Prospects for a Self-Sustaining Renewable Hydrogen Sector in California

Renewable Gas 360

Advanced Power & Energy Program
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Acknowledgements

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- **Thanks to the more than 40 industry and agency stakeholders that have provided input to the effort through interviews and comments to the docket**
- **Project information and webinar slides available at CEC docket 17-HYD-01**

Renewable Hydrogen Roadmap for California

- **One-year effort to provide a fact base for policy makers and stakeholders on what is needed to ensure a self-sustaining renewable hydrogen production base by 2030**
- **Analysis included quantitative assessment of all elements of the renewable hydrogen production and delivery chain, demand evolution and build-out requirements**

Technology Characterization (Cost and Performance)

- Electrolysis, AD, gasification
- Developer input, literature, learning-curve analysis

Feedstock Cost and Availability

- DOE billion ton report primary source for organics
- Lazard wind and solar forecast

Plant-Gate-to-Dispenser Cost Evolution

- DOE HDSAM 3.0 model
- Station size and utilization from ARB CHIT analysis
- Learning curve cost forecast

Dispensed Cost of Renewable Hydrogen Evolution

- All-in unsubsidized cost by production and delivery pathway
- Impact of environmental credits and secondary revenue (tipping fees)

Renewable Hydrogen Demand Evolution

- Industry and developer input
- State agency reports (e.g. Mobile Source Strategy)
- DOE H2@Scale and lab reports

Candidate Site Identification

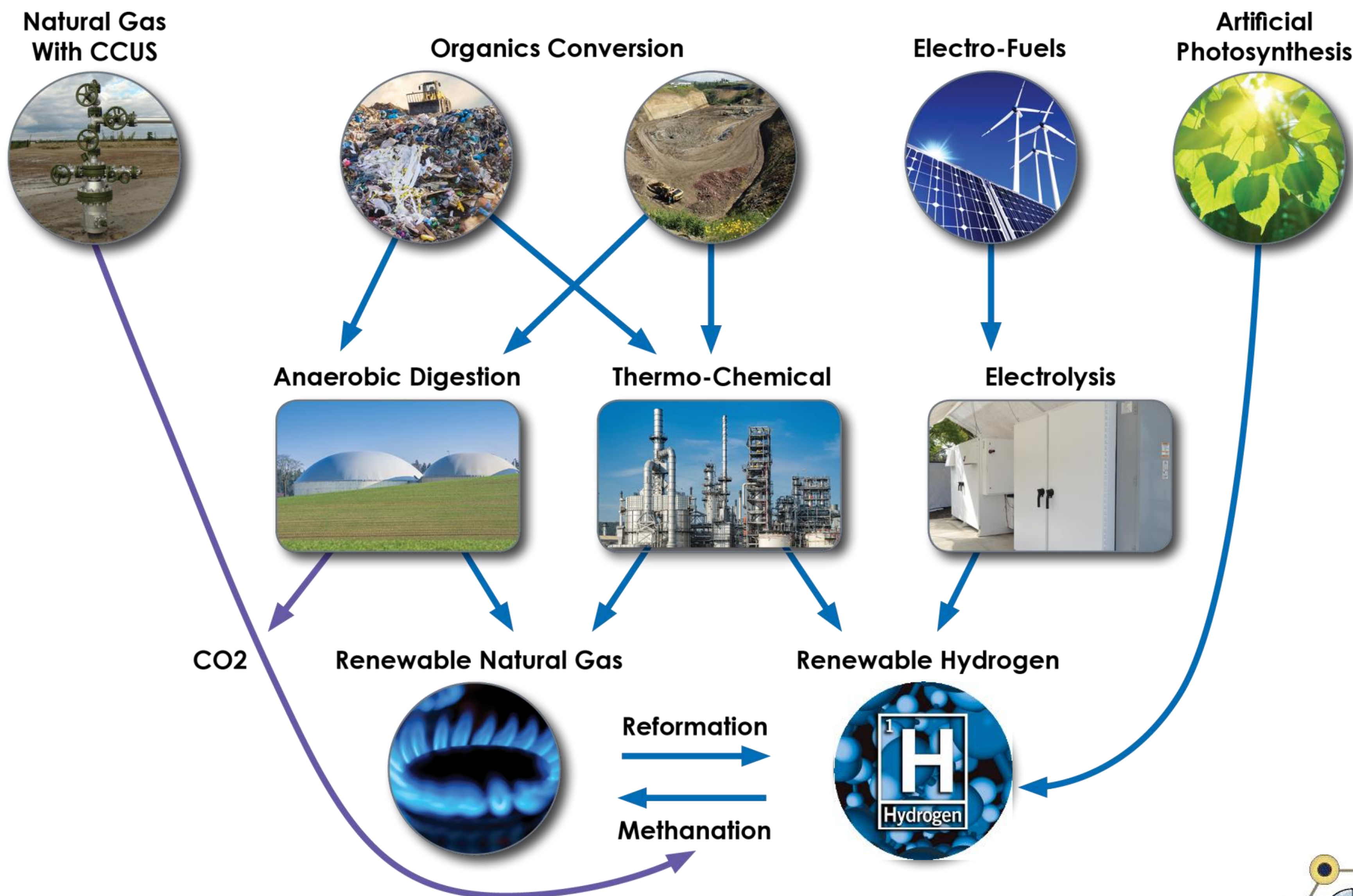
- Footprint and emissions
- Zoning / access
- DAC screen
- Developer input

Integrated Renewable Hydrogen Roadmap

- Spatial and temporal build-out scenarios (starting from existing and planned projects)
- High-level optimization and build sequencing
- Investment requirements
- Barriers and enablers + recommended actions
- Future research needs

