GEN IV International Forum

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Nuclear Supported Industrial Applications: Operational Experience for District Energy and Hydrogen Production

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Presented on behalf of industry

Workshop on Non-Electric and Hybrid Applications of Nuclear Energy

Busan, Republic of Korea

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Past experience in *operational* nuclear cogeneration, as summarized by Gen-IV International Forum signatory countries

- UK Calder Hall Magnox (heat supported onsite nuclear fuel plant, shut down in 2003)
- Norway Halden BWR (steam for the Saugbrugs paper factory, shut down in 2018)
- Switzerland Gösgen PWR (transport of steam over 2 km to a cardboard factory)
- Canada Bruce A CANDU (district and industrial heating, cogeneration stopped in 1997)
- Germany Stade PWR (salt refinery, nuclear plant shut down in 2003)
- **Switzerland Beznau (district heating)**
- Various Eastern European countries (district heating)
- >200 reactor-years operating experience with seawater desalination (mostly Japan, India, Kazakhstan; MSF, MED, RO technologies)

See Summary Report from the *GIF NEANH Virtual Workshop and Information Exchange on Development of Cogeneration Applications of Gen IV Nuclear Technologies*, July 2022.

Nuclear Supported District Energy

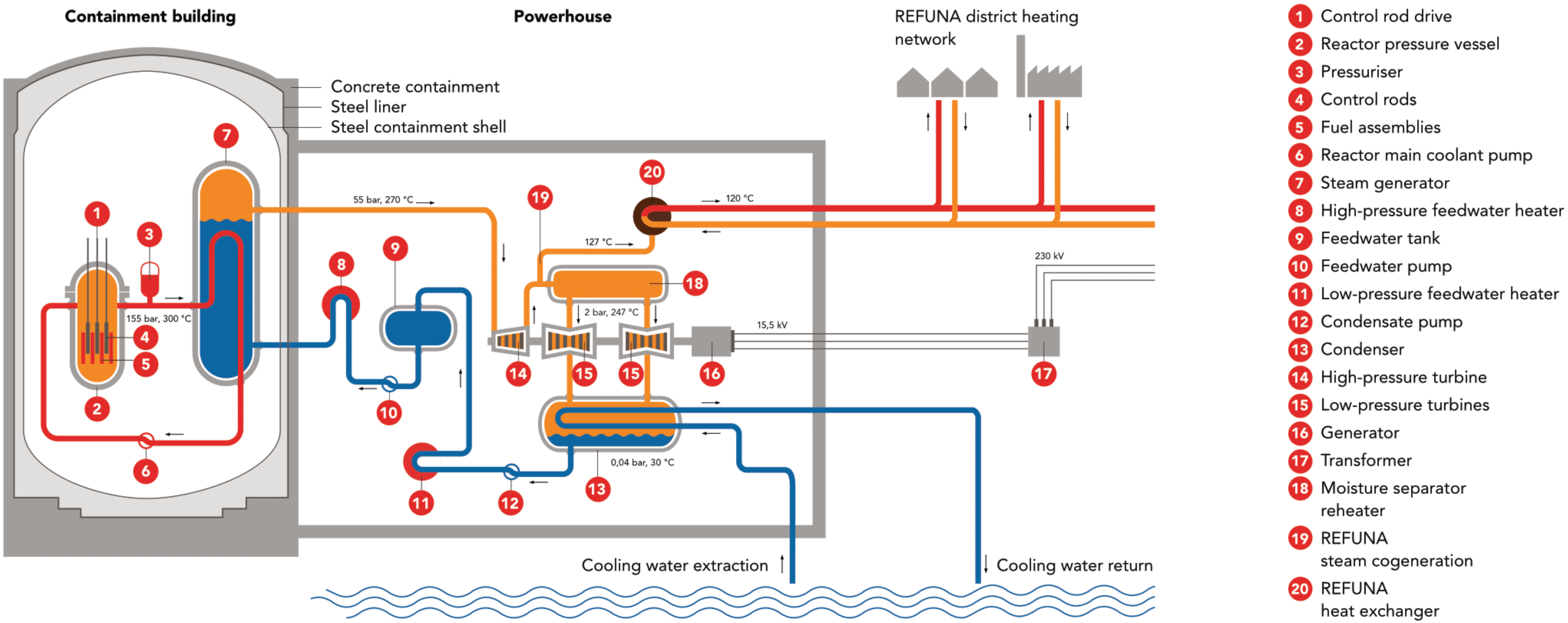
District heating using the Beznau nuclear power plant

