



Conventional Reactors and Hydrogen Production

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ESIG Spring Technical Workshop

Online webinar

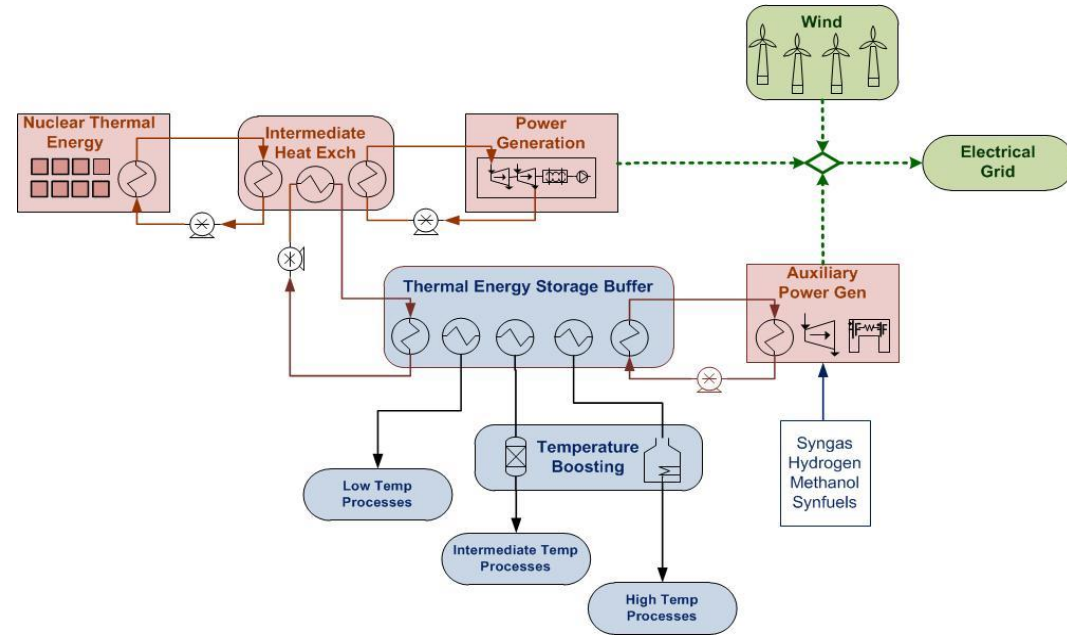
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Acknowledgments

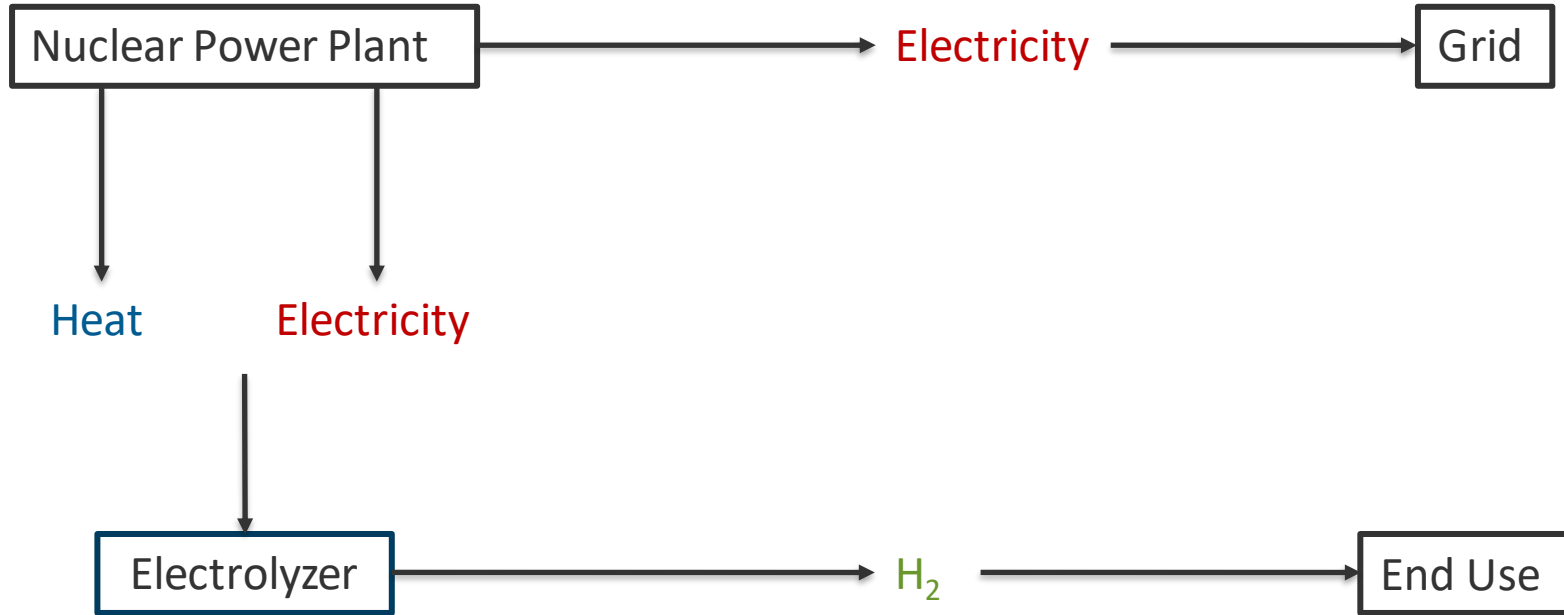
- **NREL:** Mark Ruth (PI), Daniel Levie, Jal Desai, Owen Zinaman, Doug Arent
- **Project partners:** Idaho National Laboratory, Argonne National Laboratory, Southern Company, Exelon, Xcel Energy (Colorado Public Service and Northern States Power), EPRI
- **Funding:** DOE Fuel Cell Technologies Office, DOE Office of Nuclear Energy, and project partners

