Conventional Reactors and Hydrogen Production

Bethany Frew

ESIG Spring Technical Workshop

Online webinar

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Acknowledgments

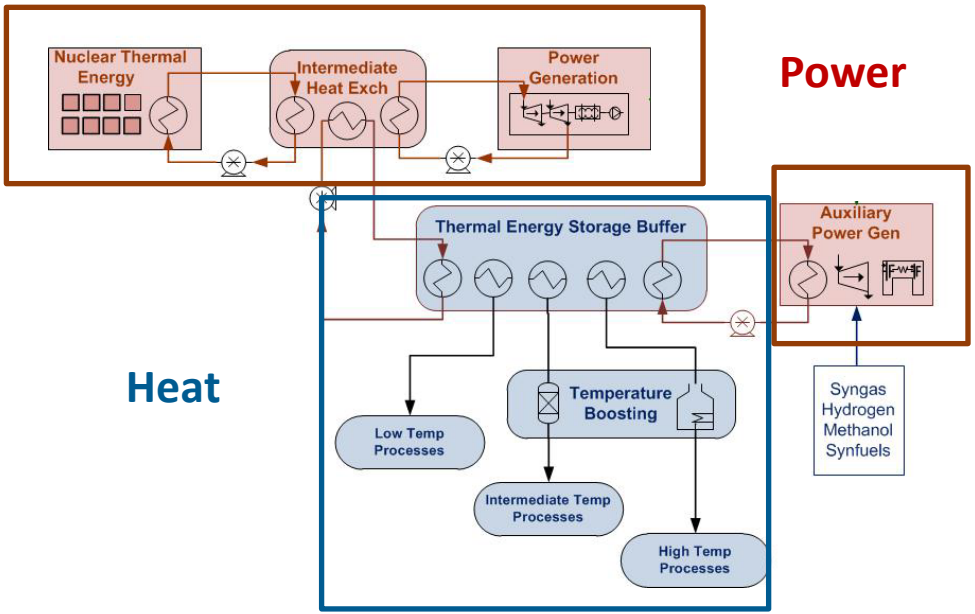
- **NREL**: Mark Ruth (PI), Daniel Levie, Jal Desai, Owen Zinaman, Doug Arent

- **Project partners**: Idaho National Laboratory, Argonne National Laboratory, Xcel Energy (Colorado Public Service and Northern States Power), Southern Company, Exelon, EPRI