- The Beznau nuclear power plant in Switzerland has been supplying Regionale Fernwärme Unteres Aaretal (REFUNA) with inexpensive energy for over 30 years.
- REFUNA supplies industry, trade and residents of 11 municipalities in the region with heat from the Beznau NPP.
- REFUNA delivers an average of about 170 GWh of thermal energy per year to over 2600 customers.
- 12,000 tonnes of fuel oil and approximately 45,000 tonnes of CO_2 saved annually.

REFUNA pipe bridge over the Aare canal

Source: www.axpo.com/content/dam/axpo19/master/files-master/dossiers/beznau-power-plant/Axpo_KKB_Broschuere_EN_12_2021.pdf

The energy cycle

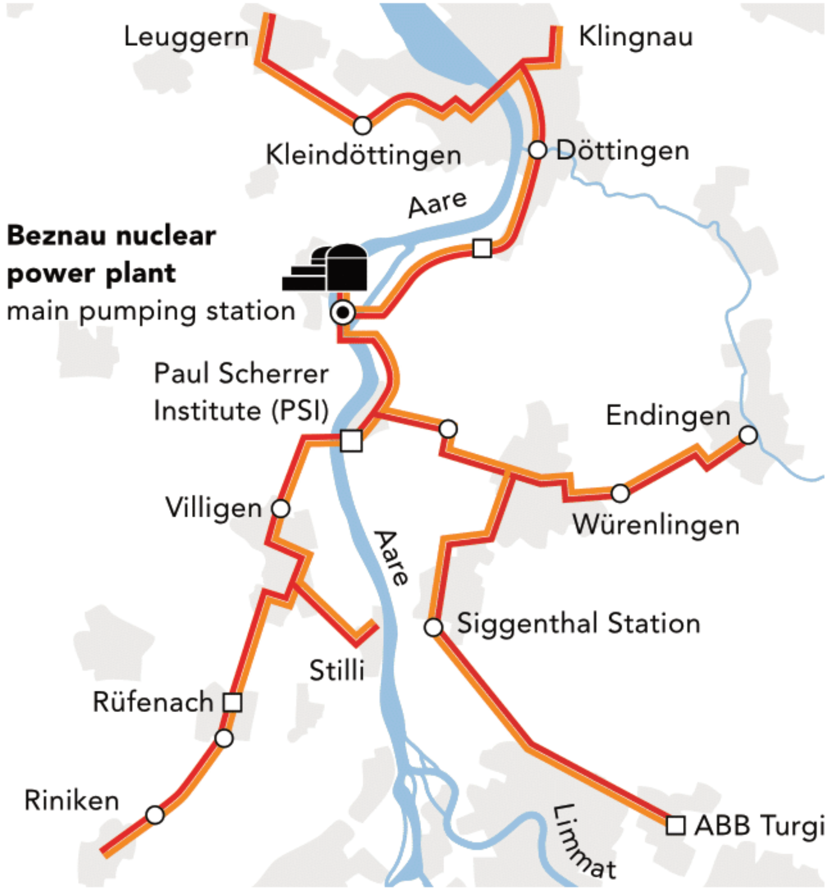


Source: www.axpo.com/content/dam/axpo19/master/files-master/dossiers/beznau-power-plant/Axpo_KKB_Broschuere_EN_12_2021.pdf

Reliable district heating for the region

- During heat extraction the power station's output decreases by up to 7.5MWe.
- Heat extraction takes place between the high- and low-pressure sections of the turbine where steam at a temperature of 127°C is extracted and routed to the heat exchanger.
- There, the heat contained in the steam is transferred to the district heating network, where the water is heated up to 120°C in the process.
- Since each of the two power plants has a heat extraction system of this kind, district heating is available at all times, even during scheduled outages.

