Analytic Framework for Optimal Sizing of Hydrogen Fueling Stations for Heavy Duty Vehicles at Ports

PI: Lorin Todd Wall, Ken Rappe (Pacific Northwest National Laboratory)

Team: Ethan Hecht, (Sandia National Laboratory)

John LeCompte (Seattle City Light), David Fujimoto (Port of Seattle)

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DOE Hydrogen Program

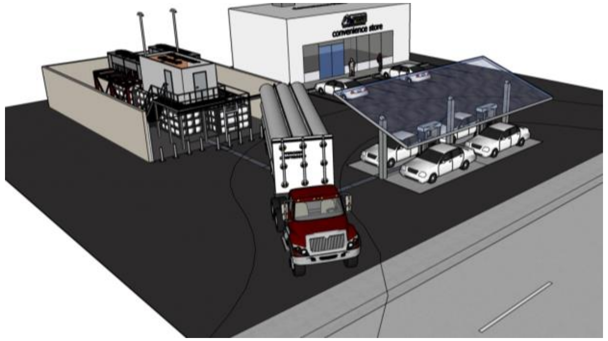
2024 Annual Merit Review and Peer Evaluation Meeting

AMR Project ID #
IN039

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

Project Goal

- Develop framework and guide for sizing and siting industrial hydrogen nodes.
- Specify designs for modular and grid optimized hydrogen nodes employing:
  - PEM electrolysis
  - Compressed gaseous storage
  - Refueling for heavy duty fuel-cell vehicles
  - Fuel cell power generation for grid ancillary services
  - Power grid and refueling resilience during contingencies
- Understand particulars of design, costs, power grid impacts, and impacts of advanced hydrogen plants at U.S. seaports.



Overview

Timeline and Budget

- Project Start Date: 03/31/2021
- FY22 DOE Funding (if applicable): $675k
- FY23 Planned DOE Funding: $675k
- Total DOE Funds Received to Date: $1.35M

Barriers and Targets

- Initiate transition to clean hydrogen for ports and identify potential scale-up opportunities.
- Demonstrate grid impacts of hydrogen production and the extent to which hydrogen can provide grid services.
- Elucidate the dynamic nature and impact of water electrolysis at large scale on the power grid.
- Determine effects of power grid reserve capacity on process design.

Partners

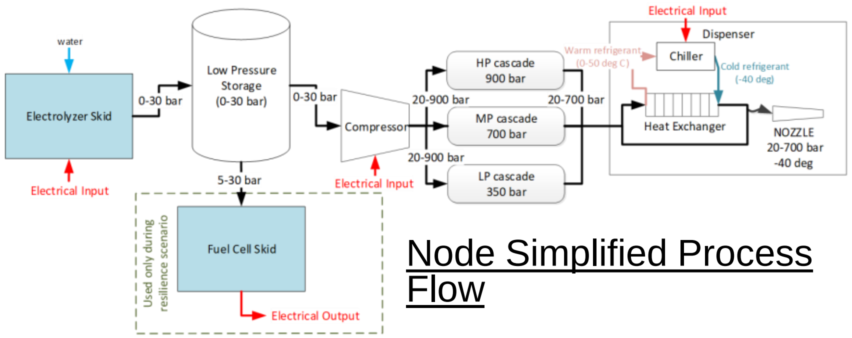
- Pacific Northwest National Laboratory
- Sandia National Laboratories
- Seattle City Light
- Port of Seattle

Potential Impact

- Produce guide for hydrogen stakeholders and potential market participants specifying what is involved in designing and sizing a commercial hydrogen node and its impacts of infrastructure.
- This project will advance DOE HFTO's goals by:
  1. Estimating to what degree hydrogen installations can provide auxiliary savings and alternative fuels to utilities and port operators, thus furthering high impact research areas for achieving Hydrogen Shot's goal of $1/kg.
  2. Identifying pathways to lower greenhouse gas emissions in port operations, vehicles, and vessels.
  3. Providing a qualitative assessment of requirements for siting and constructing clean hydrogen infrastructure.
  4. Better educating the public about the impacts and design particulars of advanced hydrogen nodes, thus advancing private sector participation.
  5. Understand the implications on process design and operational constraints of hydrogen production due to time varying distribution grid capacity and availability. Gain a comprehension of the design modifications and turn down ratios at a component level by conducting power system studies and integration and operations of a hydrogen node on actual distribution feeders. This will provide realistic operational data and design constraints for future commercial node designs.