- **Funding**: DOE Fuel Cell Technologies Office

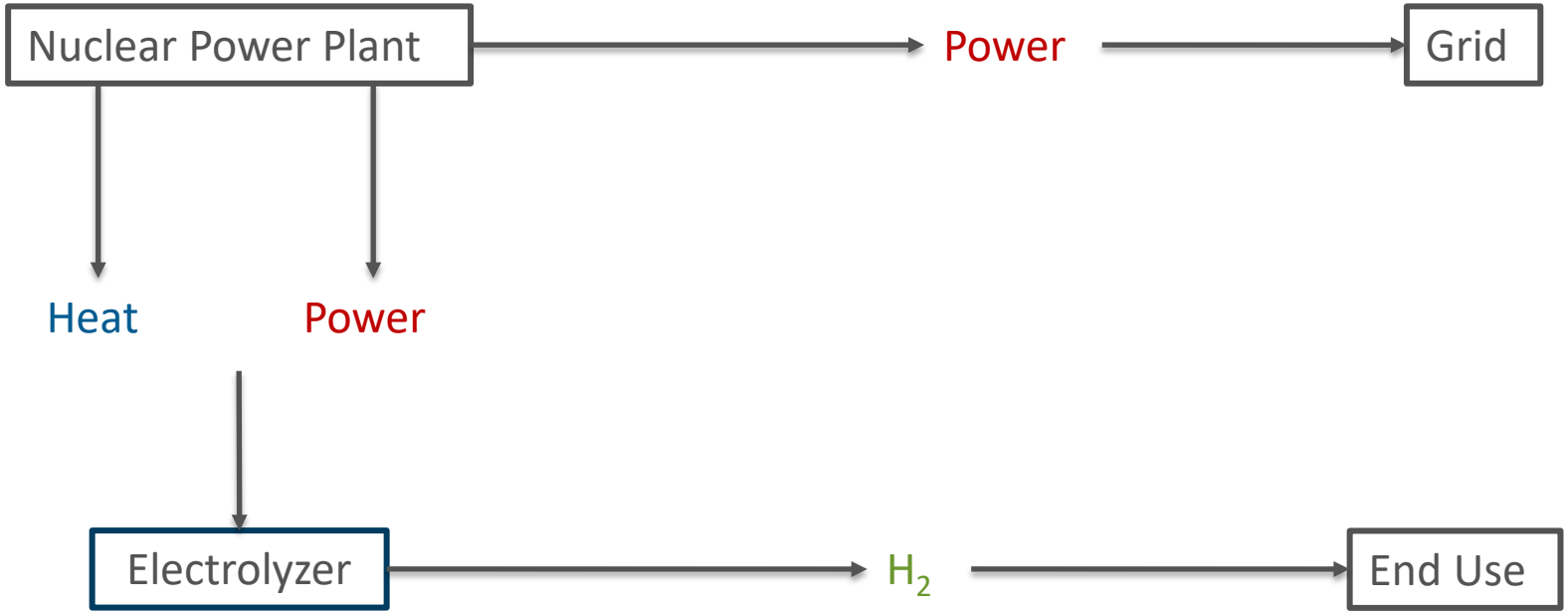
Tightly-Coupled Hybrid Energy Systems

Individual facilities which take **two or more energy resources as inputs** and **produce two or more products**, with at least one being an energy commodity such as electricity or a transportation fuel

