DOCKETED	
Docket Number:	20-EPIC-01
Project Title:	Development of the California Energy Commission Electric Program Investment Charge Investment Plans 2021-2025
TN #:	238711
Document Title:	Presentation - EPIC - The Role of Green Hydrogen in a Decarbonized California - A Roadmap and Strategic Plan
Description:	Full presentation for the July 1,2021 EPIC Workshop
Filer:	Harrison Reynolds
Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	7/7/2021 12:25:51 PM
Docketed Date:	7/7/2021

Electric Program Investment Charge: 2021-2025 (EPIC 4) Investment Plan Scoping Workshop

The Role of Green Hydrogen in a Decarbonized California - A Roadmap and Strategic Plan

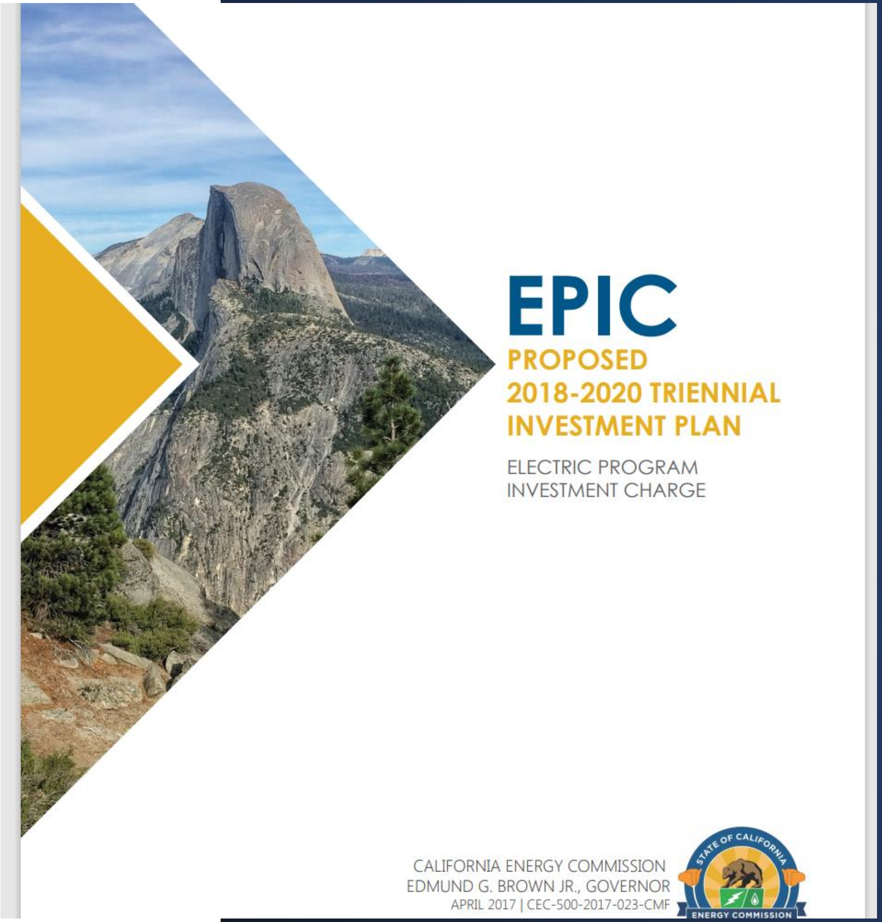
July 1, 2021

EPIC 4 Investment Plan Process, Timeline, and Public Participation

Mike Petouhoff, CEC

EPIC Investment Planning Background

- The CPUC requires each EPIC administrator to submit an Investment Plan.
- Investment Plans lay out the proposed research investments for the funding period.
- The EPIC 4 Plan will describe the CEC's proposed investments for funding collected from **2021-2025**.
- CEC develops its plan through an open and transparent stakeholder process.
- The previous CEC EPIC Investment Plan can be found at: https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M185/K575/185575884.PDF
- Draft Proposed EPIC Interim Investment Plan 2021 https://efiling.energy.ca.gov/getdocument.aspx?tn=236221



EPIC 4 Investment Plan Research Themes

Decarbonization

Reduce GHG emissions and use of fossil fuels.

Resilience and Reliability

Provide firming and shaping to balance increasing amounts of intermittent renewable generation to help match load and generation to keep the grid stable

Support Resilience for PSPS events

Entrepreneurship

Support clean energy entrepreneurs developing breakthrough technology solutions from idea to market.

Affordability

Improve the affordability of energy services for all electric ratepayers.

EQUITY is an overarching theme for EPIC investment planning. Initiatives will include funding set-asides for projects in under-resourced communities and other equity-targeting elements.

EPIC 4 Plan Schedule

Task / Event	Date(s)
Public workshops to solicit stakeholder input on specific topic gaps	May – July 2021
Public workshop to get input and feedback on the CEC's draft research initiatives being considered for the EPIC 4 Investment Plan	August 4, 2021
EPIC 4 Investment Plan considered at CEC Business Meeting for approval	September 2021 (tentative)
EPIC 4 Investment Plan submitted to CPUC	October 1, 2021 (tentative)
CPUC Decision on EPIC 4 Plan expected	Spring-2022 (tentative)
The first EPIC 4 solicitations released	Summer-Fall 2022

EPIC 4 Workshops

Workshop Title and Description	Date
Hydrogen Roadmap	Thursday, July 1, 2021 1:00 p.m.
Offshore Wind Energy R&D Opportunities for EPIC 4	Wednesday, July 14, 2021 1:00 p.m.
Industrial Decarbonization	Friday, July 16, 2021 9:30 a.m.
Technology Advancements for Energy Storage	Tuesday, July 20, 2021 9:30 a.m.
Improving the Bankability of New Clean Energy Technologies	Thursday, July 22, 2021 10:00 a.m.
Draft Initiatives for EPIC 4	Wednesday, August 4, 2021 9:00 a.m.

To stay involved in EPIC 4:

Visit CEC's website for workshop info, presentations, docket, e-commenting, and EPIC listserv sign up: www.energy.ca.gov/epic4

Submitting Written Comments:

Workshop Comments may be submitted using CEC's **e-commenting** system: https://efiling.energy.ca.gov/Ecomment/Ecomment.aspx?docketnumber=20-EPIC-01

See this event's **notice** for **e-mail and U.S. Mail** commenting instructions: https://efiling.energy.ca.gov/getdocument.aspx?tn=238093

For all comments, please include docket # **20-EPIC-01** and "EPIC 4 Investment Plan" in the subject line and on the cover page. Comments for this workshop are due **July 15, 2021.**

EMPOWER INNOVATION

empowerinnovation.net

Workshop Format

- **Keynote:** The Role of Green Hydrogen in a Decarbonized CA- A Roadmap and Strategic Plan
- **Panel 1:** Green Hydrogen for Grid Reliability- Firming and Shaping Intermittent Renewables in the Grid of the Future
- **Panel 2:** The Role of Green Hydrogen in the Decarbonization of the Transportation System as FCV and BEV's Evolve
- **Panel 3:** California End Use Applications of Green Hydrogen
- **Presentation:** DOD Activities in Green Hydrogen Research

Format

1. Panelists will provide introductory remarks
2. Moderators will provide questions and guide the discussion
3. Attendees: Please type your questions and comments in the Q&A in Zoom. CEC staff may respond in writing or during the public question session.
4. Public questions and comments can also be taken at the end of the workshop

California Energy Commission

Interim EPIC Project:

The Role of Green Hydrogen in a Decarbonized CA- A Roadmap and Strategic Plan

Presenter: Mike Petouhoff, Manager, Energy Systems Research Office, ERDD

H2 Roadmap

Data Gathering → Green H2 Generation → Distribution & Storage Technology → Priority End Uses

- Staff Collaboration
- Prior CEC research
- Information Sharing and Workshops
  - Expert Panels
  - EPIC- July 1
  - IEPR- July 28
  - Working Groups
    - Germany
    - Denmark

H2 Roadmap

Data Gathering → Green H2 Generation → Distribution & Storage Technology → Priority End Uses

- Staff Collaboration
- Prior CEC research
- Information Sharing and Workshops, Expert Panels
  - EPIC- July 1
  - IEPR- July 28
  - Working Groups
    - Germany
    - Denmark

- Current Tech
  - Alkaline
  - Proton-exchange membrane (PEM)
  - Solid oxide
  - Photon-based
- Emerging Tech
  - Salt water
  - Non-water Electrolytes

H2 Roadmap

Data Gathering	Green H2 Generation	Distribution & Storage Technology	Priority End Uses

Data Gathering

- Staff Collaboration
- Prior CEC research
- Information Sharing and Workshops, Expert Panels
  - EPIC- July 1
  - IEPR- July 28
  - Working Groups
    - Germany
    - Denmark

Green H2 Generation

- Current Tech
  - Alkaline
  - Proton-exchange membrane (PEM)
  - Solid oxide
  - Photon-based
- Emerging Tech
  - Salt water
  - Non-water Electrolytes

Distribution & Storage Technology

- Current
  - Gaseous in Tanks
  - Pipelines
  - Geologic Storage
  - Liquid H2
  - Ammonia
  - Green CH4
- Eco System Examples
  - Land Base PV-H2
  - Offshore Wind - H2

Priority End Uses

H2 Roadmap

Data Gathering	Green H2 Generation	Distribution & Storage Technology	Priority End Uses

Data Gathering

- Staff Collaboration
- Prior CEC research
- Information Sharing and Workshops, Expert Panels
  - EPIC- July 1
  - IEPR- July 28
  - Working Groups
    - Germany
    - Denmark

Green H2 Generation

- Current Tech
  - Alkaline
  - Proton-exchange membrane (PEM)
  - Solid oxide
  - Photon-based
- Emerging Tech
  - Salt water
  - Non-water Electrolytes

Distribution & Storage Technology

- Current
  - Gaseous in Tanks
  - Pipelines
  - Geologic Storage
  - Liquid H2
  - Ammonia
  - Green CH4
- Eco System Examples
  - Land Base PV-H2
  - Offshore Wind - H2

Priority End Uses

- Electric generation and storage
  - Turbines for firm decarbonized dispatchable generation
- Transportation (FCV)
- Hard to electrify applications (ex. high-heat industrial)

H2 Roadmap Approach

Keeping hydrogen's role in focus

- Establish a hydrogen (H2) roadmap with ongoing updates
- Research and demonstration projects will focus on data gaps
- Next updates will reflect research and industry progress milestones

Hydrogen Classifications

Hydrogen (H_2) is classified by color into three types according to the feedstock used and method of H_2 production: gray, blue, and green.

Gray Hydrogen

- **Gray hydrogen** is produced from fossil fuel feedstocks without carbon capture at the point of production.
- **Gray hydrogen** accounts for more than 95% of global hydrogen production today.

Blue Hydrogen

- **Blue hydrogen** is produced from fossil fuel feedstocks with carbon capture at the point of production.
- **Blue hydrogen** exhibits significant potential in reducing emissions in end-use segments in the near term.

Green Hydrogen

Green hydrogen encompasses multiple carbon-neutral production pathways:

- **Electrolytic hydrogen** or power-to-gas (P2G), is the conversion of electrical power into a gaseous energy carrier, such as hydrogen or methane, using an electrolyzer. When powered with renewable electricity, P2G is a green hydrogen source.
- **Other green hydrogen** generation pathways exist, including biogas reforming and artificial photosynthesis.

SB-1369 (2018), Skinner.
Energy: green electrolytic hydrogen.

SEC. 2. Section 400.2 is added to the Public Utilities Code, to read:

400.2. For the purposes of this article, “**green electrolytic hydrogen**” means hydrogen gas produced through electrolysis and does not include hydrogen gas manufactured using steam reforming or any other conversion technology that produces hydrogen from a fossil fuel feedstock.

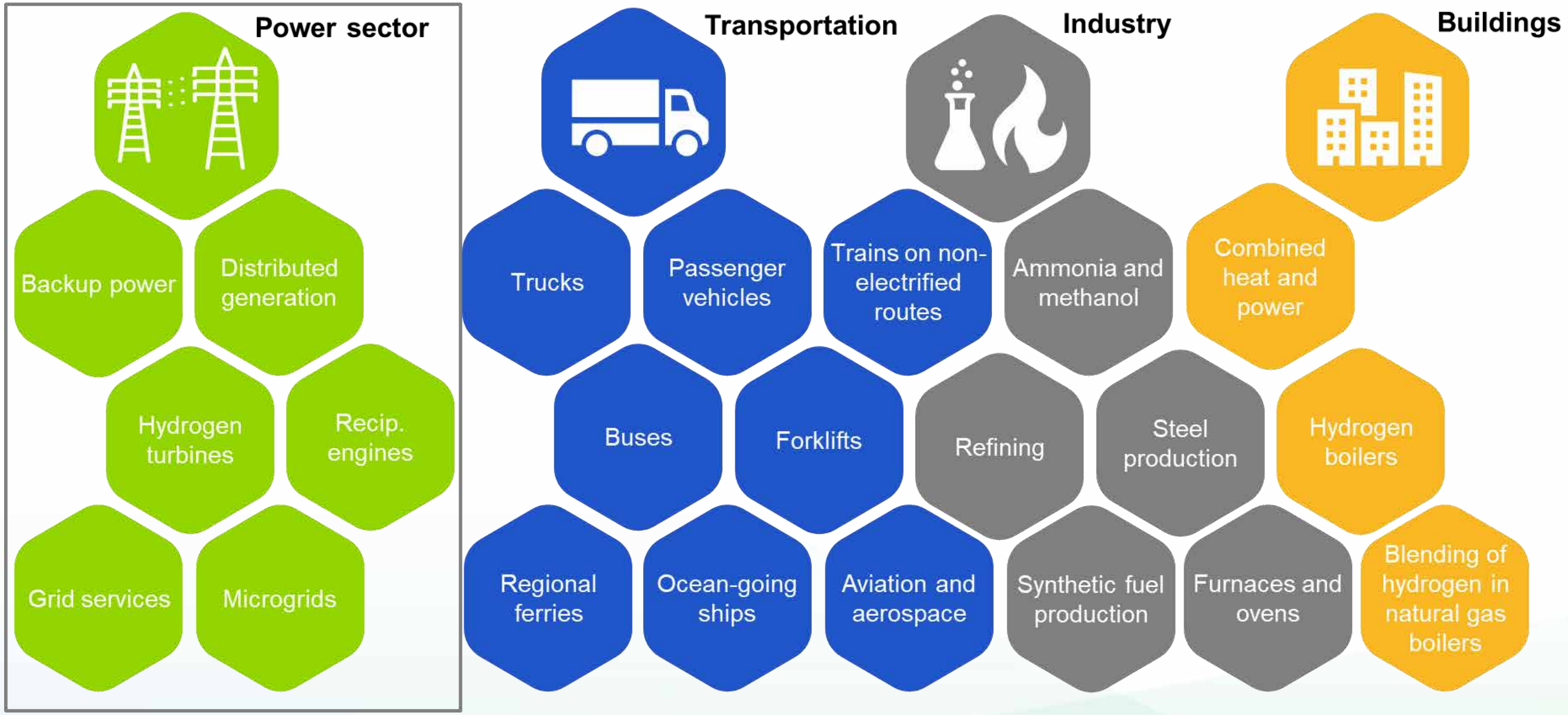
SEC. 3. Section 400.3 is added to the Public Utilities Code, to read:

400.3. The commission, State Air Resources Board, and Energy Commission shall consider green electrolytic hydrogen an **eligible form of energy storage**, and shall consider other potential uses of green electrolytic hydrogen.

Hydrogen for Decarbonization

Hydrogen as a key decarbonization lever

- Hydrogen is already used in a wide range of applications, with overall demand continuing to be dominated by its use as an industrial feedstock.
- Hydrogen has the potential to significantly expand to other use cases where it could act as a key decarbonization lever across the economy, if produced via electrolysis or coupled with CCUS.



