2024 DOE Hydrogen Program Annual Merit Review Presentation

Demonstration of electrolyzer operation at a nuclear plant to allow for dynamic participation in an organized electricity market and in-house hydrogen supply

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Project ID
TA028

Project Goals and scope and overview

Goals/Objectives

- Install a 1MW Polymer Electrolyte Membrane (PEM) electrolyzer and supporting infrastructure at an Constellation nuclear power plant
- Provide economic supply of in-house hydrogen consumption at the plant
- Simulate a scale-up operation of a larger electrolyzer participation in power markets

Timeline and budget

- Conditional award: 10/01/2019
- Removal of condition: 04/01/2020
- Go/No-Go decision made: 07/30/2021
- Project End Date: 10/01/2023
- Total Project Forecast: $14.4M

Questions, challenges

- Site Selection
  - What are the criteria for site selection?
- Regulatory
  - What are the relevant regulations that affect nuclear H2 production?
- Market-related
  - What is the effective electricity price that the electrolyzer pays?

Partners

- Constellation Energy Corporation
- Idaho National Laboratory
- National Renewable Energy Laboratory
- Argonne National Laboratory
- Nel Hydrogen

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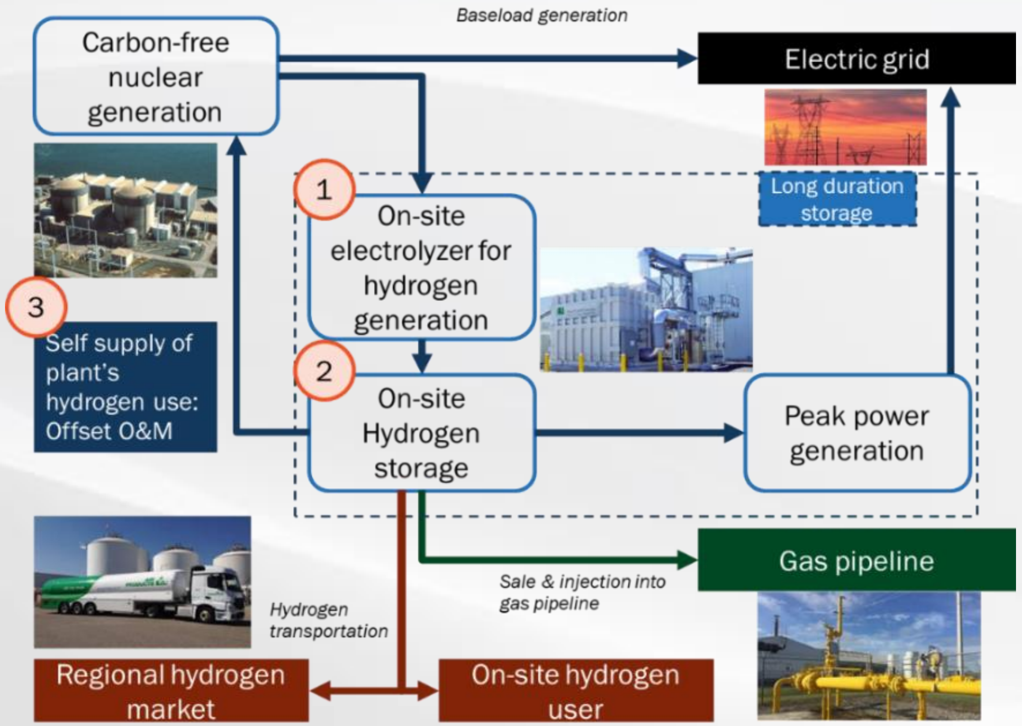
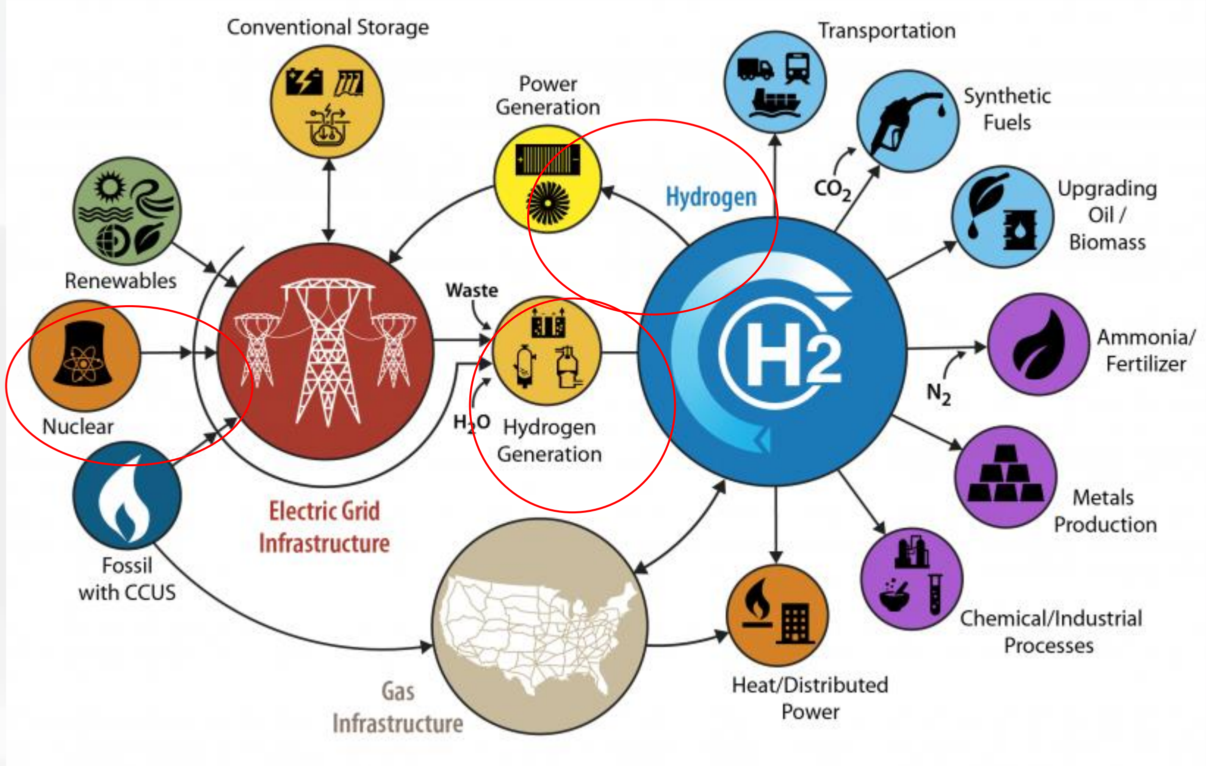
Relevance: The project demonstrates nuclear hydrogen pathway described in H2@scale vision

