SA175: May 2020 Hydrogen Fuel Cell Technology Office Annual Merit Review

Region Hydrogen Energy Technoeconomic Assessment

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Overview

Timeline and Budget

- Project Start Date: 09/01/2018
- Project End Date: 03/2020
- Total Project Budget: $350,000
  - Total Recipient Share: $200,000
  - Total Federal Share: $100,000
  - Total CRADA Partner In-kind: $50,000

CRADA Partners

- Southern Company
- Exelon Corporation
- Xcel Energy (cash-in)
- Idaho National Laboratory
- National Renewable Energy Laboratory
- Argonne National Laboratory

Barriers

- Tools and methods for the assessment of optimization of regional natural resources and energy production
- Detailed capital investment pro-forma and life-cycle assessments for hydrogen markets
- Market options for otherwise-curtailed electricity
- Understanding interfaces for connecting variable and baseload plants to industry in hybrid operation.

DOE Sponsors

- EERE- Fuel Cell Technology Office

Relevance

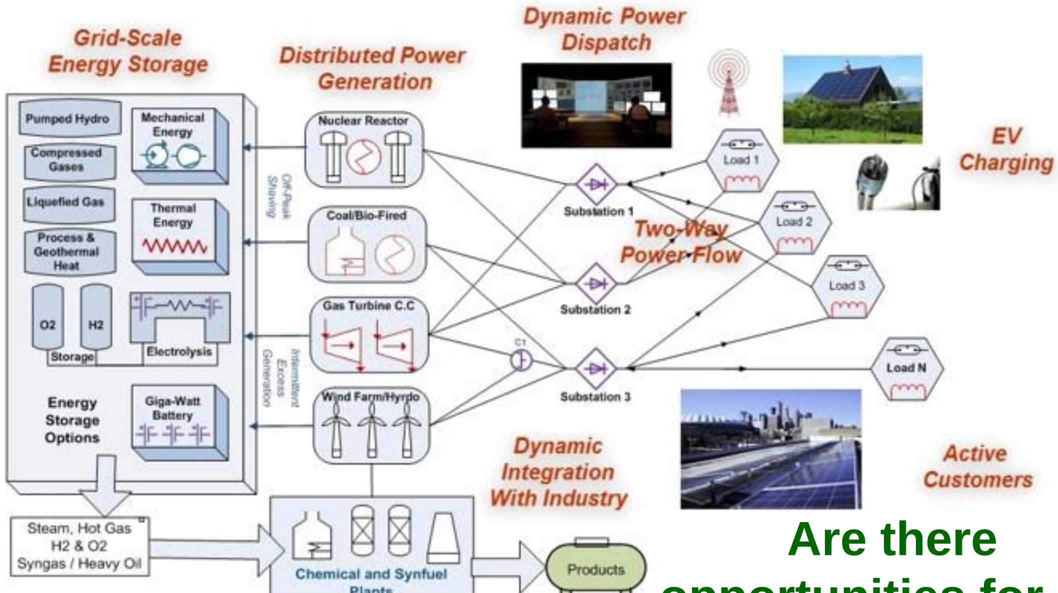
This study was designed to look at the potential to produce hydrogen based on electricity pricing in the following regions:

- Southeast Region (relative to the Southern Company regulated utility region where solar energy has moderate potential)
- Central Upper Midwest Region (where Exelon Corporation operates several nuclear power plants)
- The region stretching from Minnesota to Western Texas and Eastern New Mexico (which has great potential wind and solar capacity).

Xcel Energy has set an ambitious goal of providing low-emission power to its customers within this diverse region.

- Electricity markets vary by region.
- Renewable energy growth varies by region.
- Regional hydrogen markets depend on logistics of natural resources, transportation systems, and other infrastructure.

The grid is evolving….



Are there opportunities for H_2?