Approach

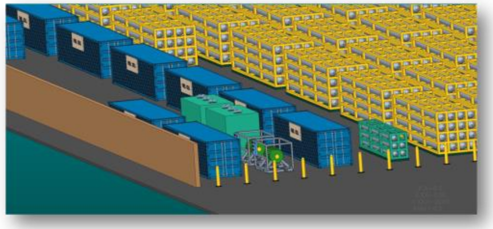
Goal: Produce commercial node employing water electrolysis, low pressure storage, fuel cell for resilience and ancillary services, compression, cascade storage, and vehicle fueling

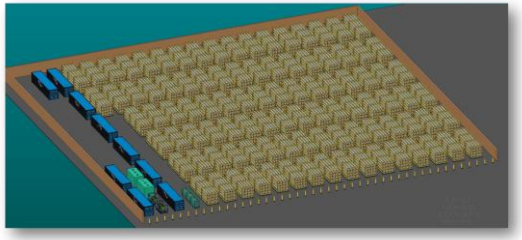


Node Simplified Process Flow

Resilience Plant Footprint

H2 Production, HP Storage, and Refueling Area





Resilience LP Storage,
10 Days, 10,000 kg, 30 bar, 50 kg/hr, 2.5 MW Electrolyzer

Original Approach

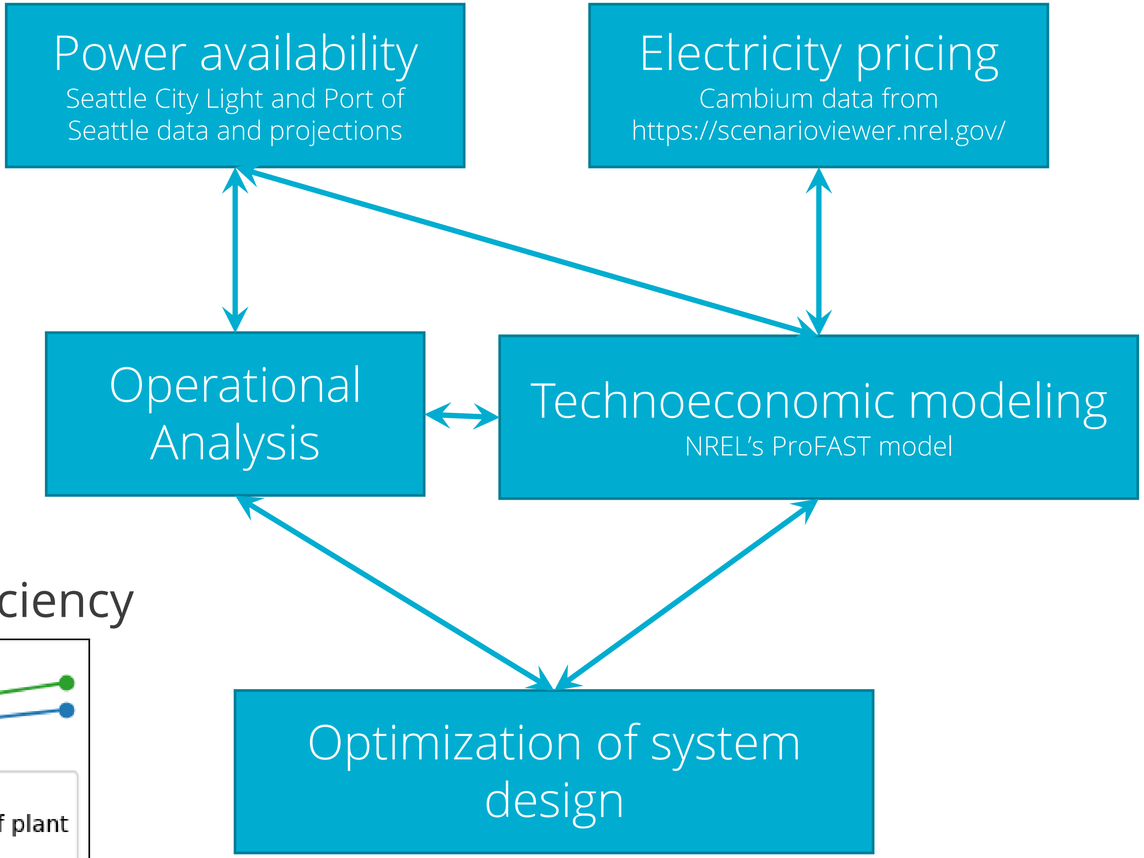
Modular Design	•Apply process design principles to produce modular plant •300 kg/day, 770 kW Electrolyzer, Ancillary Loads
Elucidate Goals for Commercial Scale-Up	•Resilience (10-days) for vehicles & Cranes •Critical grid-connected loads •Peak shaving, Defer Feeder Upgrades •Identify prospective physical locations for node
Scale to Commercial Size	•Use commercial goals as design criteria to scale-up modular design •Specify equipment capacities, footprint, capital ccost, $/kg based on feeder •Develop operational profiles and schedules
Conduct Grid Modeling and Node Impacts	•Build power system models and apply to existing feeder model(s) •Conduct time series and dynamic modeling representing operational profiles of node •Identify grid violations and areas of concern
Assess Ancillary Services	•Ascertain degree to which commercial node can support grid services dependent on resilience and refueling goals