Technical Goals and Objectives

- Install a 1MW PEM electrolyzer and supporting infrastructure at an Constellation NPP
- Provide economic supply of in-house hydrogen consumption at the plant
- Simulate a scale-up operation of a larger electrolyzer participation in power markets





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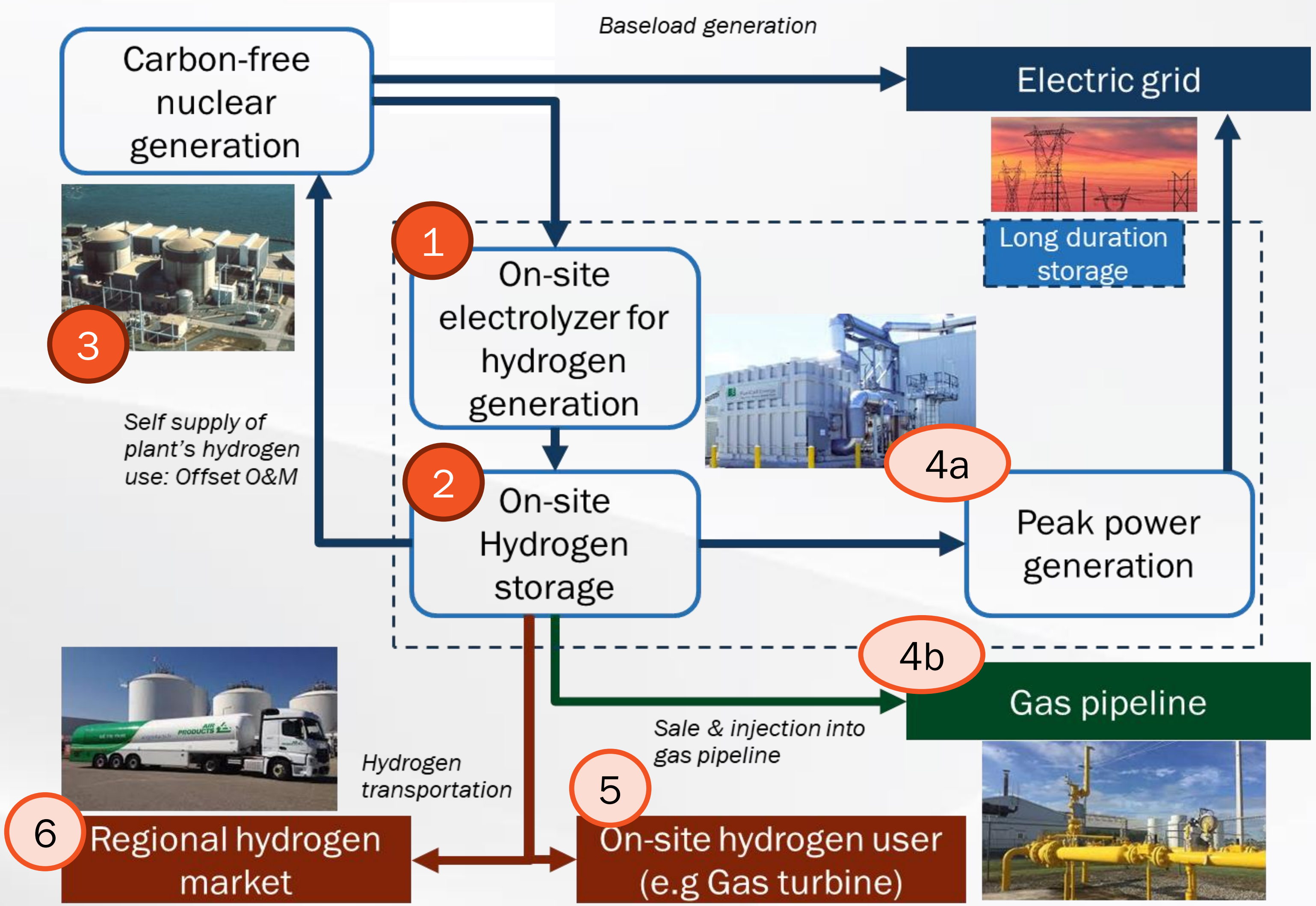
Relevance: The project demonstrates nuclear hydrogen pathway