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

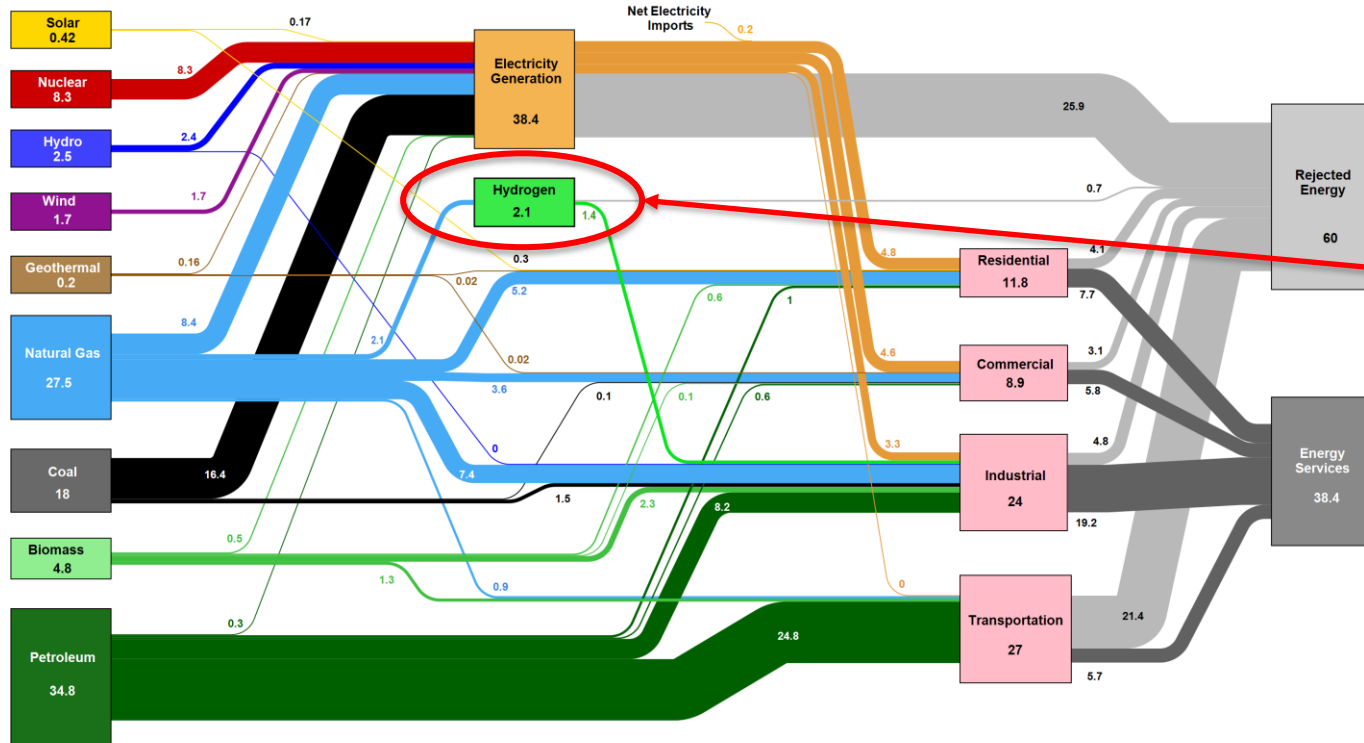


Nuclear-Hydrogen Hybrid System



Why do we care about hydrogen (H₂)?

