Conventional Reactors and Hydrogen Production

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Online webinar

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Acknowledgments

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

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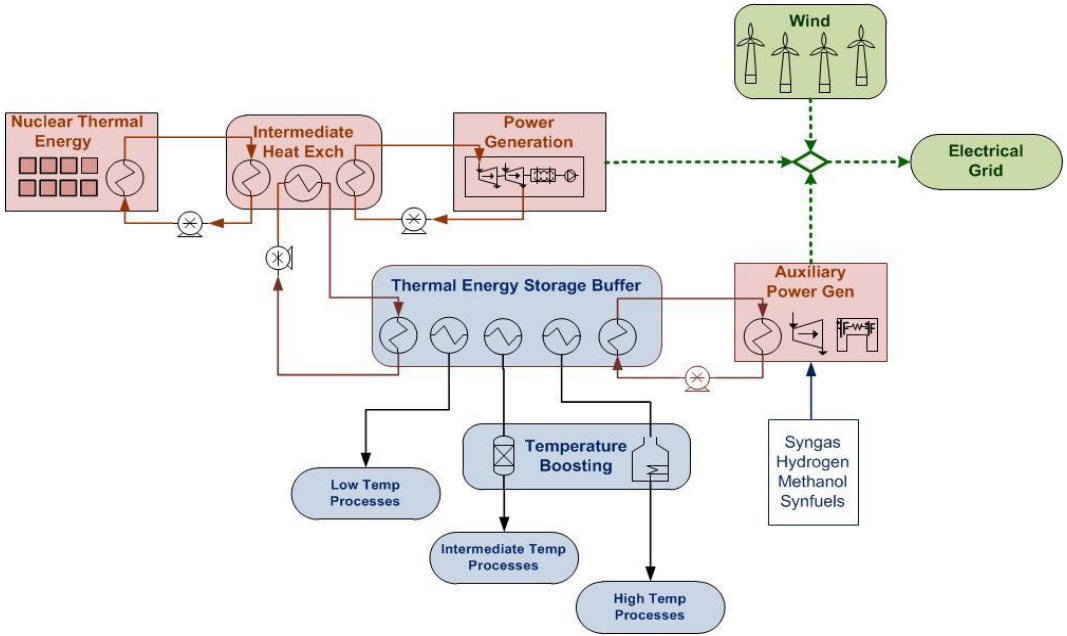
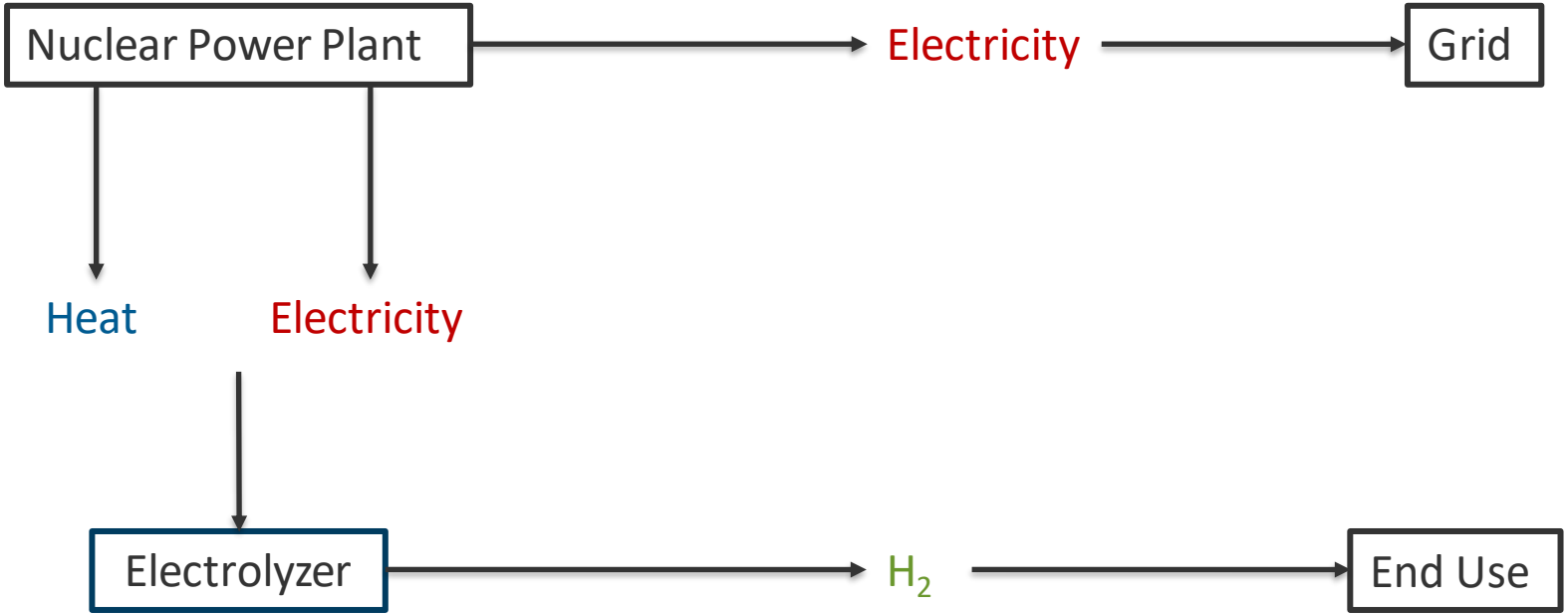
Tightly-Coupled Hybrid Energy Systems