The main lines are 31 km long, and the local lines are 103 km long.



Hot feed
Cooled-down return
Standby heating plants
Booster pump stations

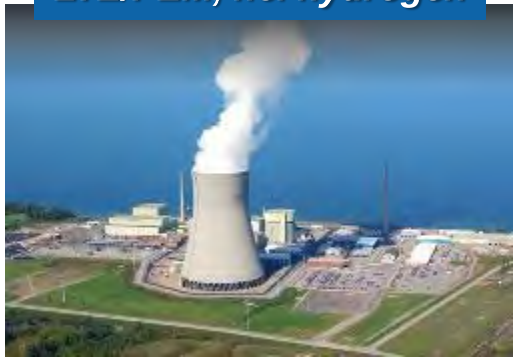
Co-located Nuclear Energy and Hydrogen Production

H_2 production demonstration projects in the U.S.

Multiple projects have been announced for demonstration of hydrogen production at nuclear power plants

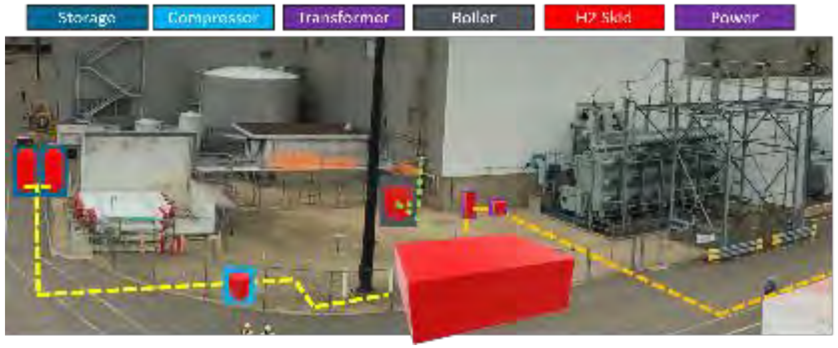
- Demonstrate hydrogen production using direct electrical power offtake from a nuclear power plant for a commercial, 1-3 MWe, low-temperature (PEM) and high temperature steam electrolysis modules
- Acquaint NPP operators with monitoring and controls procedures and methods for scaleup to large commercial-scale hydrogen plants
- Evaluate power offtake dynamics on NPP power transmission stations to avoid NPP flexible operations
- Evaluate power inverter control response to provide grid contingency (inertia and frequency stability), ramping reserves, and volt/reactive control reserve
- Produce hydrogen for captive use by NPPs and first movers of clean hydrogen

Nine Mile Point Nuclear Power Plant LTE/PEM, nel hydrogen



Davis-Besse Nuclear Power Plant, LTE/PEM

Thermal & Electrical Integration at Xcel Energy Prairie Island Nuclear Plant



H2@Scale
U.S. Department of Energy

LWRS
LIGHT WATER REACTOR SUSTAINABILITY

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SELECTED REGIONAL CLEAN HYDROGEN HUBS

Location
Federal Cost Share

https://www.energy.gov/oced/regional-clean-hydrogen-hubs-selections-award-negotiations

Nuclear-based hydrogen production has commenced in the U.S.

