCLEAR LIFETIME –

LOW DEMAND GROWTH –

ALL OTHER INPUTS USE THE MID-CASE VALUES

Analysis Approach: Projecting LMPs



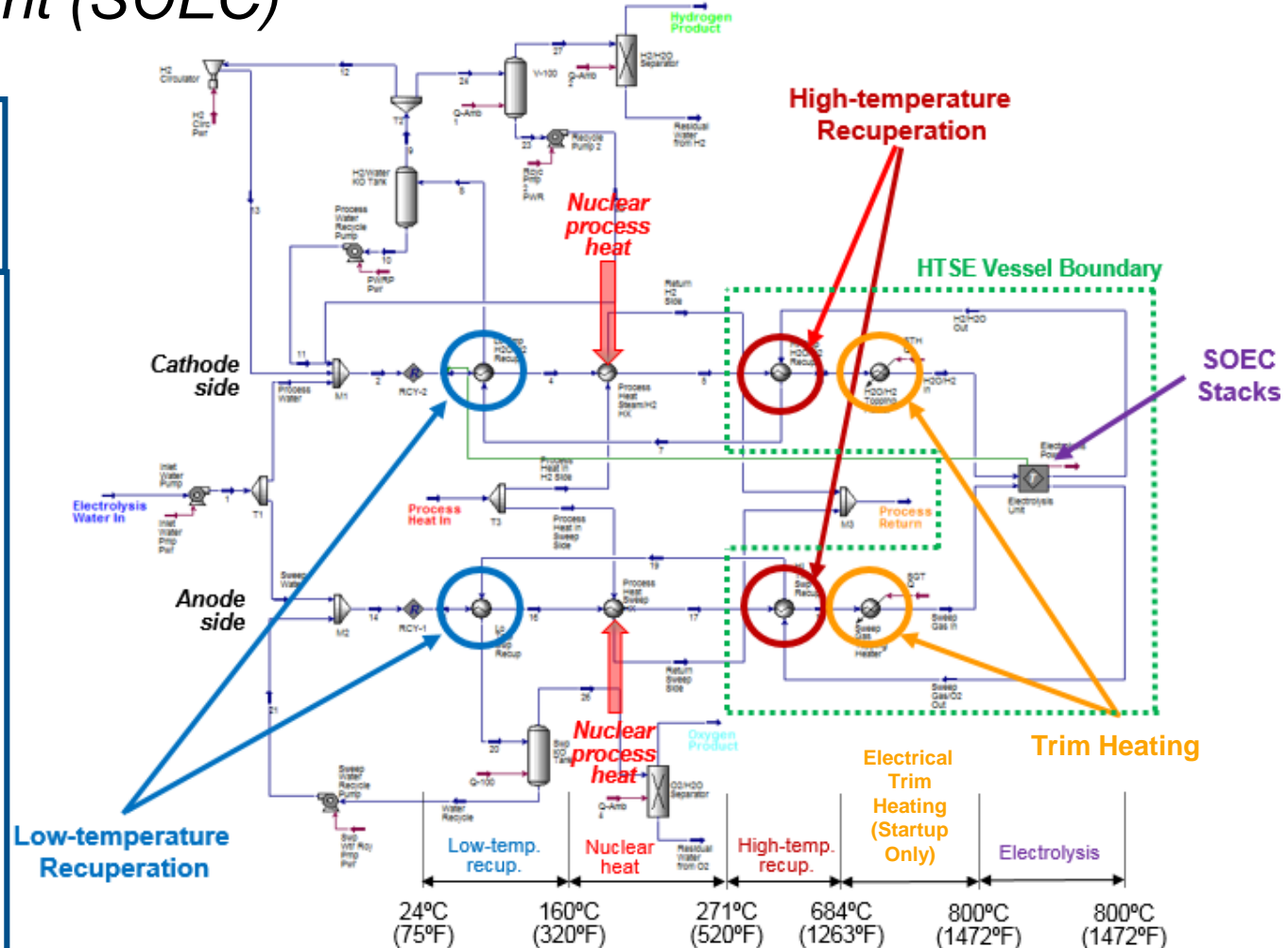


# Accomplishments

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

## Aspen Process Economic Analyzer (APEA)

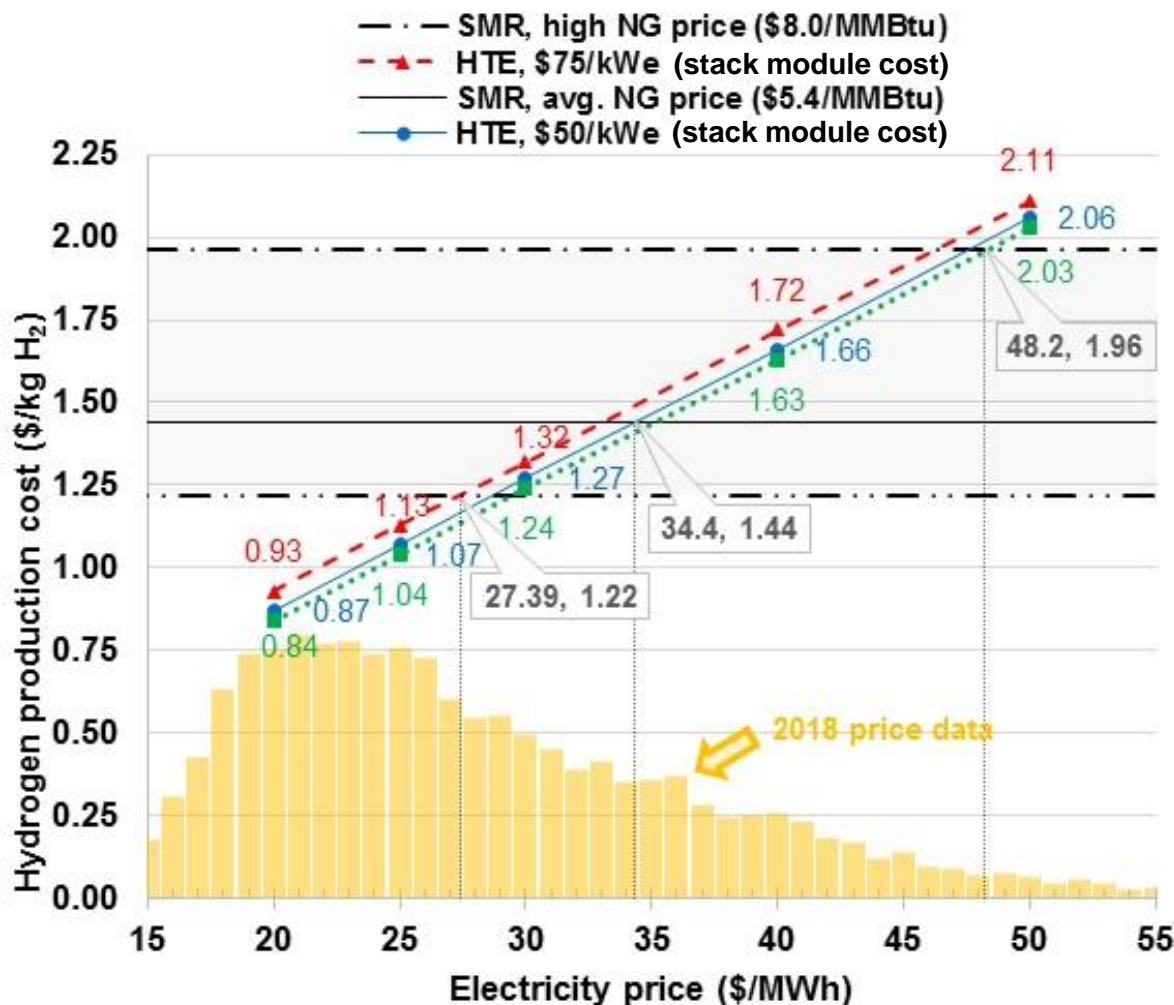
- Cost estimating software that provide CAPEX estimates and OPEX estimates for comparing and screening multiple process schemes.
- Integrated with process simulators ASPEN HYSYS and Aspen Plus.
- Map the simulator unit operations to APEA, e.g.,