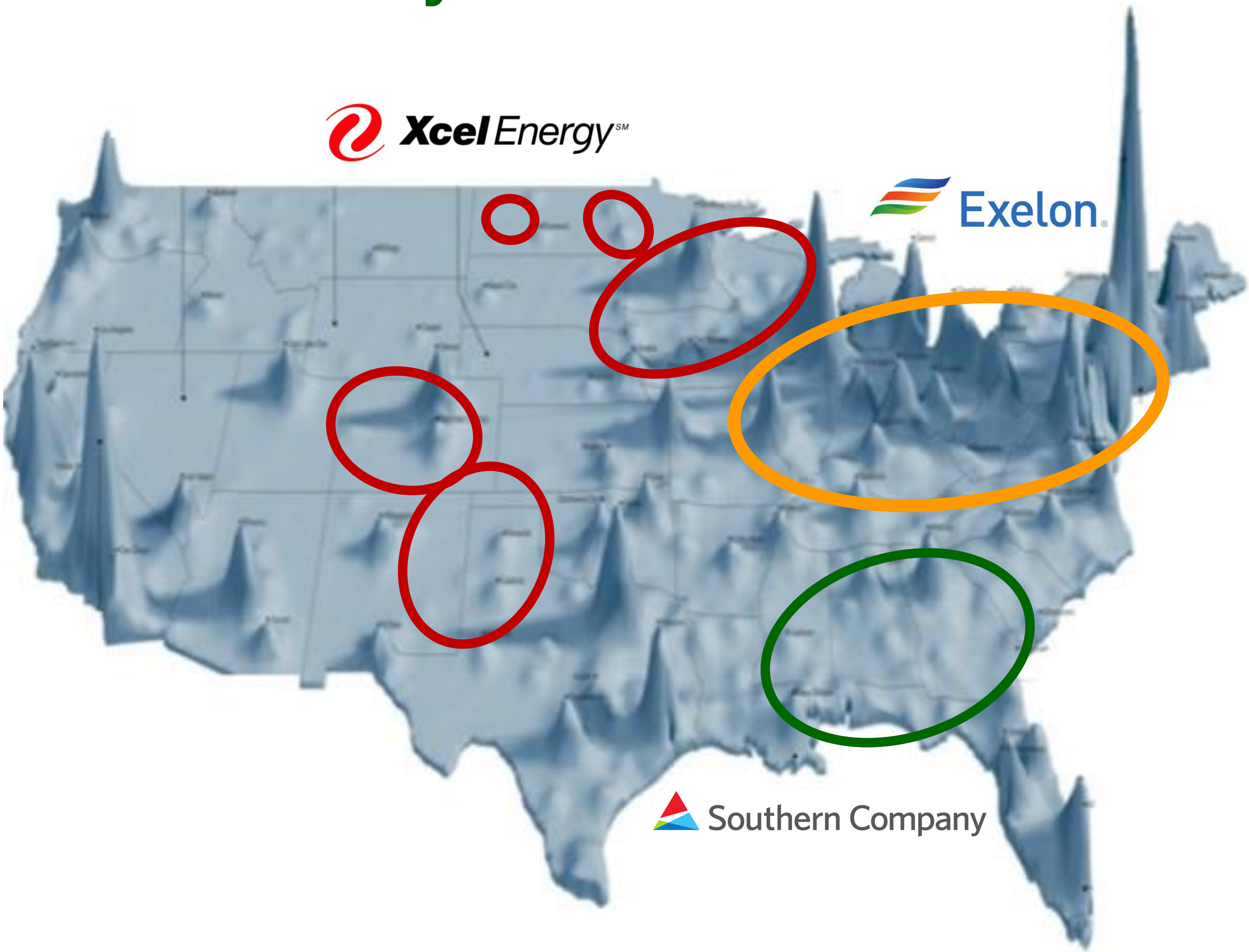
Approach

The main purpose of this CRADA was to determine whether there are economic opportunities to produce hydrogen using electricity from the grid based on various generation resource scenarios represented by the three participating utility companies. The target years for this study were 2018 through 2025. This study further evaluated the possible benefit of a nuclear power plant hybrid that produces electricity at certain times of the year to exploit capacity payments that are available to the plant. In this case, hydrogen storage would likely be required to satisfy customer requirements for hydrogen supply, so that all the electrical power generated is either used for hydrogen production or grounded (during periods of time when electrical power generation exceeds the electrolysis plant capacity).

Major Tasks Completed:

- Demand Analysis: Identified, validated, and ranked regional hydrogen markets relative to the location of a representative nuclear power plant or regional location selected by the utility partners.
- Supply Analysis: Established price-duration or production-duration curves, computed the cost of hydrogen production using low-temperature electrolysis (LTE) or high-temperature steam electrolysis on a scale that matches the power-generation source.
- Evaluated the market potential for producing hydrogen in various locations selected for evaluation.
- Evaluated the cost of producing hydrogen using a dedicated solar farm assuming the system is not connected to the grid.

Utility Focus Areas



Graph Source: "http://geographer-at-large.blogspot.com/
2011/12/map-of-week-12-12-2011us-population.html

Accomplishments and Progress

This project has been completed. A limited distribution report was published March 2020.

This presentation, therefore, shares only a sample of the in-depth content and summary of the project's conclusions. The report numbers 160 pages.

Additional details on the outcomes of this study may be obtained by contacting the participating utility company, who are CRADA partners.

INL/LTD-19-55247

Region-specific Merchant Hydrogen Market and Techno-economic Assessment of Electrolytic Hydrogen Generation

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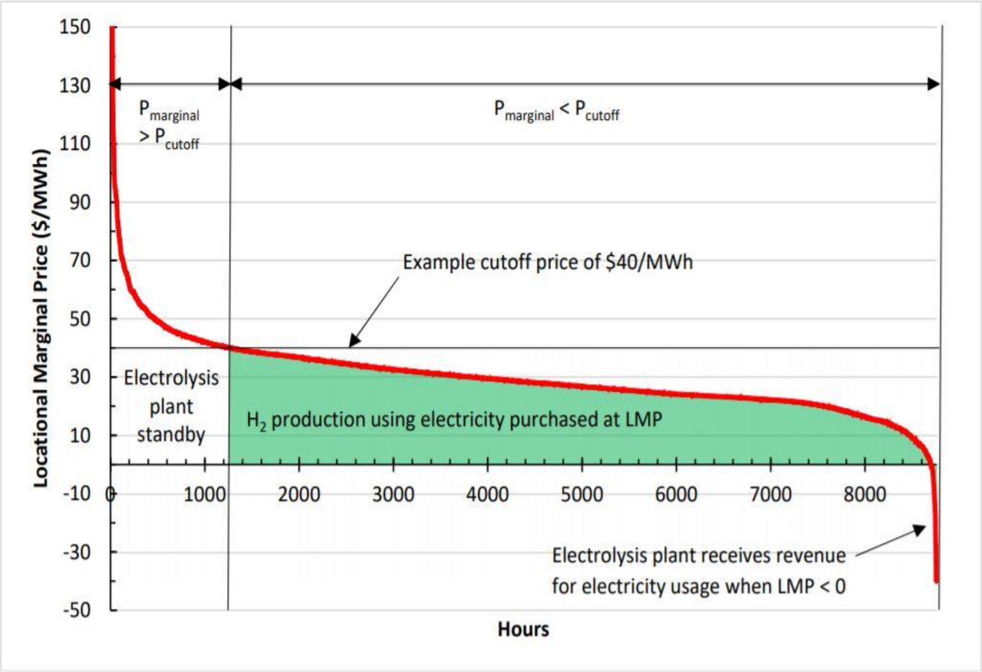
March 2020