Stakeholder Engagement

Renewable and Zero-Carbon Gas Pathways



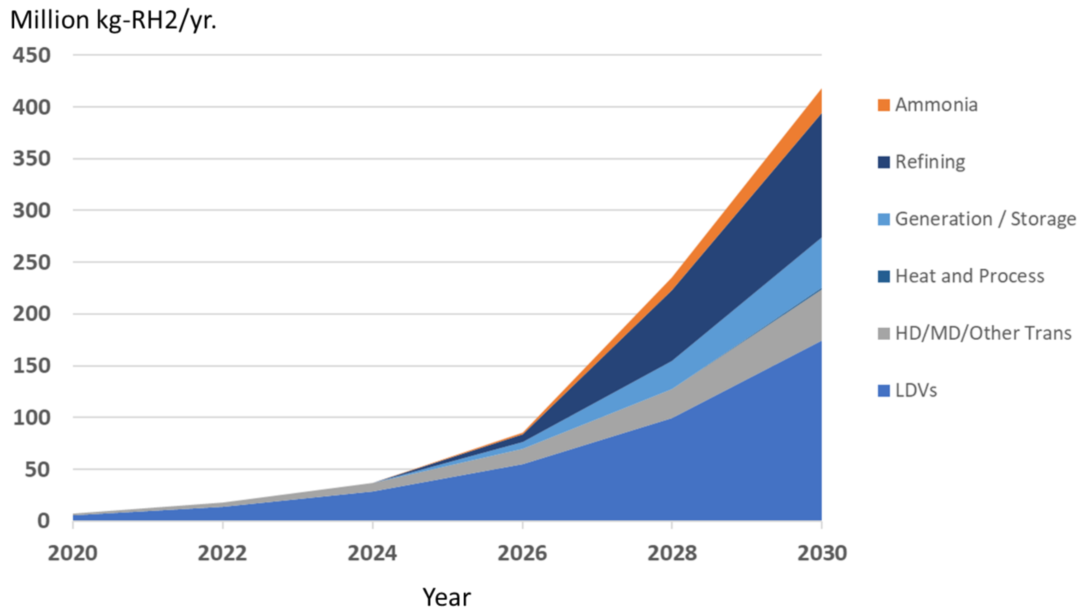
Key Findings

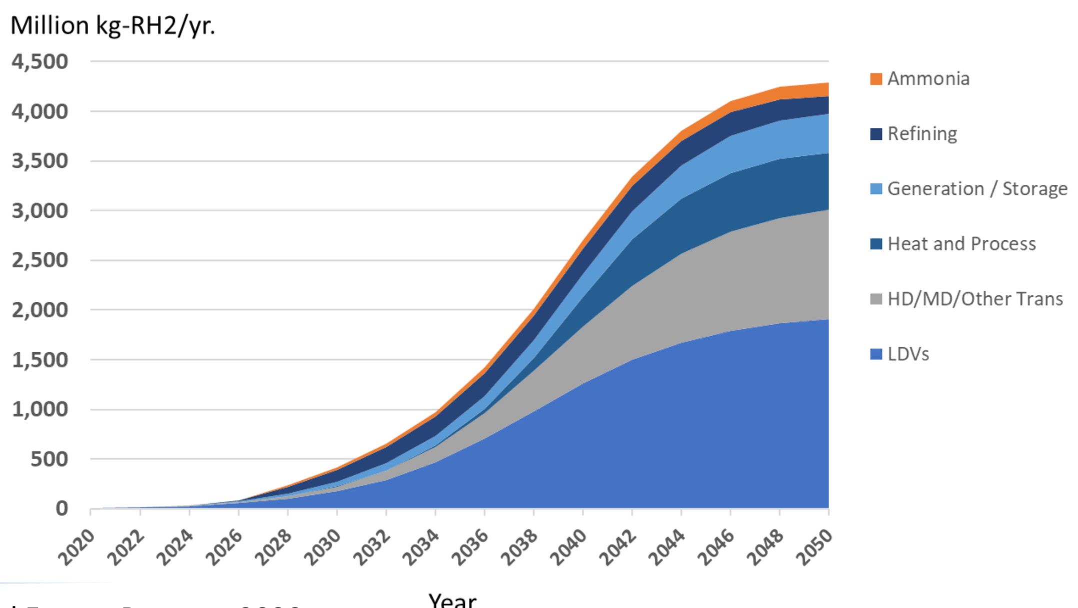
- **Transportation**
  - **A self-sustaining hydrogen transportation sector appears to be possible by the mid to late 2020's assuming progress on cost reduction meets base-case projections and LCFS credit prices remain above ~$100/credit**
  - **The mid-term (3 -5 year) target of reaching a dispensed price of renewable hydrogen between $6 and $8.50 per kilogram is achievable through scale economies and increased network utilization**
  - **The long-term (beyond 2030) forecast is that the price of RH2 tracks toward $5 per kilogram with $4 per kilogram on the low end of the forecast range**
- **Other applications**
  - **Renewable hydrogen for thermal applications and power generation can reach a price point of $16/MMBtu or below by 2030**
  - **Implied carbon price of $250/ton assuming $4/MMBtu natural gas in 2030**
  - **Below marginal abatement cost for many applications**
- **RH2 demand could reach over 400 million kg/yr by 2030 and 4,200 million kg/yr by 2050 (equivalent to about 25% of current vehicle fuel demand)**