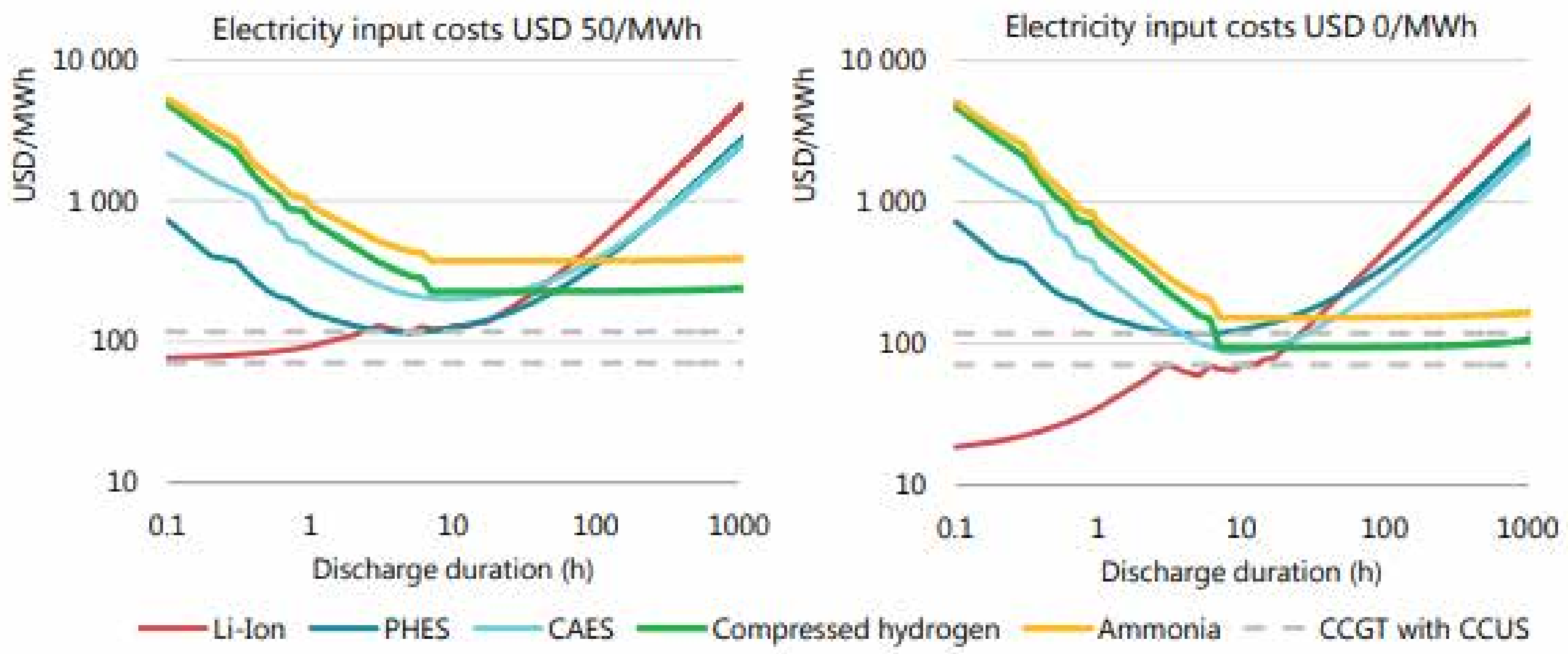
Key Driver: H2 for Grid Reliability

- SB100 Scenarios show up to 15 GW of Firm Dispatchable Generation May be needed (p 13)- Trade off w long duration storage
- The incremental cost between the SB100 “Core” and SB100 “Study” (no combustion) option is about $8B/Year
- Less land use impacts as well

Why H_2? Long Duration Storage Medium

Hydrogen's value as a storage medium is derived from its ability to be cost-effectively stored for long durations relative to other current storage technologies such as Lithium Ion.

Figure 64. Levelised costs of storage as a function of discharge duration



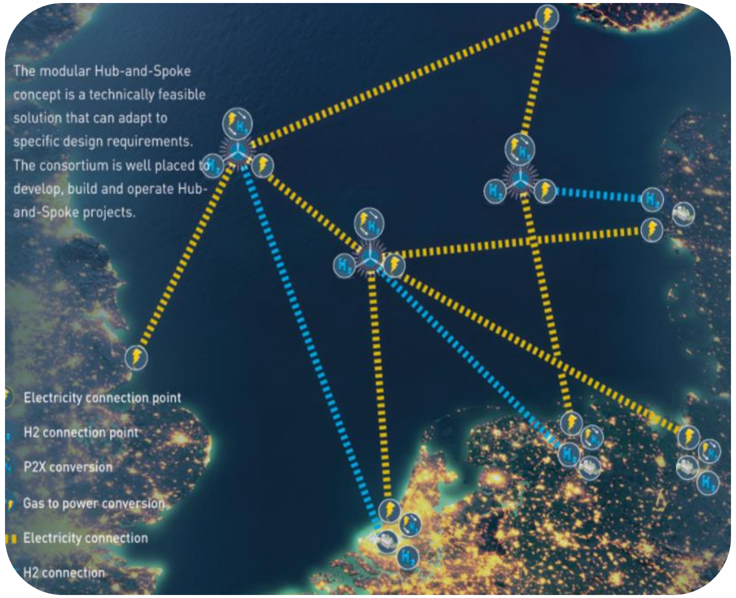
Notes: PHES = pumped-hydro energy storage; CAES = compressed air energy storage; Li-Ion = lithium-ion battery. Compressed hydrogen storage refers to compressed gaseous storage in salt caverns, ammonia storage to storage in tanks.

Source: IEA 2019.

Green H2 Ecosystem examples

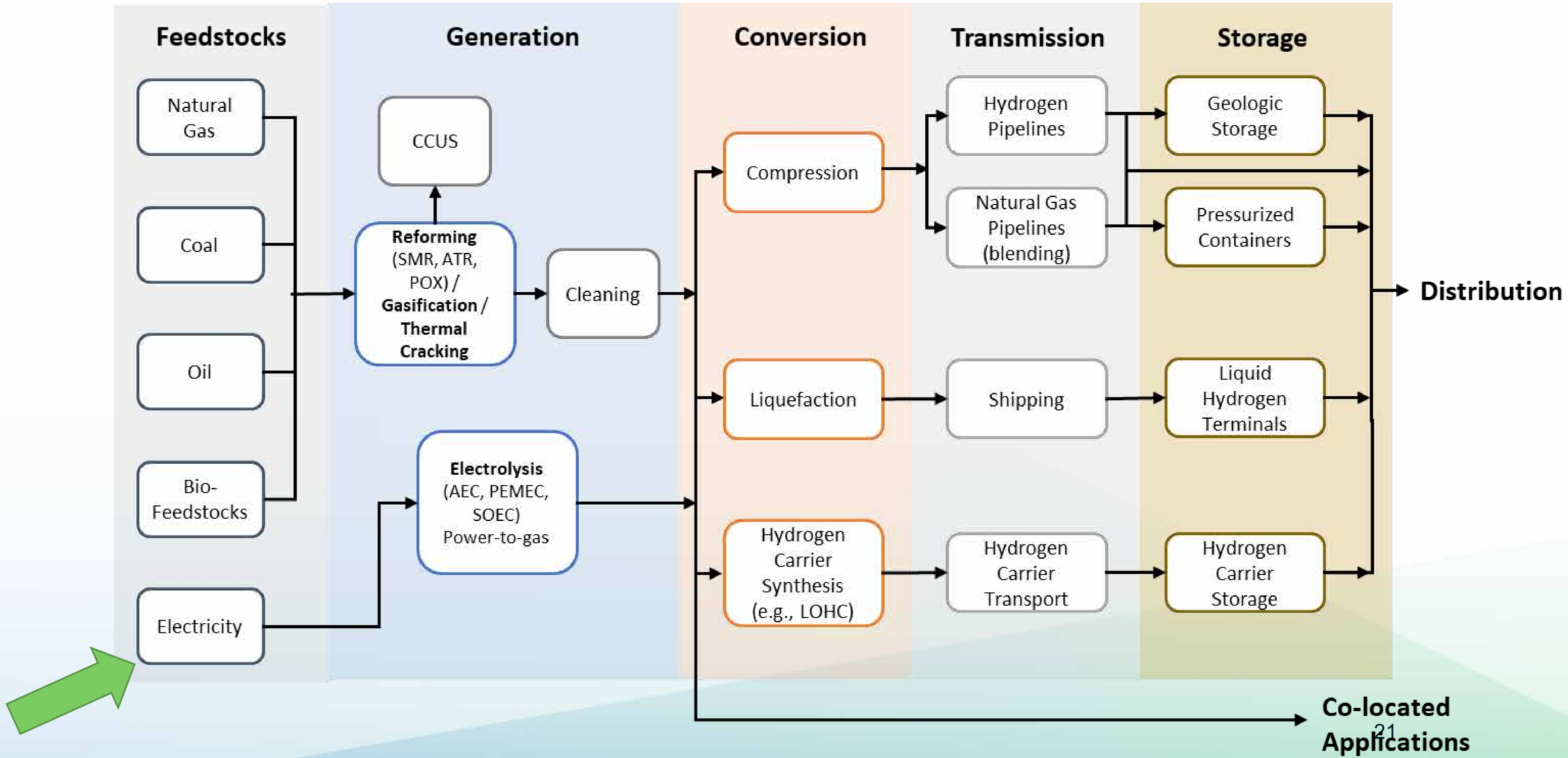
CA Land Based PV + H2

CA Land Offshore Wind + H2

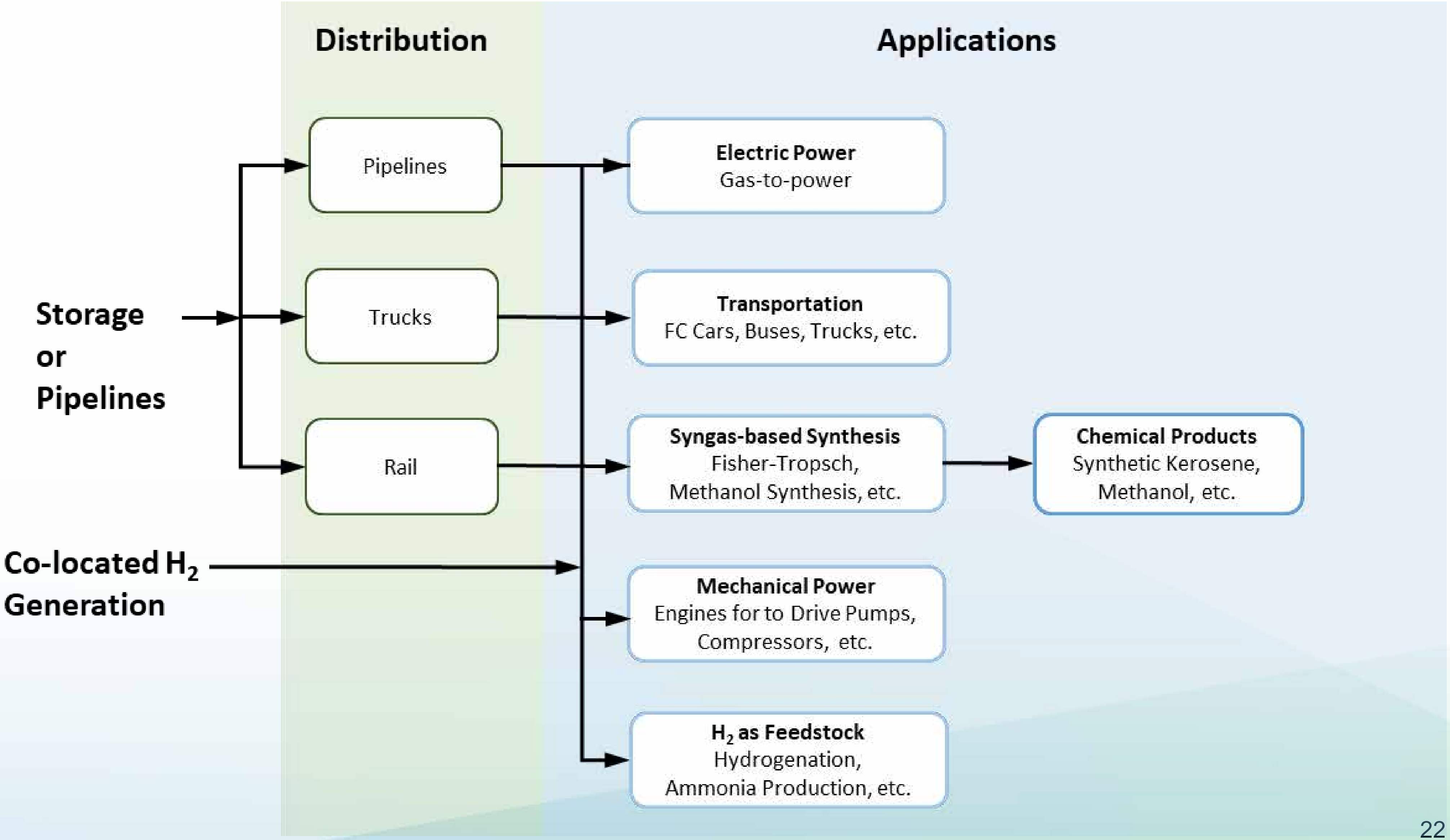


Example: North Sea Wind + H2

H_2 Supply Chain Map (1/2)

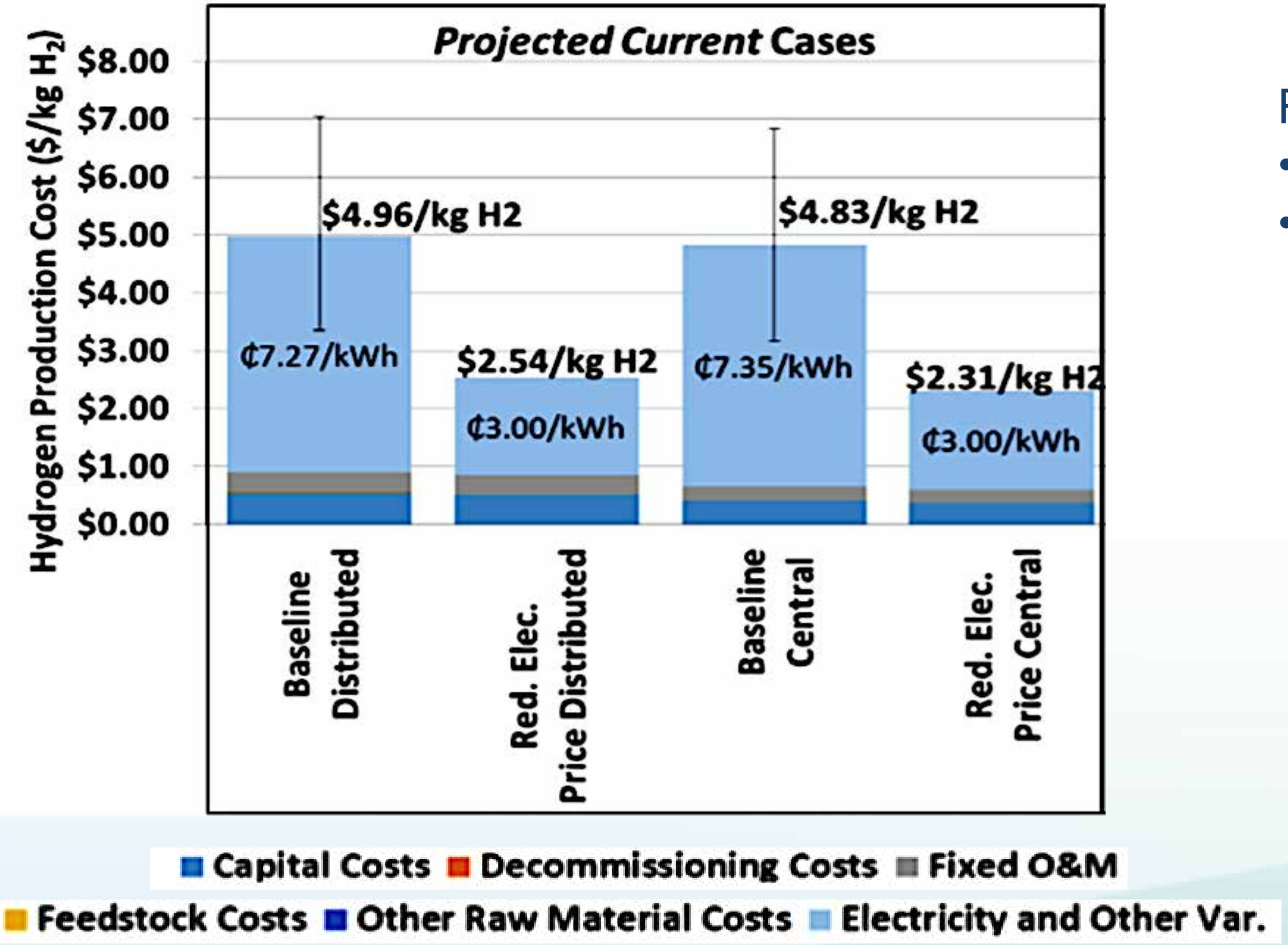


H_2 Supply Chain Map (2/2)



Electricity input costs dominate the economics for electrolysis

Note the difference when ¢/kWh costs drop from 7¢ to 3¢.