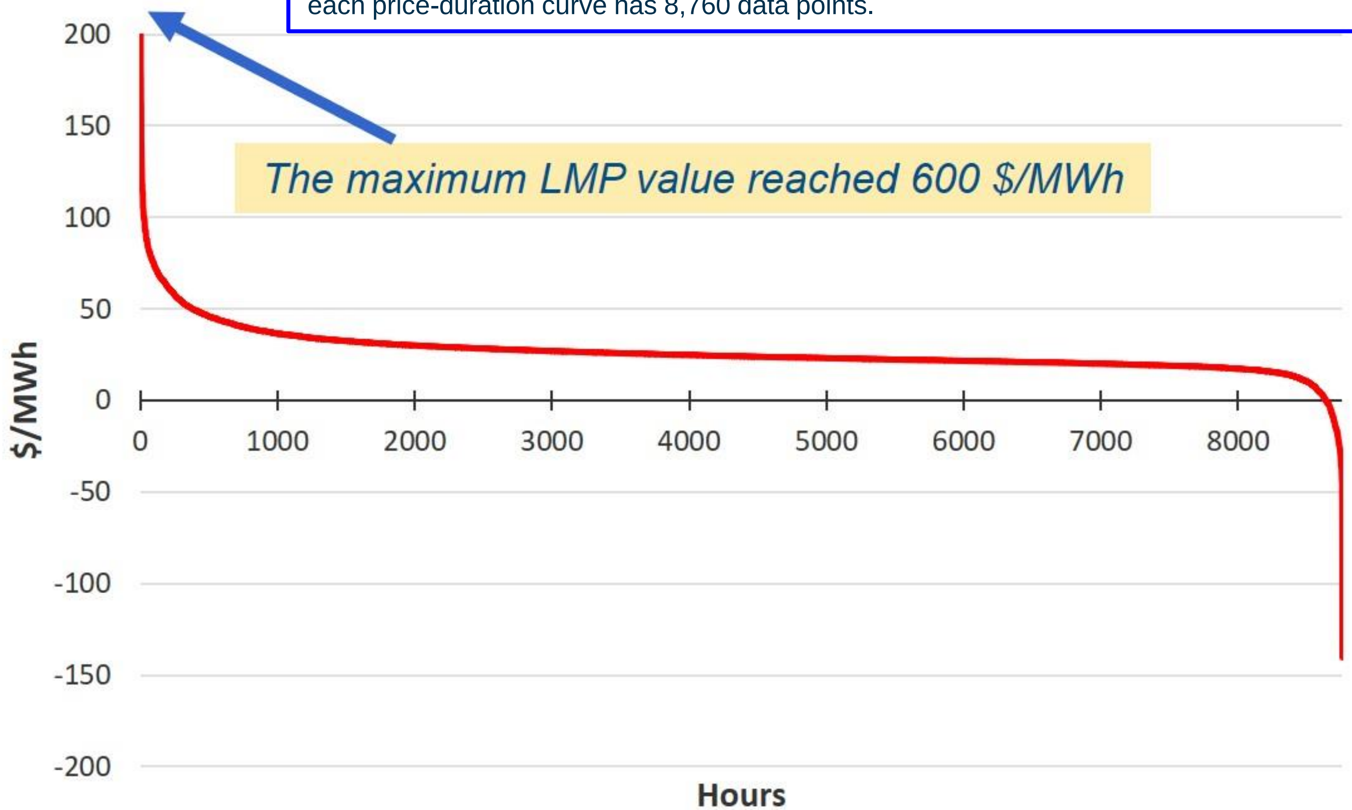
The INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance



Example: Project analysts developed an algorithm to determine the cut-off price that activates hydrogen production to optimize the revenue of a hybrid power/hydrogen production plant.

Price Duration Curves were Developed for Several Locations Selected by the Utility Partners

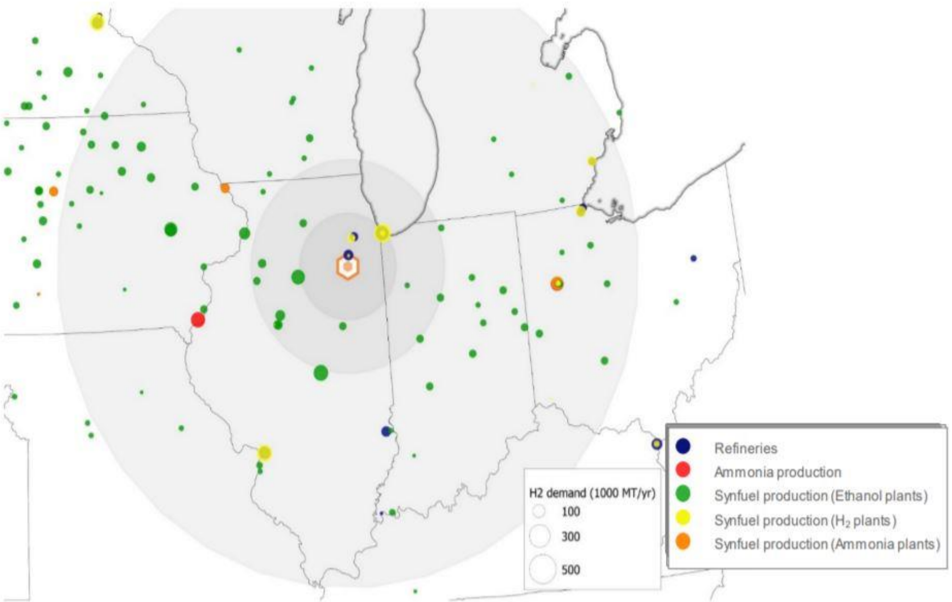
A price-duration curve sorts its data from the largest positive to the most negative numbers. A typical price-duration curve has a flat, middle section between two tails at the extreme ends of the data set. The data collected by NREL was hourly, and therefore, each price-duration curve has 8,760 data points.