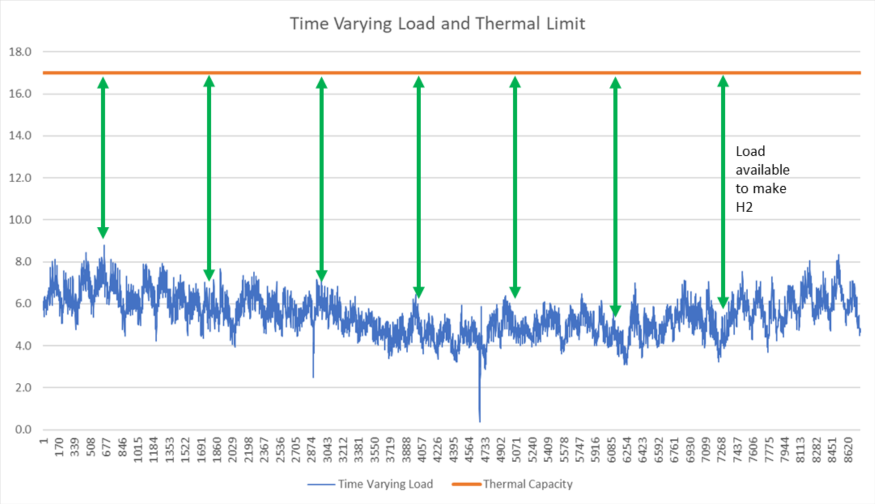
Revised 2024 Approach

Elucidate Goals for Commercial Scale-Up	•Feeder reserve capacity determines node capacity •Node size directly proportional to time-varying load on feeder and reserve capacity •Identify design implications, e.g., turn down ratio requirements, mass balance
Scale to Commercial Size	• Determine available H2 production rates based on feeder availability • Produce process commercial design • Peak shaving, Defer Feeder Upgrades