The project will demonstrate pathways 1-3. In budget period 2, the team will implement installation, operation and scale-up analysis. #4 is being pursued with a state grant

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Tasks and Milestones

Task #	Task	Description	Verification	Month from start
1.0	**Successful selection of an optimal site.**	Site selection is announced to project partners		1
2.0-A	**30% conceptual engineering design complete**	30% Engineering report is completed		11
4.0	**Demonstrate dynamic operation of a ~1 MW electrolyzer**	Perform factory acceptance testing and demonstrate dynamic operation of a ~1 MW electrolyzer.		11
4.0	**Simulation model of electrolyzer operation**	Verified by inspecting the results of a simulation model of the local electrical grid including interactions between the grid and the nuclear station and a 1 MW PEM system		9
5.0	**Identification of optimal sites for scale-up.**	Verified by a technical report comparing candidate sites and down selecting the optimal location for future scaleup.		11
2.0-B	**Site specific Final Engineering design**	100% design engineering is completed with input from Nel		18
6.0	**Economic feasibility assessment of scale-up**	Verified by a technical report assessing the economic feasibility of future scaleup.		35
8.0	**Start of steady state operation of electrolyzer**	Verified by the steady state hydrogen production		29
9.0	**Demonstration of dynamic operation at site**	Verified by the demonstration of remote connection and dynamic operation of the installed 1 MW electrolyzer.		35
10.0	**Perform a project specific assessment of cyber security issues**	A report documenting a project specific assessment of cyber security aspects in accordance with recommendations		35

Completed

In progress

Not started

Nine Mile Point Hydrogen Production- Hydrogen Safety updates

- Constellation installed a 1.25 MW Nel PEM electrolyzer producing 531 kg/day of clean hydrogen at Nine Mile Point power station in Oswego, New York.
- On March 7th, hydrogen production started.
- Engaged DOE hydrogen safety panel
- Incorporated NFPA guidance into the design
- Incorporated the unit into the plant design so that any changes are reviewed to ensure NFPA standards are maintained
- Added the system into operations training for both new operators and a continuing refresher for current operators
- Reviewed NFPA requirements against Constellation safety procedures

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Responses to 2023 Reviewers' Recommendations

1. In the long term, it would be desirable to see Constellation include clean hydrogen production with carbon capture for the subsequent production of carbon-neutral, non-electric energy products (syngas, methanol, Fischer–Tropsch fuels, etc.) to assist in decarbonization of other sectors. The recommendation is appreciated
2. DOE should ask Constellation if the utility is willing to do a no-cost extension of the schedule to include the collection and dissemination of electrolyzer operational results. More extended-operational data of electrolyzers in real-world applications is needed. - Constellation has extended the period of performance and is in communication with NREL on data sharing.
3. It is recommended that the project revisit the simulation based on the performance observed in the installed dynamic operations. This is (understandably) not included in the scope but should be considered by DOE as a follow-on project.- The recommendation is appreciated
4. The project needs to produce more electrolyzer operating data in the rest of the project time period. The project should specify how waste heat would be utilized for the electrolyzer operation to enhance the overall system efficiency. Please see answer to question 2.
5. There are no recommendations for changes to project scope.