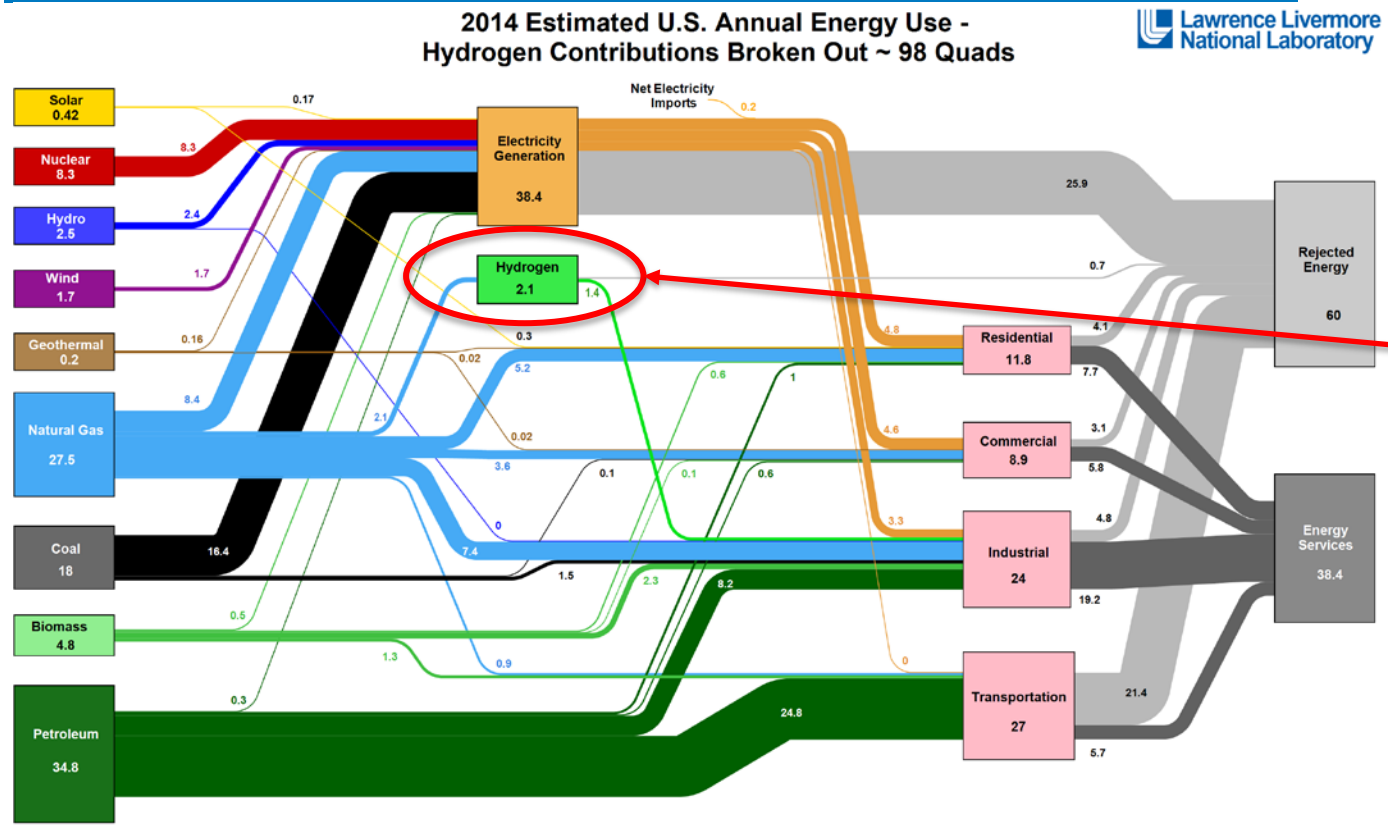


Source: RUTH, Mark F., ZINAMAN, Owen R., ANTKOWIAK, Mark, BOARDMAN, Richard D., CHERRY, Robert S., BAZILIAN, Morgan D. "Nuclear-renewable hybrid energy systems: Opportunities, interconnections, and needs," Energy Conversion and Management, Volume 78, February 2014, Pages 684-694, ISSN 0196-8904, http://dx.doi.org/10.1016/j.enconman.2013.11.030. (http://www.sciencedirect.com/science/article/pii/S0196890413007516)

Nuclear-Hydrogen Hybrid System



Why do we care about hydrogen (H_2)?



2% of U.S. primary energy use goes to producing H_2

…and there's a lot of room for growth

Demand potential of H_2 market by 2050 is >9X

Other applications are possible based on technology and policy growth as well as smaller applications

Application	2050 Demand Potential (MMT/yr)	2015 Market for On-Purpose H2 (MMT/yr)
Refineries and the chemical processing industry (CPI) [a]	8	6
Metals	12	0
Ammonia	4	3
Biofuels	4	0
Synthetic fuels and chemicals	14	1
Natural gas supplementation	10	0
Seasonal energy storage for the electricity grid	15	0
Industry and Storage Subtotal	**67**	**10**
Light-duty fuel cell electric vehicles (FCEVs)	21	0
Medium- & Heavy-Duty FCEVs	11	0
Transportation Fuel Subtotal	**32**	**0**
Total	**99**	**10**

Preliminary Results

Source: Ruth, Mark, et al. The Technical, Demand, and Economic Potential of H2@Scale within the United States. Nov. 5, 2019. H2@Scale Workshop at the Fuel Cell Seminar. Long Beach, CA.

Definition: The demand potential is the estimated market size constrained by the services for which society currently uses energy, real-world geography, system performance, and by optimistic market shares but not by economic calculations.

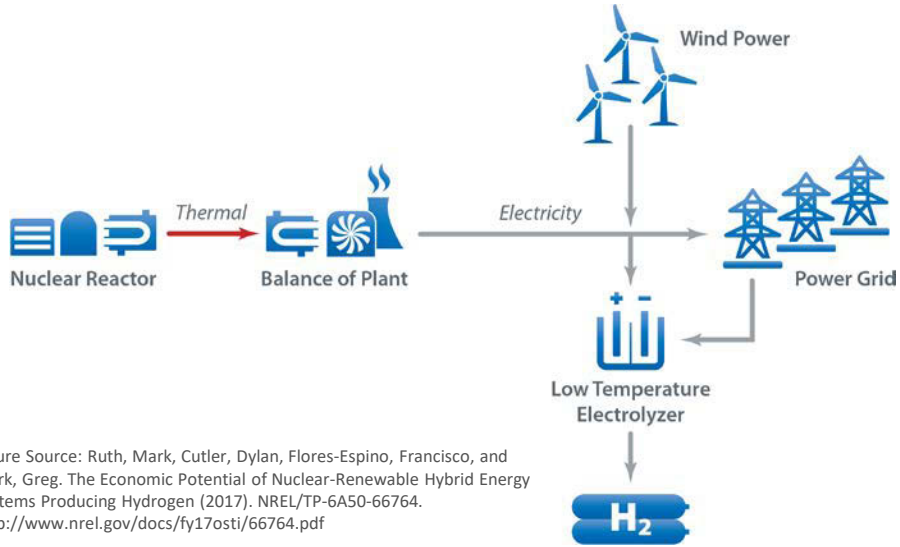
Two options for H_2 Production

LTE (low temperature electrolysis)

