Hydrogen as an IES for LWRs

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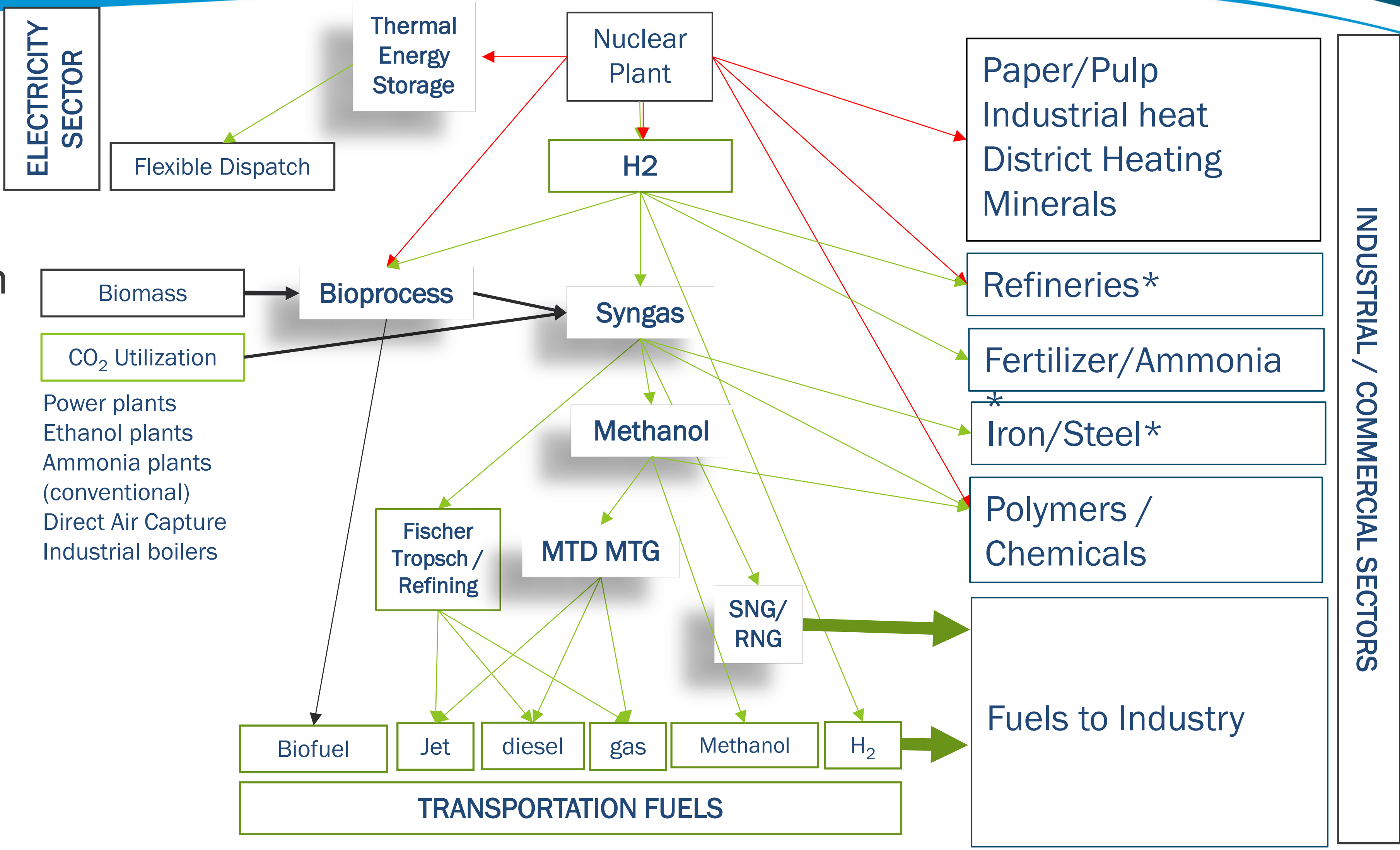
Background

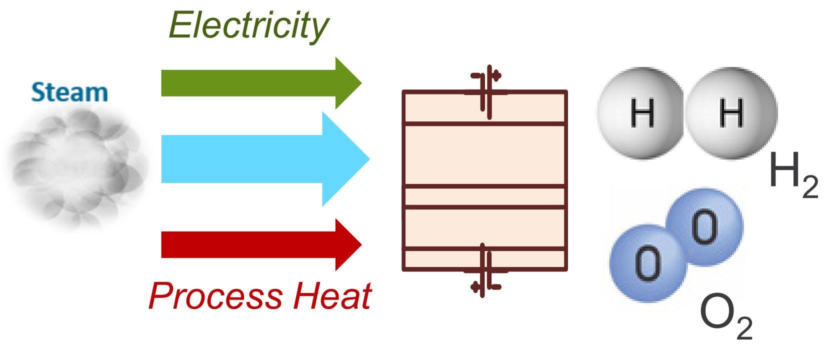
- Existing light water reactor (LWR) power stations can couple electrical and thermal energy flexibly with hydrogen and synthetic fuels production to:
  - Diversify revenue generation of nuclear plants
  - Flexibly produce hydrogen and synfuels along with grid electricity



[1] Knighton, L et al (2021) Techno-Economic Analysis of Product Diversification Options for Sustainability of the Monticello and Prairie Island Nuclear Power Plants. https://doi.org/10.2172/1843030
[2] Wendt, D et al (2022) High Temperature Steam Electrolysis Process Performance and Cost Estimates. https://doi.org/10.2172/1867883
[3] Westover, T et al (2023) Preconceptual Designs of Coupled Power Delivery between a 4-Loop PWR and 100–500 MWe HTSE Plants.
[4] Boardman, R et al (2024) Guidance on Near-Term Hydrogen Production using Nuclear Power. INL/RPT-24-78729
[5] Garrouste, M. et al (2023) Integrated Production of Fischer-Tropsch and Methanol-to-Diesel Synfuels from Light Water Reactors and Small Modular Nuclear Reactors. INL/RPT-23-74752.

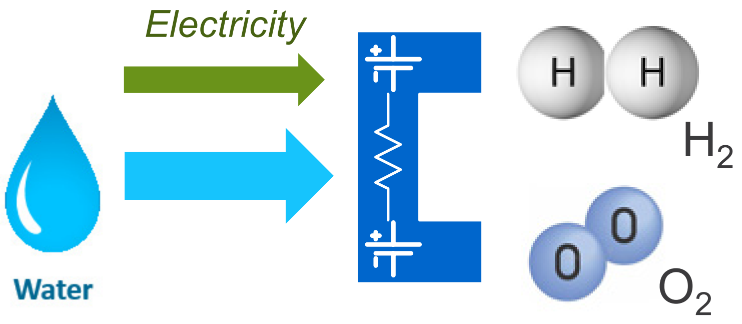
Comparison of Electrolysis Processes

- **High Temperature Steam Electrolysis (HTSE)**
  - Electricity & Heat Input
  - Higher H_2 production efficiency, 30% less electricity use
  - LWR Nuclear heat can provide energy to vaporize water to steam
  - Stack cost lower – Balance of plant cost higher