Collaboration and Coordination

Partner	Role
Constellation	Lead applicant responsible for overall project, design, installation and operation of the 1MW electrolyzer. Licensing, regulatory market deliverables.
Nel	Vendor supplier for prototype test unit. Providing support for prototype electrolyzer testing
INL	Development of front end controller, dynamic operation of prototype electolyzer
NREL	Development of front end controller, dynamic operation of prototype electolyzer
ANL	Analysis for scaled-up hydrogen production, hydrogen market analysis

Summary of accomplishments, progress, potential impact and future work

- **Project achievements and progress**
  - 100% Final Engineering design completed
  - Installation and start of steady state operation of electrolyzer (started operation on 3/7/2023)
  - ANL has completed mapping hydrogen demand and infrastructure for potential scaleup sites
  - Successfully kicked-off $12.5M follow-on NYSERDA grant to install hydrogen fuel cell at NMP as a long duration storage
  - Submitted hydrogen hub application for Mach H2 based on learnings from the project
  - Received Nuclear Energy Institute's Top Innovative Practice (TIP) award in 2023
- **Potential impact**
  - On March 7th, hydrogen production started clean hydrogen production facility at Constellation's Nine Mile Point Nuclear Plant in Oswego, New York
  - The project leverages DOE grant of $5.8 million to demonstrate hydrogen production and end use for the plant's own consumption of hydrogen
  - The PEM electrolyzer uses 1.25 MW of power behind the meter to produce 560kg/Day of clean hydrogen, more than enough to meet the plant's hydrogen use.
- **Future work**
  - The additional hydrogen production is being explored as a long duration energy storage system in a separate grant project supported by NYSERDA.
  - Constellation has committed to invest $900 million through 2025 for commercial clean hydrogen production using nuclear energy. This includes participation in the Midwest Alliance for Clean Hydrogen (MachH2)
  - Any proposed future work is subject to change based on funding levels

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Acknowledgments

- Financial support from DOE EERE Fuel Cell Technology Office under award **#DE-EE0008849**
- DOE program manager: Michael Hahn
- Constellation team and project manager: Robert Beaumont
- National lab teams
- Nel Hydrogen team

Technical backup slides

Technology transfer and commercialization activities

- On March 7th, hydrogen production started clean hydrogen production facility at Constellation’s Nine Mile Point Nuclear Plant in Oswego, New York
- The project leverages DOE grant of $5.8 million to demonstrate hydrogen production and end use for the plant’s own consumption of hydrogen
- The PEM electrolyzer uses 1.25 MW of power behind the meter to produce 560kg/Day of clean hydrogen, more than enough to meet the plant’s hydrogen use.
- The additional hydrogen production is being explored as a long duration energy storage system in a separate grant project supported by NYSERDA.
- Constellation has committed to invest $900 million through 2025 for commercial clean hydrogen production using nuclear energy. This includes participation in the Midwest Alliance for Clean Hydrogen (MachH2)

Special recognition and awards: 2023 Nuclear Industry Top Innovative Practice award

- Nuclear Energy Institute Top Innovative Practice Awards
  - These awards highlight the nuclear industry's most innovative techniques and ideas. They promote the sharing of fresh ideas and best practices, and consequently improve safety, work processes and the competitive position of the industry.
- 2023 TIP award was given to "Demonstration of Clean Hydrogen Production at Nine Mile Point"
  - Constellation's Nine Mile Point plant is using PEM electrolyzers behind the meter to produce clean hydrogen to meet it's in-house hydrogen consumption. This project is a first of a kind demonstration in the U.S. that paves the way for scaled-up production of hydrogen from nuclear power.
- Issue Solution Benefit
  - Issue: Hydrogen gas used for chemistry control and turbine generator cooling. Currently, hydrogen is made from fossil fuels and sold by industrial gas companies at expensive price due to long distance transportation
  - Solution: The project leverages $5.8M in DOE funding to produce hydrogen in-house using a PEM electrolyzer connected behind the meter at NMP station to supply the plant's hydrogen consumption
  - Benefit: The electrolyzer saves the plant more than $800k annually in external hydrogen purchase cost. The project is first-of-a-kind demonstration of nuclear hydrogen production in the U.S. and establishes a precedent for scale-up projects