Key Findings

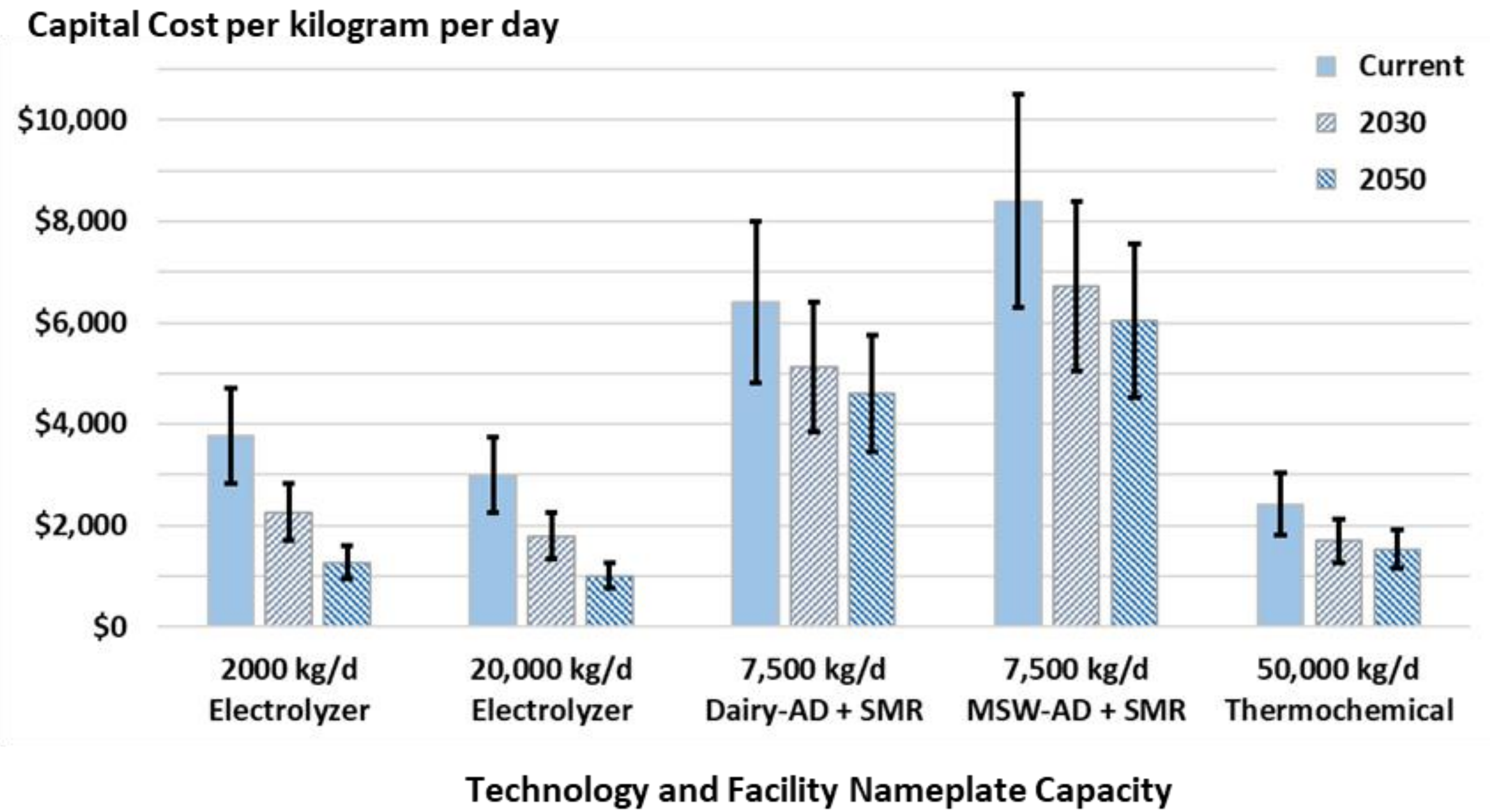
- **Reformed biomethane (predominantly landfill gas) is the primary source of renewable hydrogen currently but policy support for initial commercial deployment of electrolytic and thermochemical production facilities is needed to meet demand**
- **All primary RH2 production pathways (reformed biomethane, electrolysis and gasification) have the potential to compete in the market by the mid 2020's**
  - **Assuming LCFS prices remain robust**
  - **Organic waste mandates will ensure that the in-state organic feedstock will be developed – allocation among RH2, RNG and renewable liquids is uncertain**
  - **Electrolytic hydrogen will be needed to meet demand over the long term**
  - **Electrolyzer and thermochemical systems need commercialization support**
- **Key areas of policy support needed to achieve self-sustainability include:**
  - **Continued support for the LCFS program including price stability**
  - **Funding / financing support for commercial gasification and electrolysis pilots**
  - **Streamlining of citing and permitting**
  - **Access to wholesale electric markets for electrolyzers (and liquefaction facilities)**
  - **Elimination of regulatory barriers to energy storage in which energy input and energy output are not co-located**
  - **RD&D supporting cost reduction, technology diversity and market understanding**

High-Case California Renewable Hydrogen Demand to 2050





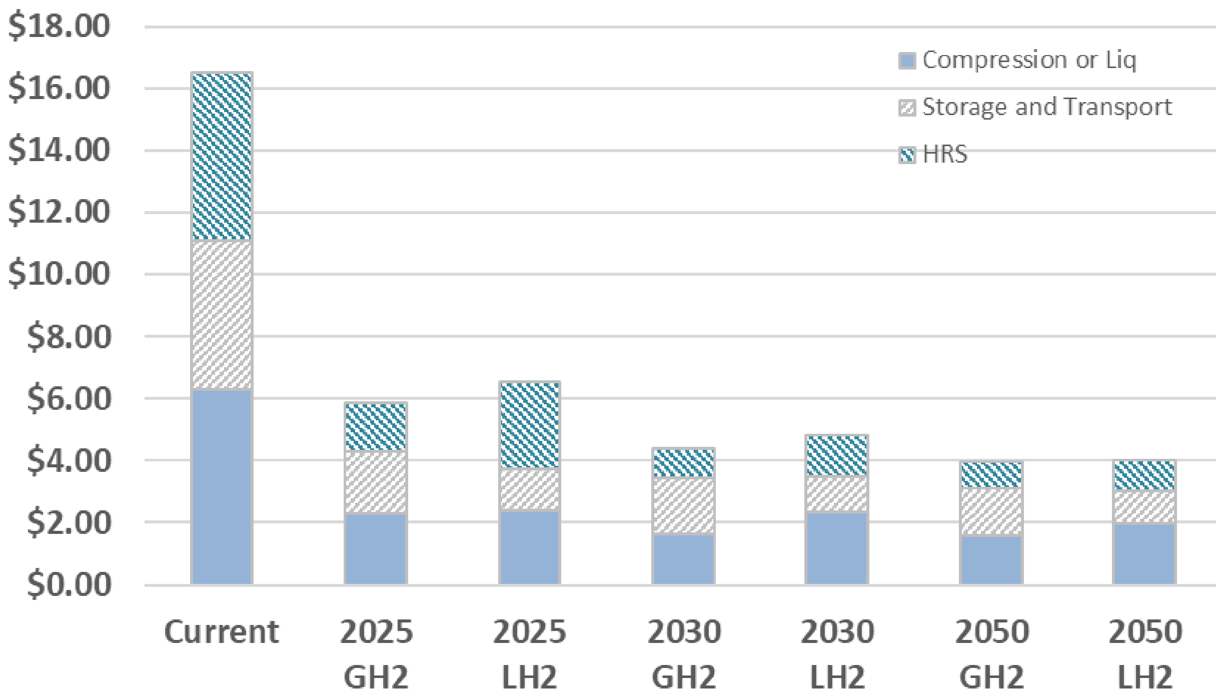
Learning Curve and Other Methods Project Significant Cost Reduction for all RH2 Production Technologies