Heat Recuperation Improves efficiency

# Accomplishments

➤ *H2A model prediction and sensitivity studies completed*



## ☐ LWR/HTE (SOEC)

- 1191 MWe
- 755 tons/day H<sub>2</sub> (639 tons/day H<sub>2</sub> with an operating capacity efficiency of 84.7%)
- \$403/kWe (DC power input)
- TCI of \$434 M

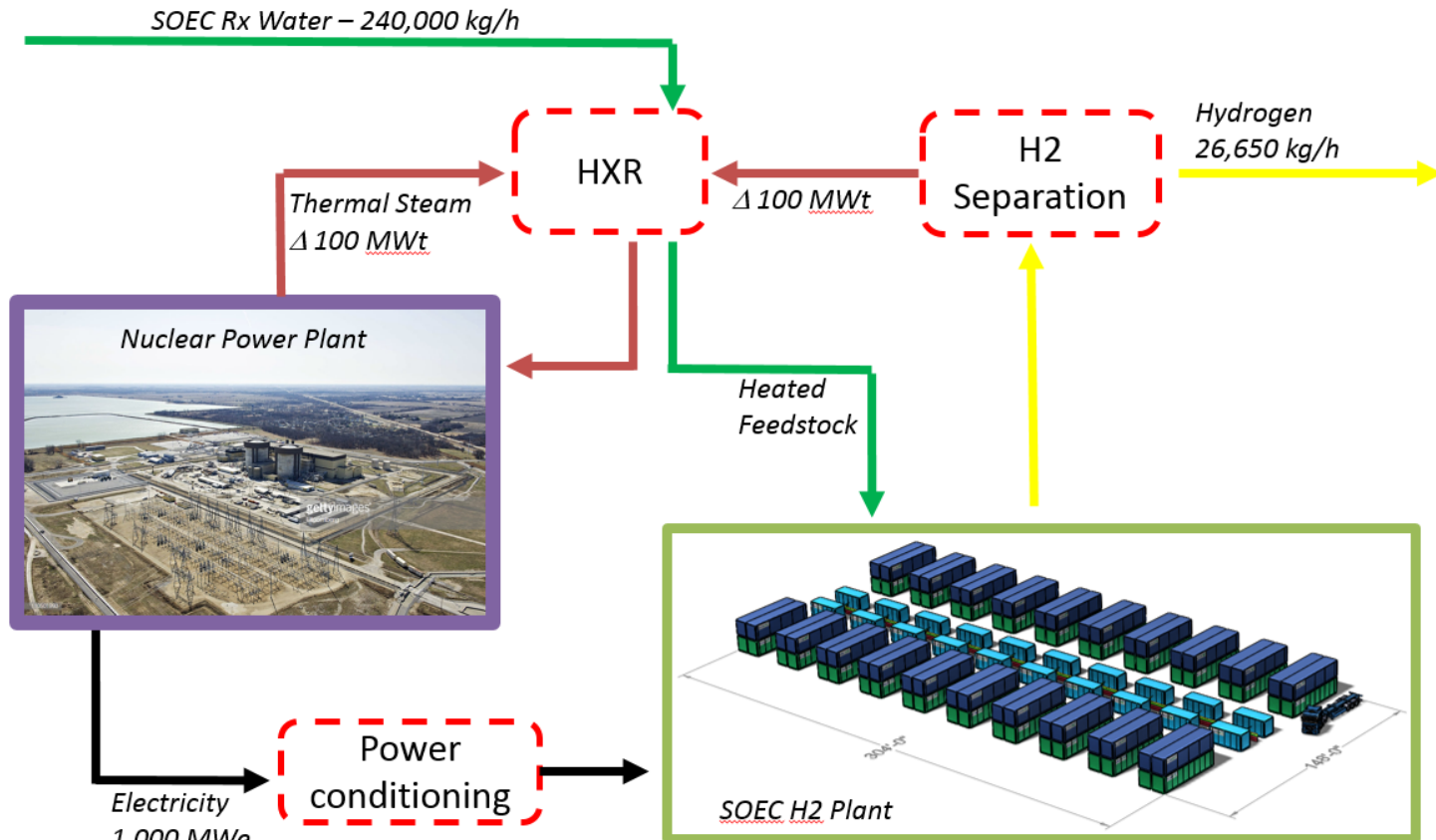