- lower efficiency
- lower costs
- more nimble and simpler to integrate

HTE (high temperature electrolysis)

- higher efficiency
- currently higher cost but could end up lower due to low-cost catalyst
- less nimble



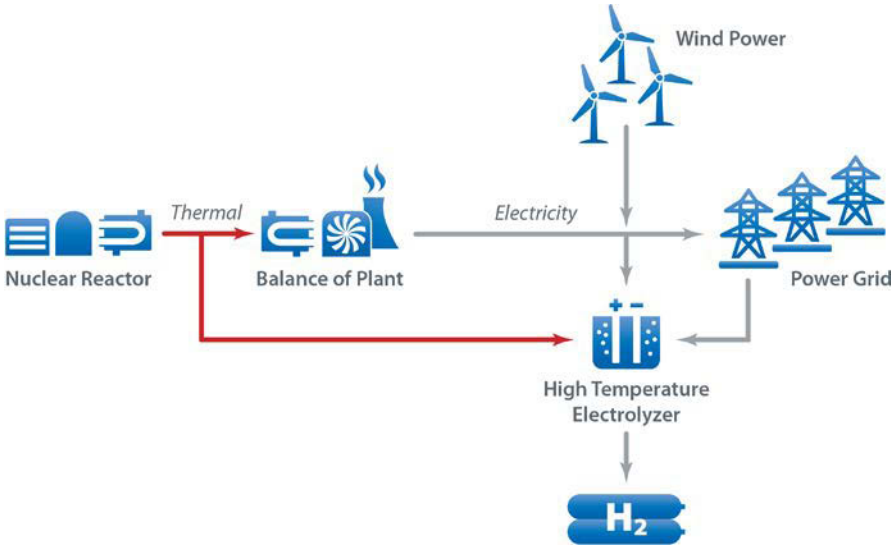
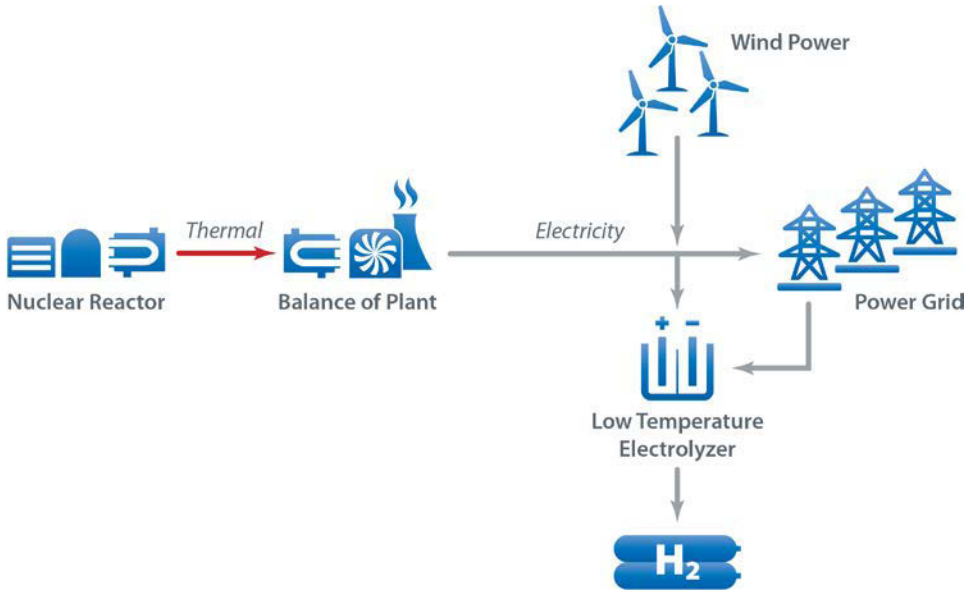


Figure Source: Ruth, Mark, Cutler, Dylan, Flores-Espino, Francisco, and Stark, Greg. The Economic Potential of Nuclear-Renewable Hybrid Energy Systems Producing Hydrogen (2017). NREL/TP-6A50-66764. http://www.nrel.gov/docs/fy17osti/66764.pdf