Relevant to

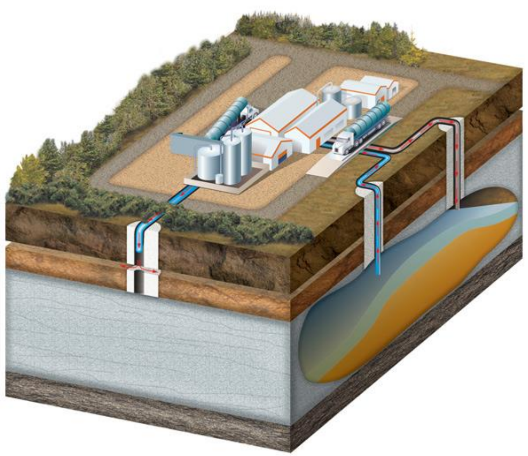
- Curtailed Clean PV or Wind
- *Optimizing* Purpose Built PV or Wind

PEMEC Example

The cost of electricity is the top (light blue) section of each stacked bar

- The two bars on the left are for distributed H_2
- The two bars on the right are for centrally produced H_2

H2 Storage and Distribution Technologies



- Compressed gaseous H2 tanks
- Pipelines for gaseous H2
- Geologic storage
    - depleted oil and gas fields or storage structures
- Liquid H2 tanks

A variety of H_2 storage options need to be considered for California

To meet the needs of distributed systems as well as provide strategic, long-term storage, a variety of storage options will need to be deployed.

- **Compressed gaseous H_2 tanks** will continue to be the most visible form of H_2 storage, including for onsite systems generating H_2 and users in remote locations.
- **Pipelines**, Pure H_2 or blending into NG pipelines, provide efficient movement of gaseous H_2 produced offsite.
- **Geologic** gaseous storage for regional or state-level strategic inventory control to meet seasonal needs and long duration needs; often viewed as critical to substantial use of H_2 in the long term.
- **Liquid H_2** (LH_2) and **ammonia** both have existing industrial applications in California in addition to being a storage medium; thus, benefits accrue from both storage and decarbonization of H_2.
- **Methanol,** another chemical with existing industrial application, is considered a representative of a group called Liquid Organic H_2 Carriers (LOHCs) that can be stored at ambient temperatures.

End Use Pain Points (1/2)

Cost of H_2 Power Solutions- H2 Turbines more cost effective than H2 Fuel Cell

- Fuel cell (FC) upfront costs vary widely but are significantly higher than turbine or reciprocating engine generator solutions of comparable size
- Large FC systems require more modules, limiting upfront savings from scaling up
- Initial H_2-capable turbines available commercially from major manufacturers may carry a price premium relative to incumbent systems designed for NG
- Initial H_2-capable reciprocating engines available commercially from major manufacturers may carry modest (<10%) price premiums relative to incumbent NG or diesel systems

H_2 in Natural Gas Pipelines

- **H_2** is limited in natural gas pipelines to blending of 20% by volume and 7% by weight due to metallurgical embrittlement and related issues.
- **H_2** may be transmitted in dedicated purpose-built pipes at 100%- and these are common in the petroleum industry
- A process can convert Green H2 + CO2 > Green CH4, which can be transmitted in natural gas pipelines and used in the same way as natural gas, but which is decarbonized

End Use Pain Points (2/2)

Technical Challenges

- Despite some strong track records, reliability of various FC technologies is not uniformly high.
- NO_x management via Dry Low Emissions (DLE) is a major area of R&D by NG turbine manufacturers, having H_2 blending impacts. (See graphic below)

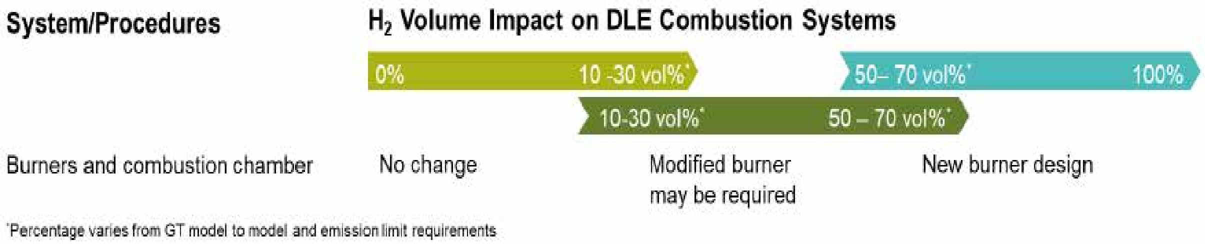


Figure 7: Hydrogen fuel volume impacts on DLE combustion systems

https://new.siemens.com/global/en/products/energy/technical-papers/download-hydrogen-capabilities-gt.html

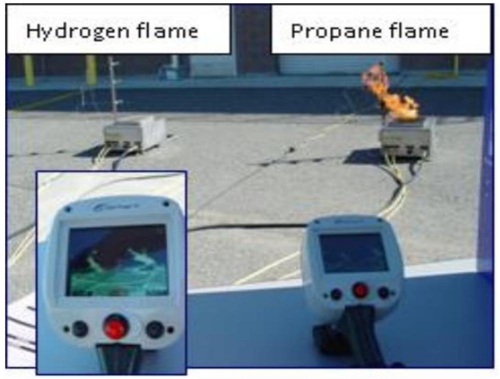


Figure 5 - Hydrogen and Propane Flames in Daylight (Photo courtesy of HAMMER)

Figure 6 - Hydrogen and Propane Flames at Night (Photo courtesy of ImageWorks)

Accelerating Hydrogen Research in ERDD

Investment Area	$19M invested
Generation and storage	• Wind to H2 storage for load shifting when prices are high • Solar to H2 for 100-hour storage in metal hydrides • Lowering the energy and cost of electrolysis with advanced non water electrolytes
Mobile H2 for PSPS	• Mobile H2 production and energy storage, emergency power & PSPS resiliency
Transportation	• Fuel Cell Railway switcher locomotive • Fuel Cell Tugboat • Fuel Cell Harbor craft and mobile refueling system

Upcoming Research for ERDD

Investment Area	Details
Generation	• Cost Reduction and Efficiency Improvement for Renewable H2 Production • Developing and Demonstrating H2 Power Generation Systems
Delivery & Storage	• Green Hydrogen, A Roadmap and Strategic Plan for a Decarbonized CA • Hydrogen Roadmap for the Natural Gas System • Hydrogen Blending Validation
Transportation	• H2 Fuel Cell Truck and Bus Tech, Integration and Demonstration • Advanced Hydrogen Refueling Infrastructure Solutions for Heavy Transport
Buildings and Industrial	• Effects of Hydrogen in end use Appliances for Large Commercial Buildings and Industrial Applications • Likely Industrial Candidates for Hydrogen Adoption

Fuels and Transportation Investments

Investment Area	***$194.5M invested***
Fueling Infrastructure	$169.4M
Hydrogen Production	$7.9M
Fuel Standards and Equipment Certification	$3.9M
Light-Duty ZEV Deployment (CVRP support)	$0.7M
Medium- & Heavy- Duty Advanced Vehicle Technology Demonstration	$11.9M
Regional Alternative Fuel Readiness and Planning	$0.8 M

H2 Comparison to Alternatives

"Detailed Technical Analysis needs to be completed on each on each sector to assess how green hydrogen compares to other alternatives for each of the potential uses"

"The role of Green H2 in a Decarbonized CA- A Roadmap and Strategic Plan"

Evaluation of Green H2 End Uses & Alternatives

The project statement requires that we consider alternatives to H2 for each end use

End Use	Green H2	Green CH4
Firm Dispatchable Decarbonized Grid Generation FDDG *(SB100 report shows that up to 15 GW of FDDG may be needed)*	1. Needs updated H2 Turbines and delivery system 2. Compare costs to long term energy storage	1. Can use existing Generation and pipeline 2. Compare Costs to long Term Energy Storage
Transportation Uses *(contextualize with BEVs)*	Fuel cell vehicles (*for applications not well-served by BEVs*)	Initially provided easy conversion of combustion engines, but those are being phased out
Stationary End Uses *(in the context of electrification)* *(e.g. legacy building stock)* *(e.g. selected high-heat industrial)*	- may need end use appliance change and new delivery systems - delivery cost needs to be defined	- Same appliances - Same pipeline

Green H2 to Green CH4 Case Study: Audi e-gas plant in Werlte, Germany

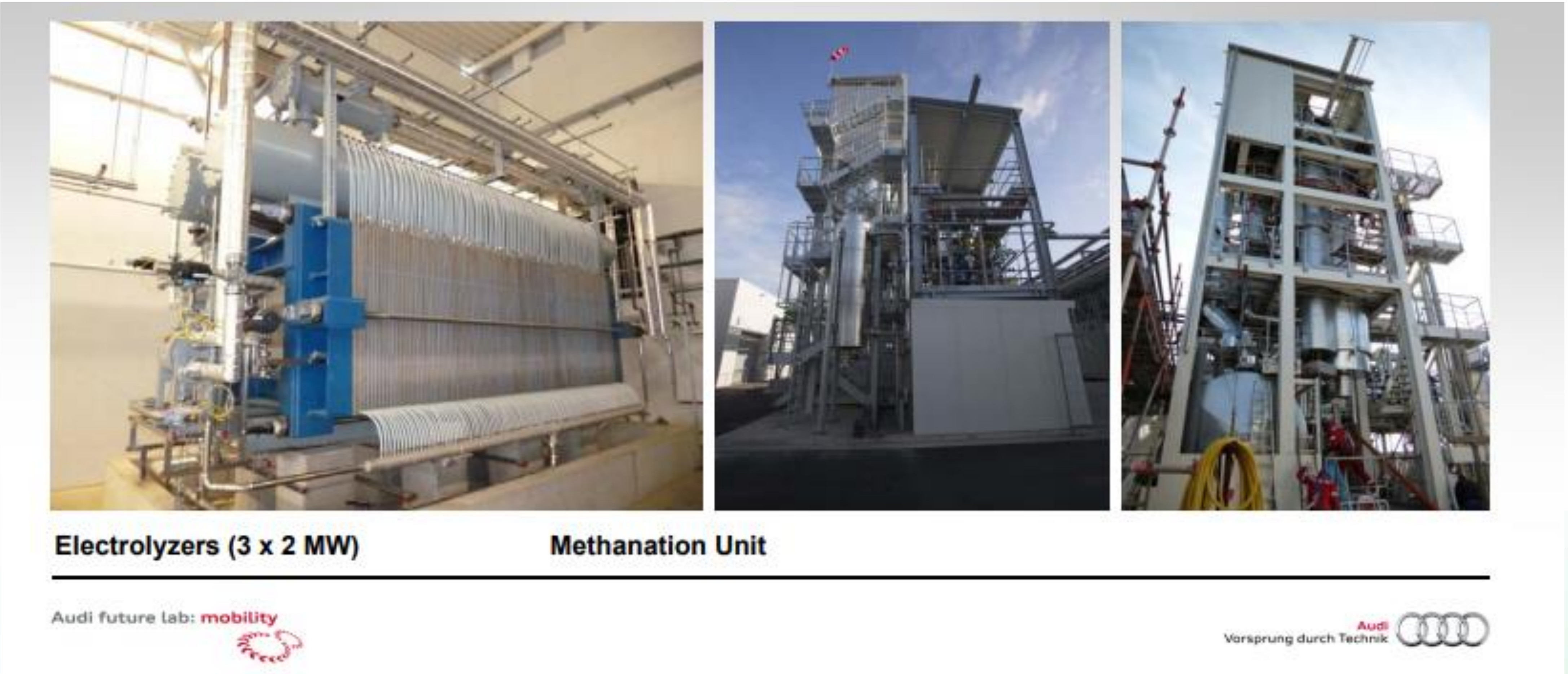
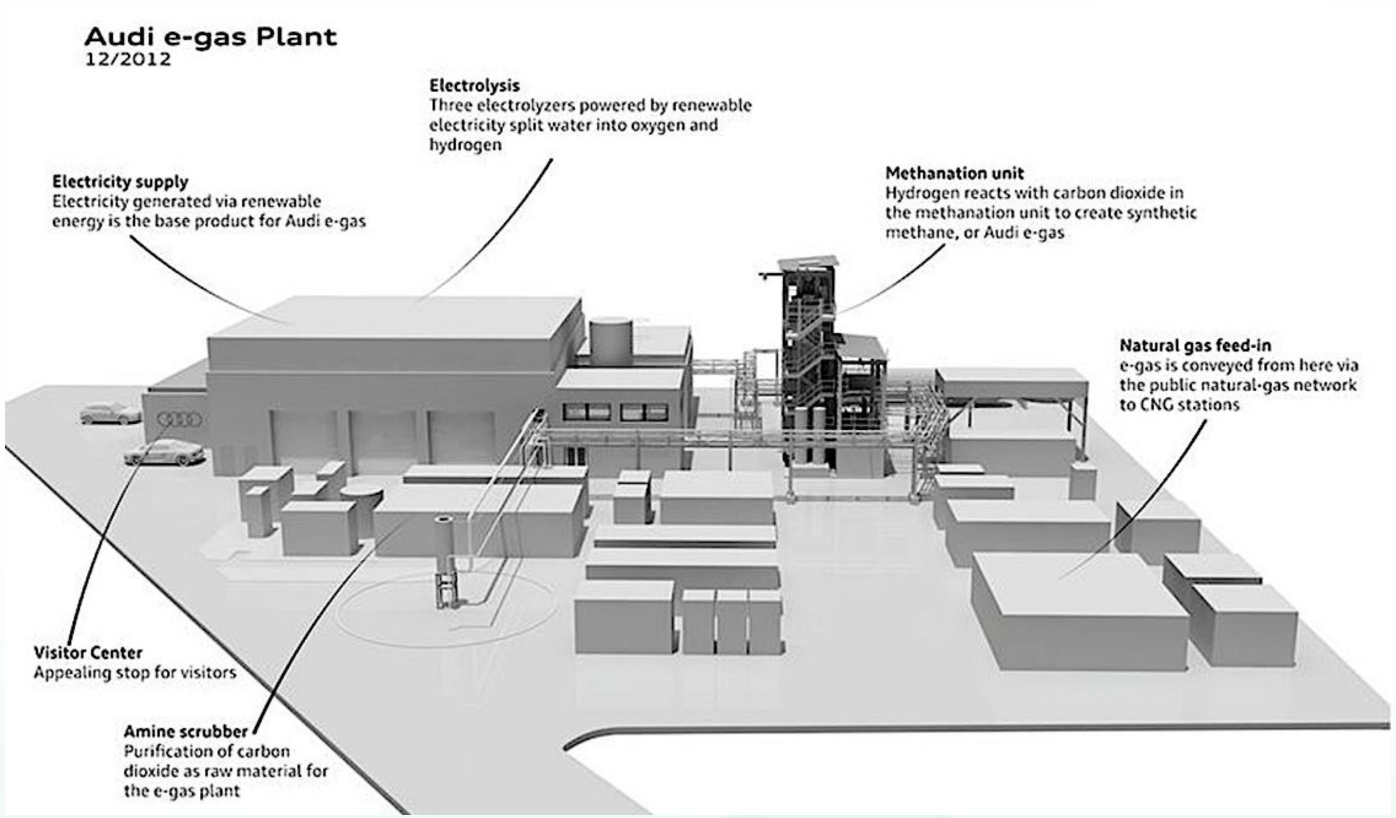