## ☐ SMR

- 639 tons/day H<sub>2</sub> with an OCF of 90%
- TCI of \$292 M

➤ High Temperature Electrolysis Plant Design Layout



## Nuclear Plant to SOEC H2 Plant System Architecture





- ❑ 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*

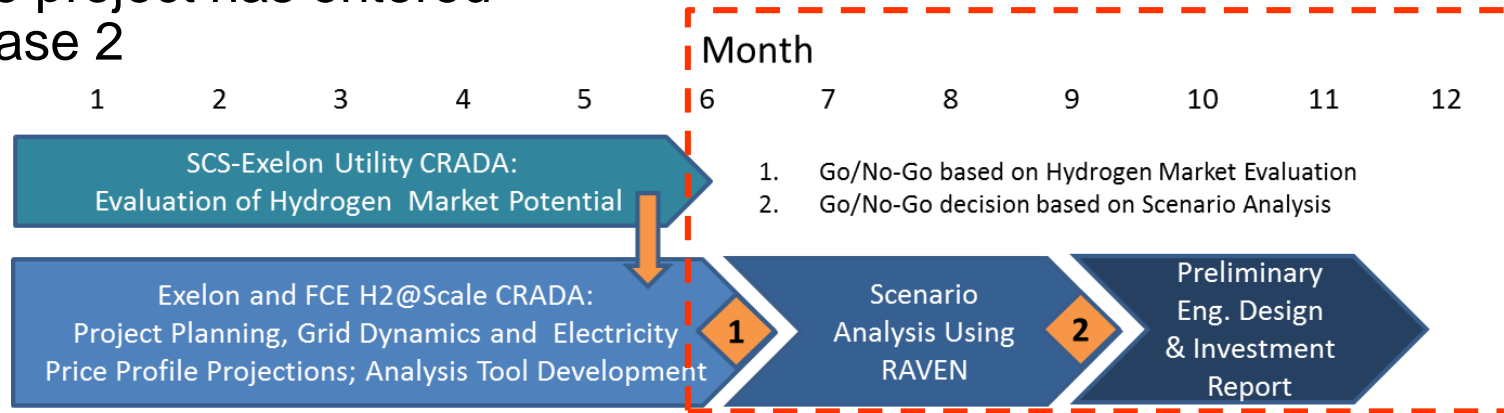
*Cooperation and confidentiality underscores this CRADA*