Potential Benefits of Hybridization

Dynamically adjust product slate to maximize income

- When the price of electricity is high, maximize generation to the grid (minimizing H_2 production)
- When the price of electricity is low, maximize H_2 production (minimizing electricity to the grid)
- May become a H_2 plant that provides peaking capacity to the grid



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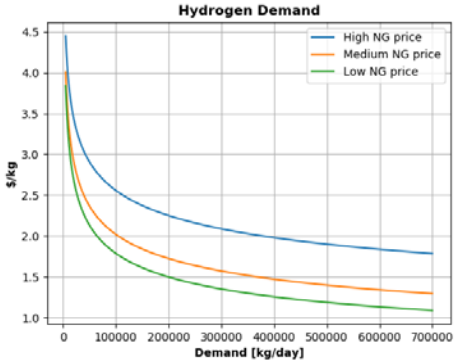
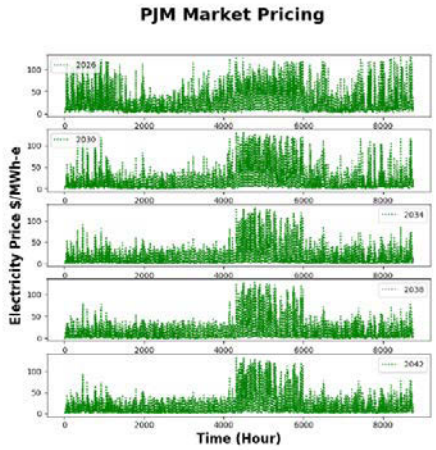
NREL and others are analyzing both LTE and HTE options

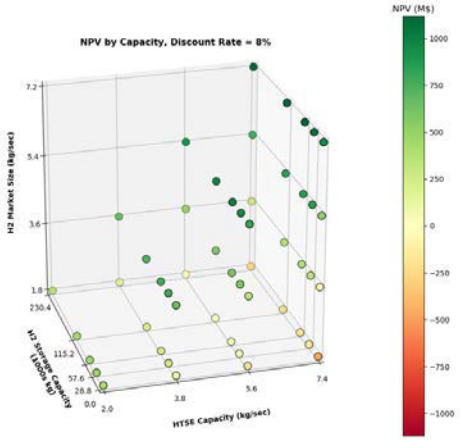
H_2 Market Assessment
ANL



Electricity Price Estimation
NREL



Techno-economic Analysis
INL



NPV Profitability

Source: Frick et al. "Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest" (2019). https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_18785.pdf

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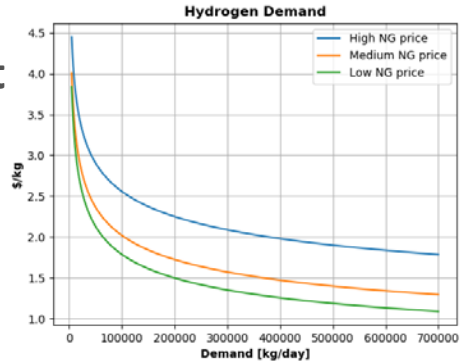

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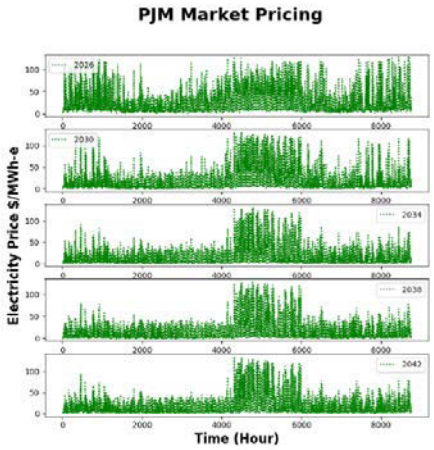

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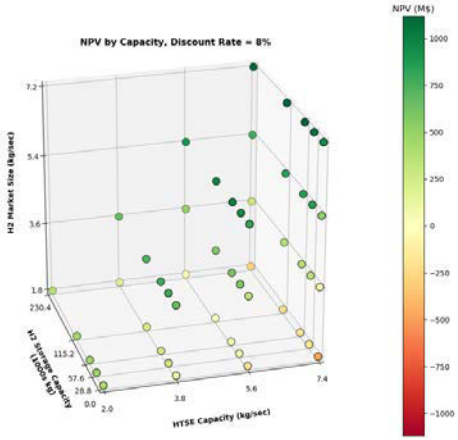