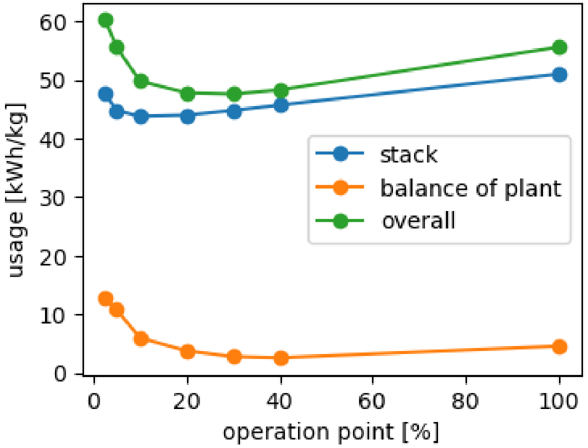
Approach: Using power availability and economics to optimize hydrogen node design

- Power availability at the port is constrained
- System design can be greatly impacted by operations and vice-versa
- Economics are a driver for decision making
- Currently focusing on production – the largest H_2 node power draw



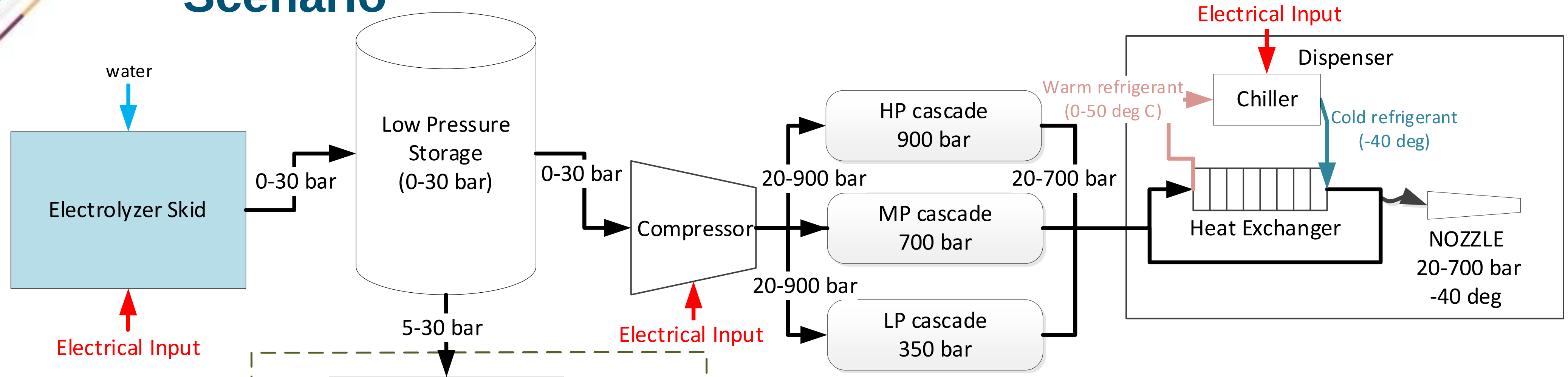


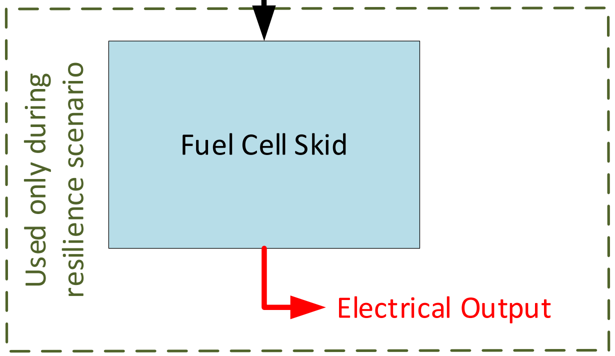
PEM electrolyzer efficiency



Data from Badgett et al. 2023