2014 Estimated U.S. Annual Energy Use -
Hydrogen Contributions Broken Out ~ 98 Quads



2% of U.S. primary energy use goes to producing H₂

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

...and there's a lot of room for growth

Demand potential of H₂ 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 H ₂ (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

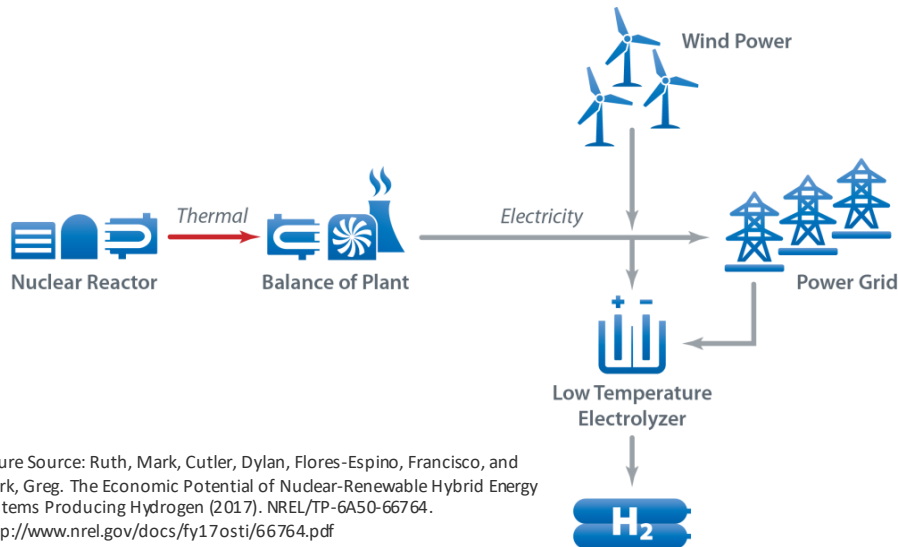
Source: Ruth, Mark, et al. The Technical, Demand, and Economic Potential of H₂@Scale within the United States. Nov. 5, 2019. H₂@Scale Workshop at the Fuel Cell Seminar. Long Beach, CA.

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 H₂ Production

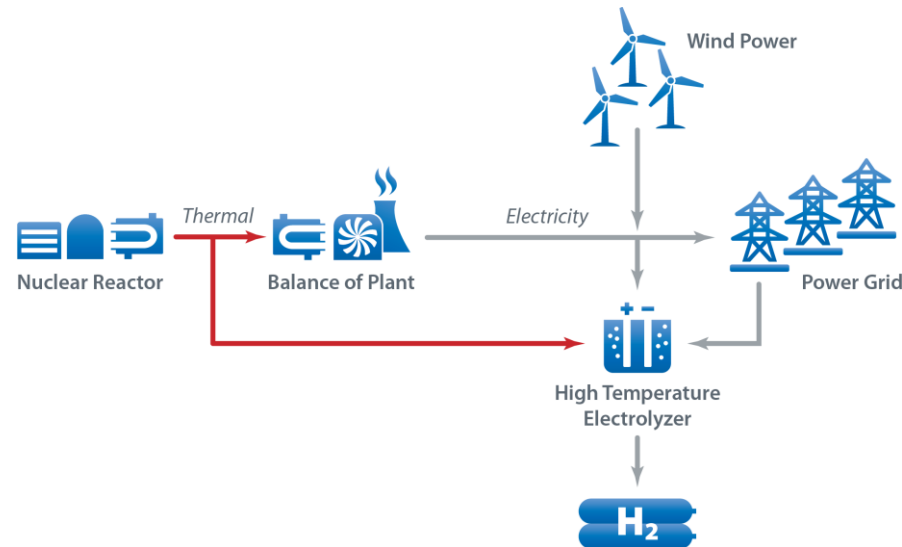
LTE (low temperature electrolysis)

- 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



Potential Benefits of Hybridization

Dynamically adjust product slate to maximize income

- When the price of electricity is high, maximize generation to the grid (minimizing H₂ production)
- When the price of electricity is low, maximize H₂ production (minimizing electricity to the grid)
- May become a H₂ plant that provides peaking capacity to the grid