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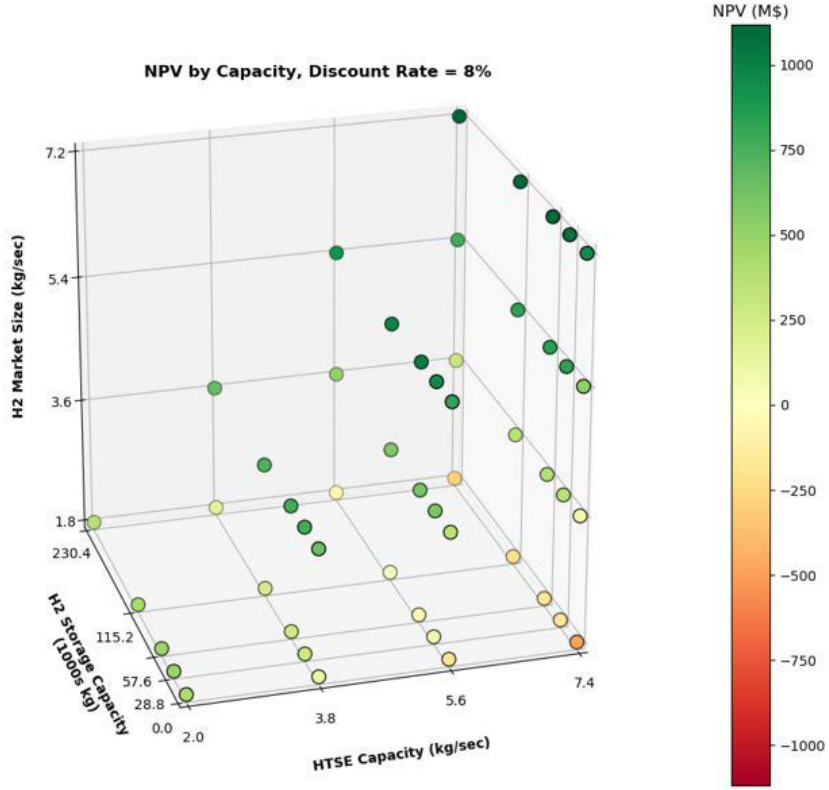
Techno-economic Analysis (INL)

- Goal is to design hybrid nuclear-H_2 system to maximize net present value (NPV)
- 3 dimensions: H_2 market size, H_2 storage capacity, and electrolyzer size
- Profitability depends on:
  - H_2 vs. electricity market prices
  - Aligning electrolyzer size with H_2 demand
  - Proper sizing of H_2 storage
- **Key finding: nuclear power plants have the *potential* to substantially increase current profit margins by hybridizing and producing H_2**



Source: Fig 46 (p.75) from Frick et al. "Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest" (2019). https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_18785.pdf

Thank you!

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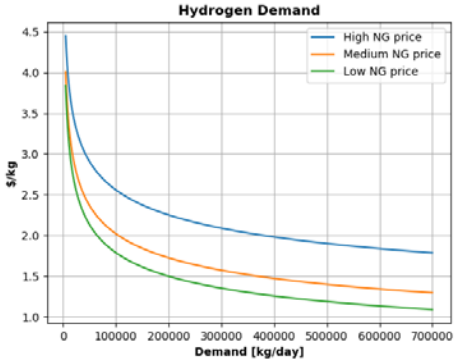
Extra Slides

NREL and others are analyzing both LTE and HTE options

H2 Market Assessment
ANL



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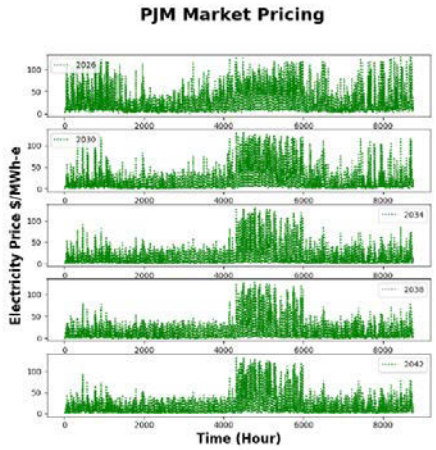