Publications and presentations

- Organized in-person launch event at NMP in January 2023. Continue media engagements on local and national level: S&P Global, World Nuclear News, Nuclear Engineering International, RTO insider, Utility Dive, Power Engineering, Axios, Oswego County today, The eagle tribune, Power Magazine,
- Continue to attend Conferences, industry events to knowledge share: IAEA, EPRI, ANS, Hydrogen Americas, MIT CANES
- Prepare technical publications in research journals: IEEE
- News articles below

Date	News outlet	Title
10/21/22	Baltimore Sun	Baltimore-based Constellation Energy pursues 'hydrogen economy' to meet global climate goals
10/17/22	Tomorrow's World Today	Nation's First Nuclear-Powered Clean Hydrogen Production Announced
10/07/22	Northern NY Newspapers	Constellation celebrates clean hydrogen production facility at Nine Mile Point
10/04/22	Nuclear Engineering International	Constellation reports progress on the first US nuclear-powered hydrogen facility
09/29/22	Oswego County Business Magazine	Constellation Joins State and Local Officials to Celebrate Progress on Nation's First Nuclear-Powered Clean Hydrogen Facility
09/28/22	Palladium Times	Constellation celebrates progress on hydrogen production facility at Nine Mile Point
09/28/22	WRVO, 89.9 FM (Oswego NPR affiliate)	Oswego County nuclear plant aims to use nuclear power to address climate crisis
09/28/22	Spectrum News 1	Hydrogen production to start next year at Oswego nuclear power plant, CEO says
09/28/22	Syracuse Post Standard	Oswego nuclear plant looks to future, wil be first in U.S. to make hydrogen
09/28/22	Business Wire	Constellation Joins State and Federal Officials to Celebrate Progress on Nation's First Nuclear-Powered Clean Hydrogen Facility

NMP: Hydrogen Pilot Demonstration Project: Project Manager – Robert Beaumont

Pouring concrete for electrolyzer on left, rigging power supply into place on right

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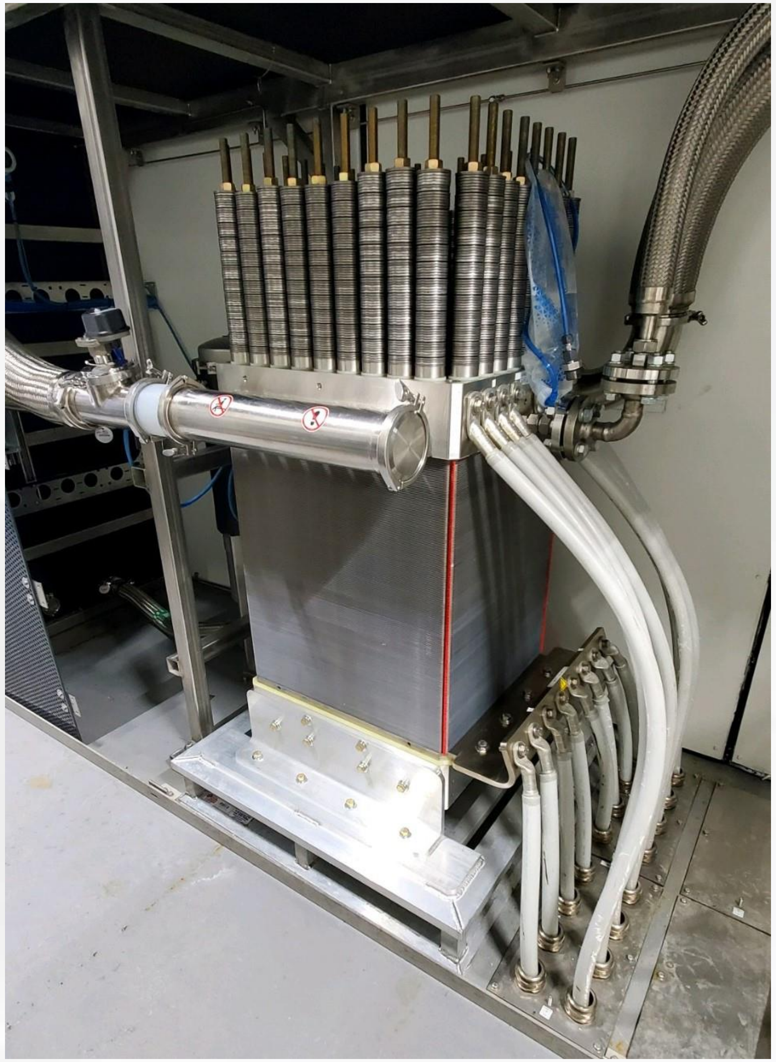
NMP: Hydrogen Pilot Demonstration Project: Project Manager – Robert Beaumont



Electrolyzer Area to left: backup generator, power supply, and electrolyzer

Cell stack installed to right.