Press release:
https://www.constellationenergy.com/newsroom/2023/Constellation-Starts-Production-at-Nations-First-One-Megawatt-Demonstration-Scale-Nuclear-Powered-Clean-Hydrogen-Facility.html

Constellation Starts Production at Nation's First One Megawatt Demonstration Scale Nuclear-Powered Clean Hydrogen Facility

State-of-the-art facility will demonstrate the value of producing hydrogen with carbon-free nuclear energy to help address the climate crisis

OSWEGO, NY (Mar. 7, 2023) — Hydrogen production has commenced at the nation's first 1 MW demonstration scale, nuclear-powered clean hydrogen production facility at Constellation's Nine Mile Point Nuclear Plant in Oswego, New York, an advancement that will help demonstrate the potential for hydrogen to power a clean economy.

Photos courtesy Constellation, https://www.ans.org/news/article-4810/constellation-starts-hydrogen-production-at-nine-mile-point/

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

P.I.- Uuganbayar (Ugi) Otgonbaatar, Ph.D.
Director, Grants R&D and Partnership, Constellation
5/7/2024

Project ID
TA028

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project Goals and scope and overview

Goals/Objectives

- Install a 1MW Polymer Electrolyte Membrane (PEM) electrolyzer and supporting infrastructure at a 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