Electrolyzers show the greatest reduction -- nearly 70% by 2050

Hydrogen Supply-chain Costs also Forecast to Decline Rapidly

Increased station network utilization and station economies of scale are the biggest contributors to cost reduction

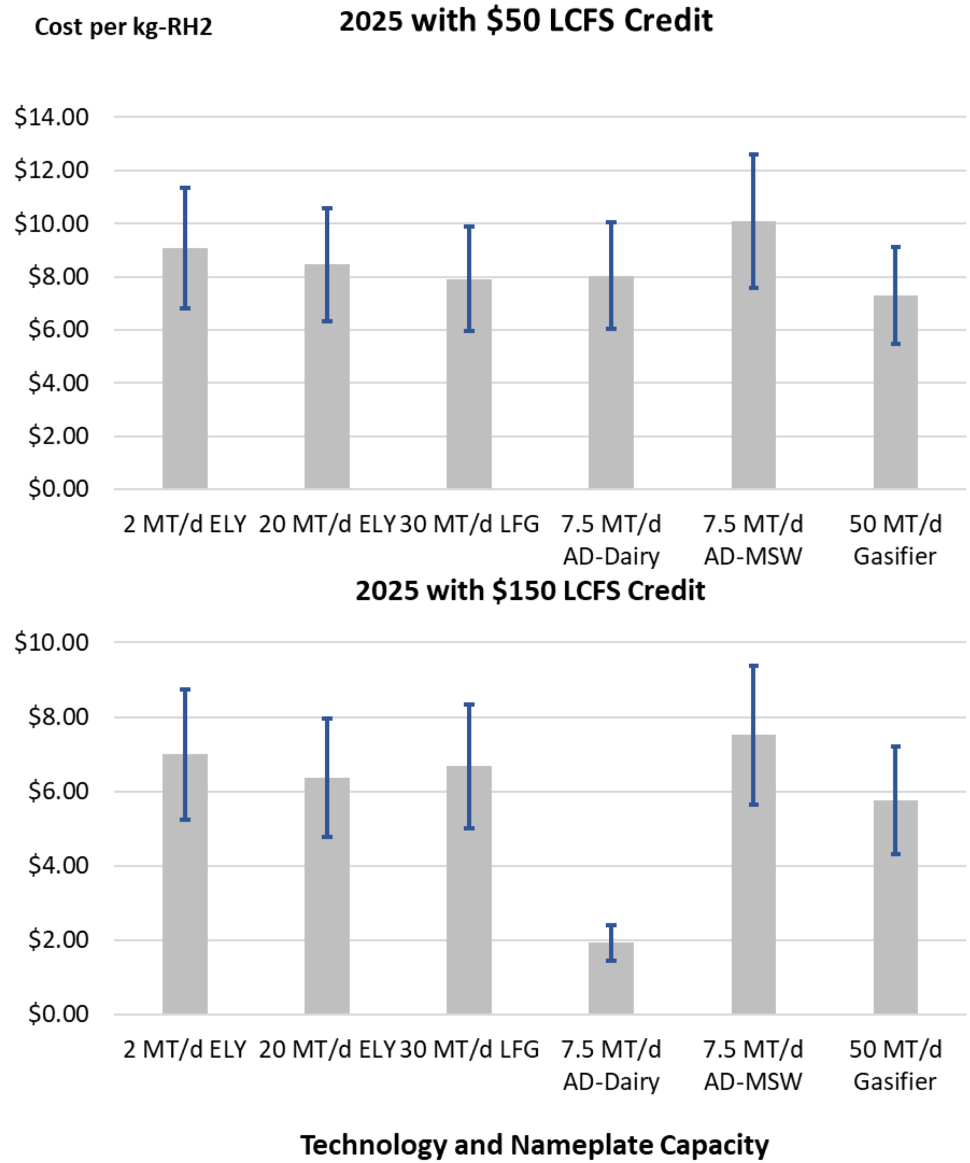


Input Assumptions

	Current	2025	2030	2050
Station Size Kg/d	300	600	1200	1500
Utilization	40%	70%	80%	80%
Production Volume	Low	Medium	High	High