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NMP: Hydrogen Pilot Demonstration Project: Project Manager – Robert Beaumont

Electrolyzer and cooling unit to left
Compressor below

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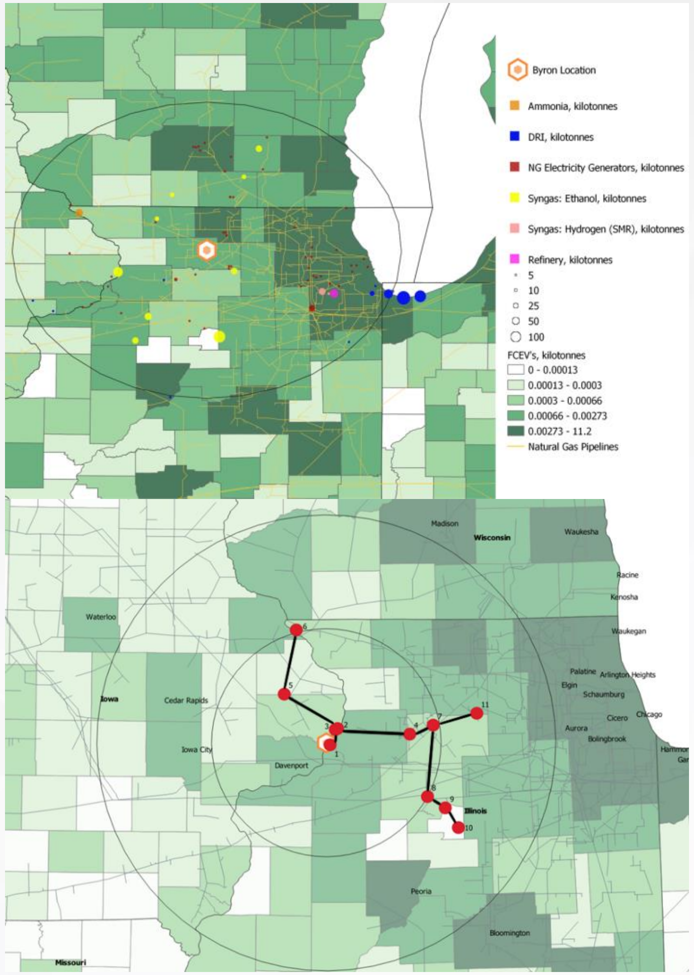
ANL: Market demand, GHG emissions and delivery cost evaluation

H_2 markets and potential demand estimates for following generating station were evaluated:

1) Dresden GS
2) Quad Cities
3) Clinton GS
4) Limerick GS
5) Ginna GS
6) La Salle GS
7) Braidwood GS
8) Byron GS
9) Calvert Cliffs GS

- The potential H_2 market demand was calculated for near-term and long-term opportunities of refinery operations, ammonia production, H_2/NG electricity generators, synthetic fuels (synfuels) near CO_2 sources, direct reduction of Iron and in proximity to these nuclear power plants.
- Life cycle emissions were calculated for nuclear produced H_2.
- Emissions associated with end use applications are evaluated and compared to conventional technologies.
- Delivery costs were evaluated by simulating a pipeline network and using Hydrogen Delivery Scenario Analysis Model (HDSAM).
- Transportation and storage are major cost drivers for utilizing H_2
- Cost of avoided CO_2 was estimated for different end use applications using nuclear-H_2.