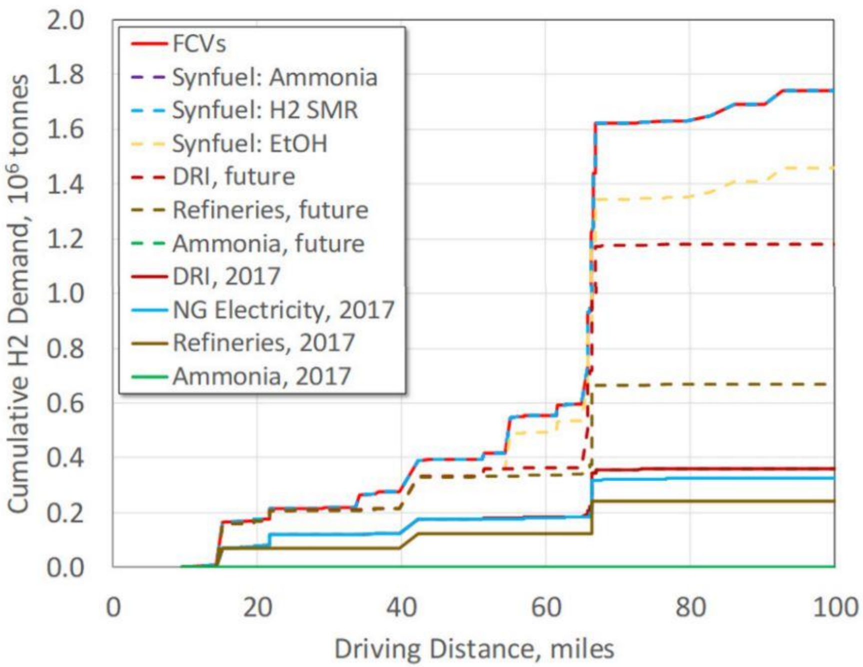


LMP $/MWh	Number of Hours
>$50	385
>$45	542
>$40	764
>$35	1175
>$30	2026
>$25	3902
>$20	7042
>$15	8313
>$10	8513
>$5	8587
>$0	8639
<$0	121

Example: Northern Illinois Hub 2017 Price Duration Curve.

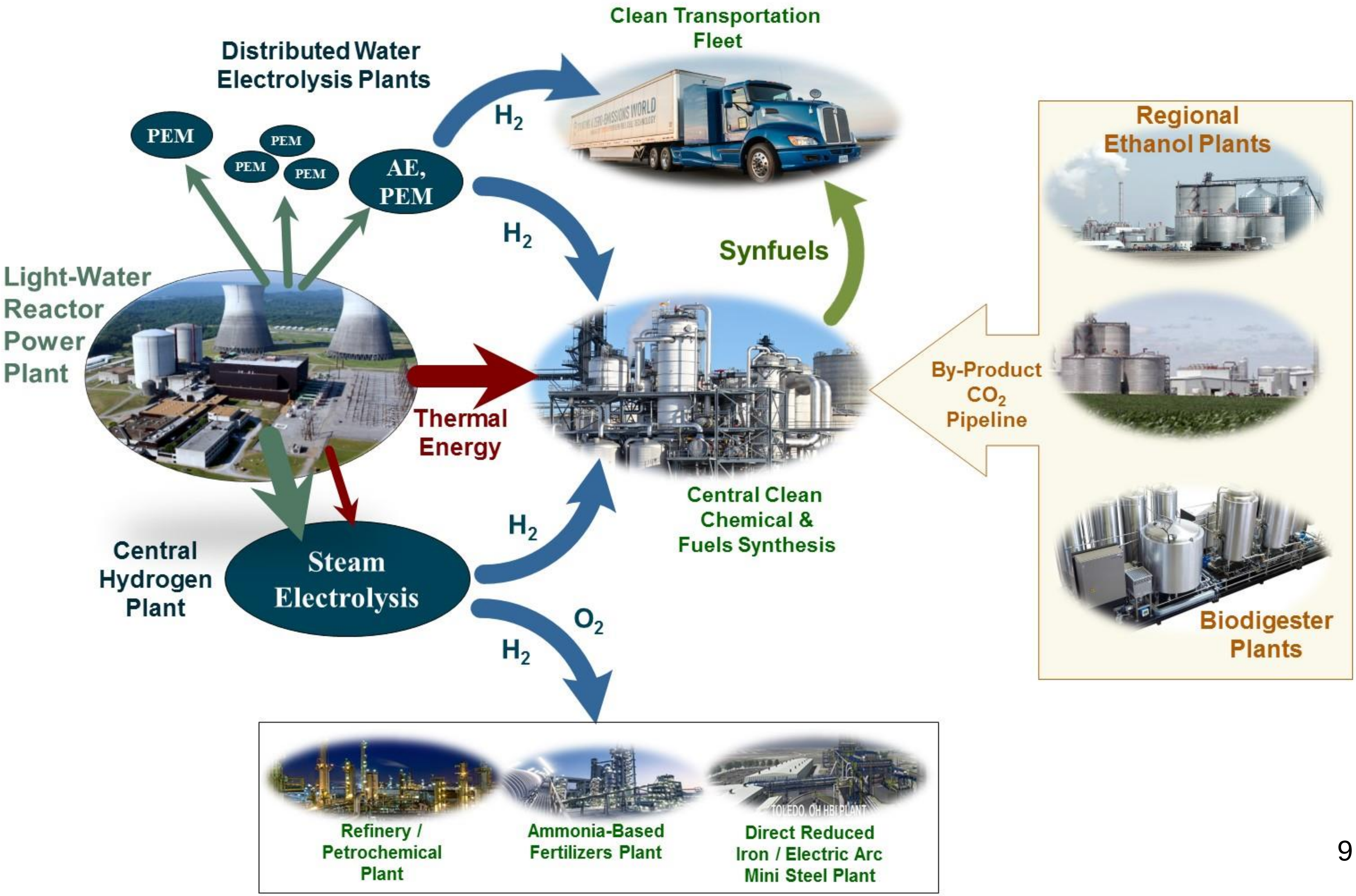
Current and Future Hydrogen Markets Relative to Power Plants and Key Grid Locations in Each Region were Identified and Assessed