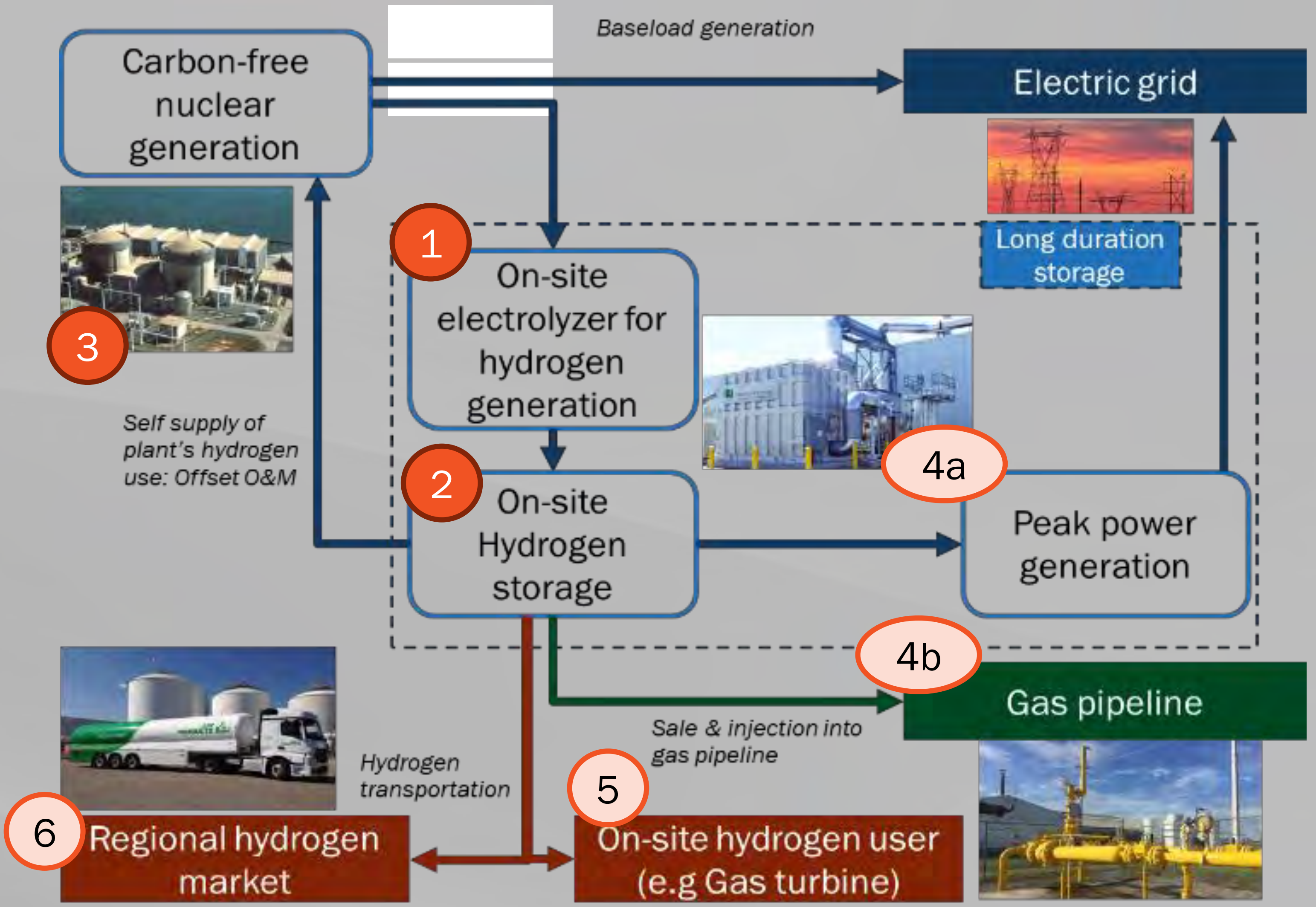
Questions, challenges

- 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

Relevance: The project demonstrates the nuclear production of 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

NMP: Hydrogen Pilot Demonstration Project

Pouring concrete for electrolyzer

Rigging power supply into place

Constellation

NMP: Hydrogen Pilot Demonstration Project

Left: Electrolyzer Area, including backup generator, power supply, and electrolyzer

Right: Cell stack installed.

NMP: Hydrogen Pilot Demonstration Project

Electrolyzer and cooling unit

Compressor

Constellation.

Technology transfer and commercialization activities

- March 7, 2023, 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 560 kg/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).

Constellation

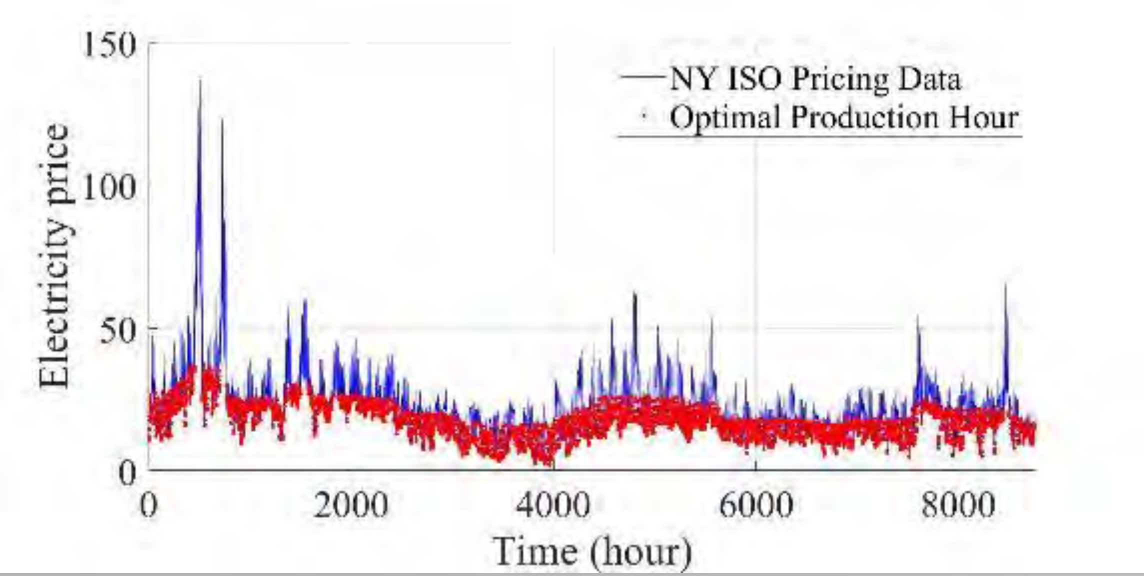
Simulations of Scaled Economic Dispatch Using Front-End Controller