Solid-Oxide Cell

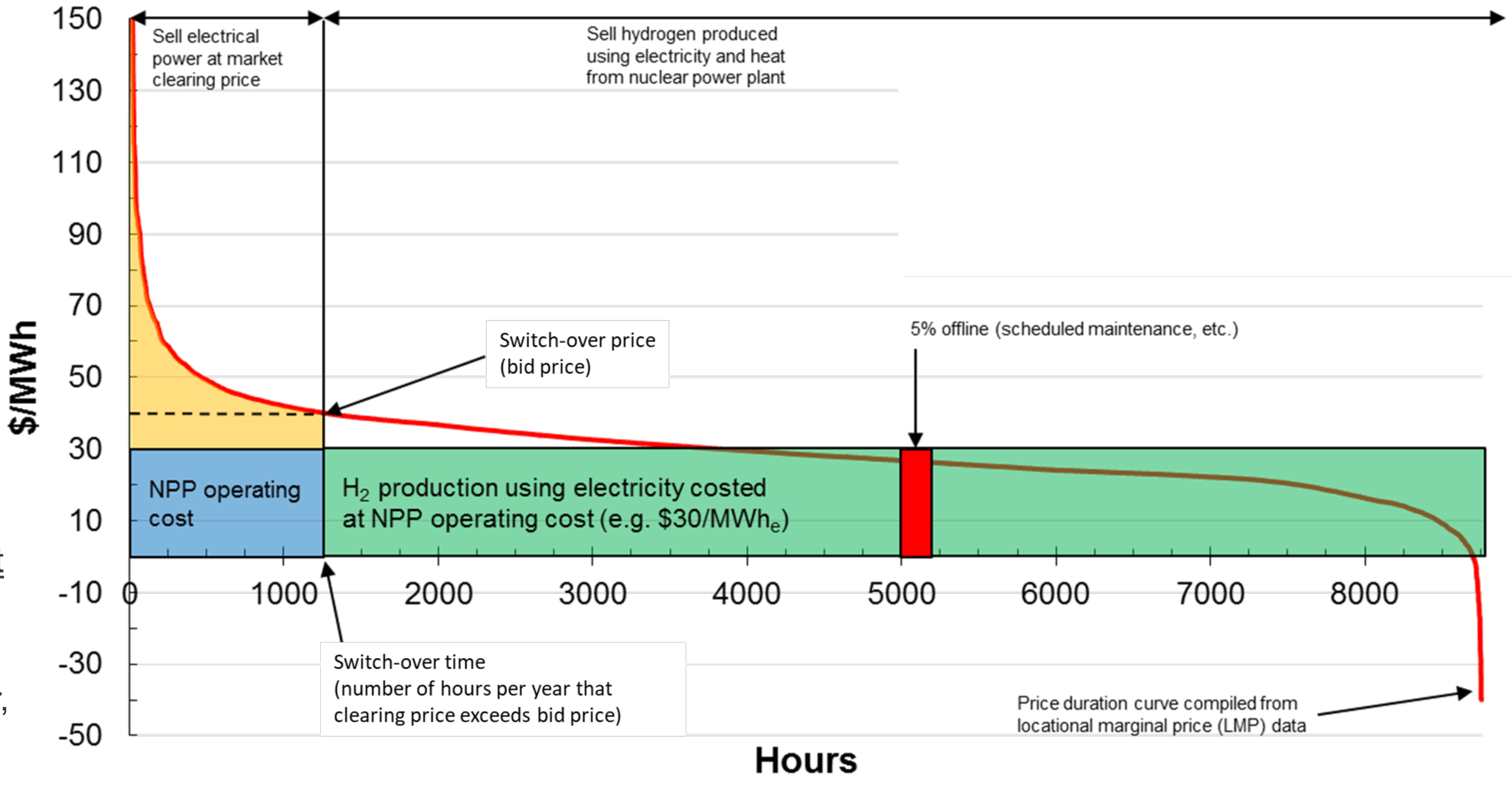
- **Low Temperature Electrolysis (LTE)**
  - Electricity Input Only
  - Lower H_2 production efficiency
  - Stack cost higher – Balance of plant cost lower
  - No cost/complexity for thermal integration



LTE or Proton-Exchange Membrane

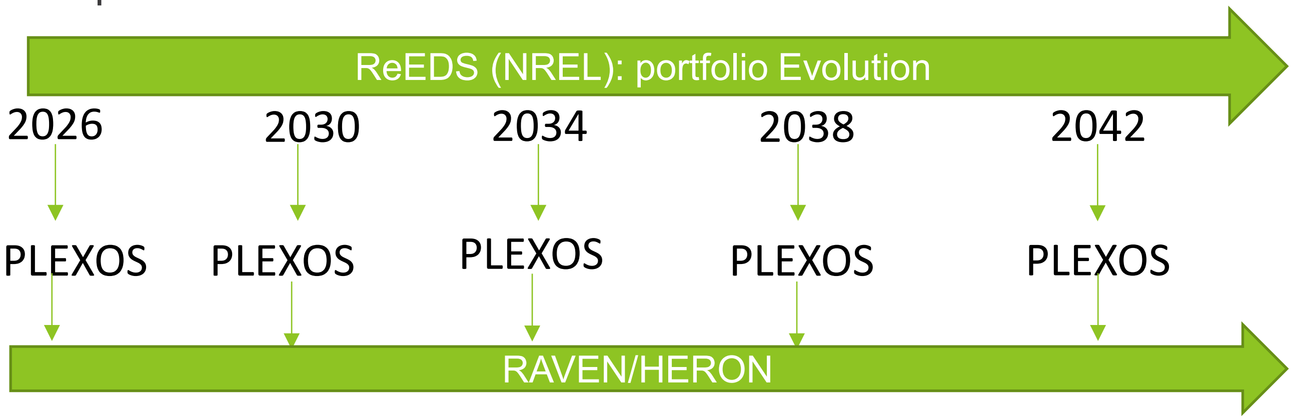
- Market case for flexible nuclear hydrogen production – **take advantage of market conditions to optimize revenue**.
- Electricity at marginal electricity selling price could be sold to the grid or used to generate hydrogen.
- **Switch-over price** - when the marginal price of electricity is high, the HTSE is rapidly turned down to dispatch electricity to the grid. Conversely, when the price of electricity is low, then the plant will ramp up hydrogen production.
- For a dedicated industrial user, hydrogen storage will be necessary.