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

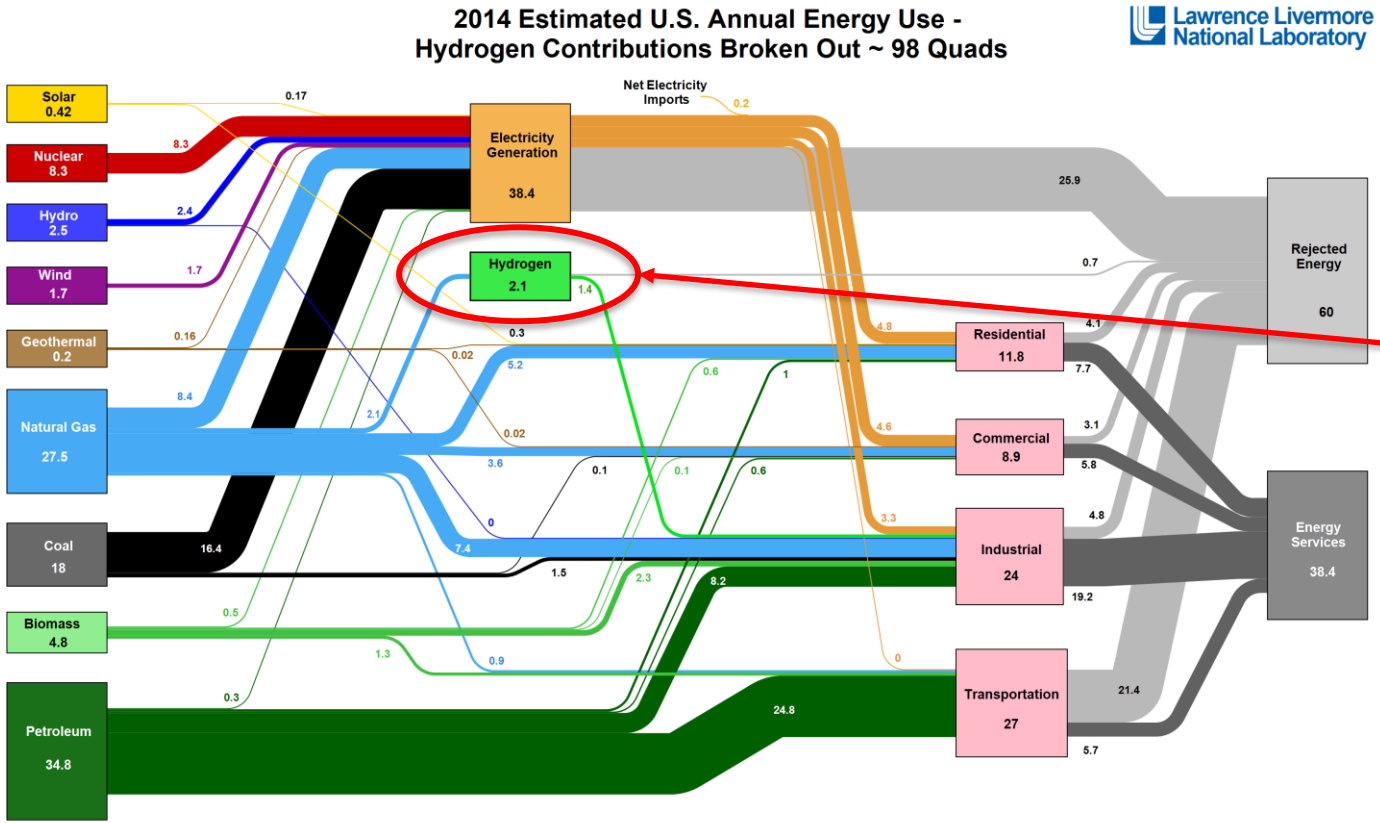


Source: RUTH, Mark F., ZINAMAN, Owen R., ANTKOWIAK, Mark, BOARDMAN, Richard D., CHERRY, Robert S., BAZILIAN, Morgan D. "Nuclear-renewable hybrid energy systems: Opportunities, interconnections, and needs," Energy Conversion and Management, Volume 78, February 2014, Pages 684-694, ISSN 0196-8904, http://dx.doi.org/10.1016/j.enconman.2013.11.030.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

Nuclear-Hydrogen Hybrid System



Why do we care about hydrogen (H_2)?