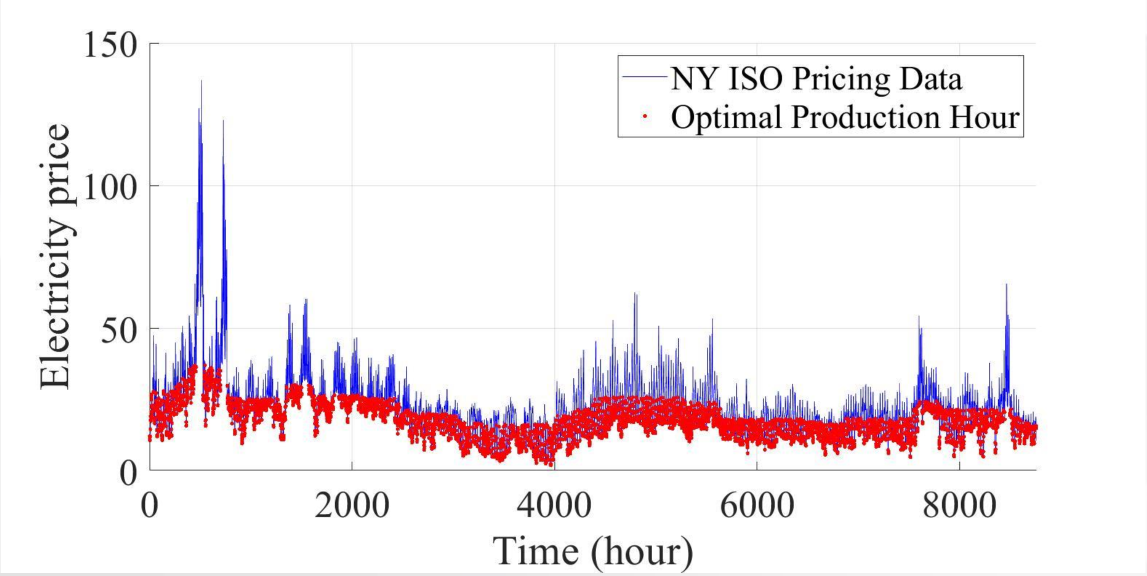
Simulations of Scaled Economic Dispatch Using Front-End Controller

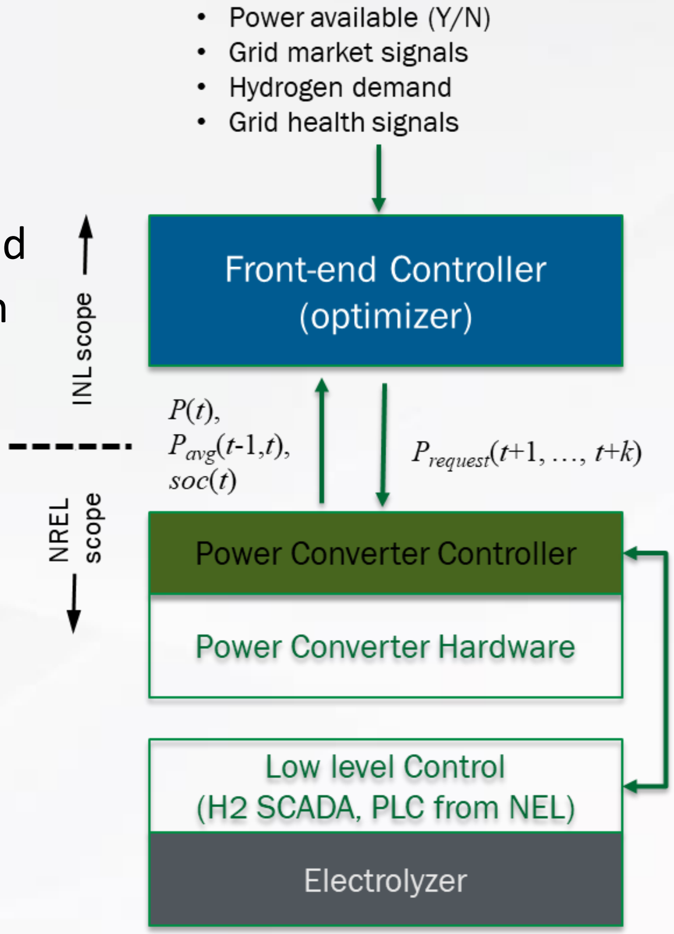
Accomplishments

- Developed and tested front-end controller that uses data from power markets, grid, and the electrolyzer to optimize dispatch of hydrogen production

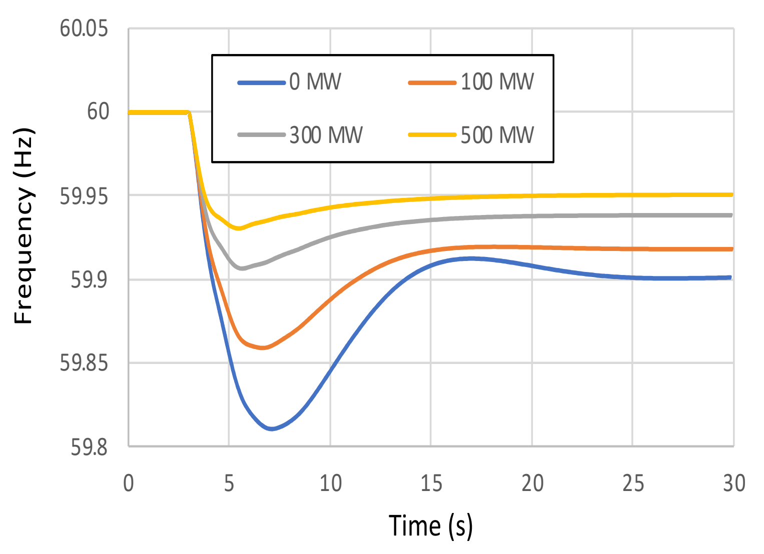
Results

- With fixed H_2 demand, electrolyzer daily capacity factor is ~constant and buffered by storage. Cost projections enable using lowest cost electricity for H_2 production to maximize system profits