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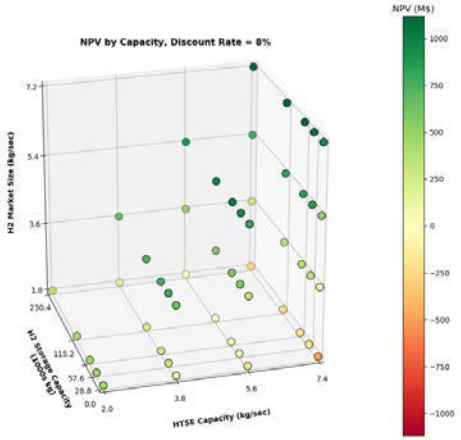

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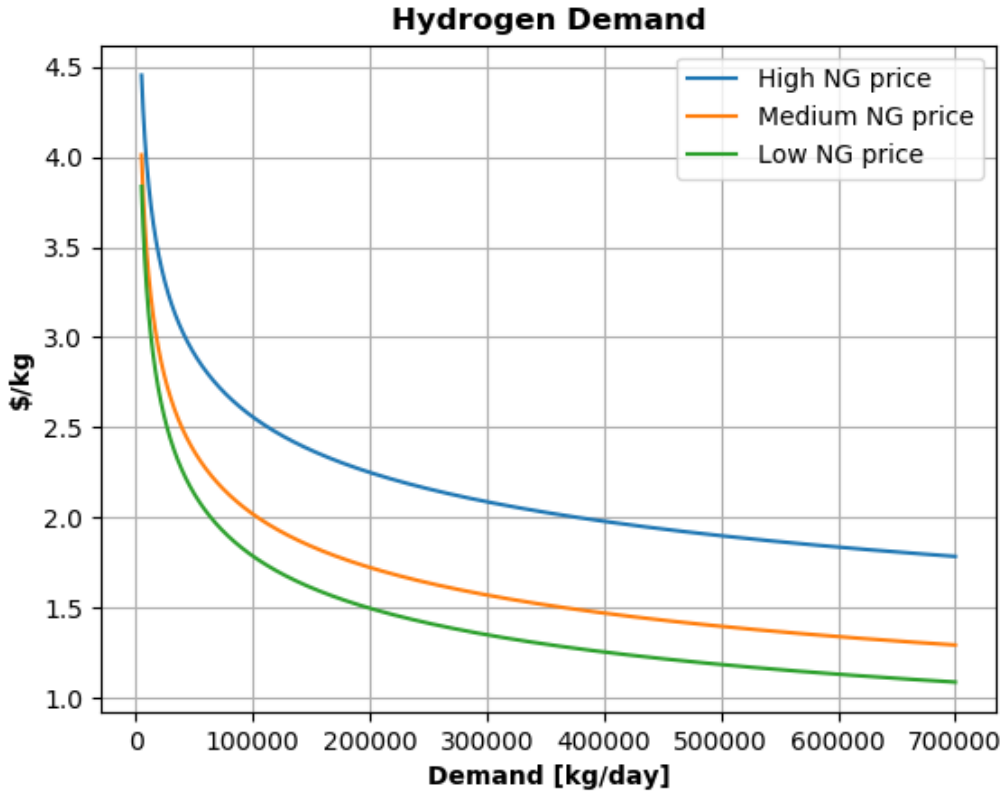

Source: Fig 24 (p.38) from Frick et al. "Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest" (2019). https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_18785.pdf

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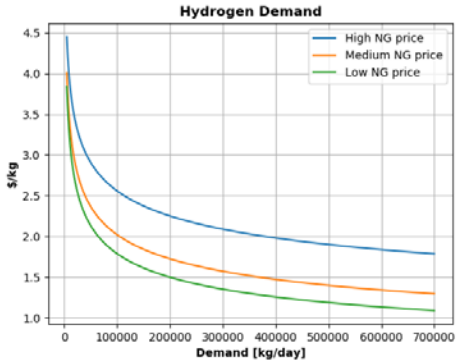