Hybrid nuclear power/hydrogen plant concept for the price-dependent electricity market

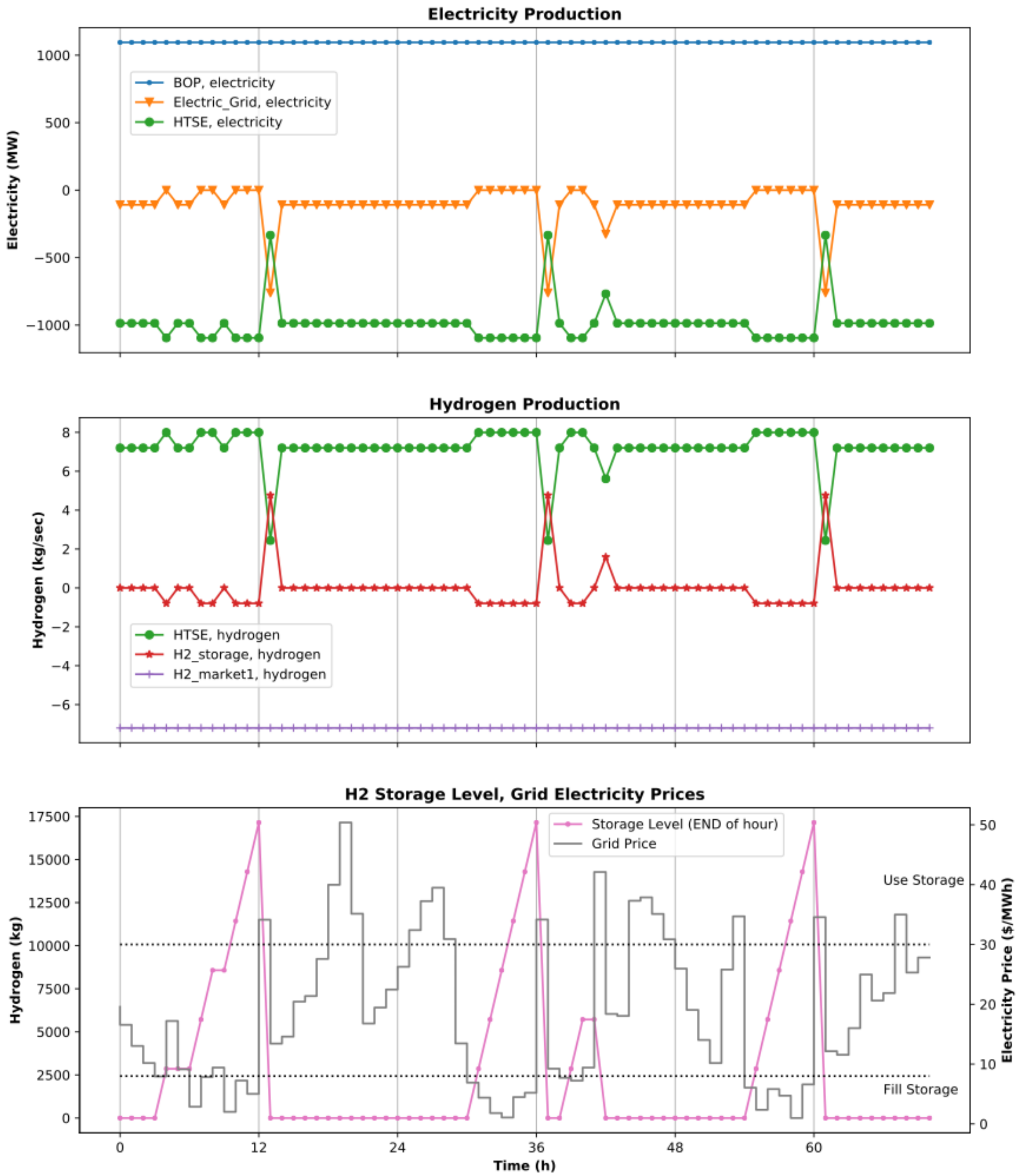


Plant- and Region-Specific Case Analyses

- **Generate synthetic data for future grid pricing**
  - NREL: ReEDs and PLEXOS used for capacity expansion and discrete time step grid pricing
  - INL: RAVEN/HERON used to generate continuous, hourly grid price data

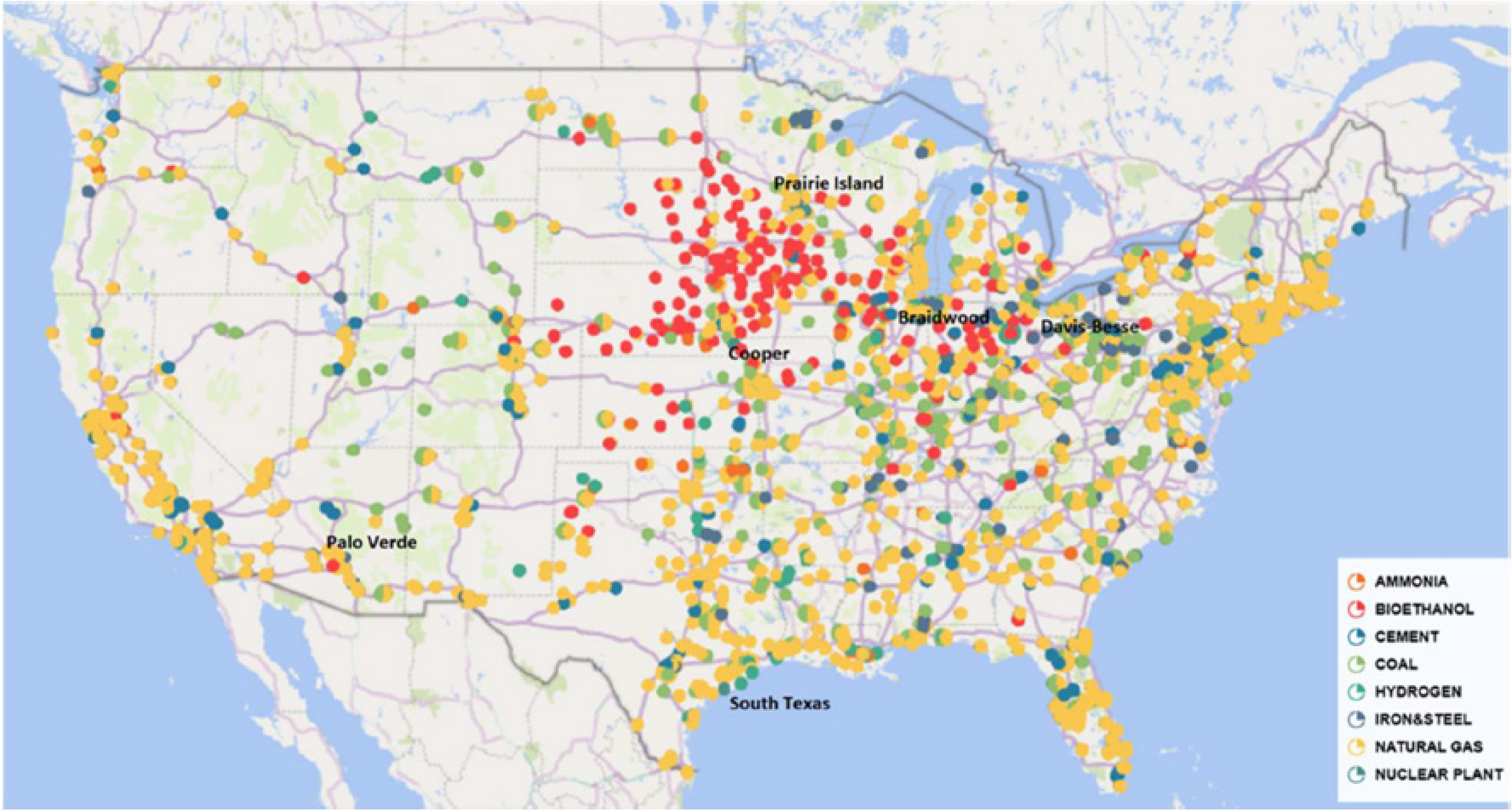


- **Developed time-dependent physical models of nuclear plant and hydrogen production systems**
  - Dispatch power between grid and hydrogen production to optimize revenue
  - Optimized hydrogen plant and storage capacity based on discounted cash flow economics