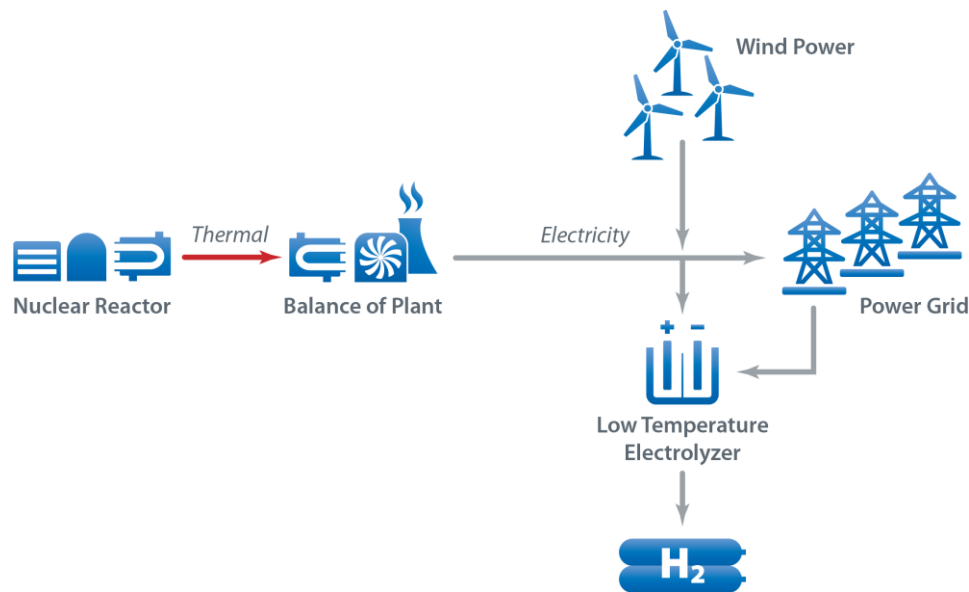
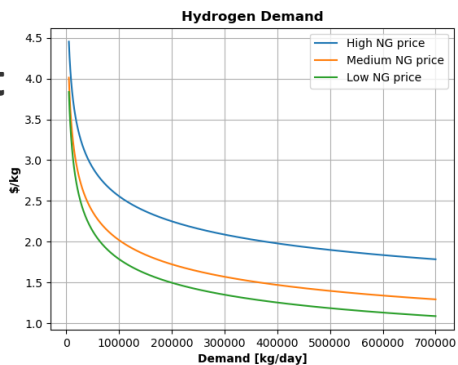


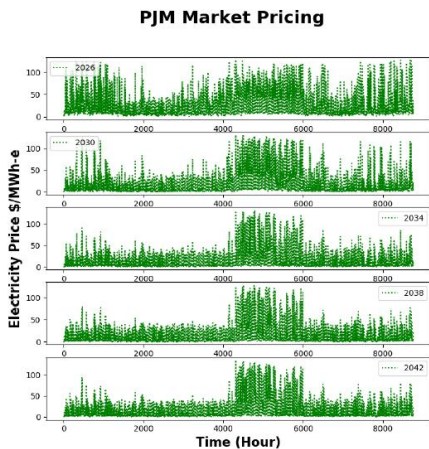
Figure Source: Ruth, Mark, Cutler, Dylan, Flores-Espino, Francisco, and Stark, Greg. The Economic Potential of Nuclear-Renewable Hybrid Energy Systems Producing Hydrogen (2017). NREL/TP-6A50-66764. <http://www.nrel.gov/docs/fy17osti/66764.pdf>