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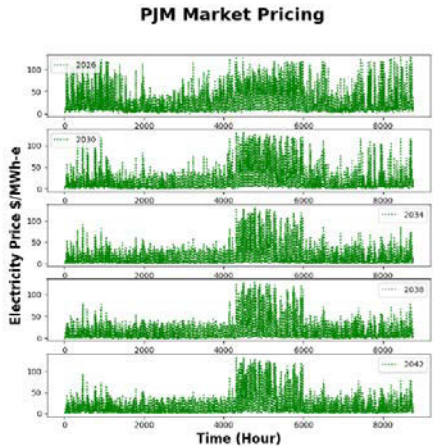

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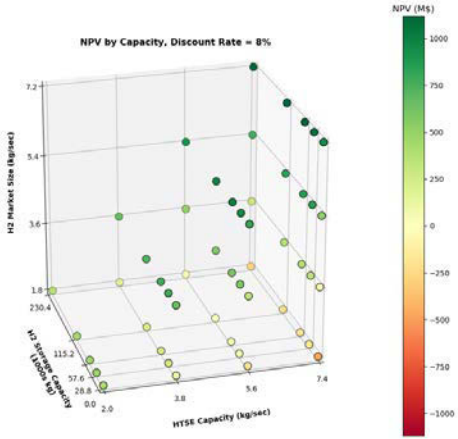

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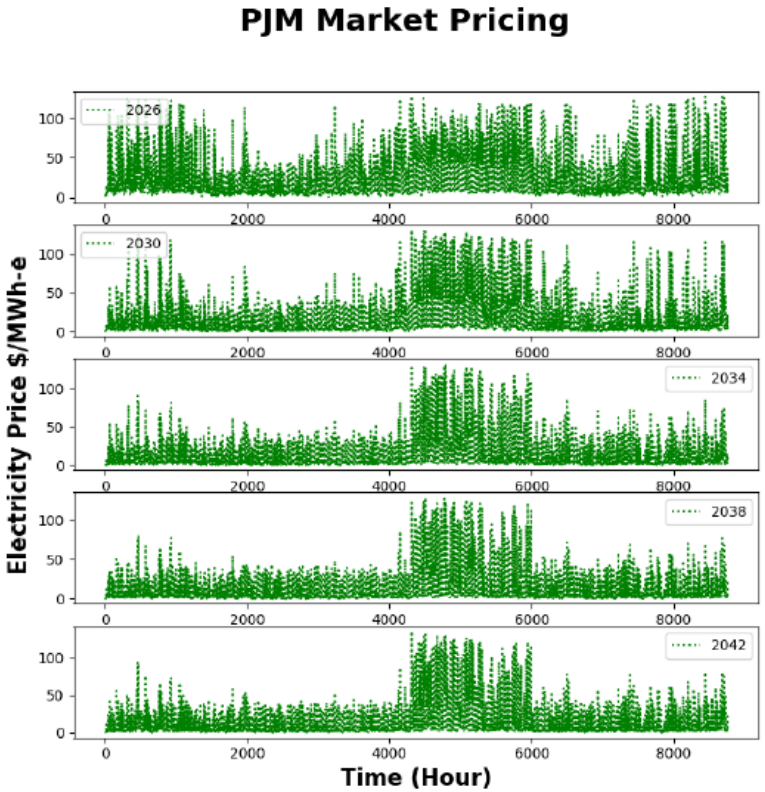
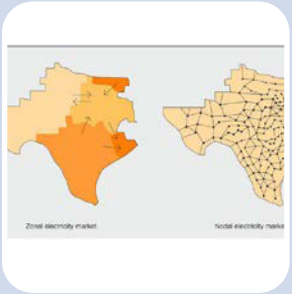
Electricity price estimation (NREL)

- Evaluate 5 future years
- Use nodal production cost model of Eastern Interconnection to estimate locational prices for energy and 3 operating reserve products (regulation, spinning, and flex)
- Use historic capacity market prices from 2018-2022 auctions



Source: Fig 33 (p. 52) from Frick et al. "Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest" (2019). https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_18785.pdf

Nuclear Electricity Market Analysis



Converts ReEDS outputs for each year and into an input database for PLEXOS

Identifies capacity retirements and additions in ReEDS results

Previous method: 205 balancing areas only thus zonal production cost modeling only

Now: Divides the balancing areas into individual nodes in the current North American transmission system.

Result: Higher resolution PLEXOS model – improves analysis of impacts on a specific generator