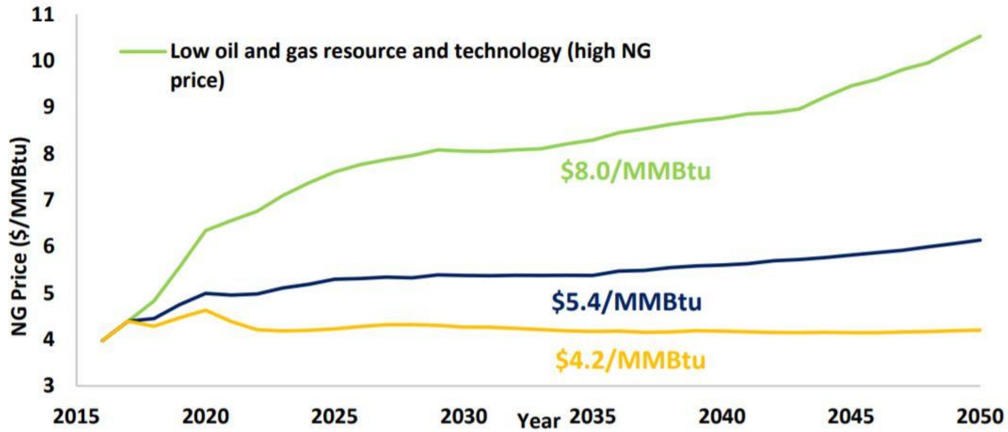
Example: Demand for hydrogen near an Exelon Nuclear Power Plant.

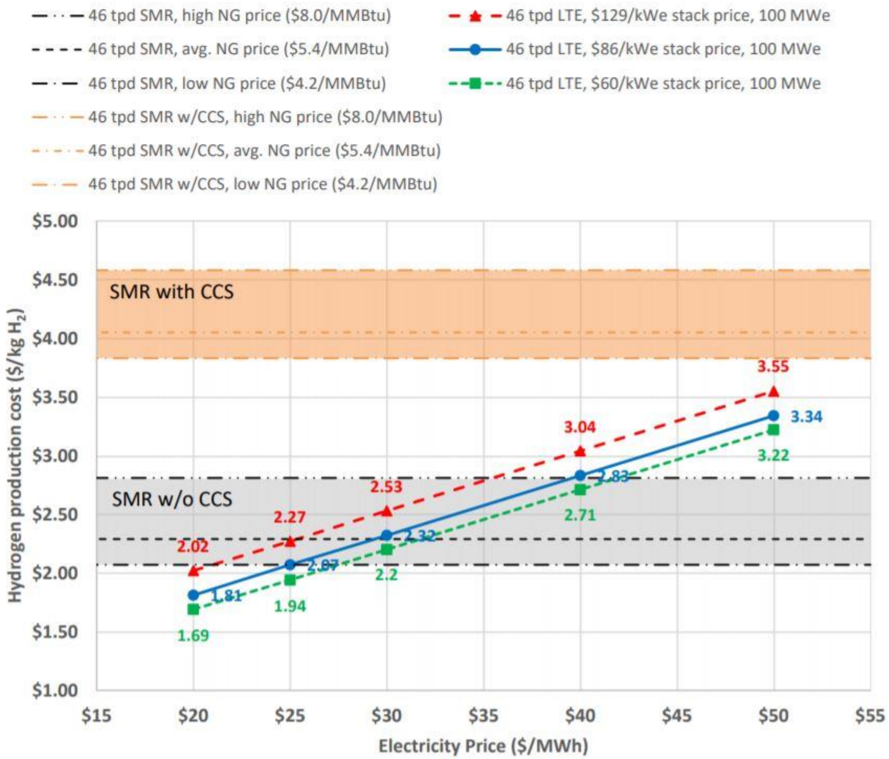
Example Uses of Hydrogen Considered



Hydrogen Production Costs were Determined for Low Temperature and High Temperature Electrolysis and Steam Methane Reforming

Natural gas price projections in DOE/EIA Advanced Energy Outlook for 2018 (USD2017) used for steam methane reforming hydrogen production cost assessment.





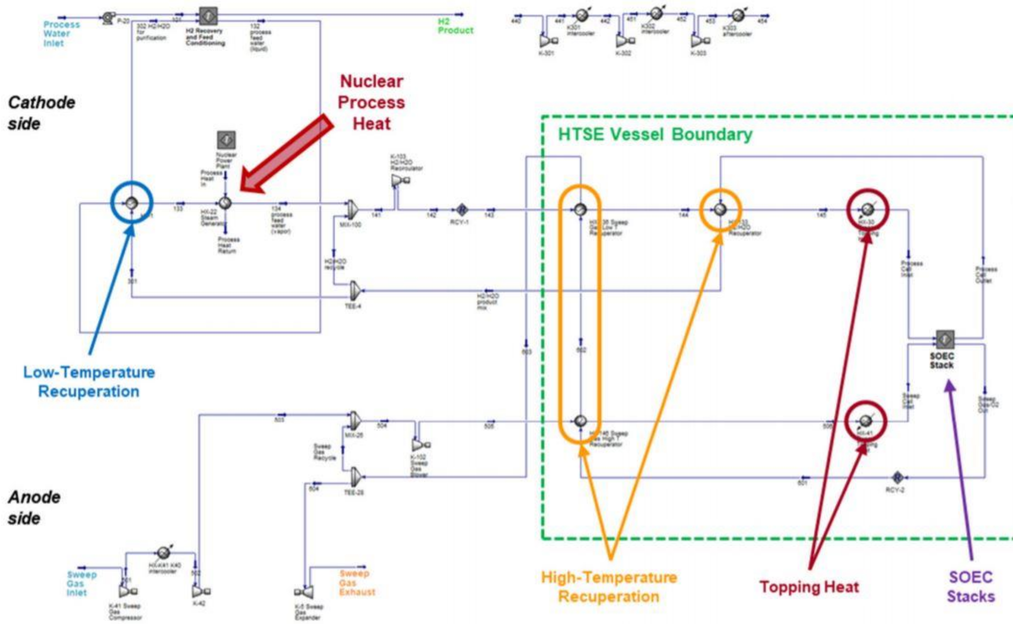
Comparison of hydrogen-production costs for 46 tpd small-scale/steady-state LTE using energy from a light water reactor versus and steam methane reforming plants.