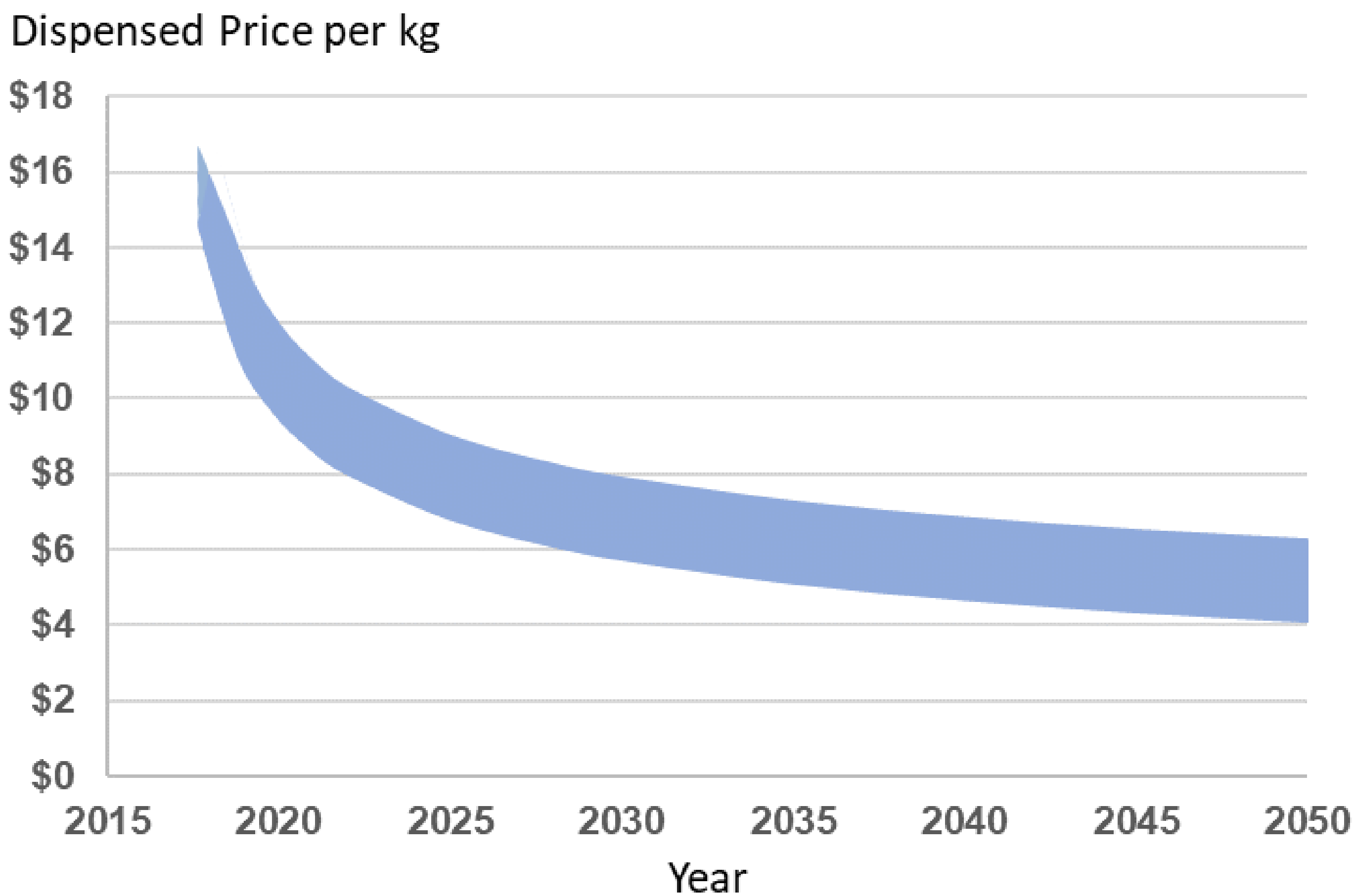
Source: UCI APEP using HDSAM 3.1

Comparative Dispensed RH2 Cost Range with Credits 2025

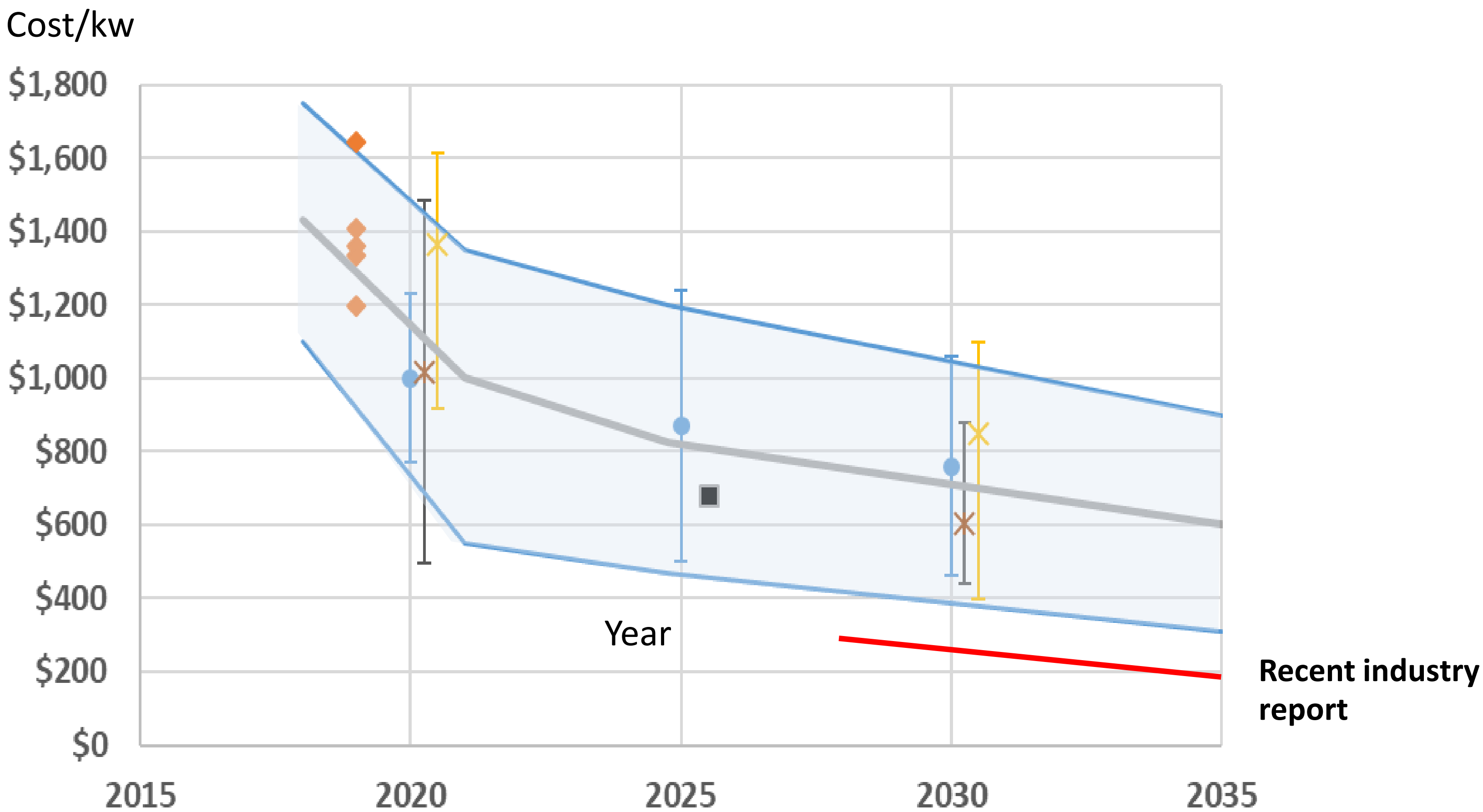


- **All technologies are within competitive band at both $50 and $150/ton LCFS credit value**
- **Gasification and landfill gas less dependent on LCFS credits**
- **Landfill diverted material may require higher tipping fees to compete effectively as an RH2 source**
- **Dairy has a strong advantage at higher credit values**