NREL and others are analyzing both LTE and HTE options

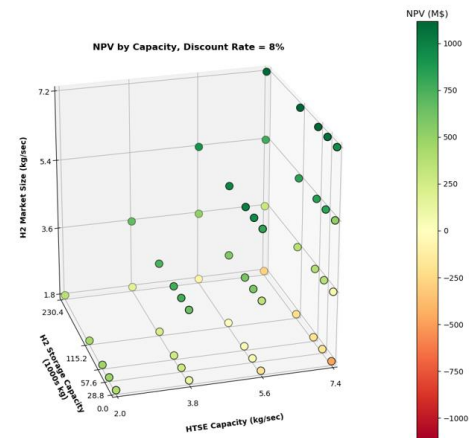
H₂ Market Assessment ANL



Electricity Price Estimation NREL



Techno-economic Analysis INL

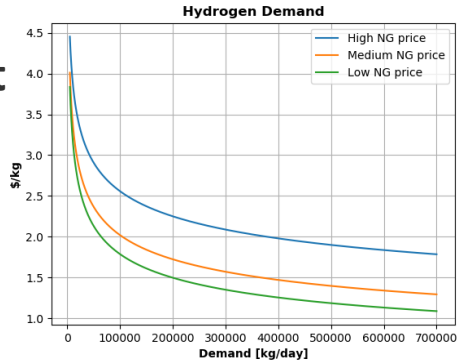


NPV Profitability

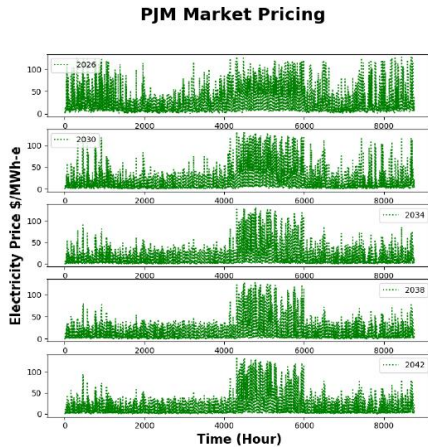
Source: Frick et al. "Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest" (2019). https://indigitallibrary.inl.gov/sites/sti/sti/Sort_18785.pdf

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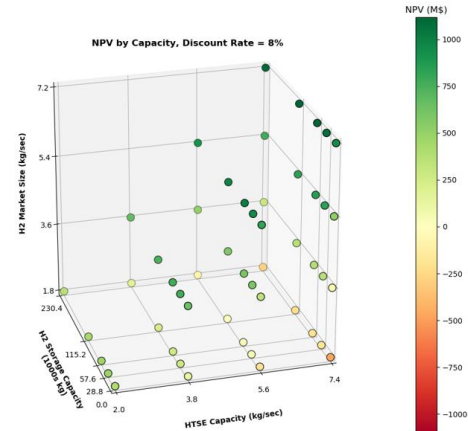


Electricity Price Estimation NREL



Techno-economic Analysis INL

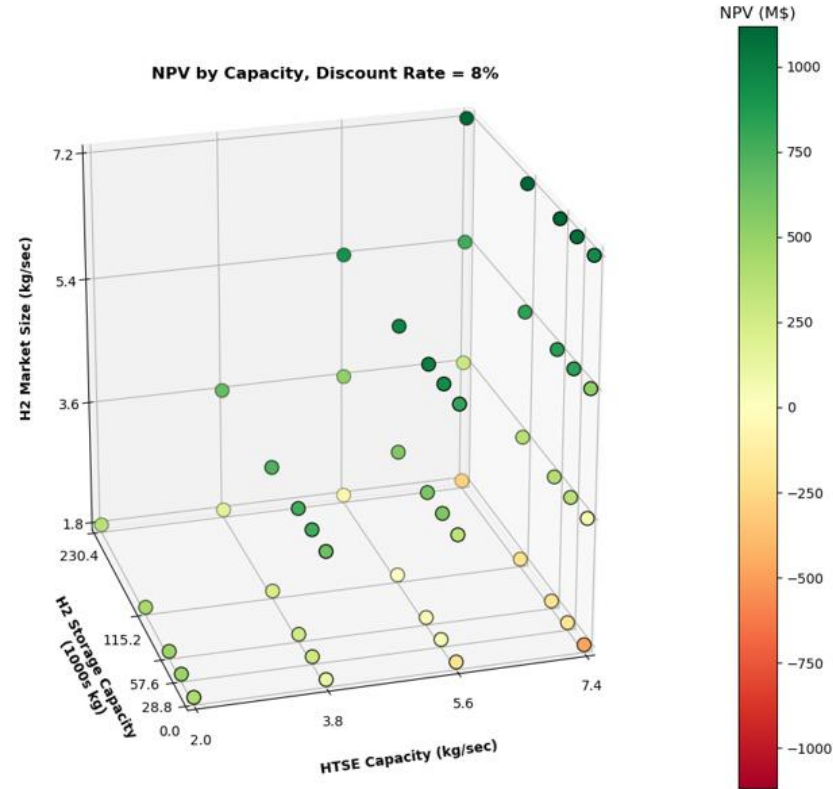
NPV Profitability



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Techno-economic Analysis (INL)

- Goal is to design hybrid nuclear-H₂ system to maximize net present value (NPV)
- 3 dimensions: H₂ market size, H₂ storage capacity, and electrolyzer size
- Profitability depends on:
 - H₂ vs. electricity market prices
 - Aligning electrolyzer size with H₂ demand
 - Proper sizing of H₂ storage
- **Key finding: nuclear power plants with regional demands for H₂ have the *potential* to increase profit margins by hybridization with H₂ production**



Thank you!

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