Example of
Optimization of electricity to the grid or H_2 production and H_2 Storage modeling and sizing

Geographical Distribution of CO_2 Sources for Potential Chemicals & Fuels Production

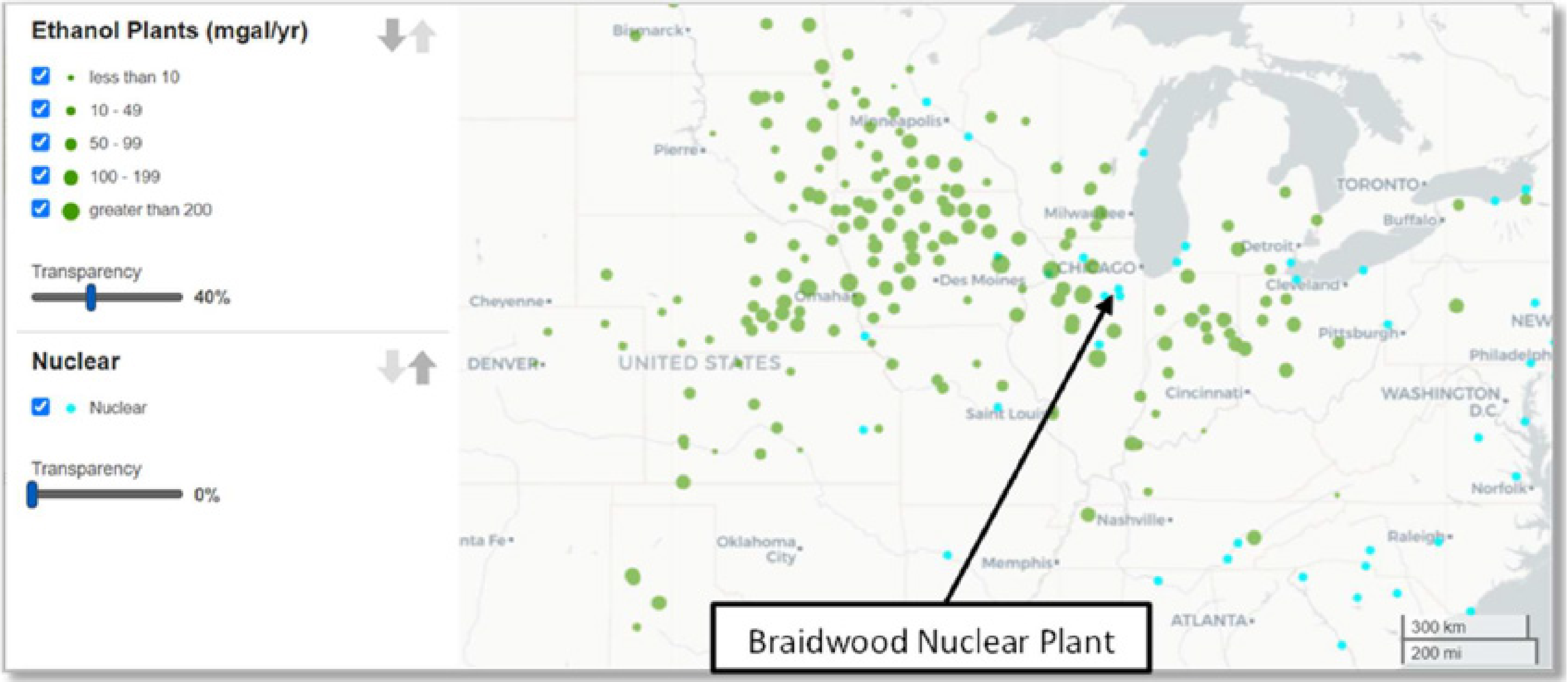


High purity CO_2 sources are available near NPPs

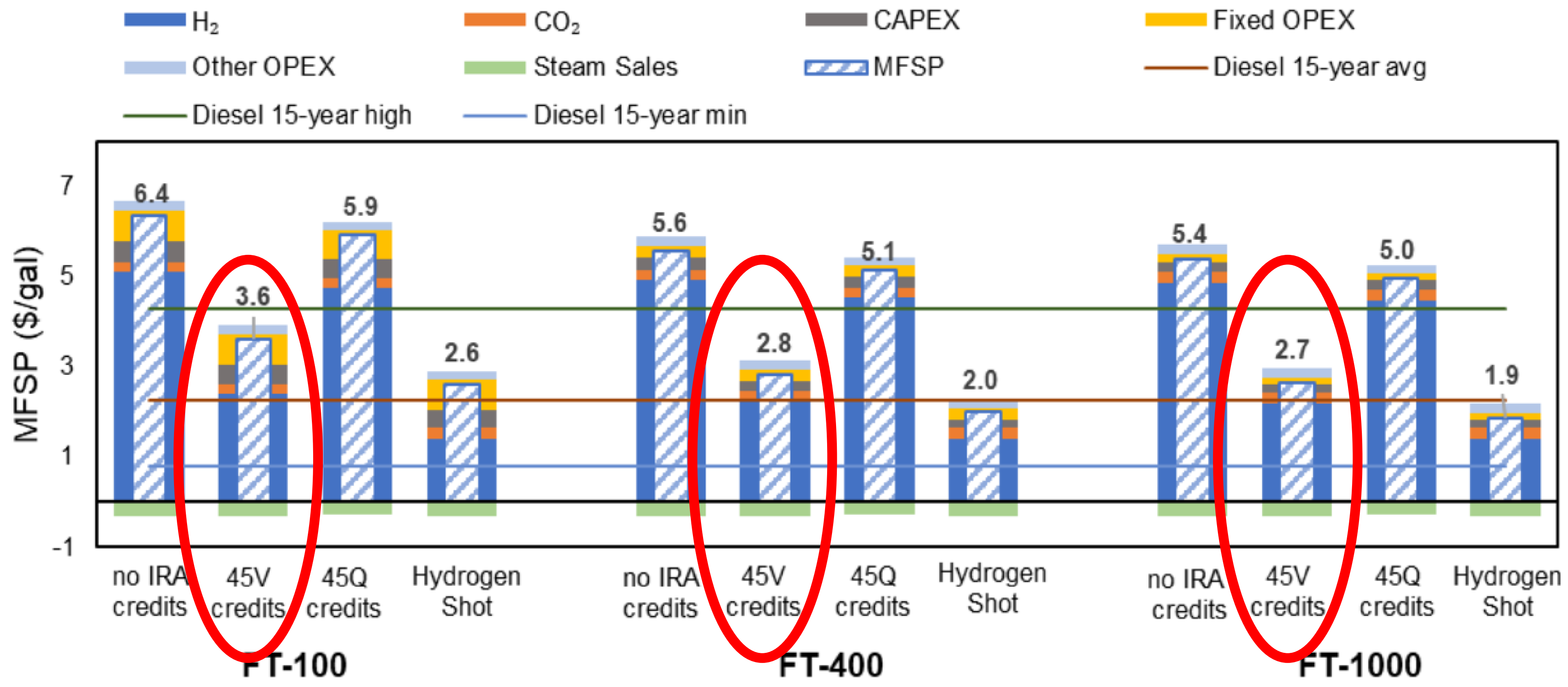
Liquid fuels:

- Are more transportable and storable than H_2
- Increase domestic fuel supply
- Compatible with existing transportation infrastructure

Ethanol Plant Locations as High Purity CO_2 Source for Synfuels



FT Fuels Production Cost – Braidwood Nuclear



- Hydrogen cost is key cost driver for synfuels production, even with 45 V tax credit.
- The impact of 45Q is smaller than that of 45V using nuclear energy.

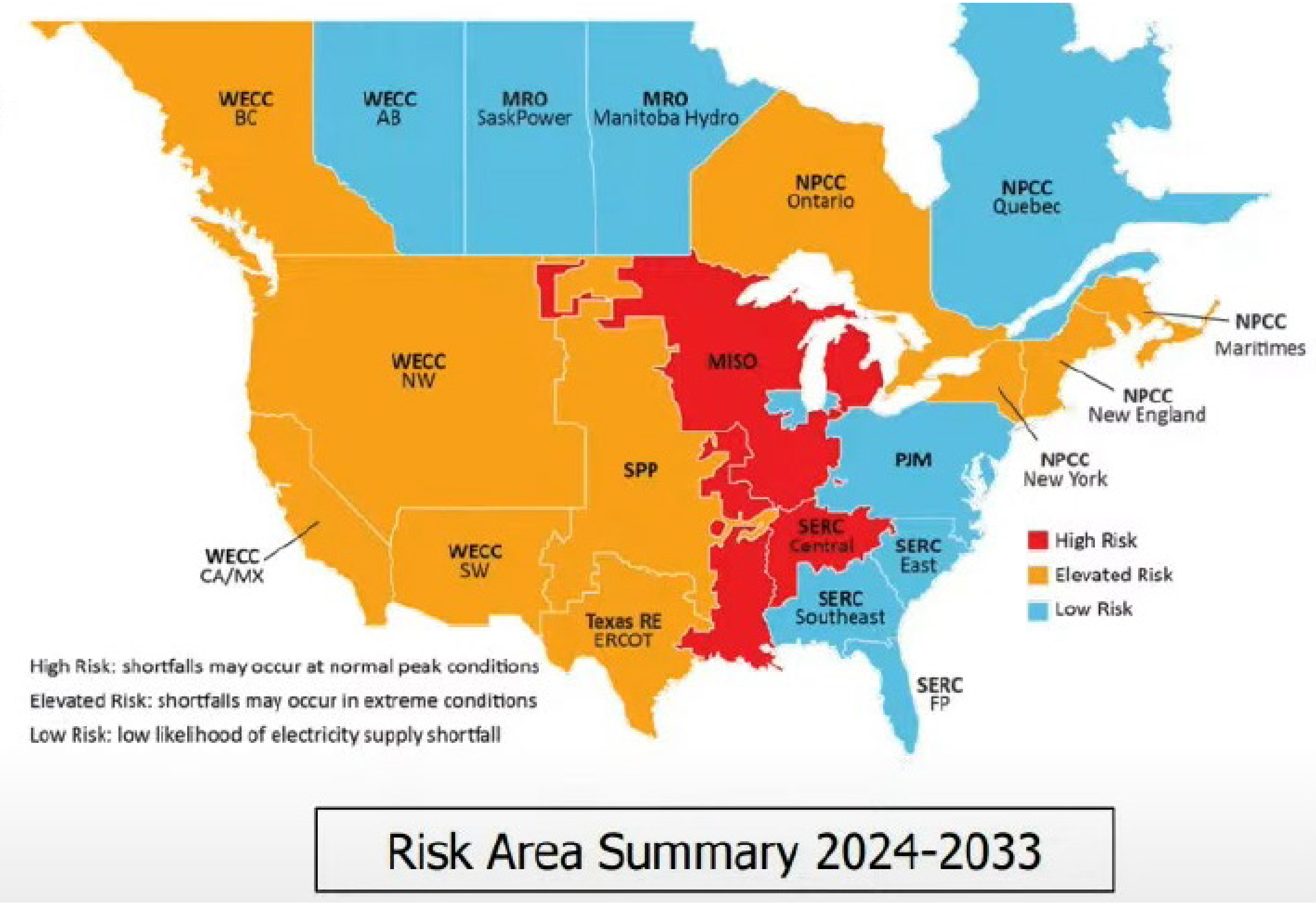
LWRS LIGHT WATER REACTOR SUSTAINABILITY

Sustaining National Nuclear Assets

lwrs.inl.gov

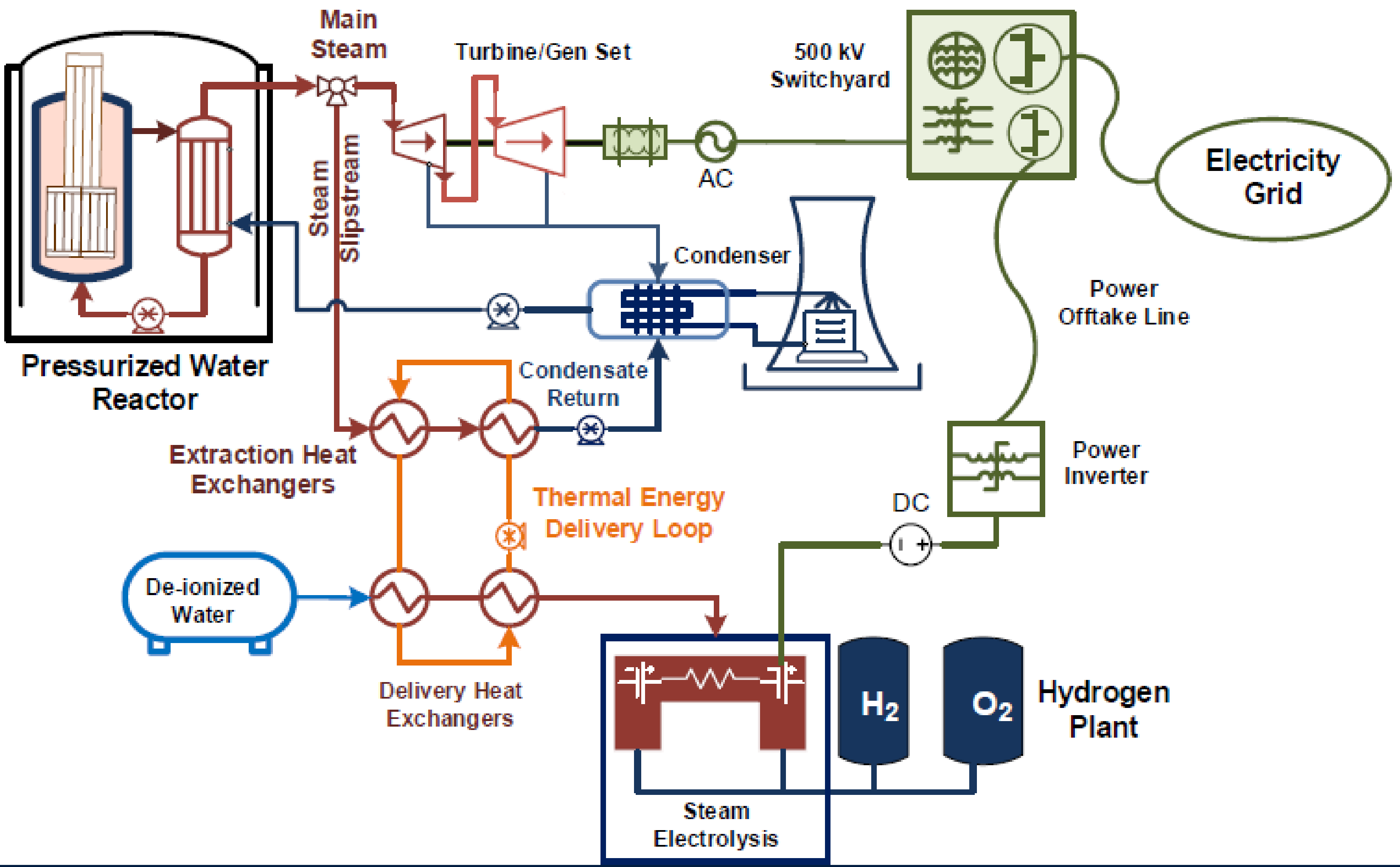
Backup

Risk area for grid shortfalls during peak / extreme conditions