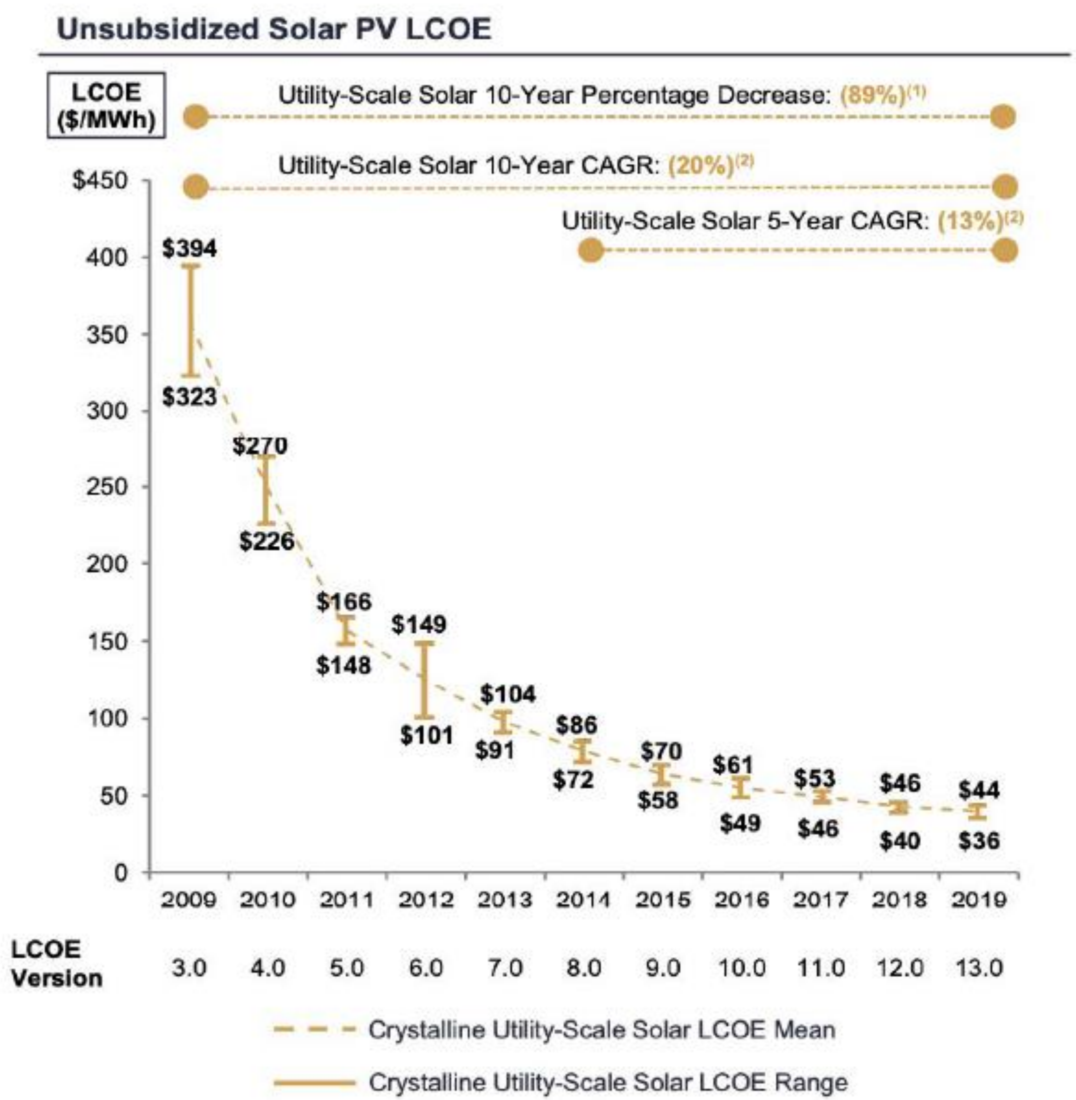
Pump Price of Renewable Hydrogen Evolution



Electrolyzer Cost Forecast



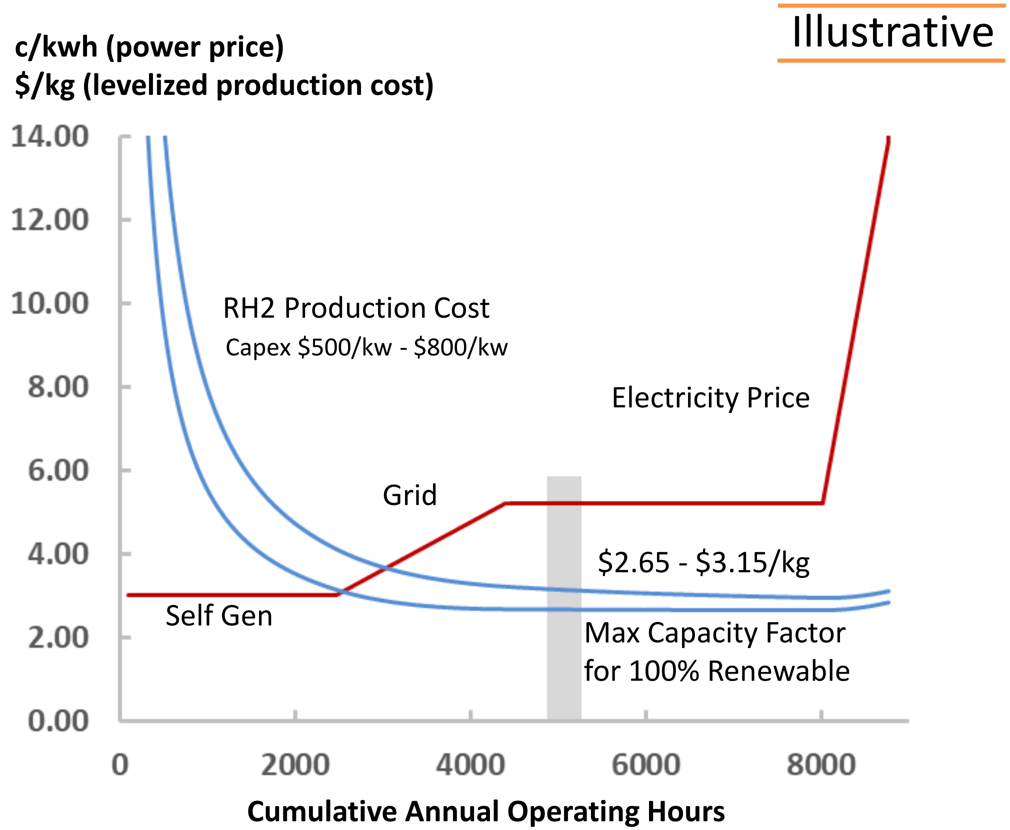
Renewable Power Costs Continue to Decline