Image source: http://hybalance.eu/wp-content/uploads/2020/09/20200924_HyBalance_Hydrogenics_vFINAL.pdf

Green H2 to Green CH4 Case study: Audi e-gas plant in Werlte, Germany

- **Proximity:**
  - The electrolyzer is onsite with respect to the methanation plant
- **Availability of resources:**
  - Wind power provides the green electricity resources to produce green hydrogen
  - CO_2 is provided from biofuel production by a nearby EWE plant
- **Economics:**
  - This project is funded by Audi



Specifications

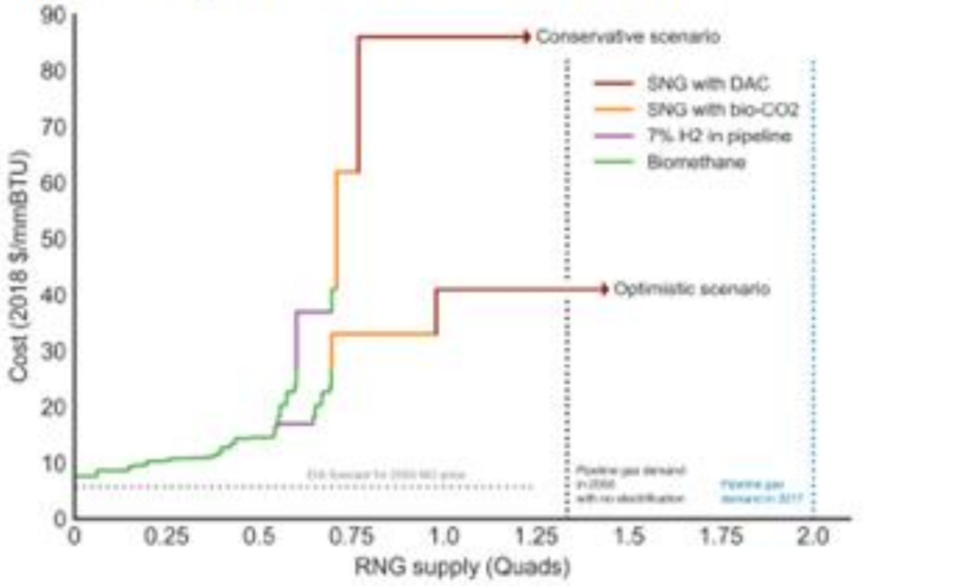
- **Operational year:** 2013
- **Total cost:** 6 million EUR?
- **Hydrogen Capacity:** 2.8 mt H_2 per day *
- **Power Capacity:** 6.0 MW *
- **Electrolyzer technology:** AEC
- **Footprint:** 4,100 m^2 (roughly 64m x 64m)

* Based on electrolyzer specs. Given CH_4 production rate, capacity factor is ~50%.

How Green CH4 Relates to Green H2

The Price of Green CH4 relates to the total budget for all end uses

Figure 6: California Renewable Natural Gas Technical Potential Supply Curve in 2050, Assuming All Biomass Is Directed to Renewable Natural Gas



The biomethane supply curve segments (green) are based on allocating California's population-weighted share of United States waste and residue biomass entirely to biomethane. In the PATHWAYS scenarios, much of the biomass is used for liquid fuels to displace petroleum consumption in transportation and industry.

Source: E3

- Green H2 can be converted to Green CH4 through a CO2 sequestration process:
- **Green H2 + CO2 > Green CH4**

- This could also be combined with CH4 from Biomass

- Either could be used ubiquitously in the Natural Gas Pipeline System or in natural gas appliances

- ***Uses would need to be very limited due to cost concerns- see supply curve- need to stay in the "green zone"***

Key Considerations Going Forward

- How much H2 will we need as these evolve?
  - Long duration storage and reliability as we move to higher levels of intermittent renewables
  - Future of Transport in a BEV context
  - Projected Legacy Buildings and Specific Industrial End Use

- Identify key system conversion efficiencies and expected costs
- Define H2 infrastructure and configurations
- Explore Future of the Natural Gas Pipeline System

Panels

And now for our panels!

Panel 1: Green Hydrogen for Grid Reliability- Firming and Shaping Intermittent Renewables in the Grid of the Future

- Moderator: Mike Petouhoff, CEC

A. Janice Lin, Green Hydrogen Coalition

B. Peter J. Sawicki, Pacific West Mitsubishi Power Americas, Inc.

C. Mårten Lunde, Hydrogen Pro

D. Alex Morris, California Energy Storage Association

E. Julia Levin, BioEnergy Association of CA

Panel 1: Some Key Questions to Answer Along the Road Ahead?

- How much of the energy storage capability planned for the state should be green hydrogen?
- The SB100 report shows that about 15 GW of firm dispatchable generation is needed- depending on trade offs with LDS- how much of this should be H2?
- What is the capacity need for seasonal energy storage that green H2 could be well suited to address?
- What is the current price of H2 what trajectory do you expect it to take over time? The DOE Earth shot goal is to reduce the price of H2 to $1/kg in a decade.
- What is the rough cost/efficiency of electrolyzers?
- What is the ideal size paring of an electrolyzer and the RE generating asset to ensure optimal utilization of each?
- What is the rough cost/efficiency of an H2 Turbine- what is the cost/kWh for electricity generated from an H2 Turbine? What are issues w NOx?
- What are industry plans for H2 Turbines, when will 50% and 100% turbines be available?
- What is an H2 eco-system likely to look like for land based PV and off shore wind
- Should H2 sources from organic sources such as reforming Green CH4 be considered Renewable H2? Is it decarbonized?
- Can Green CH4 be used for grid support generation? What are the trade offs with Green H2? Can Storage be used with Green CH4 generation to reduce criteria pollutants?

Role of Green Hydrogen in a Decarbonized California

Panel 1: Green hydrogen for Grid Reliability

Janice Lin
Founder and President of the Green Hydrogen Coalition
7.1.2021

GREEN HYDROGEN COALITION

About the GHC

Mission

Facilitate policies and practices to advance the production and use of green hydrogen in all sectors where it will accelerate a carbon free energy future

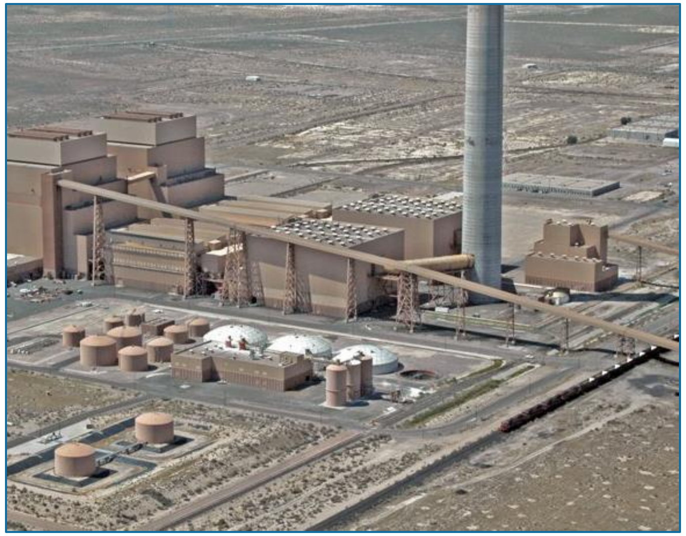
Approach

Prioritize green hydrogen project deployment at scale; leverage multi-sector opportunities to simultaneously scale supply and demand

*The GHC is a 501(c)(3) Tax Exempt Nonprofit Organization

GHC Focus: Accelerating the green hydrogen economy

Core effort: Coalition Building – The Intermountain Power Project



Establish appropriate legal and regulatory framework to enable an at-scale power-gas-power green hydrogen project: IPP
Link

Initiative 1: Regional Collaboration - Western Green Hydrogen Initiative

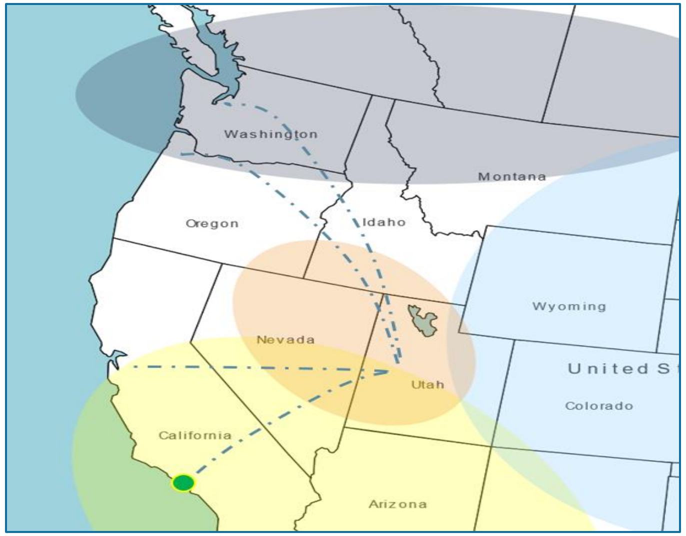
Western Interstate Energy Board

NASEO
National Association of State Energy Officials

GREEN HYDROGEN COALITION

Foster regional green hydrogen collaboration to develop needed green hydrogen infrastructure and address grid reliability Link

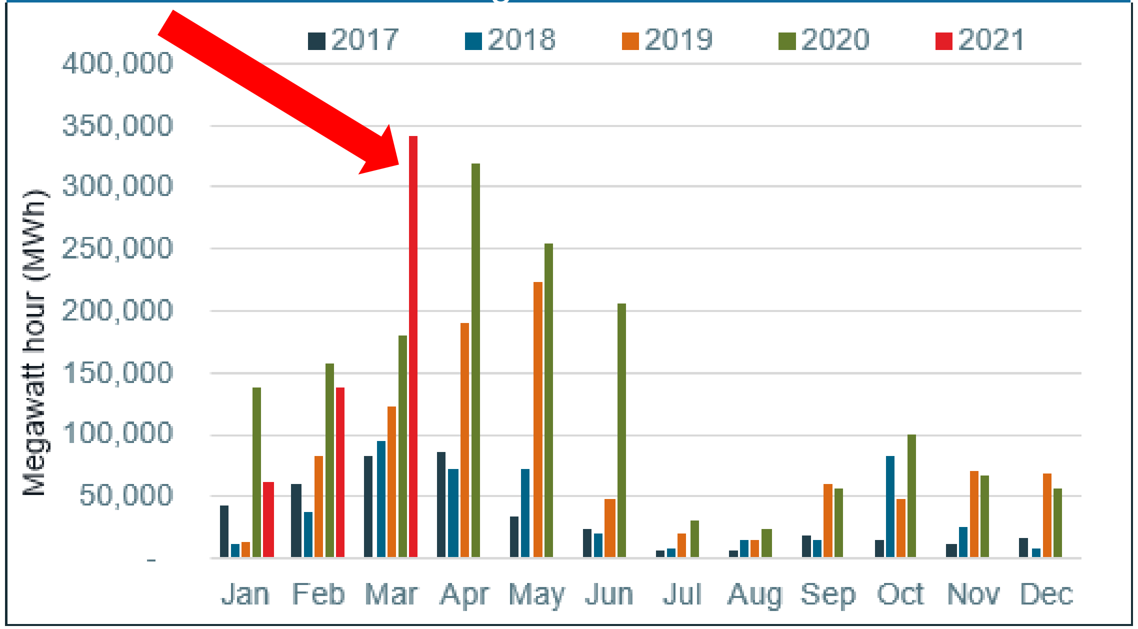
Initiative 2: Commercialization - HyDeal North America



Aggregate multi sectoral demand and develop high-volume supply chain & infrastructure to achieve $1.50/kg delivered green hydrogen in strategically targeted locations.

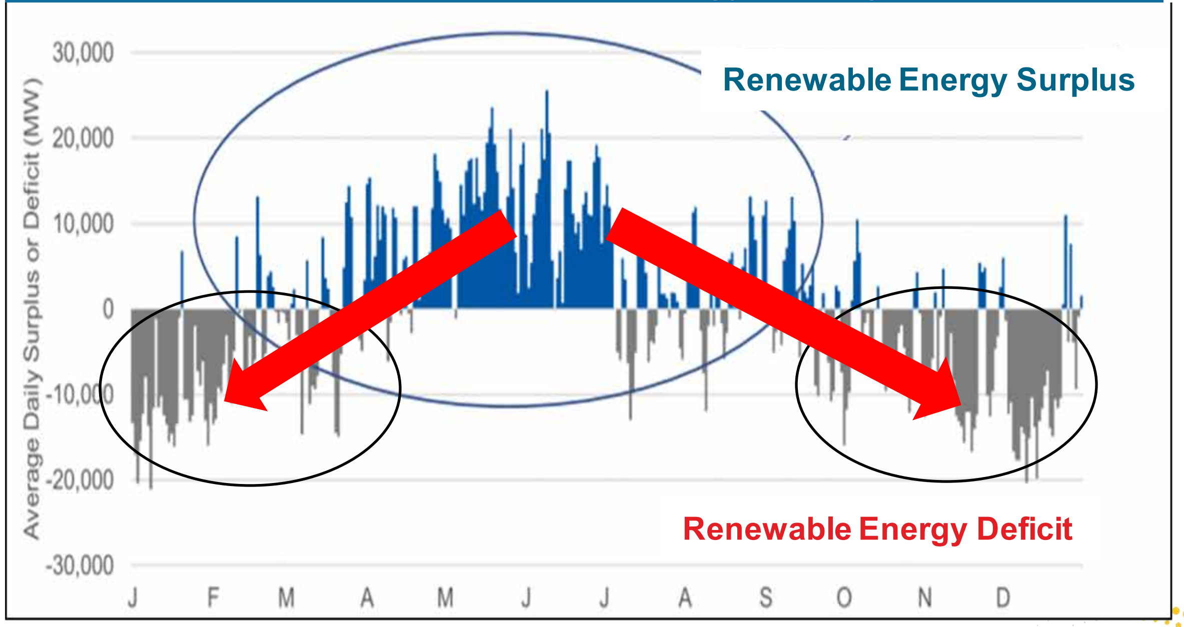
Why is green hydrogen important now for California?