Source: LLNL September 2015. Data is based on DOE/EIA-0035(2015-03) and Annual Energy Outlook DOE/EIA-0383(2014). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate". The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-676987

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.

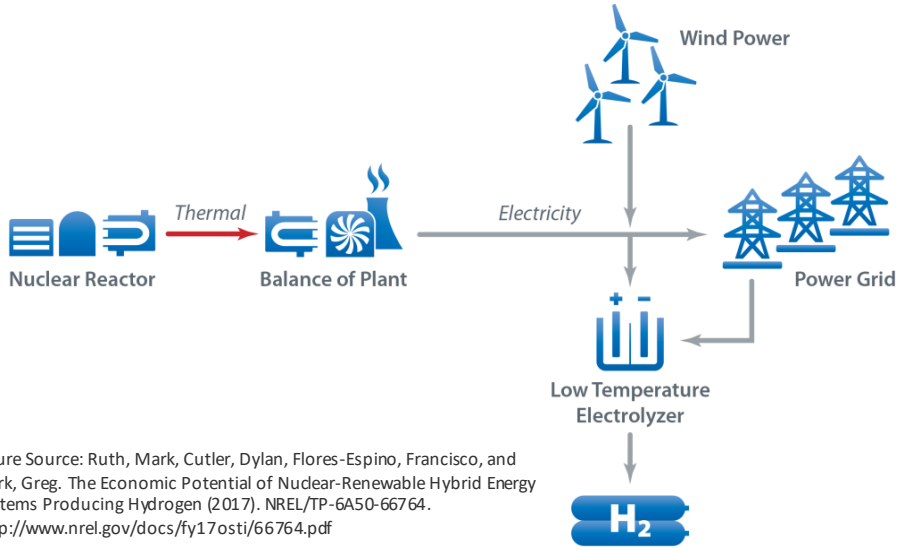
Two options for H_2 Production

LTE (low temperature electrolysis)

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

HTE (high temperature electrolysis)

- higher efficiency
- currently higher cost, with potential for improvement through cell component R&D
- less nimble