Source: Lazard Levelized Cost of Renewable Energy

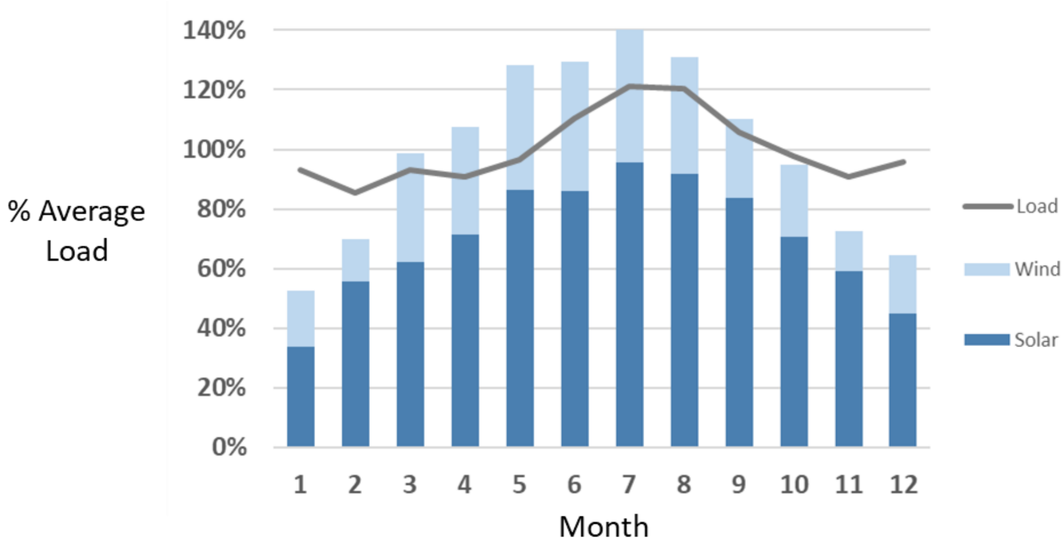
Cost of Producing Green Electrolytic Hydrogen

Electrolytic Hydrogen Production Cost in 2025 Timeframe

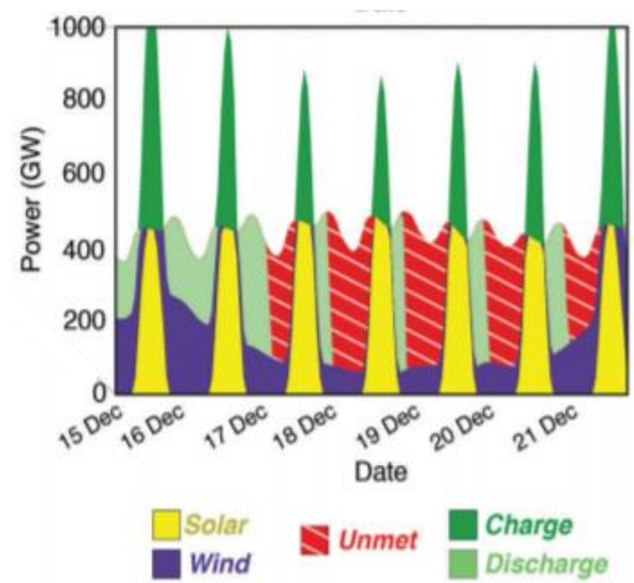


- **Representative case of self-generated solar augmented with wind PPA or spot purchases**

Hydrogen is a Long-term Storage and Renewables Integration Solution



From Shaner et al. 2018



RH2 Cost	Cost of Firm Renewable Power*
$1/kg	$0.047/kwh
$2/kg	$0.092/kwh
$3/kg	$0.142/kwh

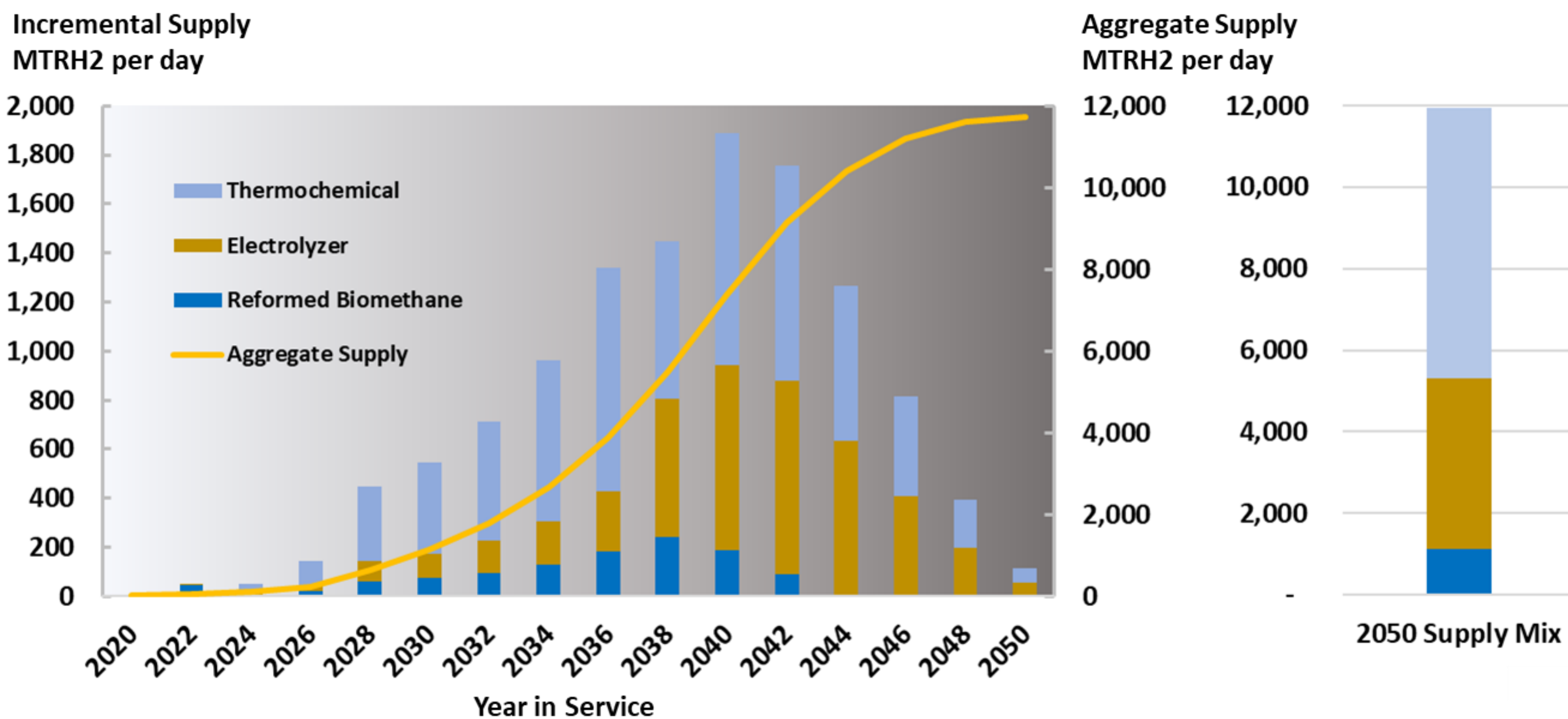
* Energy cost at 60% efficiency; i.e. existing GTCC