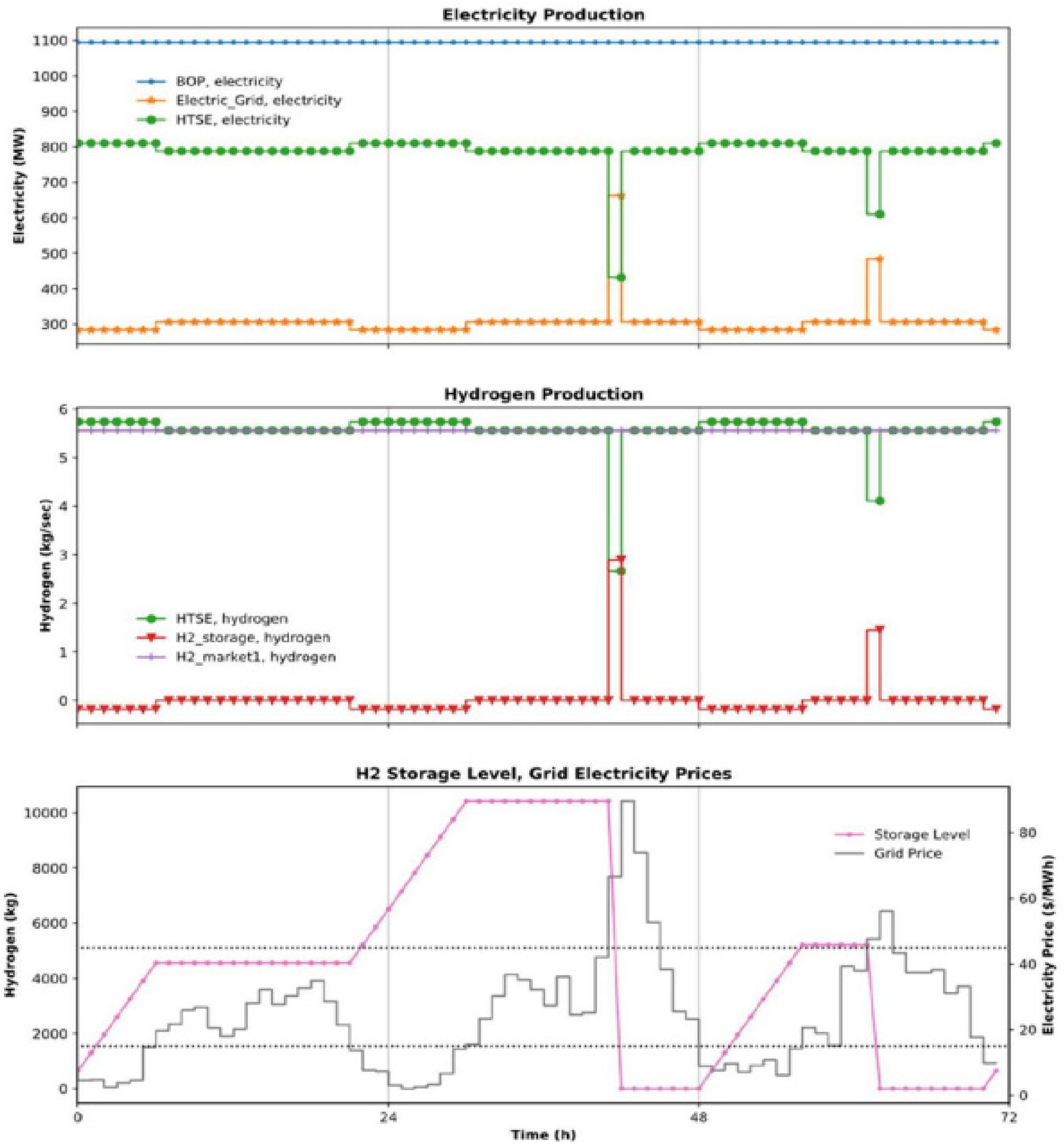
Low to mid risk areas are prime target for LWR FPOG

Grid Generation Risk area summary from NERC's Long-Term Reliability Assessment 2023



Conceptual design of a hybrid FPOG plant grid electricity and producing hydrogen via HTSE flexibly

Talk about both HTSE and LTE—figures for HTSE and LTE to follow???



Example of plant operation optimization for a hybrid grid/hydrogen market –

Optimization of electricity to the grid or H_2 production and H_2 Storage modeling and sizing

Table 2. Feedstock demand and product capacity for different plant scales. Reproduced from [34].