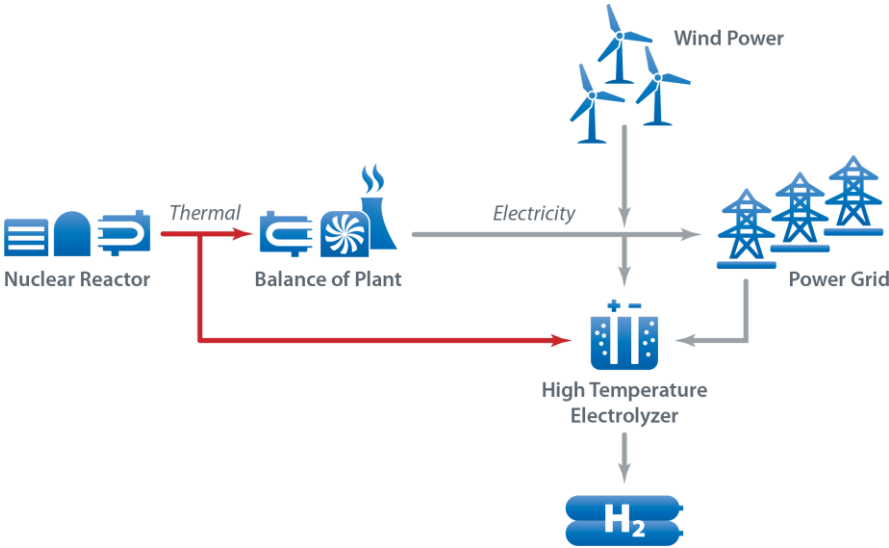
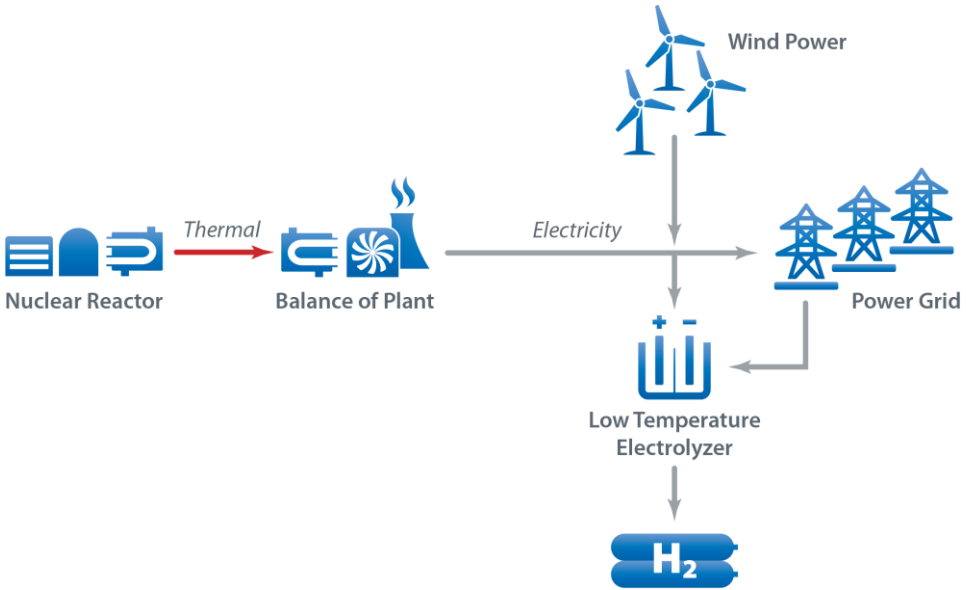


Figure Source: Ruth, Mark, Cutler, Dylan, Flores-Espino, Francisco, and Stark, Greg. The Economic Potential of Nuclear-Renewable Hybrid Energy Systems Producing Hydrogen (2017). NREL/TP-6A50-66764. http://www.nrel.gov/docs/fy17osti/66764.pdf

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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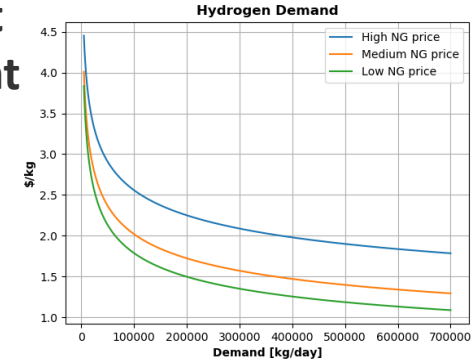
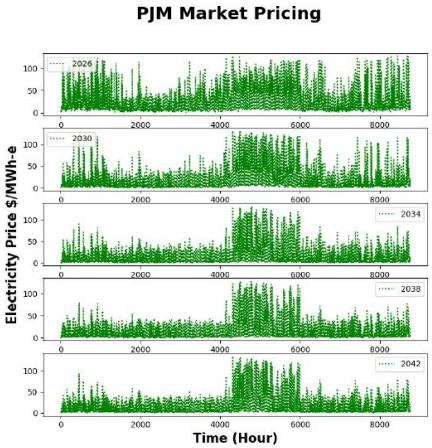
NREL and others are analyzing both LTE and HTE options