Accomplishment: Developed Hydrogen Node Design for Resilience Scenario





Resilience scenario: backup power for 10 days of critical container movement

10x drayage trucks fuel cell electric

1x STS crane direct electric

2x RTG crane direct electric

5x yard trucks battery

2x top/side-picks battery

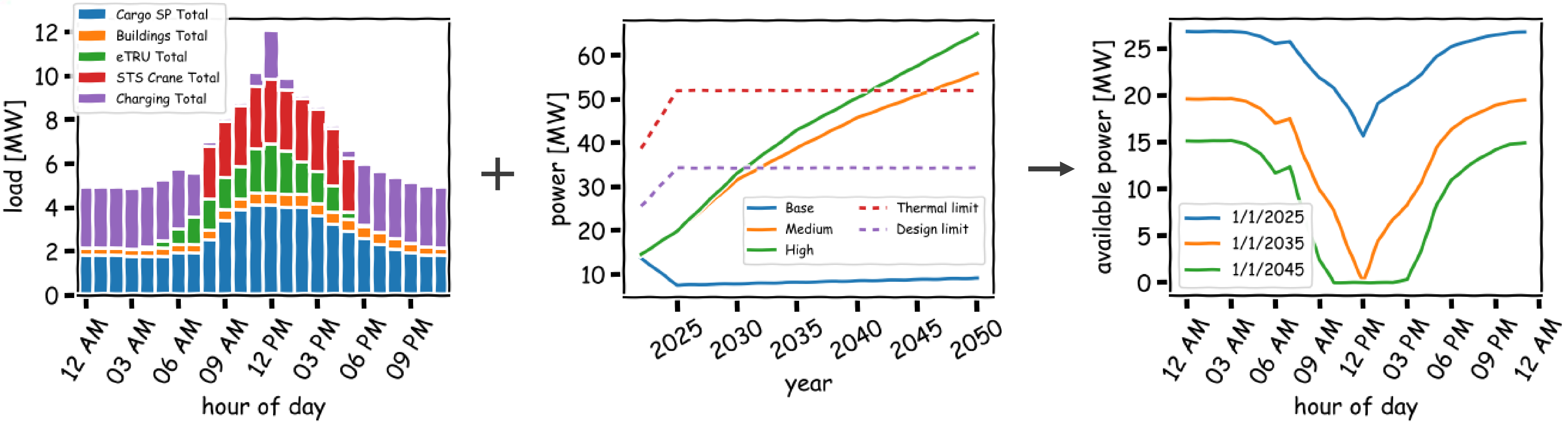
10x reefer direct electric

5x car EV battery

5x pickup EV battery

*images for illustrative purposes only. No specific systems have been used for analysis