		FT-100	FT-400	FT-1000
Feedstock	H_2 (MT/d)	56	255	601
	CO_2 (MT/d)	348	1,580	3,724
Products	Naphtha (MT/d)	39	176	414
	Jet fuel (MT/d)	47	213	502
	Diesel (MT/d)	26	118	278
	Total FT fuel (gal/d)	40,430	183,030	431,050
Carbon conversion		99%	99%	99%

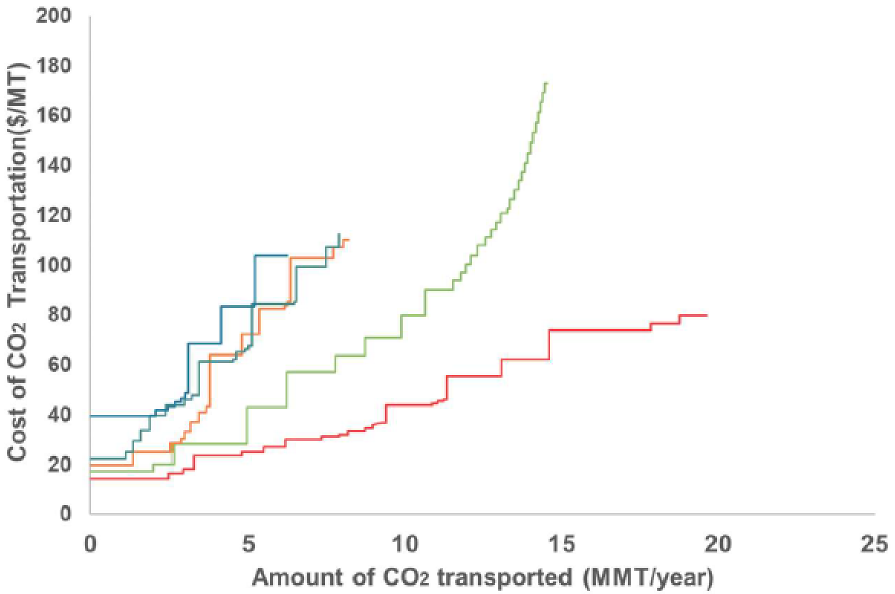
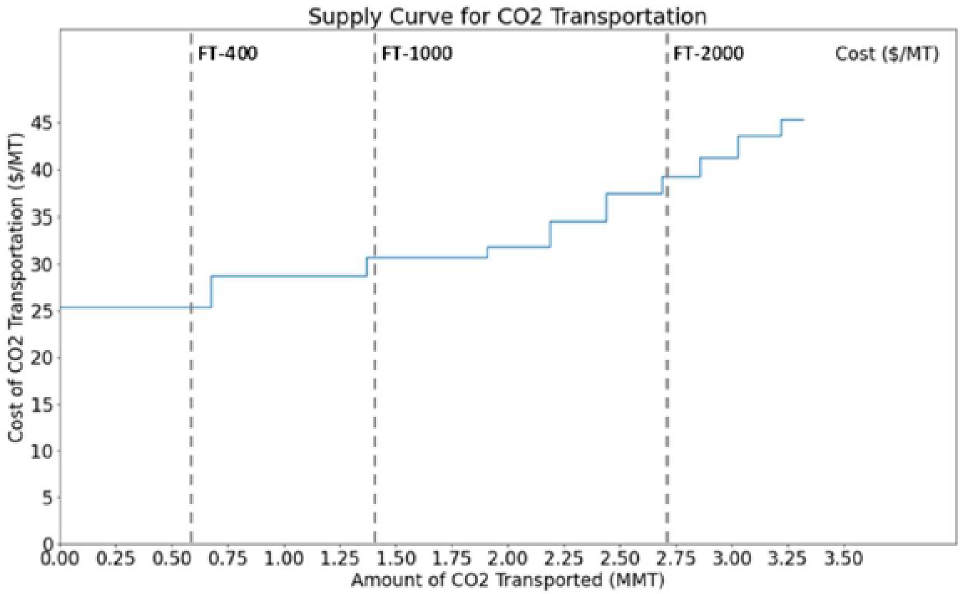


Figure 15. Supply curve for CO_2 transportation to all nuclear plant.



gure 19. Supply curve for CO_2 transportation to Braidwood NPP.

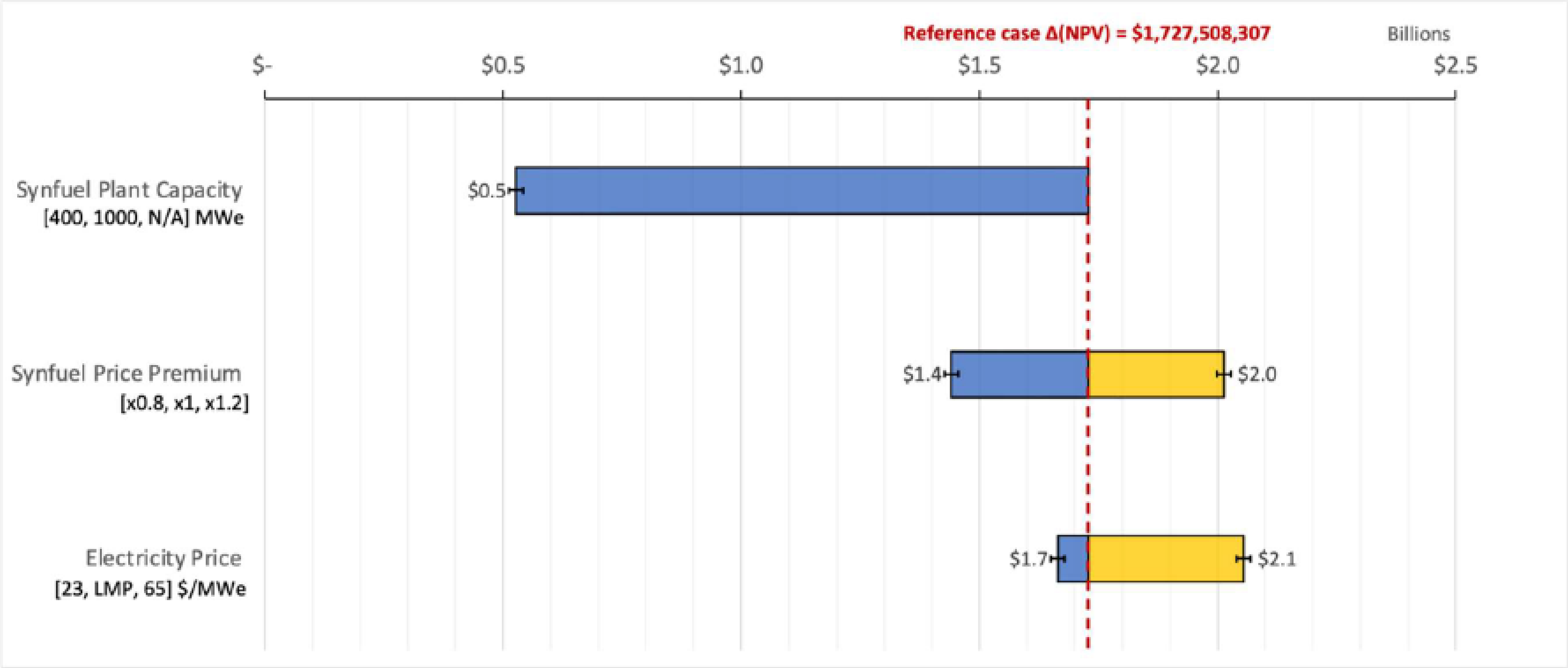


Figure 23. Synfuel production process sensitivity analysis results: influence of economies of scale, synfuel pricing, and electricity pricing.