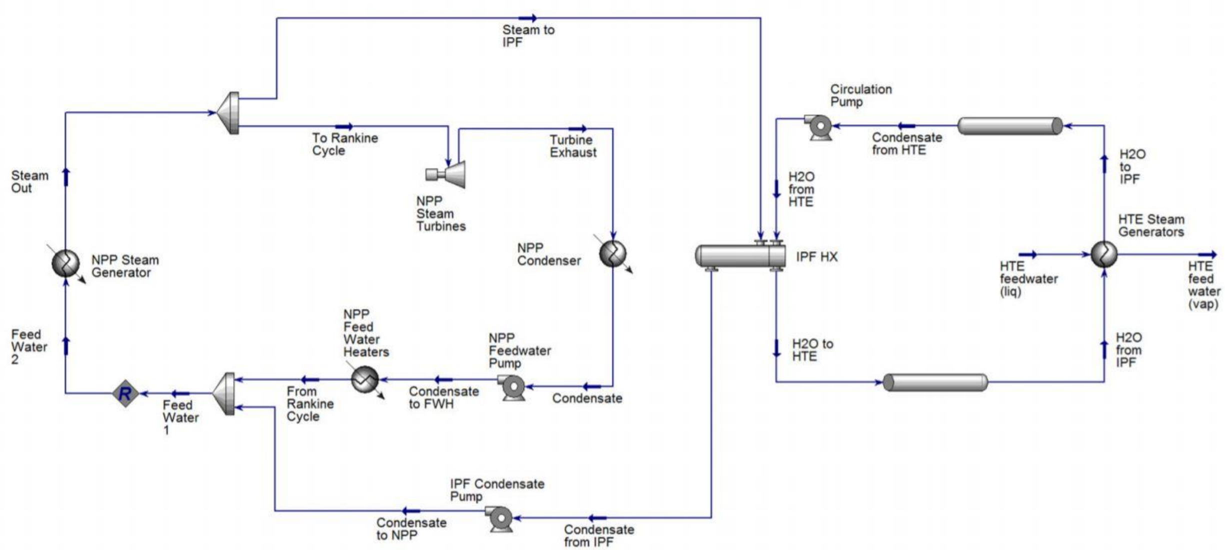
Key assumptions:

- Nth-of-a-kind LTE plant taking electricity from the grid
- 97% on-line capacity factor
- SMR with 90% on-line capacity factor
- No LTE oxygen sales
- No capacity-payment credits.

Hydrogen Production Costs Were Determined for High Temperature Electrolysis

Hydrogen production with steam and electricity provided by a nuclear reactor.