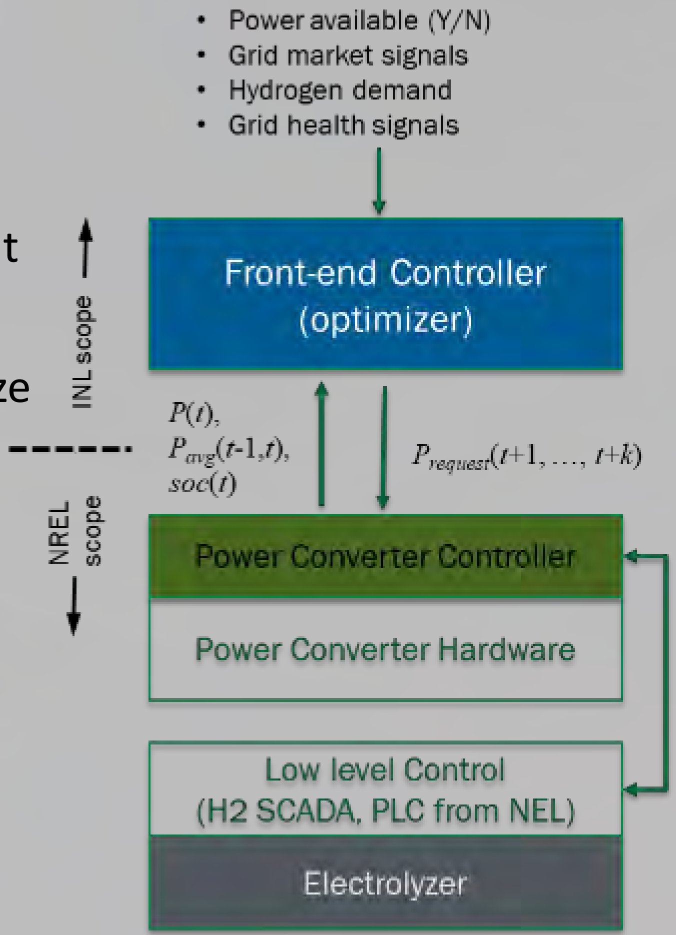
Accomplishments

- 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 approximately constant and buffered by storage.
- Cost projections enable using lowest cost electricity for H_2 production to maximize system profits.