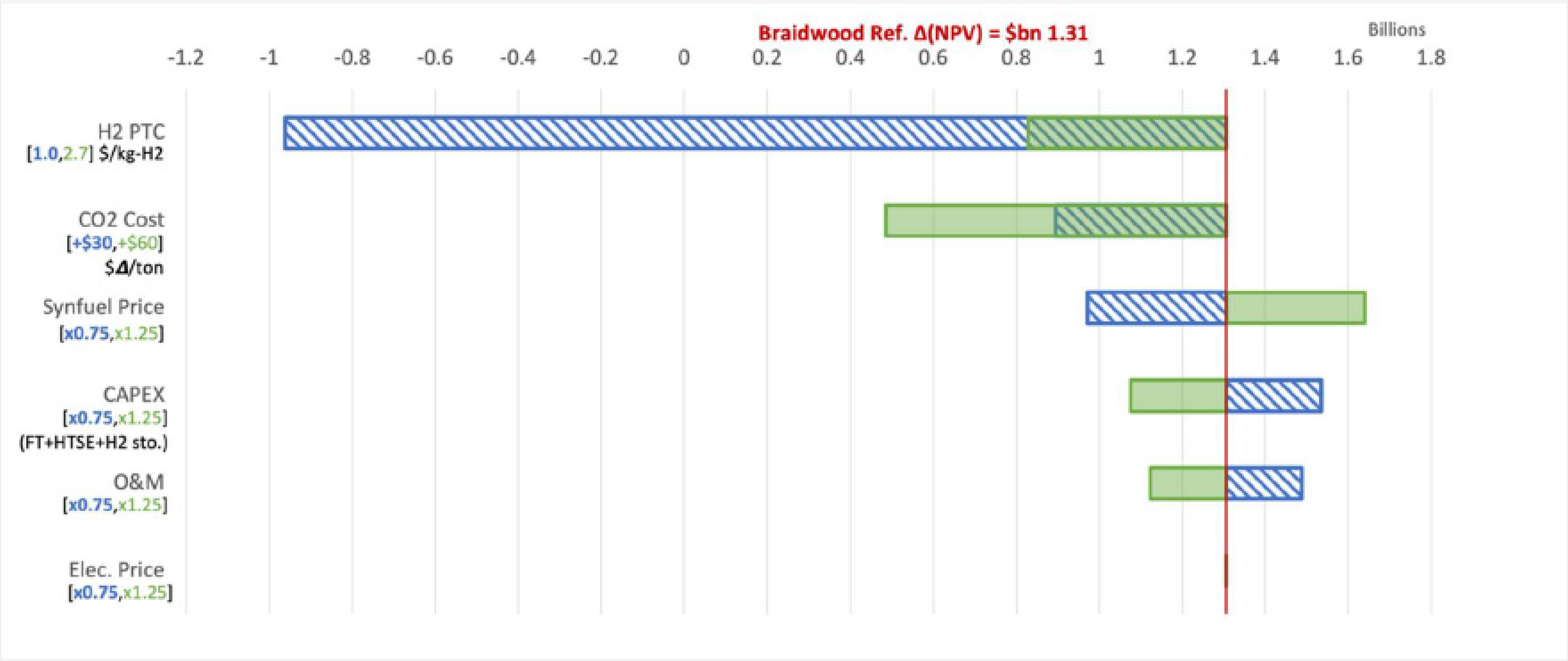


Figure 31. Sensitivity analysis results, Braidwood location, synfuel price, CAPEX, CO_2 feedstock cost, O&M costs, and H_2 PTC value.

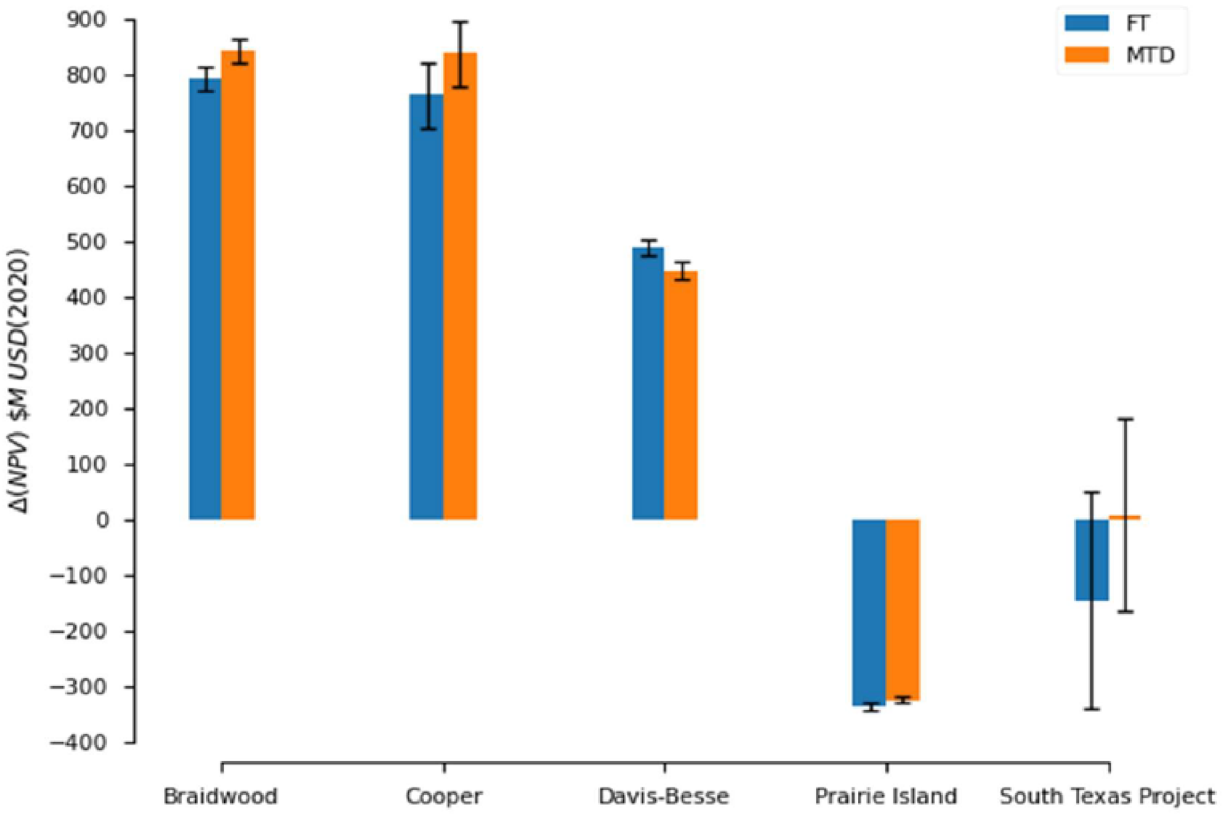


Figure ES-1. Δ(NPV) for the synfuel IES compared to the BAU case at each LWR NPP location.