California Wind and Solar Curtailments Hit Record High in March 2021



Data Source: CAISO, Compiled April 2021

100% Renewable Energy Scenario in California Signals a Need for Seasonal Energy Storage



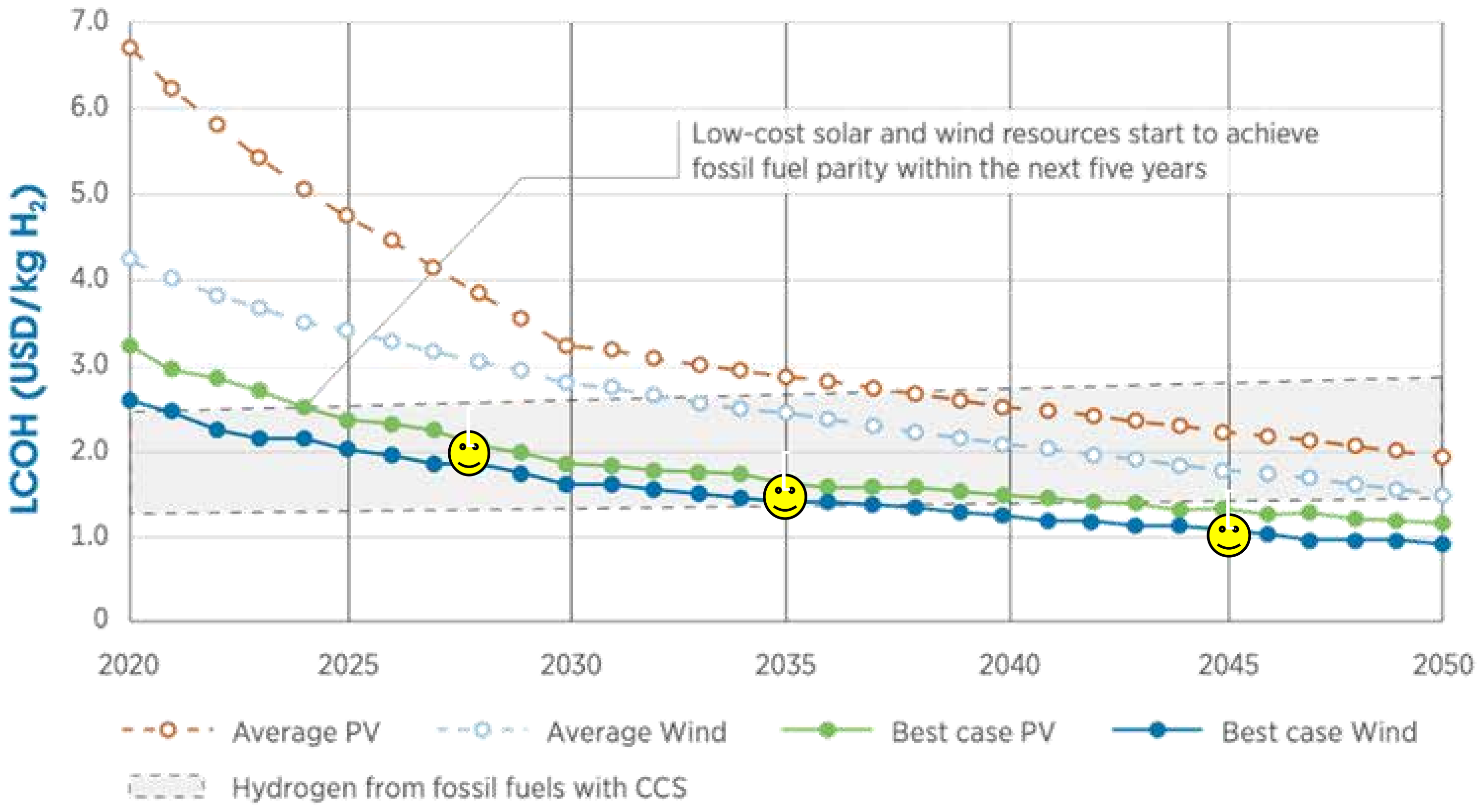
Data Source: Armonk Cohen Testimony

Information Source: Mitsubishi Power Americas

GREEN HYDROGEN COALITION

Green hydrogen is commercially viable now and on trajectory for lowest cost

Hydrogen production costs from solar and wind vs. fossil fuels



Source: IRENA, 2019. Hydrogen: A Renewable Energy Perspective. International Renewable Energy Agency (IRENA). Report.

GREEN HYDROGEN COALITION

With green hydrogen, 100% renewable energy is possible at competitive costs with today's wholesale electricity prices

	Explanation	Variable	Units	2028	2035	2045
Hydrogen Blended Costs	Hydrogen Cost Assumptions	Delivered GH2 Commodity Cost[5]	$/kg	$2.00	$1.50	$1.00
		Green Hydrogen Levelized Cost, *a*	$/MWh	$116	$87	$58
	IPP Plant at 100% Green Hydrogen	% Hydrogen Plant Consumption	%	100%		
		Power Plant Capacity Factor[1]	%	65%		
		Heat Rate[2]	BTU/kWh	6400		
		CCGT Units, *b*	$/MWh	$26		
	Carbon Abatement Cost Assumptions	GHG Cost[4]	$/metric ton CO_2	$50		
		GHG Savings, *c*	$/MWh	($17)		
	PPA Cost Assumptions	Blended Renewable Energy PPA Cost, *d*	$/MWh	$15		
	Blended GreenH_2 + PPA cost to achieve 24x7 100% renewable electricity	25%(*a*+*b*+*c*) +75%(*d*)	$/MWh	$42	$35	$28

1. Capacity Factor based on generic CC plant from modeling performed for CEC 1368 Requirements;
2. Heat rate based on levelized heat rate of advanced class units;
3. CC Unit costs based on minimum costs for O&M of equipment, based on utility grade requirements (O&M, financing, excludes fuel);
4. GHG Costs are provided as a floating variable. Reference IEPR Reports for cost projections;
5. Hydrogen commodity cost is based on projections from DOE based on technology development;
6. Hydrogen levelized costs of hydrogen generation based on green hydrogen including storage and transporation, and CCGT equipment modifications required;
7. Solar and wind $/MWh costs may fluctuate with market price. Sourced from Pacificorp's tariffs. Seeing rates currently at $5/MWh

GREEN HYDROGEN COALITION

Green Hydrogen can repurpose existing infrastructure & jobs

Source: DNV GL

Source: LADWP

Enabling an affordable & responsible transition

What's the barrier to our green hydrogen economy?

Infrastructure and Economies of Scale

Cost of Green Hydrogen

GREEN HYDROGEN COALITION

HyDeal Los Angeles

Architecting the Green Hydrogen Ecosystem For a Deeply Decarbonized LA

Steering Committee Funders

SoCalGas
A Sempra Energy utility

LA DWP Los Angeles Department of Water & Power

MITSUBISHI POWER

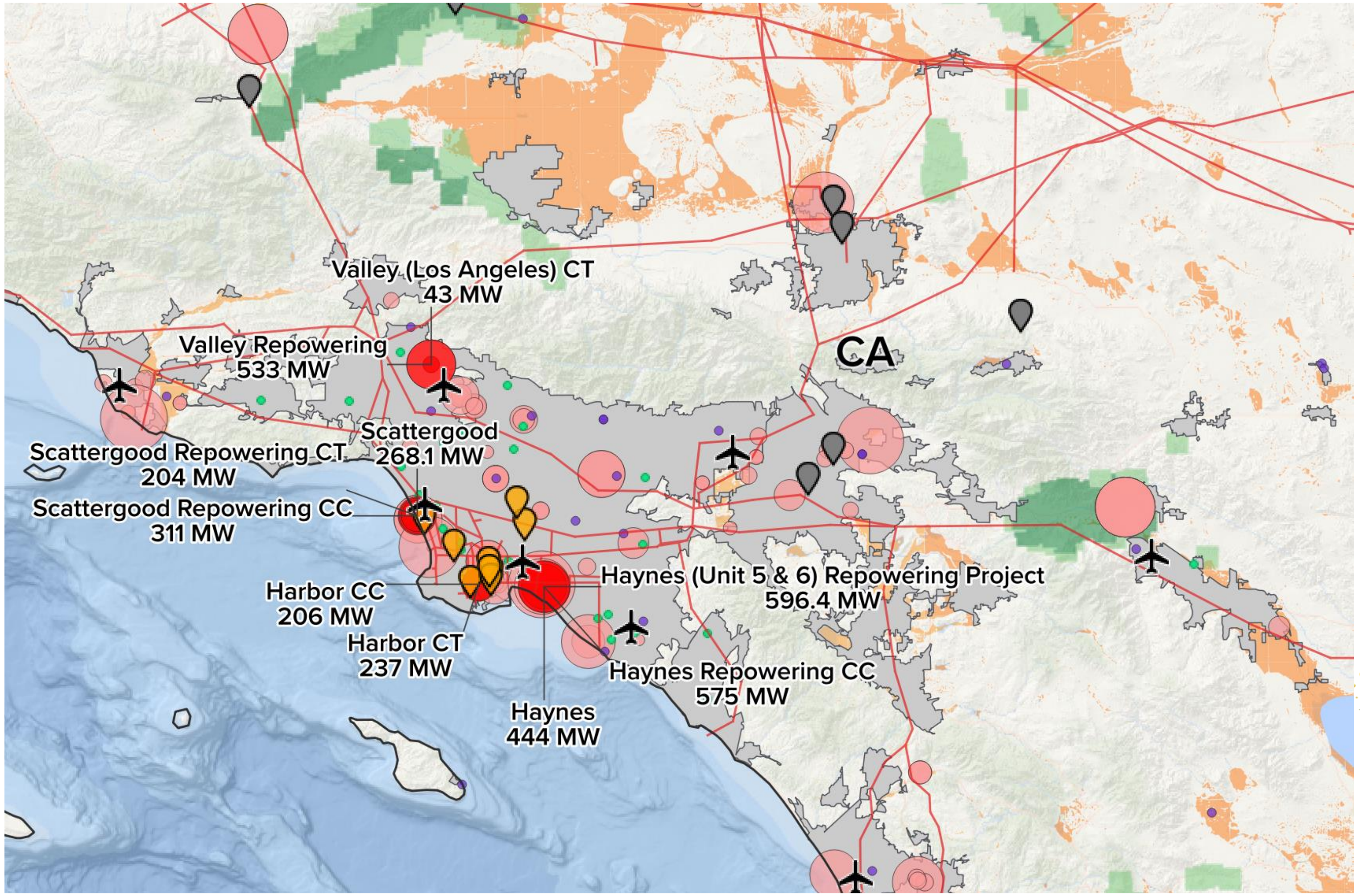
174 POWER GLOBAL

Image Source: Josh Miller, Unsplash

Los Angeles has abundant at scale green hydrogen offtakers

HyDeal Los Angeles will support Green LA and the 2028 Los Angeles Olympic Games

- Natural Gas Pipelines
- Gas Power Plants
- LAWP Power Plants
- Wind Resource
- Solar Resource
- Urban Areas of LA and LA County
- Oil Refineries
- Cement Plants
- Airport
- Backup Generators
- Hydrogen Fuel Stations



GREEN HYDROGEN COALITION

HyDeal LA vision: Establish North America's first green hydrogen industrial hub

LA will be the first in North America to…

Achieve 100% renewable electricity affordably and reliably

Decarbonize fuel refining and move to renewable fuels

Provide green ammonia fueling to maritime goods movement (and for fertilizer production)

Demonstrate green hydrogen fuel cell passenger flight (Long Beach Airport to Sacramento)

Export low-cost green hydrogen at scale

GREEN HYDROGEN COALITION

High-Level Regulatory and Policy Roadmap

2020-2025

- In-basin electrolytic production
- Issues:
  - Definition of green hydrogen; RPS & SB 100 compliance
  - Siting and permitting
  - Ancillary services value streams
  - Electrolysis tariff (if third party owned)
  - Thermal power plant permitting
  - Cost allocation and cost effectiveness

2025-2030

- Injection into existing gas pipelines (blend)
- Issues:
  - Pipeline integrity/safety
  - Regulations: Blending/injection tariff
  - Guarantees of origin/program eligibility
  - Feasibility of synthetic green methane
  - Cost allocation and cost effectiveness

2030-2035

- 100% H2 pipeline is needed to achieve $1.50/kg and to manage seasonal demand via connection with geologic storage
- Issues:
  - No US economic regulatory precedent
  - Long lead time
  - Eminent domain and permitting
  - Cost allocation and cost effectiveness

HyDeal LA Project Team Leverages Experience from HyDeal Europe and Ongoing GHC California Policy/Regulatory Work

CONTRACTS	INDUSTRIAL PLAN & ECONOMICS	FUNDING	POLICY & REGULATORY	PROJECT MANAGEMENT
CLIFFORD CHANCE	CVA Corporate Value Associates	MARATHON CAPITAL	STRATEGEN	GREEN HYDROGEN COALITION
SheppardMullin	STRATEGEN	Cranmore Partners	SheppardMullin	STRATEGEN
	ENERGEIA	SheppardMullin	CLIFFORD CHANCE	
		CLIFFORD CHANCE		

HyDeal Los Angeles Advisors & Supporting Partners

Advisors

Tyson Eckerle
California Gov's Office of Business & Economic Development

Jack Brouwer
National Fuel Cell Research Center, UC Irvine

Rachel Fakhry
Natural Resources Defense Council

Keith Wipke
National Renewable Energy Laboratory

Michael Colvin
Environmental Defense Fund

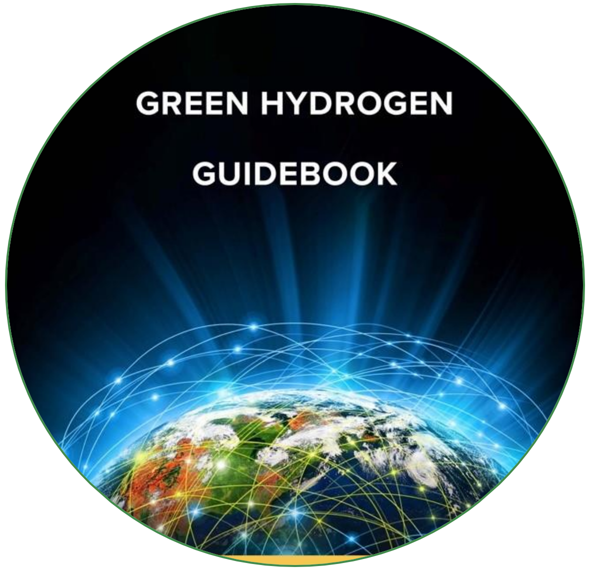
Jeffery Preece
Electric Power Research Institute

Supporting Partners

California Governor's Office of Business and Economic Development
Green Hydrogen Coalition
California Stationary Fuel Cell Collaborative CaSFCC
California Hydrogen Business Council
CESA California Energy Storage Alliance
Colorado Hydrogen Network
EPRI Electric Power Research Institute
Advanced Power & Energy Program University of California, Irvine
M-RETS Renewable Electricity