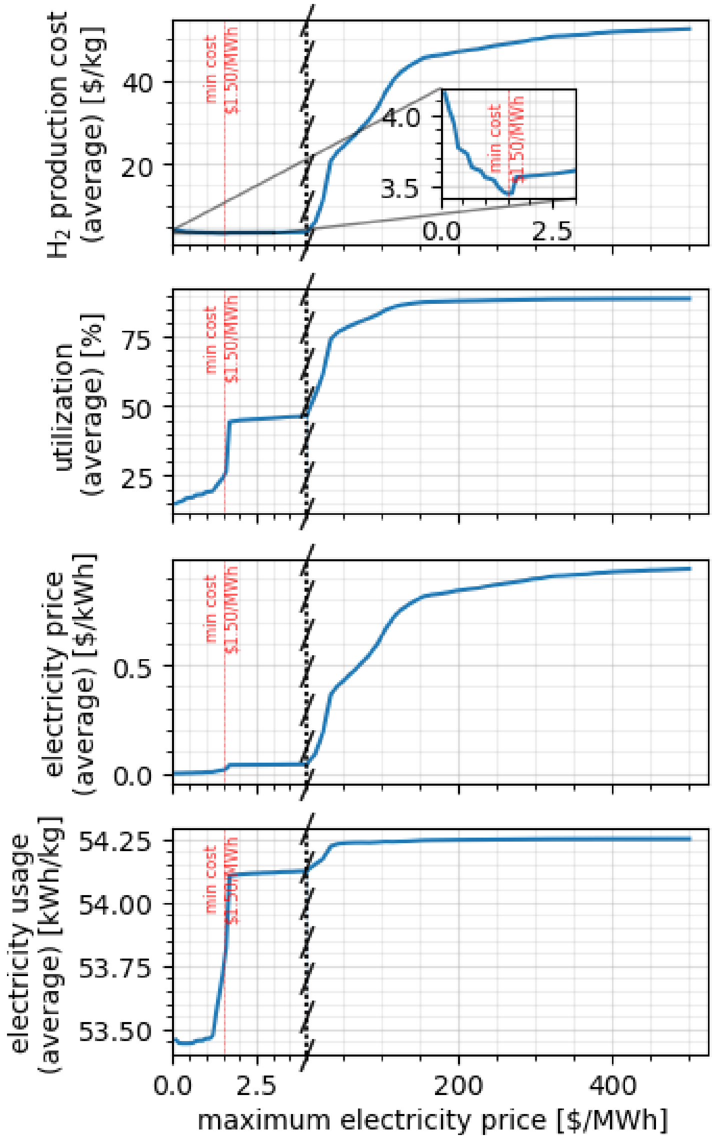
Accomplishment: Developed constraints on power availability



- Hourly load shape is specified
- Load growth is and limits are specified, with load shape remaining constant
- Power available is difference between feeder design limit and power used
- Provides constraints on power available for hydrogen operations (e.g., generation, compression)

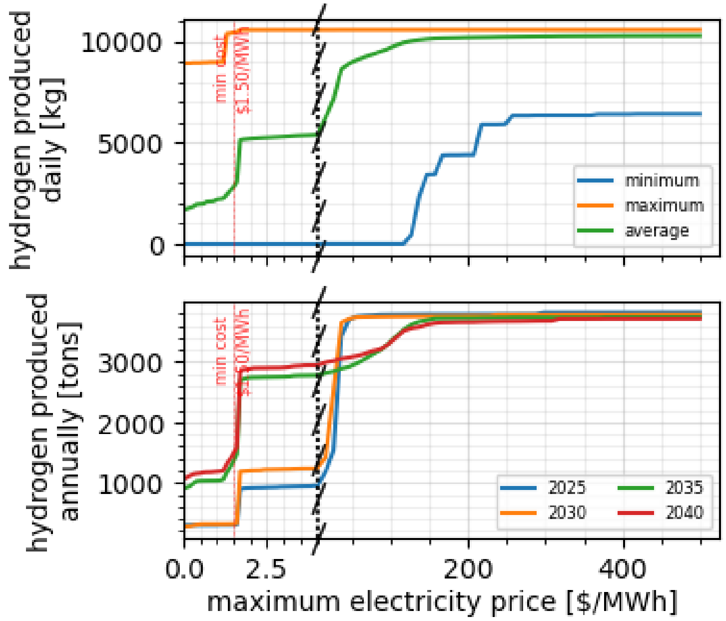
Accomplishment: As proof of concept, we calculated the levelized cost of hydrogen for a maximum energy purchase price