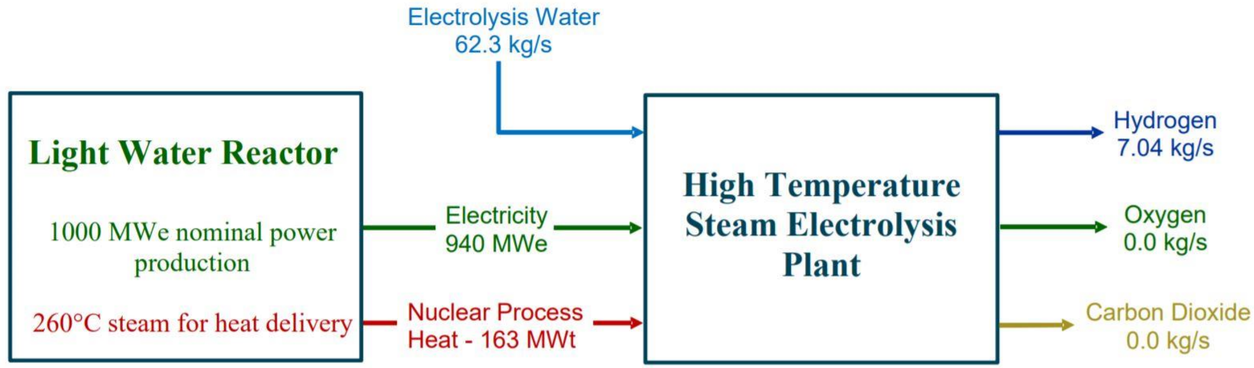


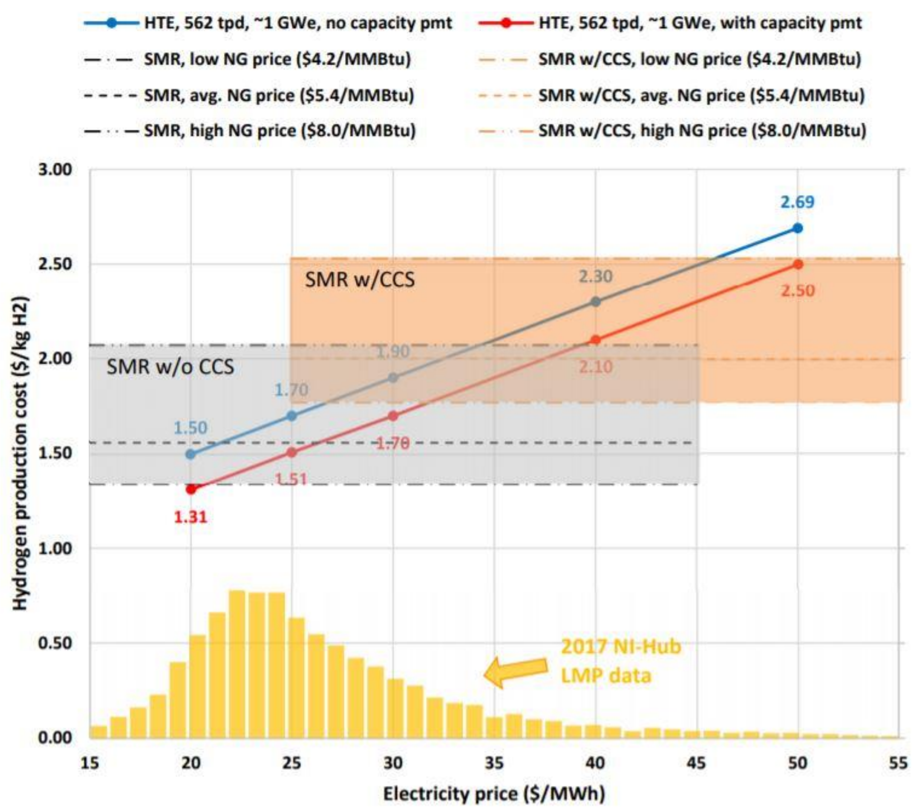


Process diagram for heat delivery from a nuclear power plant.

Hydrogen Production Costs Were Determined for High Temperature Electrolysis

Steady state hydrogen production material and energy balance



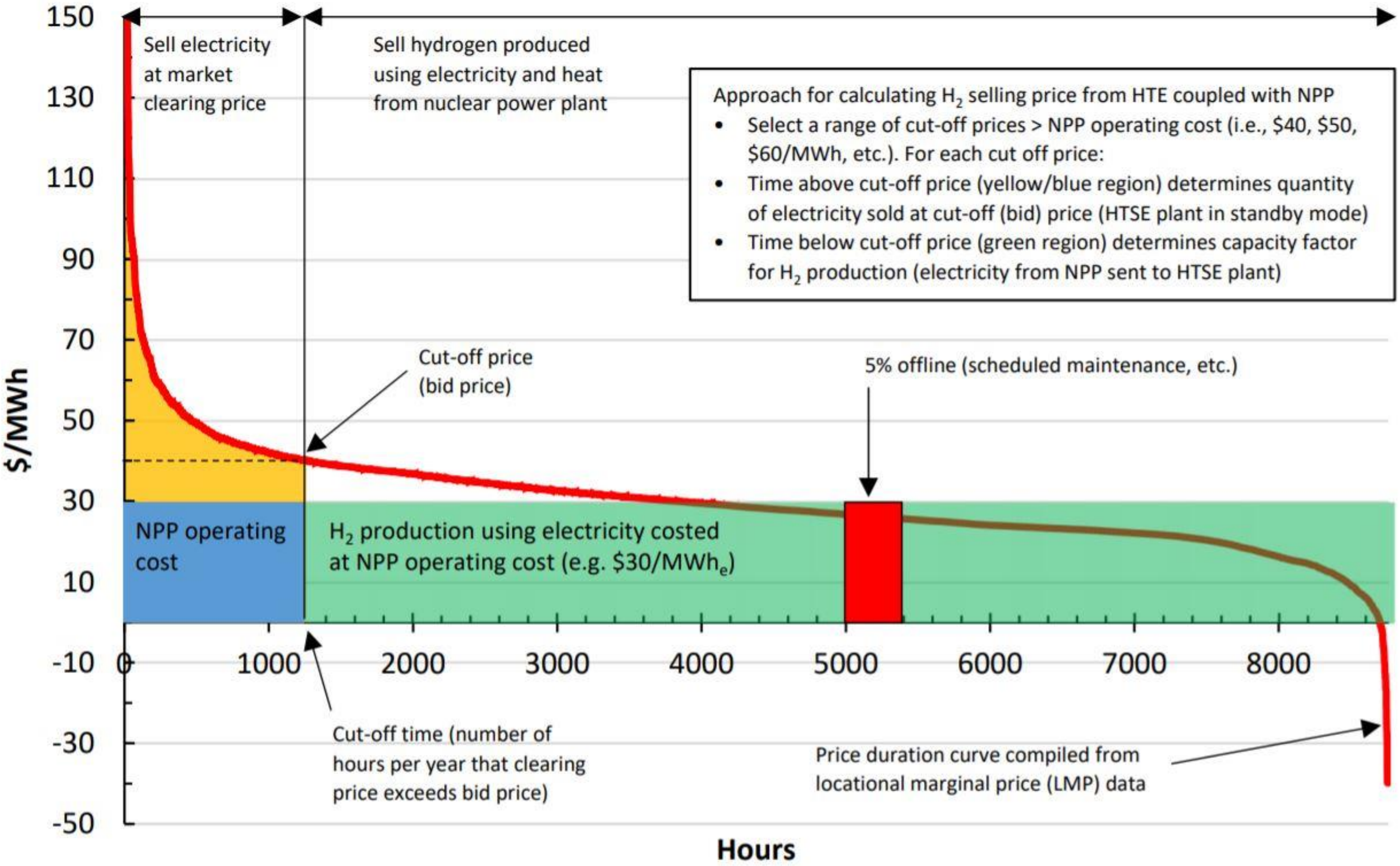


Comparison of hydrogen-production costs for 562 tpd large-scale/steady-state high temperature electrolysis (HTE) using energy from a light water reactor (LWR) versus and steam methane reforming plants.