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

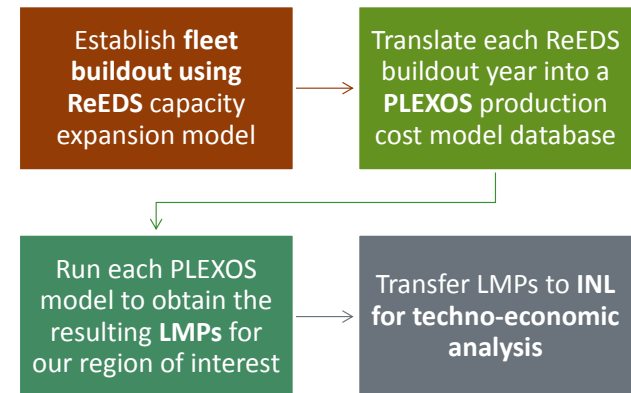
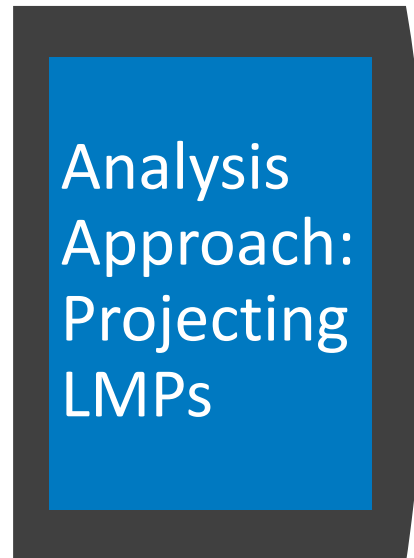
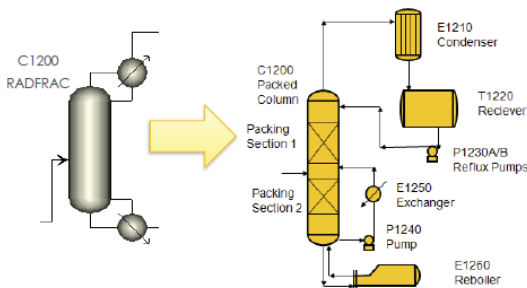
## Remaining Barriers & Challenges

- ❑ 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

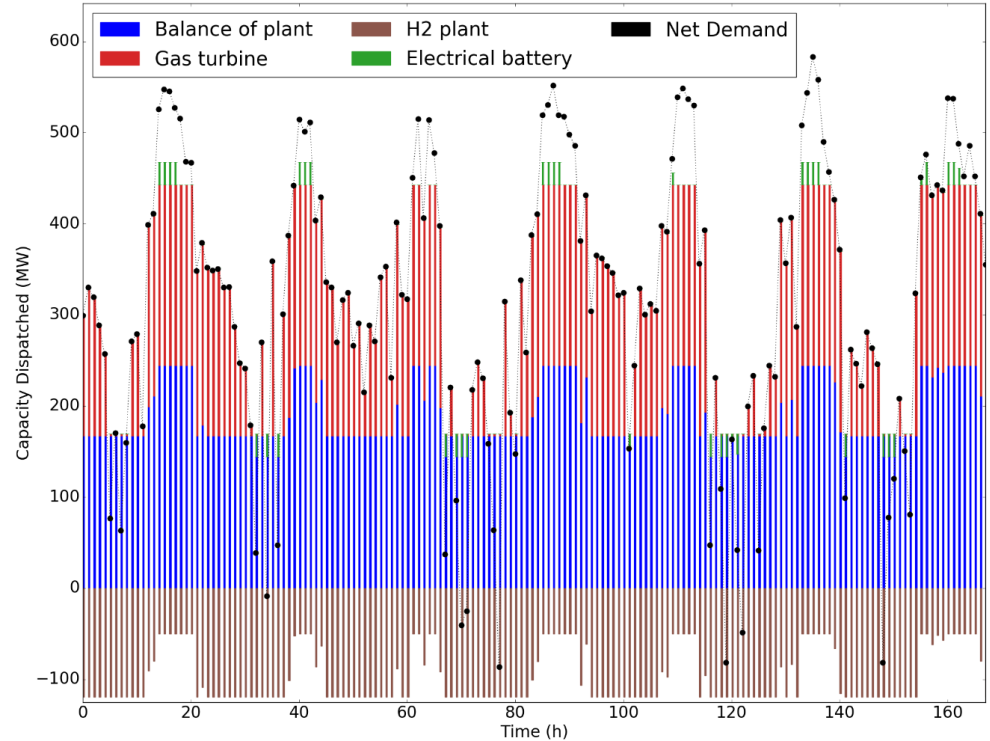
- The project has entered Phase 2



- NREL grid modeling is underway with input from Exelon & Constellation
- INL Aspen™ Modeling has commenced with input from FCE