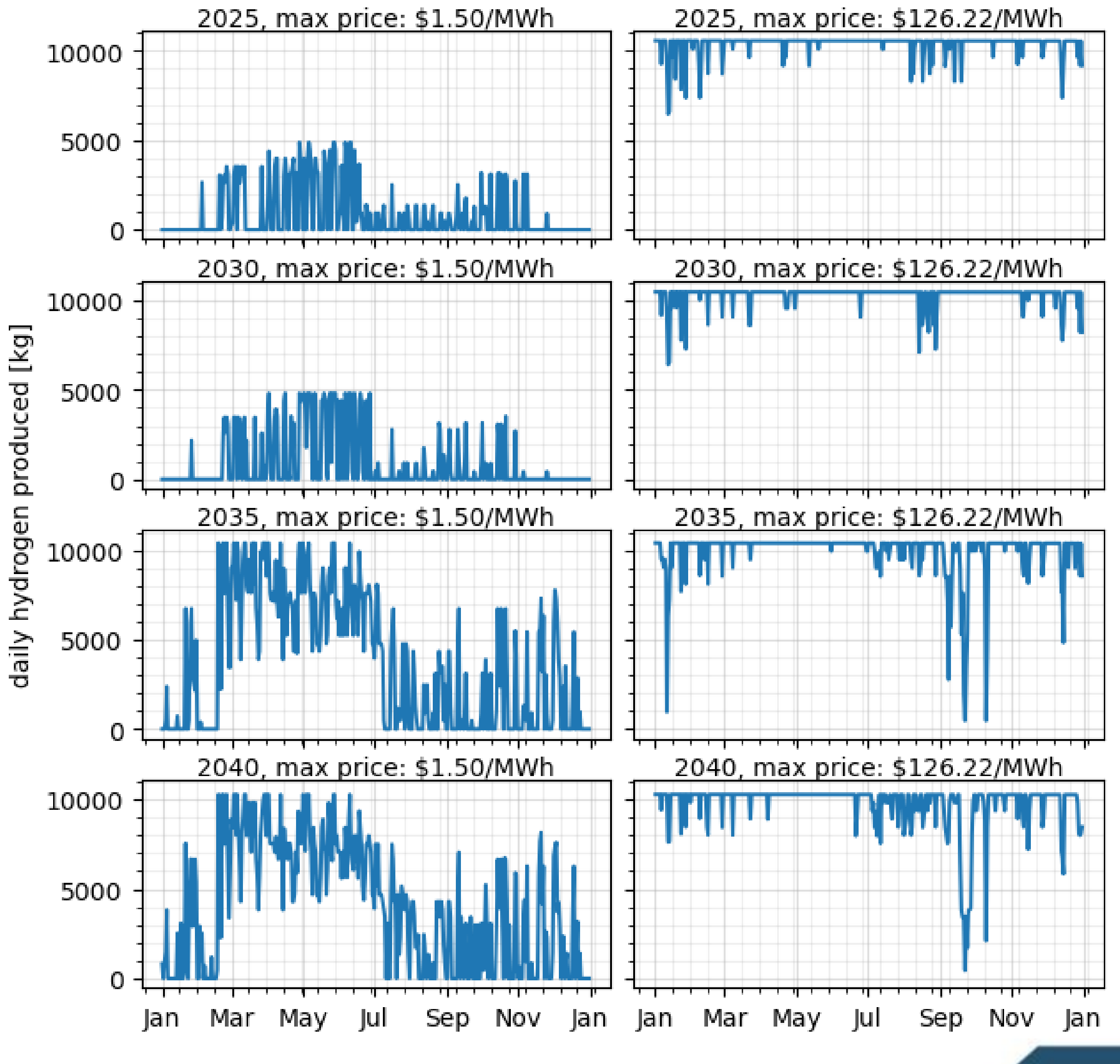
- Assumptions:
  - 20 yrs of operation
  - 26.8 MW electrolyzer
  - Electrolyzer uses excess capacity to feeder design limit if electricity price is low enough
- Minimum production cost of $3.45/kg, at a maximum electricity price of $1.50/MWh
  - 24% average utilization (6.5 MW)
  - $0.0161/kWh average electricity price
  - 53.7 kWh/kg average electricity usage
- Other production strategies not yet explored (e.g., turning down production when electricity costs are high rather than ceasing production)



Accomplishment: Although price can be minimized, there are other considerations, such as daily hydrogen production