Supply System:

- 75% Solar 25% Wind
- 1.5 x generation
- 12 Hours Storage

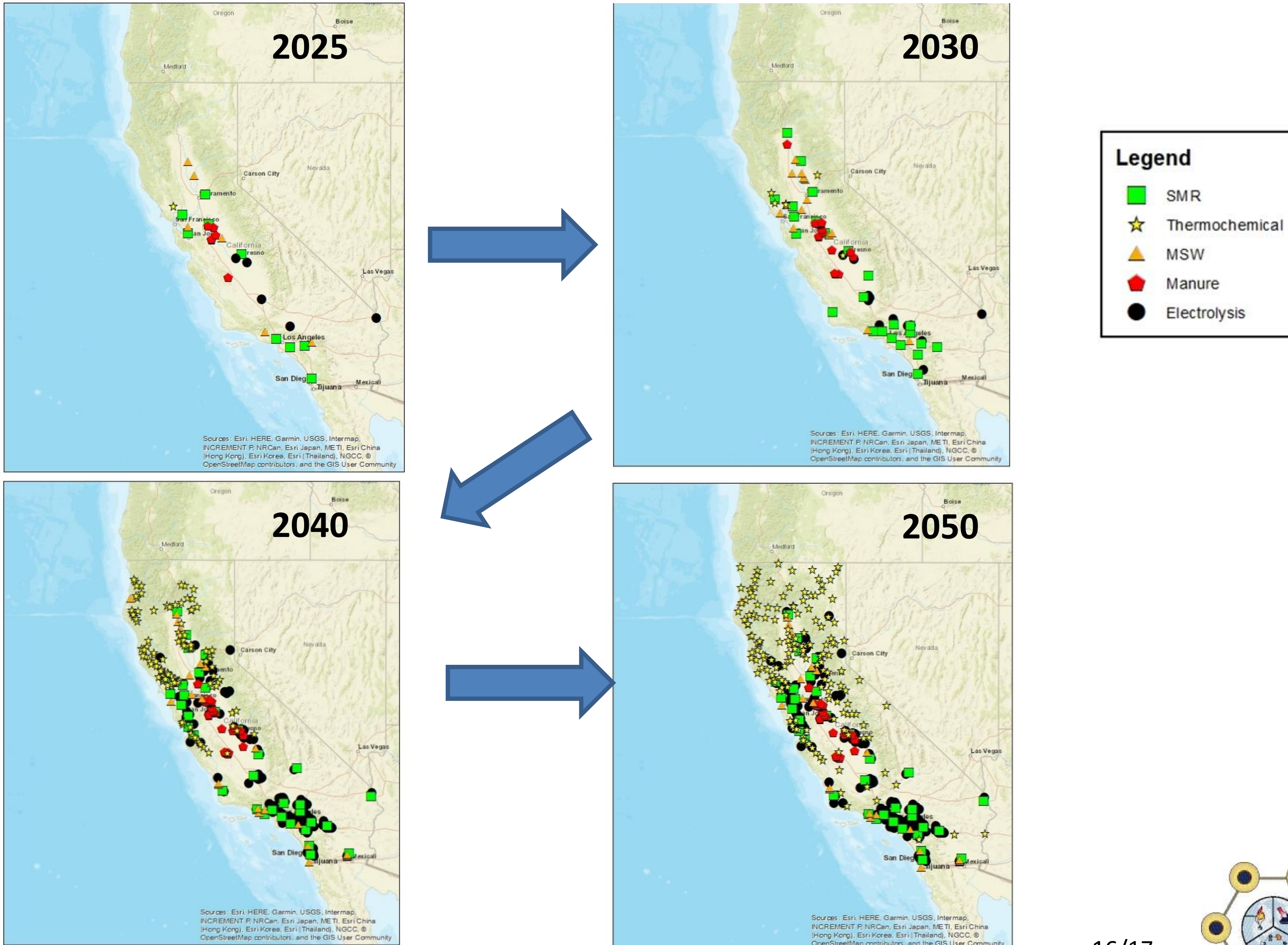
Reliability 98.7% -- nearly 5 days per year of unserved load

Build-out to Serve High-demand Case



- Build-out to meet high-demand case assuming successful commercialization of thermochemical conversion technology (base case)
- On the order of 500 new facilities needed (depending on facility size) – more than 25 new facilities in the peak year
- Aggregate investment on the order of $40 to **$50** billion

Representative Build-out



Re-cap of Primary Regulatory and Policy Needs

- Continued support for the LCFS program including price stability
- Funding / financing support for commercial gasification and electrolysis pilot projects (table below)
- Streamlining of citing and permitting
- Access to wholesale electric markets for electrolyzers (and liquefaction facilities)
- RD&D to support cost reduction, technology diversity and market understanding

Technology	Period 2022 – 25	Period 2026 - 30	State Support	Subsidy Cost
Gasification	1 x 25 MT/d	1 x 25 MT/d	50% capital cost grant or loan guarantee valued at 20% of capital cost	$35M - $85M
Electrolysis	5 x 5 MT/d	2 x 20 MT/d	50% capital cost grant for first 5 projects; 25% for next 2	~$50M
			Total State Support	$85 - $135M

Thank You. Questions and Comments?

#RH2@APEP

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Comments or questions to: jgr@apep.uci.edu