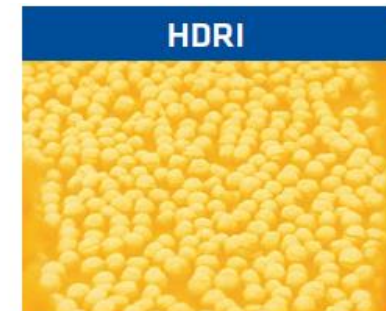


- ❑ RAVEN “system scale and operating optimization” will be completed in FY19-Q4 and FY20-Q1
- ❑ SNL will conduct safety assessment and provide guidance relative to siting a hydrogen plant near a nuclear plant
- ❑ Project team will begin discussion with hydrogen off-takers
- ❑ Investor report due to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



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

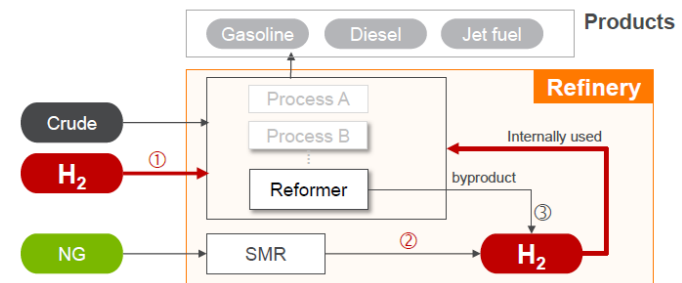
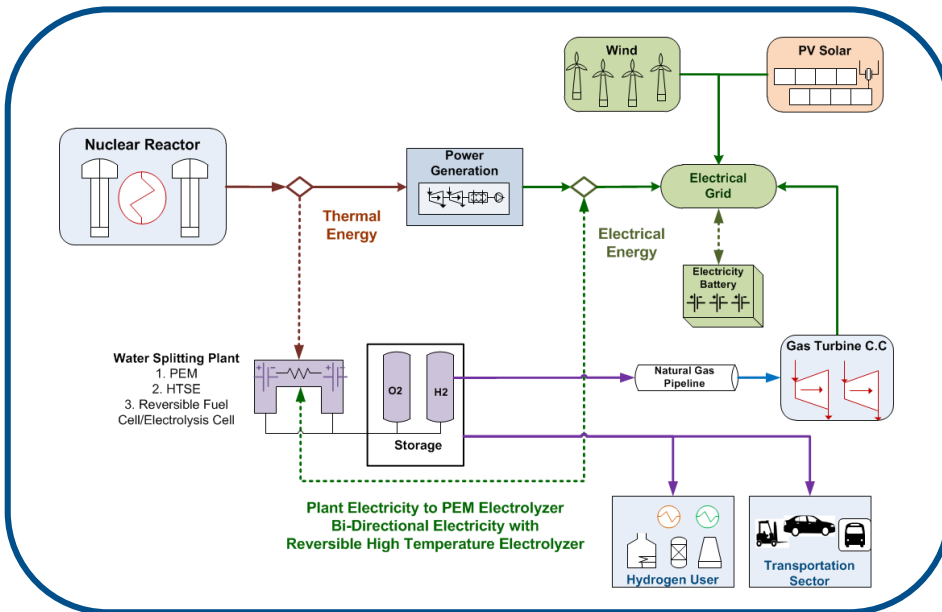
*MIDREX®  
Direct-Reduced  
Iron Products*



- 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 H<sub>2</sub>@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<sub>2</sub> appears to be possible with technology acceleration*
- ❑ *Clean hydrogen will be a game changer*



*Yes, LWR Hydrogen hybrids could this be the solution!*