Educational Materials

Green Hydrogen Resources



Download our Guidebook

Visit: GHCoalition.org/guidebook

Discover Industry Updates

Visit: GHCoalition.org

Watch our Webinars

Visit: GHCoalition.org/webinars

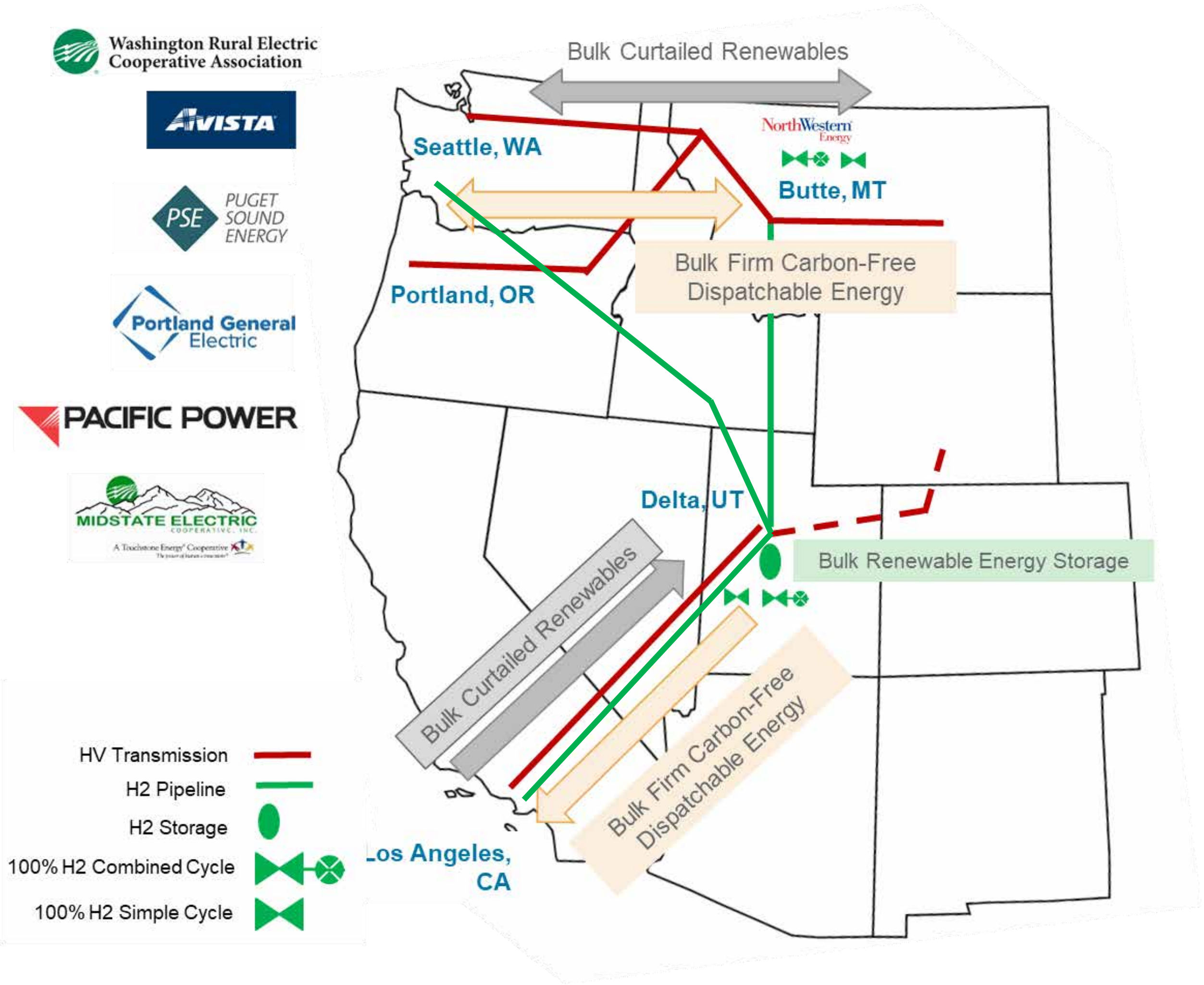
Contact information:

Janice Lin, Founder & President jlin@strategen.com
Maggie Field, Engagement Manager mfield@strategen.com

Peter J. Sawicki

Pacific West Mitsubishi Power Americas, Inc.

Mitsubishi Power Western Interconnect Strategy



Looking beyond IPA Project

Hydrogen Spokes Connected with Pacific Northwest Renewables & Transmission

- Electrical Infrastructure and Hydrogen Infrastructure Connects Northwest United States
- Enables Regional carbon-free generation and storage
- Seasonal Shifting across the region

Regional Strategy Requires a Coalition

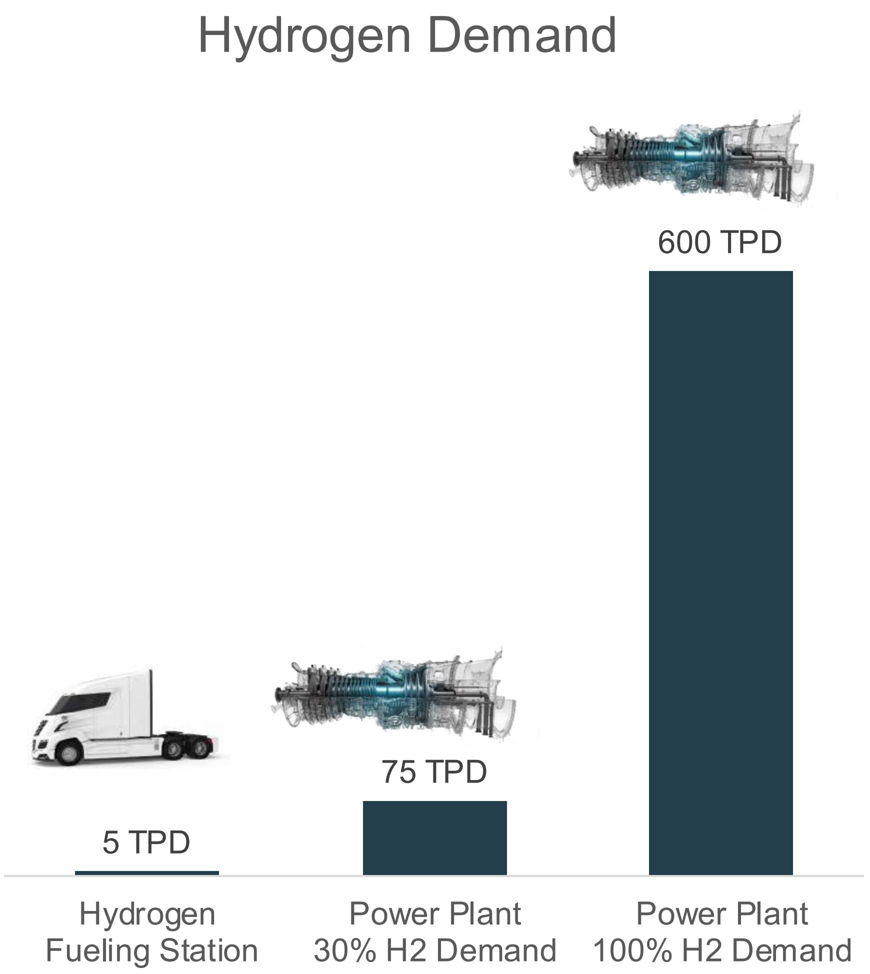
Mitsubishi Power Driving Broader Strategy

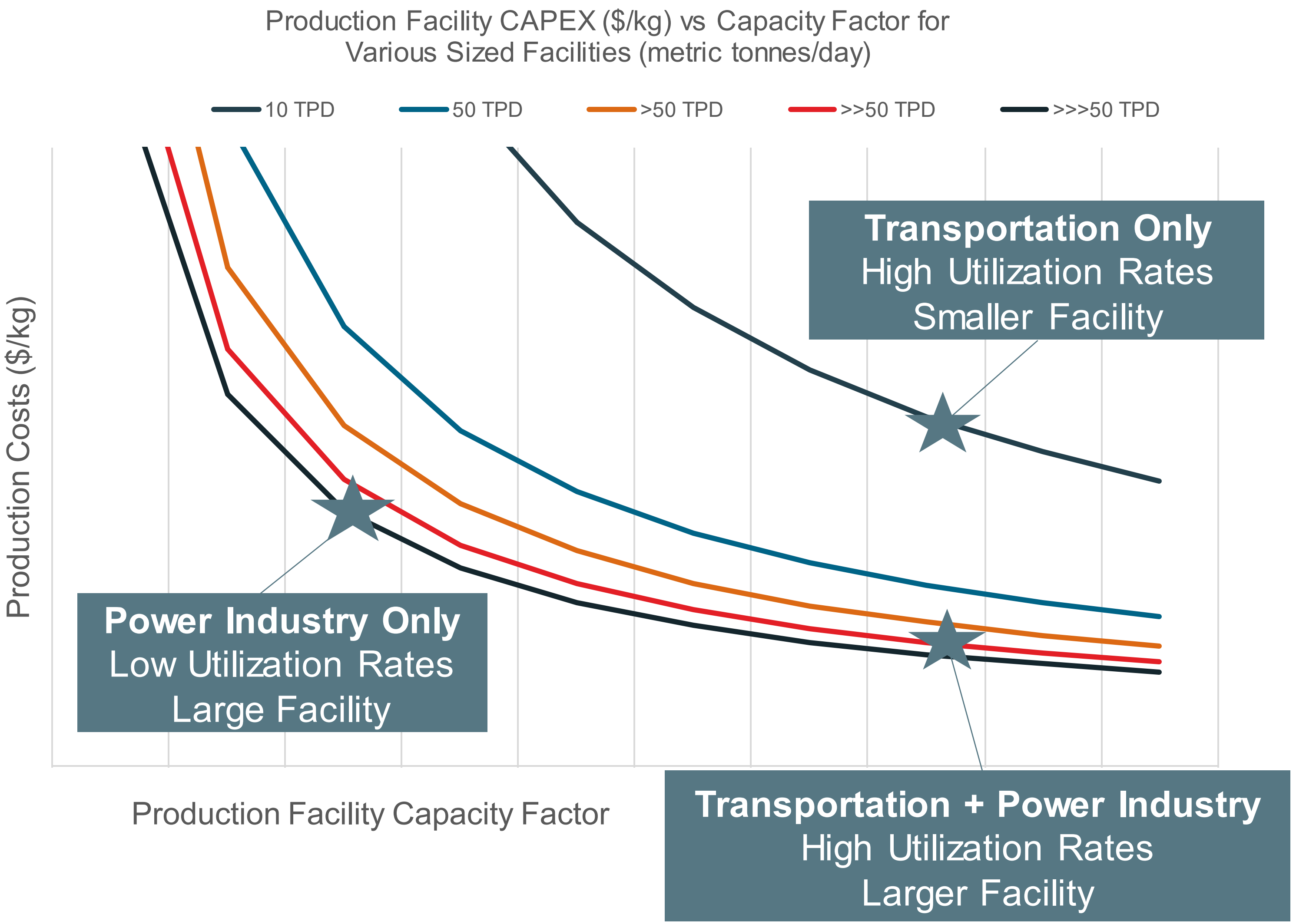
- Joint development agreements with multiple regional customers
- A Founding Member of The Green Hydrogen Coalition
- Developed PACNW CEO Round Table with PNWER
- Initiated MT legislation for state tax incentives and H2 right of ways

Utilities are stronger and more influential when acting in concert

Sector Coupling

Pricing Synergy Between Power Sector (Scale) and Transportation Sector (Utilization)





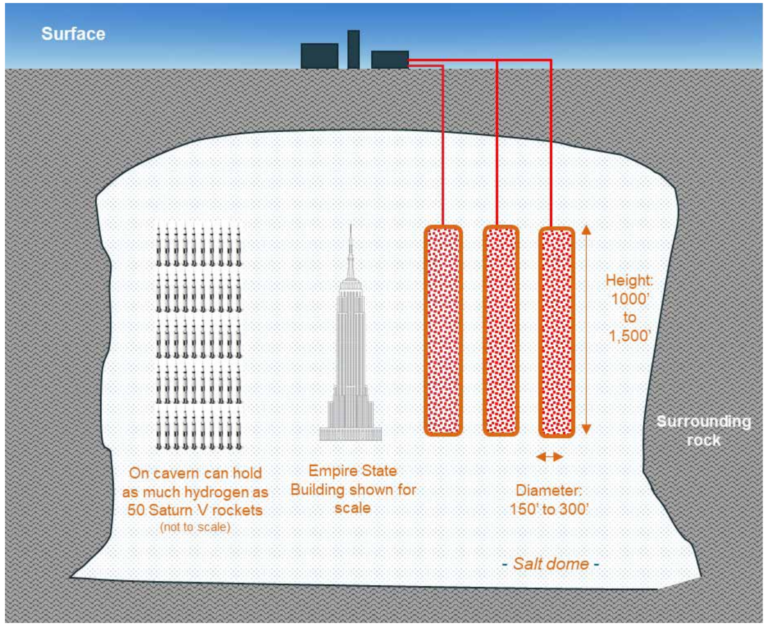
Scale of Power improves Transportation costs…Utilization Rate of Transportation improves Power Costs

Hydrogen Storage

[1] "Discharge" capability based on hydrogen GTCC
[2] Assumes ~3,000 psig to 800 psig working gas
[3] Assumes 500+MW H2-GTCC @ 100% H2 operation
[4] Assumes 500+MW H2-GTCC @ 30% H2 operation

MITSUBISHI POWER

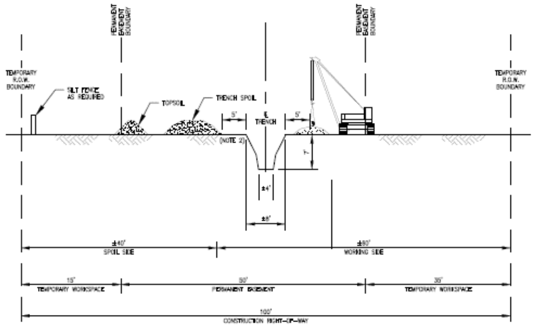
Salt Cavern



Per 1 Cavern Stats

>100,000 MWh[1]
5,500 tonnes[2] H_2
10 days[3] to 1 month[4]

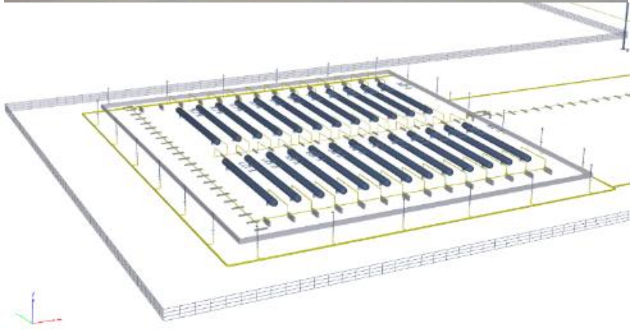
Hydrogen Pipeline Pack



Per 10-mile Stats

>1,000 MWh[1]
45 tonnes[2] H_2
2 hours[3] to 16 hours[4]

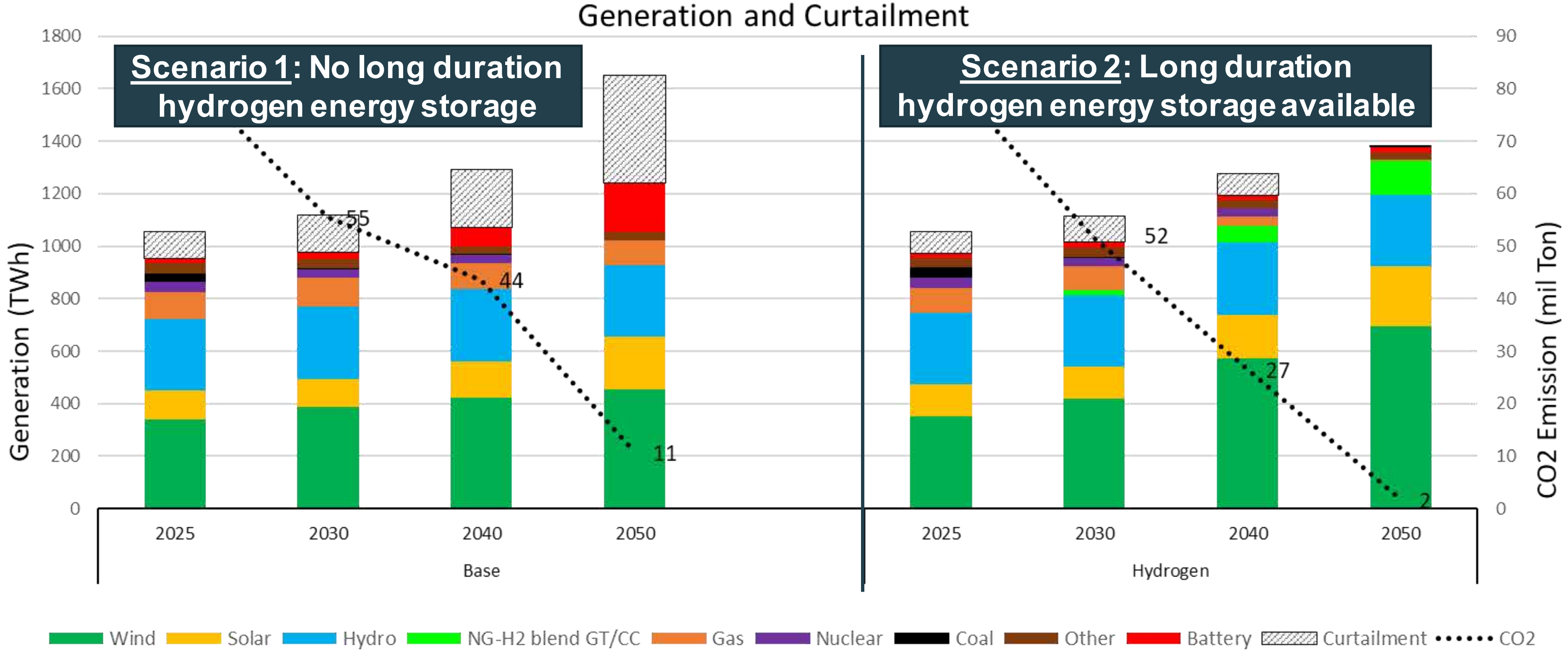
Pressurized Vessels



Per 10-Bullet Stats

>200 MWh[1]
10 tonnes[2] H_2
0.5 hours[3] to 4 hours[4]