Simulations of Scaled Electrolyzer Demand-Response Dispatch

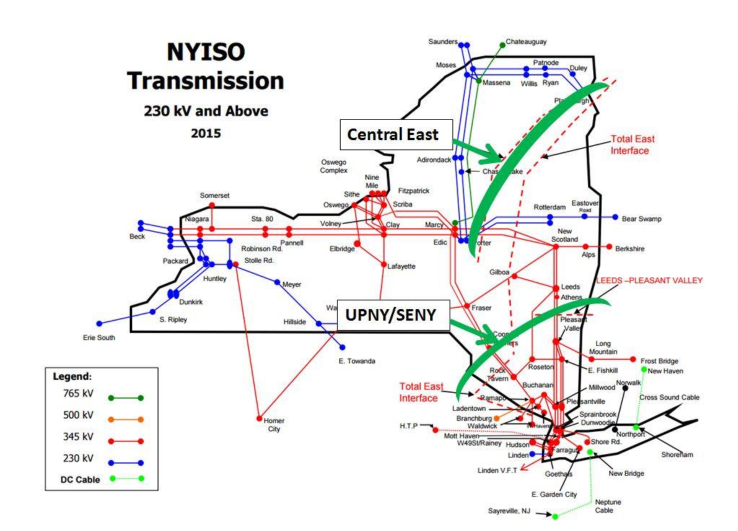


Accomplishments

- Performed transient grid analyses that indicate dynamic operation of scaled PEM system can decrease grid max. frequency delta due to generator fault.
  - Simulation used IEEE 39-bus standard (New-England Power System)
  - PEM system was located at bus 39, connected to a 1 GW nuclear power plant. A droop-based controller provided autonomous demand response
  - A generator fault (N-1 contingency) was simulated at generator 10 (250 MW) on bus 2 to create frequency transients.

Results

- Max. frequency delta decreased from 0.189 Hz without PEM system to 0.069 Hz for 500 MW PEM

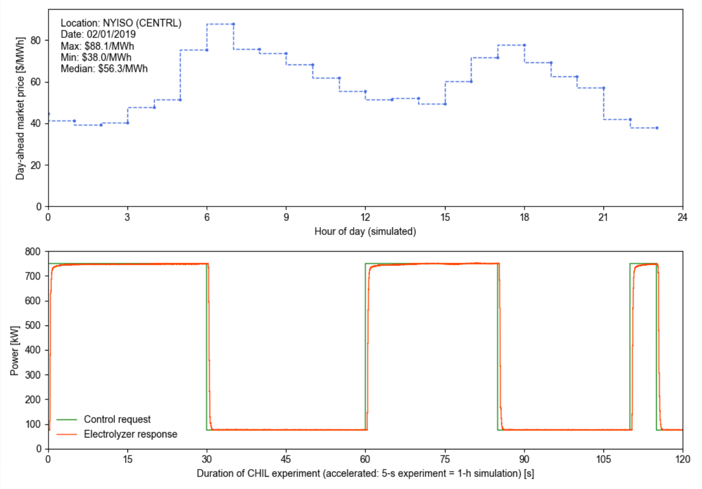


Scenario	Max. Freq. Delta (Hz)
0 MW	0.189
100 MW	0.141
300 MW	0.093
500 MW	0.069

Accomplishments and Progress: NREL

<u>Accomplishments</u>

- Established a communication link between the front-end controller (FEC) and NREL's electrolyzer testbed with a 750-kW stack
- Refined the power-to-current conversion model with temperature effects
- Performed HIL tests of the electrolyzer system using dynamic control signals from FEC while maintaining operational constraints for hydrogen systems (**completed Milestone 4.2**)
- Shared lessons learned regarding water in systems that can freeze and cause damage before systems are ready for operation



<u>Future Work/In Progress</u>

- Provide hardware validation tests at Flatirons Campus if needed
- Host a site visit NREL Flatirons Campus for the Constellation team to compare operational experience and know-how between the two similar systems

MW Scale Hydrogen Systems Capabilities at NREL