- Additional constraints or other operation strategies are likely necessary for optimizing production
- By setting a maximum price, there are days when no hydrogen is produced (especially when optimized for H_2 price)
- Depending on storage and usage of hydrogen, system design may not be acceptable





Response to Previous Year Reviewers' Comments

Comment	Response
The project should consider adding pathways for safe foot traffic (for work operations) and safe entrance and exit for the vehicular traffic (for operations) early in the project to adequately address safety concerns. Adding pathways for first responders early in the process could also be considered. The project should also consider adding accommodations for sea level rise early in the project	The project will consider the NFPA-2 requirements after the commercial scale process design has been completed. At the time of last year's AMR, the team had only concluded the design capacity for resilience, therefore the additional capacity for daily refueling and grid support had not been identified. The issues of safety, setbacks, and pathways will be addressed after the final process design has been achieved.
The project should consider including underground storage and barge-mounted storage options. The project should consult with the DOE HFTO Safety Codes & Standards program on overall design and with the Storage & Delivery program on realistic storage options.	The process design was in the very early stages during the 2023 AMR session, and the storage options were still being weighed. As mentioned above the process design of the scaled-up plant had not been developed and input data were still being collected, therefore the final layout had not been specified.

Collaboration and Coordination

	Partner	Function
	Pacific Northwest National Laboratory	Prime, Grid Modeling, Power System Impacts, Design Assistance
	Sandia National Laboratories	Partner Laboratory, Process Design, Plant Layout, Component Sizing, Siting
	Seattle City Light	Private Partner, Electric Utility, Power System Owner
	Port of Seattle	Private Partner, Port Operator
Industry Advisors and Stakeholders	Pacifica, Par Pacific, Fortescue Future Industries	Industry Advisors, Design and Plant Siting Assistance

Remaining Challenges and Barriers

- The project had to modify the original strategy to shift from end-use goals (resilience and grid support) as node design input to using distribution operations as the primary design criteria. Carrying out this shift within the remaining time will be a challenge. However, the team has all the required resources in hand.
- The distribution feeders in the Seattle Port area carry a great deal of robust design in excess of less industrial designed distribution feeders; the team will need to make the results of this project applicable by conducting analyses consistent with the less robust designs such as feeders that serve residential and commercial load sectors.

Proposed Future Work

- Conduct data analyses on 1-minute feeder loading data to identify operational periods that could have beneficial or detrimental effects on node subsystem design and operational schedules.
  - Evaluate multiple electrolyzer scenarios, as well as variations in electrolyzer sizing and operation
  - Design compression, storage, and cooling operations
- Complete the design and optimization of a hydrogen node at the Port of Seattle
- Publish the framework for hydrogen node optimization so that analyses are broadly applicable
  - Specifically, develop and publish method of designing and optimizing node to distribution feeder time-varying loading and correlate with resulting design constraints.

*For **new projects**, this criterion counts for 25% of your score.

Summary

- The conceptual designs and guides developed during this project incorporating hydrogen electrolysis, fuel-cell power system support/services, large-scale storage, and hydrogen refueling will better equip the private industry to adopt and pursue clean energy hydrogen capital projects.
- The two primary approaches to this project are:
  - Establish conceptual hydrogen plant designs to better integrate with realistic distribution feeders while optimizing hydrogen node size and operational profiles.
  - Assess long term and immediate grid impacts of larger scale hydrogen developments.
- This project has produced:
  - Modular and commercial hydrogen plant designs including component sizes and plant footprints for resilience.
  - Groupings of distribution feeder models and grid-connected load profiles to assess grid impacts of advanced hydrogen plants.
  - Results of industry collaboration including hydrogen industry experts and developers, electric utilities, and U.S. seaport operators and stakeholders.
  - Data analyses of 1-minute distribution feeder SCADA data for load trends which will inform node process design.
- The two primary areas left to complete are:
  - Assess the process design implications of time varying grid capacity on the hydrogen node at a component level.
  - Assess the grid impacts of optimized hydrogen plant.