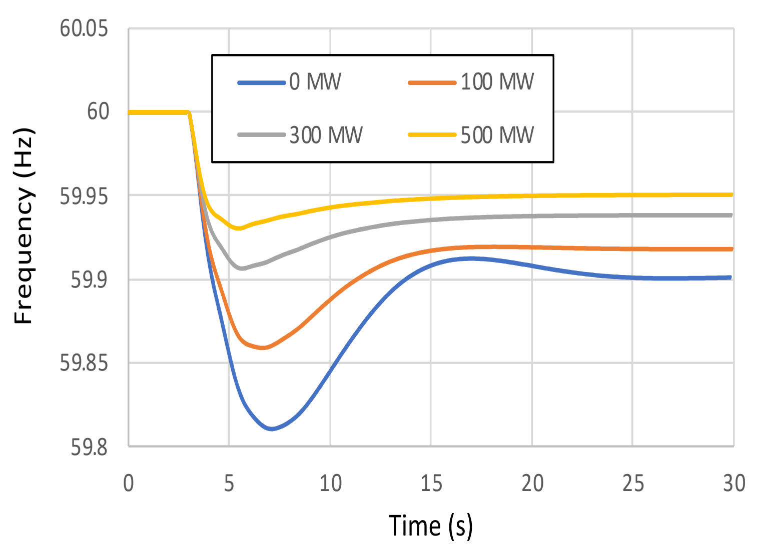




Simulations of Scaled Electrolyzer Demand-Response Dispatch

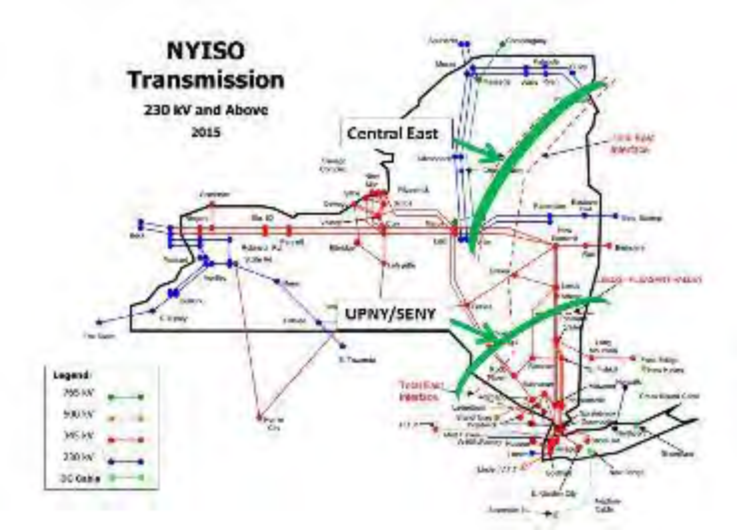
Accomplishments

- Performed transient grid analyses that indicate dynamic operation of scaled PEM system can decrease grid maximum 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

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

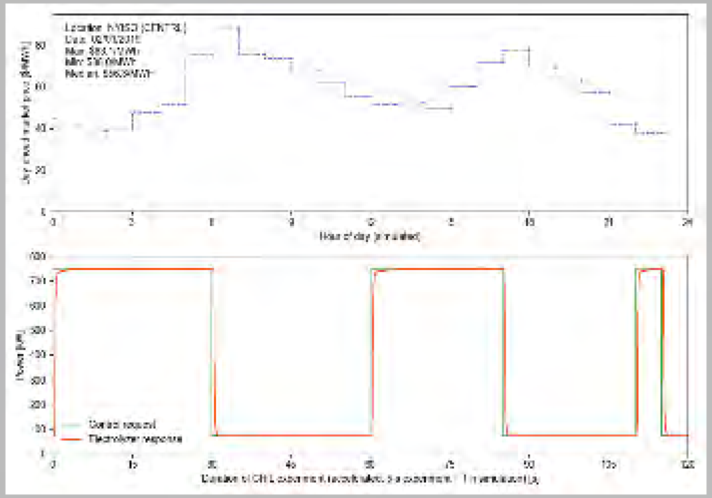


Scenario	Max. Freq. Delta (Hz)
0 MW	0.189
100 MW	0.141
300 MW	0.093
500 MW	0.069

Accomplishments and Progress: NREL

Accomplishments

- 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
- Shared lessons learned regarding water in systems that can freeze and cause damage before systems are ready for operation



Future Work/In Progress

- Provide hardware validation tests at the NREL 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

INL's Energy Technology Proving Ground

*Artist rendition

A demonstration and testbed complex that:

- Validates industrial technologies
- Designs and controls integrated energy systems
- Leverages contributions from nuclear energy beyond electricity
- Integrates and leverages testbeds across the DOE laboratory complex, e.g. NREL-ARIES

Reflections on Past Experience

Past experience in *operational* nuclear cogeneration, reflections and lessons learned

- Precedent has been established for safe, reliable operation of nuclear cogeneration systems.
- Nuclear standards and regulations have evolved since many of these systems operated and must be reviewed as a part of current efforts.
- If possible, it is important to consider heat applications at the design phase of nuclear energy systems to avoid potentially costly retrofitting of a system exclusively designed for electricity production.

See *Summary Report* from the *GIF NEANH Virtual Workshop and Information Exchange on Development of Cogeneration Applications of Gen IV Nuclear Technologies*, July 2022.

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Thank you