Key assumptions:

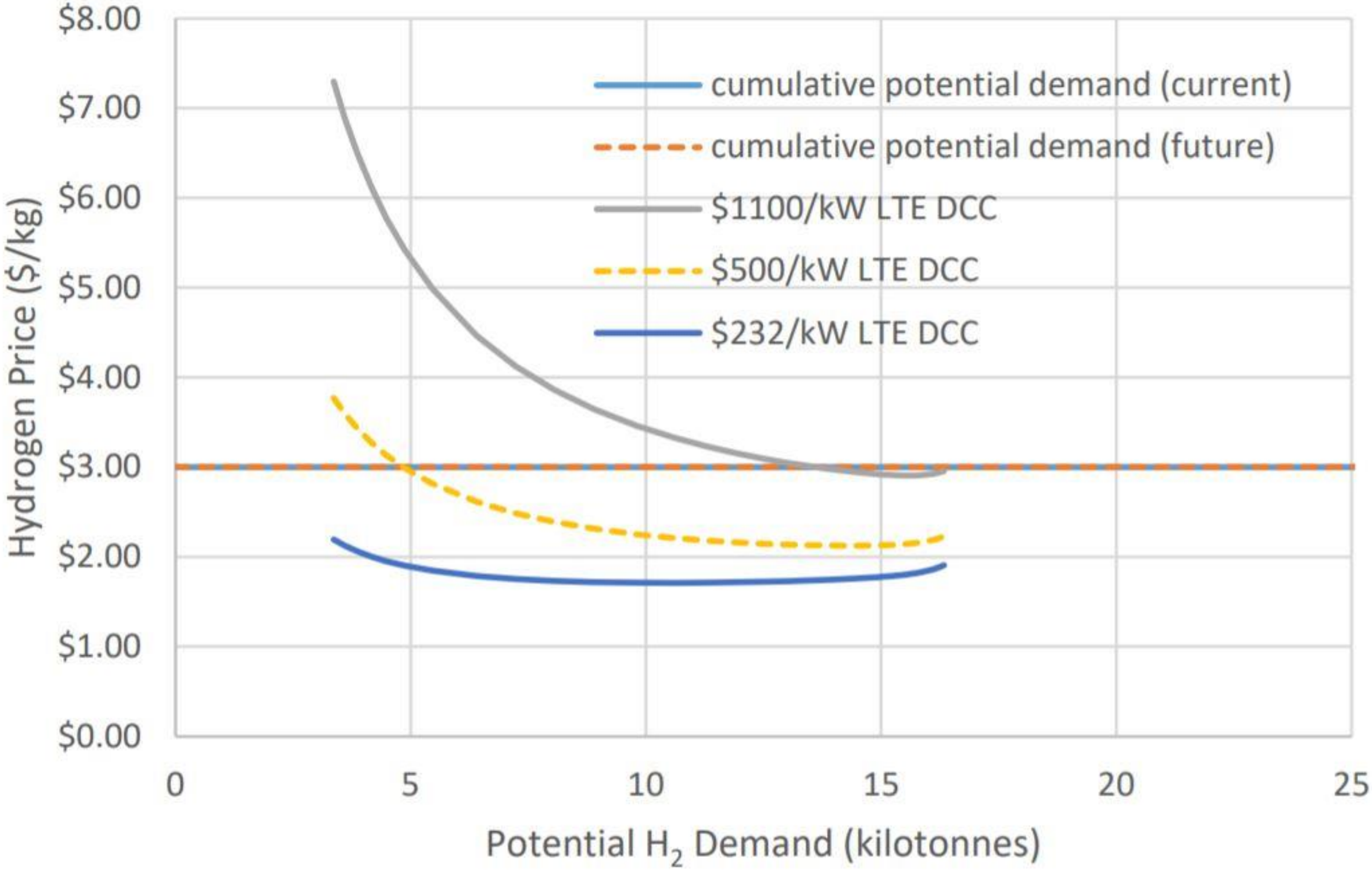
- Nth-of-a-kind 608 tpd design capacity LWR/HTE plant
- 92.4% on-line capacity factor and 624 tpd design capacity
- SMR with 90% on-line capacity factor
- No LWR/HTE oxygen sales
- Compression and delivery costs of $0.34/kg for LWR/HTE and $0.07/kg for SMR
- LWR/HTE capacity-payment credits of $0 or $132.4/MWe-day).

Hydrogen Production Costs Determined for Hybrid Power/Hydrogen Plant Concepts



Hybrid nuclear electricity/hydrogen plant approach to minimize hydrogen production costs.

Hydrogen Production Costs Determined for LTE Plant Operated at Activation Price



Xcel Energy Hydrogen Production Scenario: Minimum hydrogen sales prices corresponding to an operating strategy in which the LTE plant is operated when the local marginal price (LMP) price is less than or equal to an optimal activation price determined by the NREL study analysts.

Summary

- This CRADA addresses hydrogen merchant markets in three different regions.
- All projects objective have been completed.
- Electricity market price duration characteristics for the different regions have been obtained and were used to calculate hydrogen costs.
- Hydrogen markets have been evaluated for each utility region.
- Low-temperature and high temperature hydrogen production costs were determined as a function of plant scale, energy prices, and grid market conditions.
- A limited distribution report has been provided to the CRADA partners.
- A journal article will be prepared by the CRADA partners.

Key Outcomes & Conclusions

- LTE and HTE can compete with steam methane reforming in some regions where the LMP of electricity is relatively low, and the capital cost of LTE and HTE are reduced through nth-of-a-kind high volume manufacturing.
- There are benefits associated with hybrid plant operation (the LCOH would be minimized at an OCF of 95% in each scenario) if linking the plant operating strategy to the electrical market did not increase provide increased economic potential.
- For each HTE scenario, the LWR/HTE plant will produce hydrogen when the LMP is less than or equal to a specified “bid price” and will dispatch electricity when the LMP is greater than the bid price.
- Most of the scenarios evaluated resulted in supply curves with minimum LCOH values lower than the demand curve price for refineries ($3/kg), and in some cases, the LCOH values were lower than the demand curve price for ammonia production ($2/kg). Since LCOH decreases with reduced CAPEX, the cases with lower CAPEX were more likely to produce supply curves with potential to sell hydrogen to customers with a lower demand curve price.