WECC Analysis – Power Systems With and Without Hydrogen Storage



2050 Hydrogen Case Comparison

34 GW
Less System Overbuild

400 TWh
Curtailments Avoided

9 mil Ton CO2
Emissions Eliminated

Up to 20%
Lower System Costs

- Wind and solar provides majority of system energy needs
- Significant amount of curtailments avoided with hydrogen
- Large renewable build requires inter-weekly / longer duration storage which cannot be met with batteries alone

Hydaptive Scenario achieves larger carbon reductions, less system overbuilds, and lower system costs

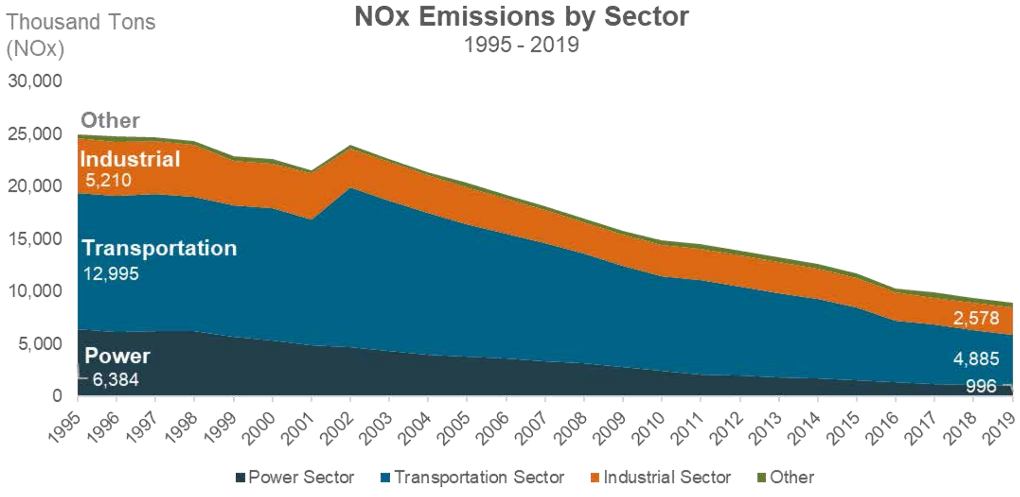
Combustion Technology Development

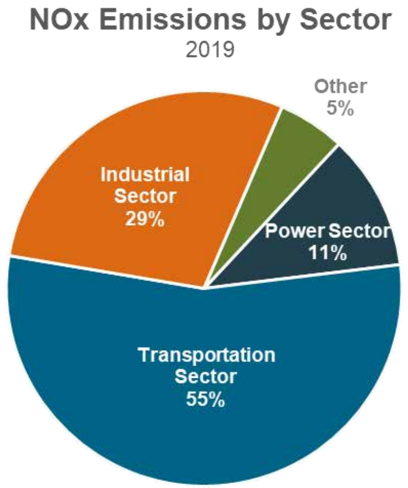
Currently, Mitsubishi Power has 3 types of combustors catering to individual project requirements and hydrogen densities

	Type	Low NO_x tech	Status	H_2 density (volume %)	Schedule
Ready	**Type 1: Diffusion** 	N_2 dilution, Water / Steam injection	Available	0 - 100%	1970 Cogen/IGCC Operation — 2025 Magnum H_2 conversion
Ready	**Type 2: Pre-Mix (DLN)** 	Dry	Available	0 - 30%	1982 DLN Operation — 2018 30% Validation Complete
Under development	**Type 3: Multi-Cluster (DLN)** 	Dry	Final Development and Validation	0 - 100%	2017 IGCC Operation - - - 2025 Validation Complete

*DLN : Dry Low NOx

NOx In Focus





Source – US EPA
*Typical yearly emissions of 1on1 baseload GTCC based on PSD permits; inclusive of steady state and start-up/shut down emissions

NOx Reductions since 1995

- 65% reduction across all sectors
- **85% reduction** in Power Sector

Natural Gas Power Emission Progress Since 1995

- 98% reduction in point-source NOx emissions
- Ultra-low plant emissions of 2 ppm are now available
- Plant yearly NOx emissions of **100 TPY*** compared to 996,000 TPY power sector-wide and 8,950,000 TPY total

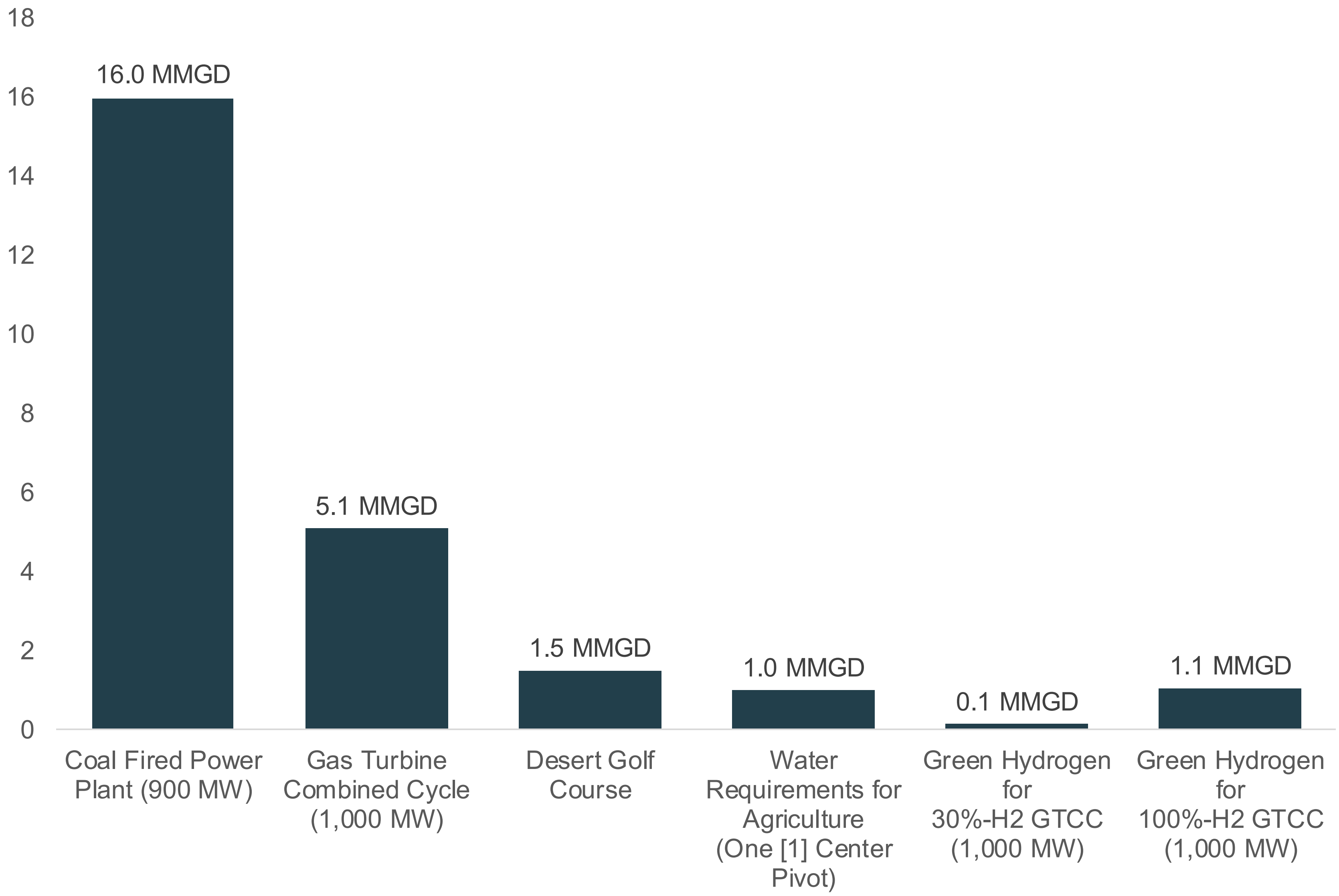
Hydrogen Power Facts

- Our target is for Hydrogen stack NOx emissions of **2 ppm**
- Combustion system in development/validation now
- CO_2, CO, VOC, and SOx emissions eliminated with hydrogen
- Power sector NOx emissions will be near zero

Significant NOx reductions already achieved… trend will continue with shift to hydrogen

Water Consumption Comparisons

MITSUBISHI POWER



HydrogenPro

CEC EPIC Webinar

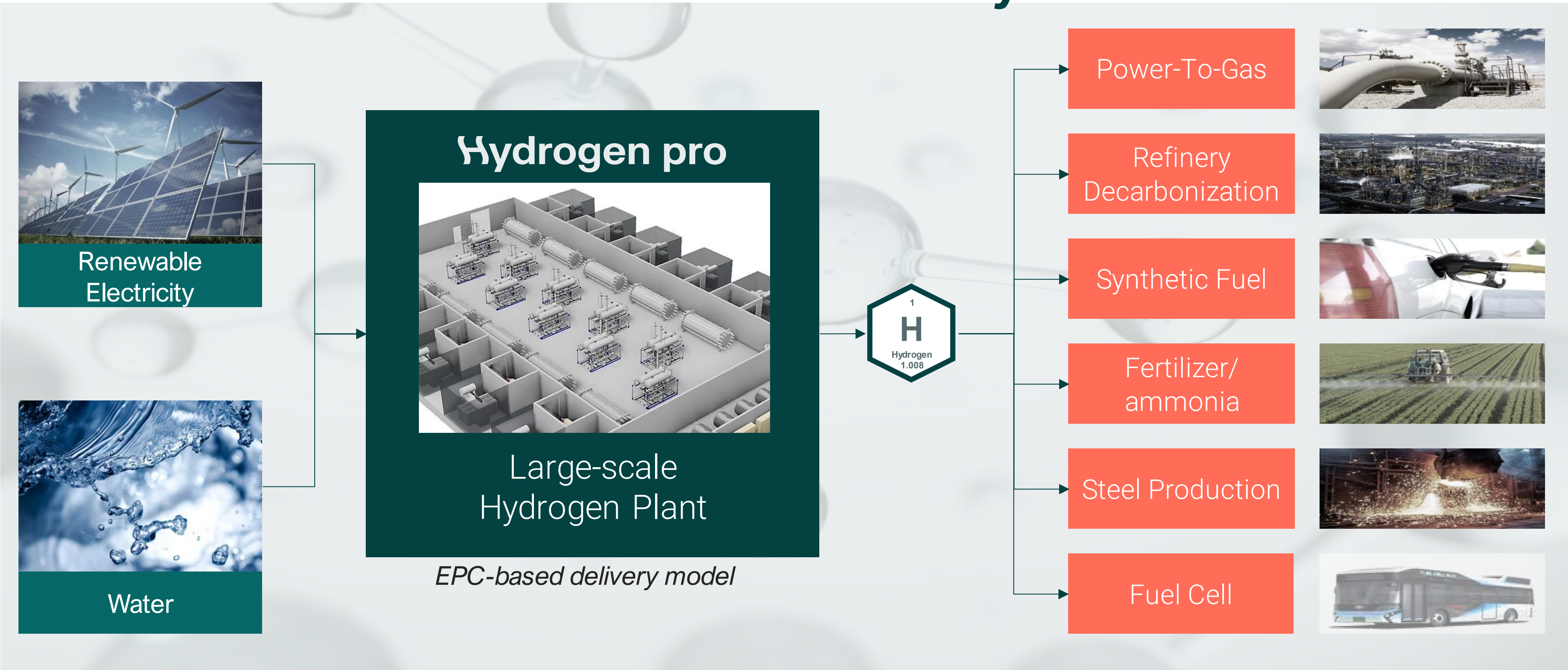
1 July, 2021

Hydrogen pro

Hydrogen pro
- in brief

- Founded 2013 by core team with several years of experience from electrolyzer industry from Norsk Hydro
- Headquartered in Porsgrunn, Norway
- Core technology developed through a combination of Norwegian and Chinese electrolyzer competence and experience
- IPO and stock listing at Oslo Stock Exchange in October 2020 raising proceeds of MNOK550
- Partnerships with Mitsubishi Power and ABB
- Chosen as supplier of electrolyser equipment for projects comprising 353MW internationally
- Ownership of next generation electrode technology

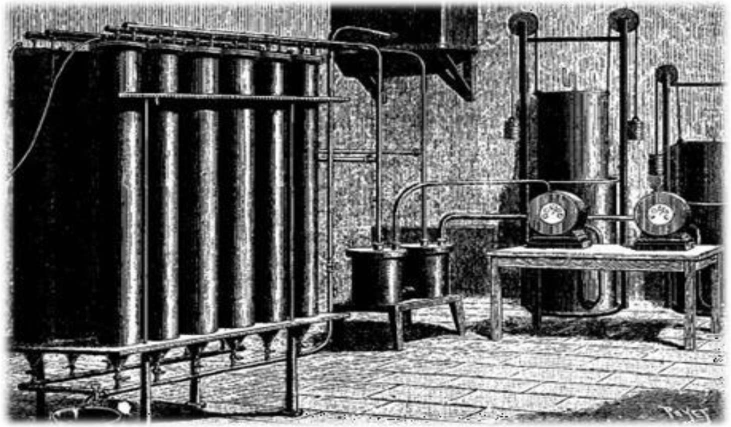
HydrogenPro delivers large-scale hydrogen plants for decarbonization of industries and society



Kokkola Plant 2014 (Finland), 9MW

3*600Nm3/h electrolyzers

The technology is old and well proven



Producing hydrogen from electrolyzis is an old, well proven technology (> 100 years)