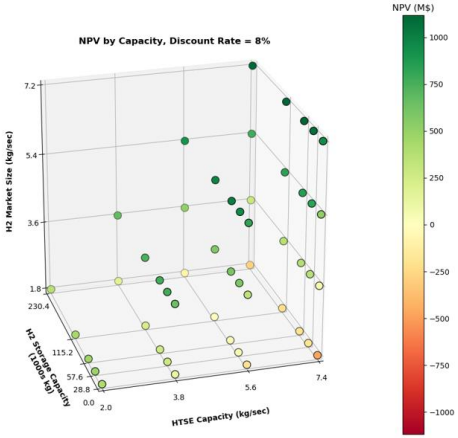
H_2 Market Assessment
ANL



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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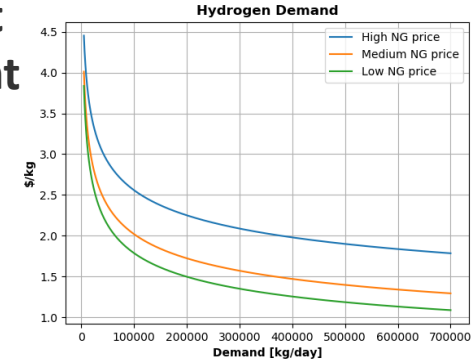

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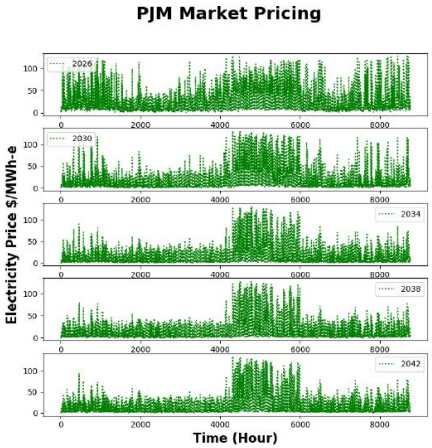

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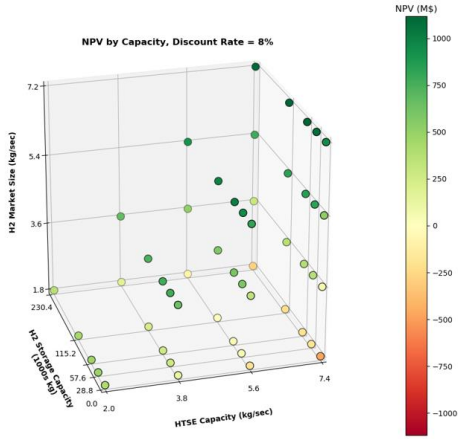

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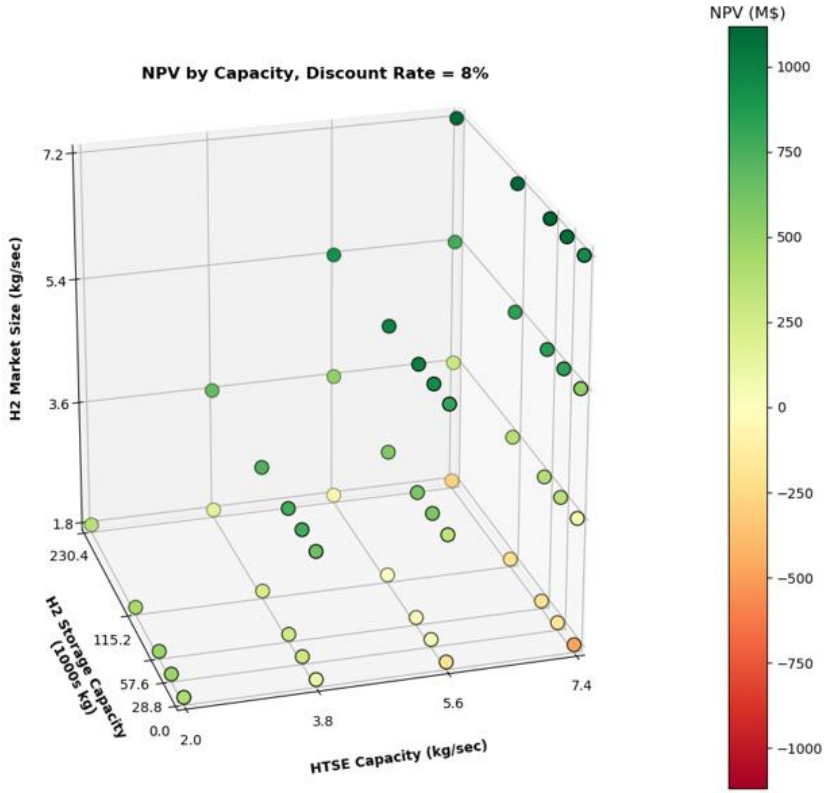
Techno-economic Analysis (INL)

- 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 with regional demands for H_2 have the *potential* to increase profit margins by hybridization with H_2 production**



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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