The electrolyzer technology has never been industrialized and scaled

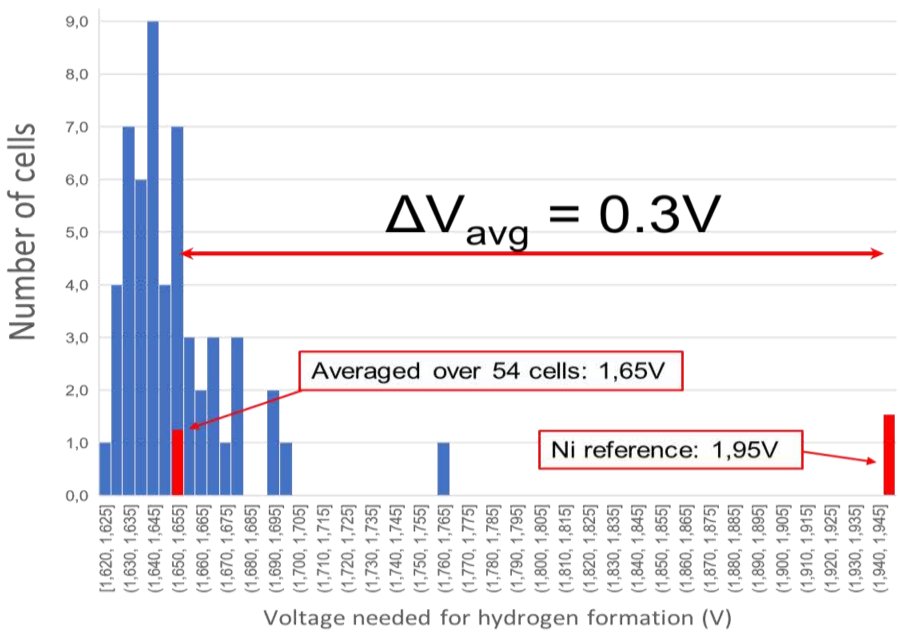
Maturing the electrolyzer technology

Market drivers	*HydrogenPro response and focus*
Price of renwable power *Decarbonization*	*Improved efficiency – HydrogenPro targetting 93% in 2022* *Industrial scale up to reduce capex* *Efficiency is the key driver in a TCO perspective*

Next generation electrolyser technology based on new advanced electrodes

Reduction of voltage for hydrogen formation

Testing of small-scale electrodes



Statistics based on 10 m^3/h pilotplant

- Based on more than 10 years of extensive R&D activities
- The new technology will lower the voltage for hydrogen formation → increased efficiency
- With standard electrodes the needed voltage is 1.95V
- The new technology reduces the needed voltage by 0.3V to 1.65V

- Potential to improve operating efficiency of electrolysers with **14%**
- Current large-scale electrolyzers consume 4.4 MW to produce 90 kg H_2/hour → Tests show that this is reduced to 3.8 MW
- Reaching an efficiency factor of 93% of theoretical maximum capacity
- 75% less cooling water needed

A large electrolyzer for the US market to be upscaled with next generation electrode technology

Mitsubishi & HydrogenPro have developed a new large 11MW electorlyzer for the US market

MITSUBISHI POWER

Hydrogen pro

Further innovation and improvement

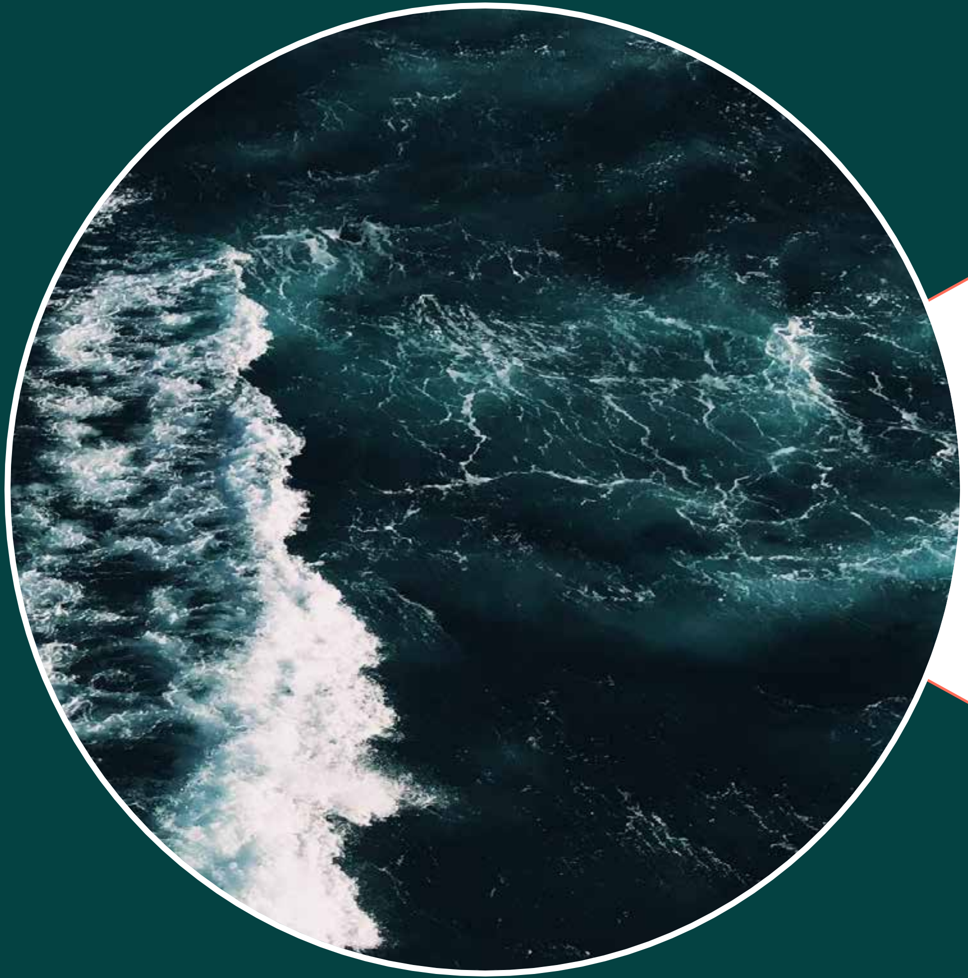
Increasing the 11MW electrolyzer to 17MW by leveraging HydrogenPro's unique electrode technology

Summary features of the high pressure alkaline electrolyzer technology

Pushing the energy transition forward

- *Ideal for large scale applications*
- *High efficiency*
- *Less cooling water*
- *No noble metals*
- *No use of poyfluorinated alkyl substances, PFAS (*)*
- *Superior TOC in life cycle perspective*

* The EU Chemicals Strategy for sustainability released on October 14th, 2020, plans for the ban and phasing out of all per- and polyfluorinated alkyl substances (PFAS).



Hydrogen pro

www.hydrogen-pro.com

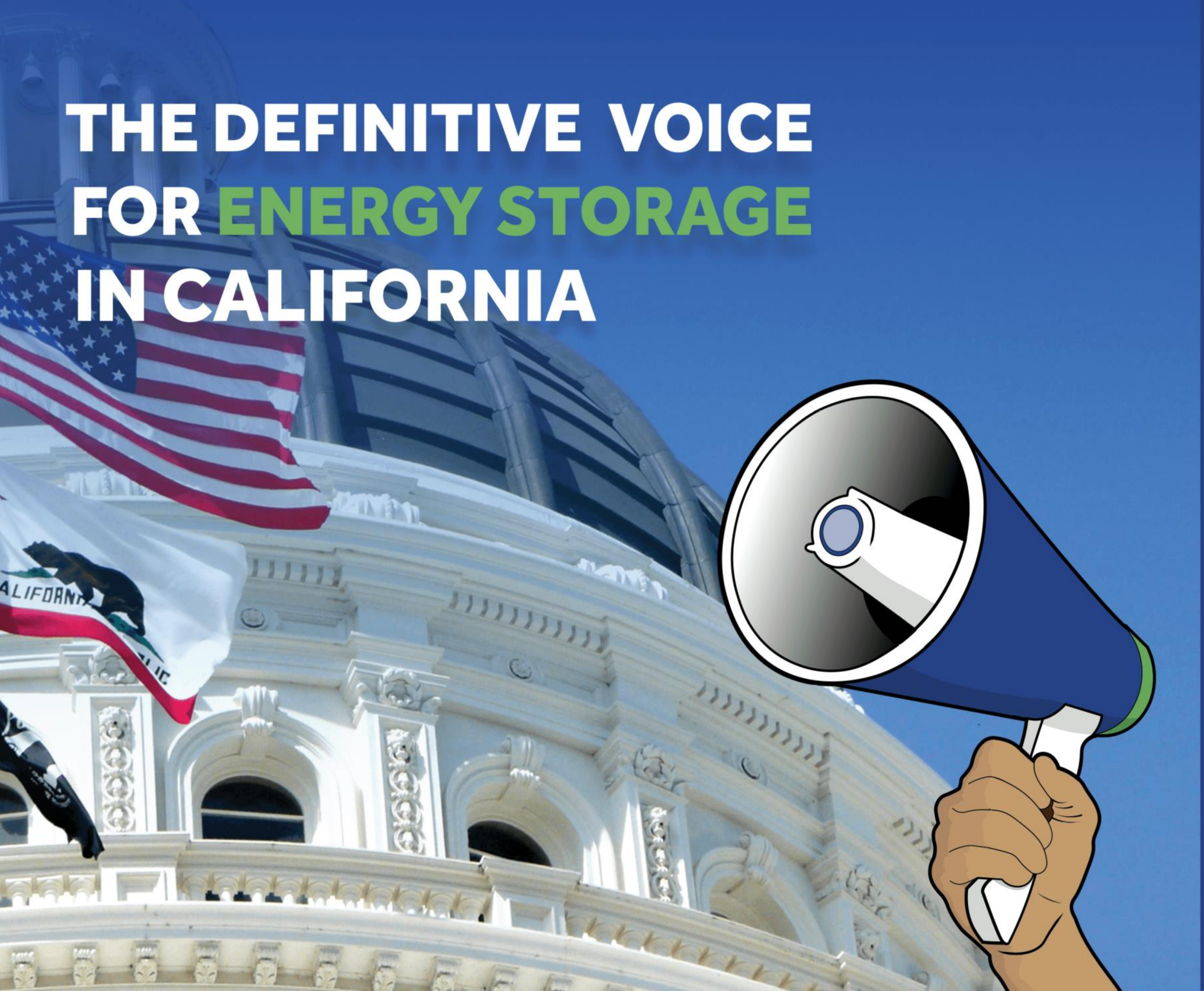
Mårten Lunde, marten@hydrogen-pro.com
Richard Espeseth, richard@hydrogen-pro.com

Long-Duration Storage and Roles for Hydrogen

Alex Morris, Executive Director
California Energy Storage Alliance (CESA)

July 1, 2021

THE DEFINITIVE VOICE FOR ENERGY STORAGE IN CALIFORNIA



CESA creates and builds energy storage markets and networks to support the grid in CA. CESA members help drive our advocacy, build relationships with our 100+ members, gain insight, and connect with energy storage policy-makers and buyers such as IOUs, CCAs, Munis, and more.

CESA 100+ MEMBERS

CALIFORNIA ENERGY STORAGE ALLIANCE

Our CESA Members

CESA 100+ MEMBERS
CALIFORNIA ENERGY STORAGE ALLIANCE

8minute Solar Energy, ENGIE, Fluence (A Siemens and AES Company), GE, Highview Power, Hydrostor, Largo Clean Energy, LG Energy Solution, Lockheed Martin, LS Power, NextEra Energy Resources, OnwardEnergy, Quidnet Energy, Recurrent Energy (A subsidiary of Canadian Solar)

RWE, Southern Power, Sunrun, Tenaska, Terra-Gen, Tesla, Trane, Wellhead

Able Grid, Ameresco, American Fire Technologies, Antora Energy, Arevon, Augwind, aypa, B2U, Borrego Solar, Boston Energy Trading and Marketing, Broad Reach Power, Carrier, conEdison, Connect California

Customized Energy Solutions, DBL, Eagle Crest Energy Company, EastPenn, Echogen power systems, EDF renewable energy, Elsys, enel, Energport, EnergyDome, ESRG, Energy Vault, EnerSmart, Enlighten

ESS Inc, esVolta, Forefront Power, Form Energy, Gridwiz, Hecate Energy, Honda, Li-ion Tamer, Malta, NGK Insulators, Ltd., Nostromo, Nuvation Energy, Nuvve, viridity energy

PXiSE Energy Solutions, redflow, Reimagine Power, Samsung C&T, Shell, Shoto Energy, Solas Energy Consulting, stem, Stoel Rives LLP, Storworks Power, Strata Clean Energy, Sumitomo Electric, swell, TRC

UL, Vesper Energy, Wärtsilä, Zelos, Zitara

Glendale Water & Power, Los Angeles Department of Water & Power, MCE, Peninsula Clean Energy, San José Clean Energy, Clean Power Alliance

Is the Storage Tool-Kit Ready?

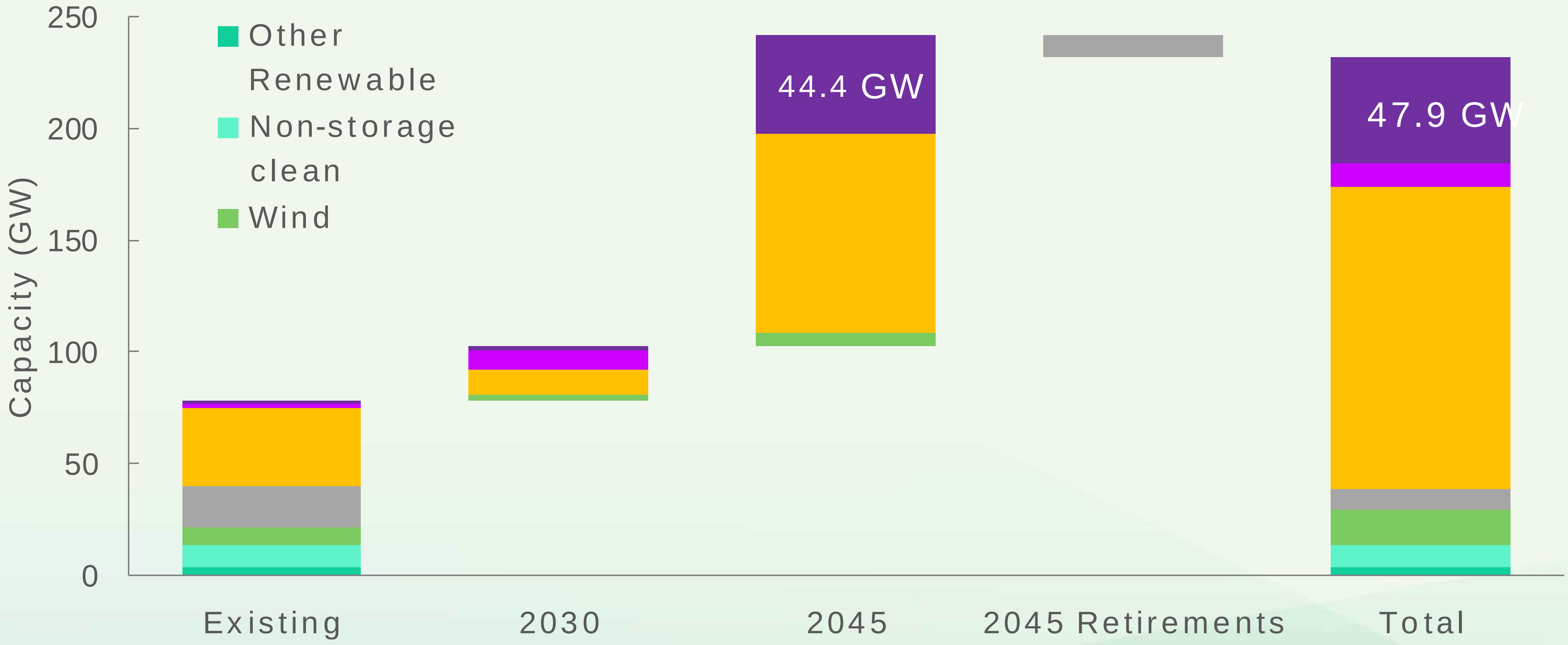
CALIFORNIA ENERGY STORAGE ALLIANCE

- CESA supports 'readiness' of storage tool-kit in advance of gigantic market needs

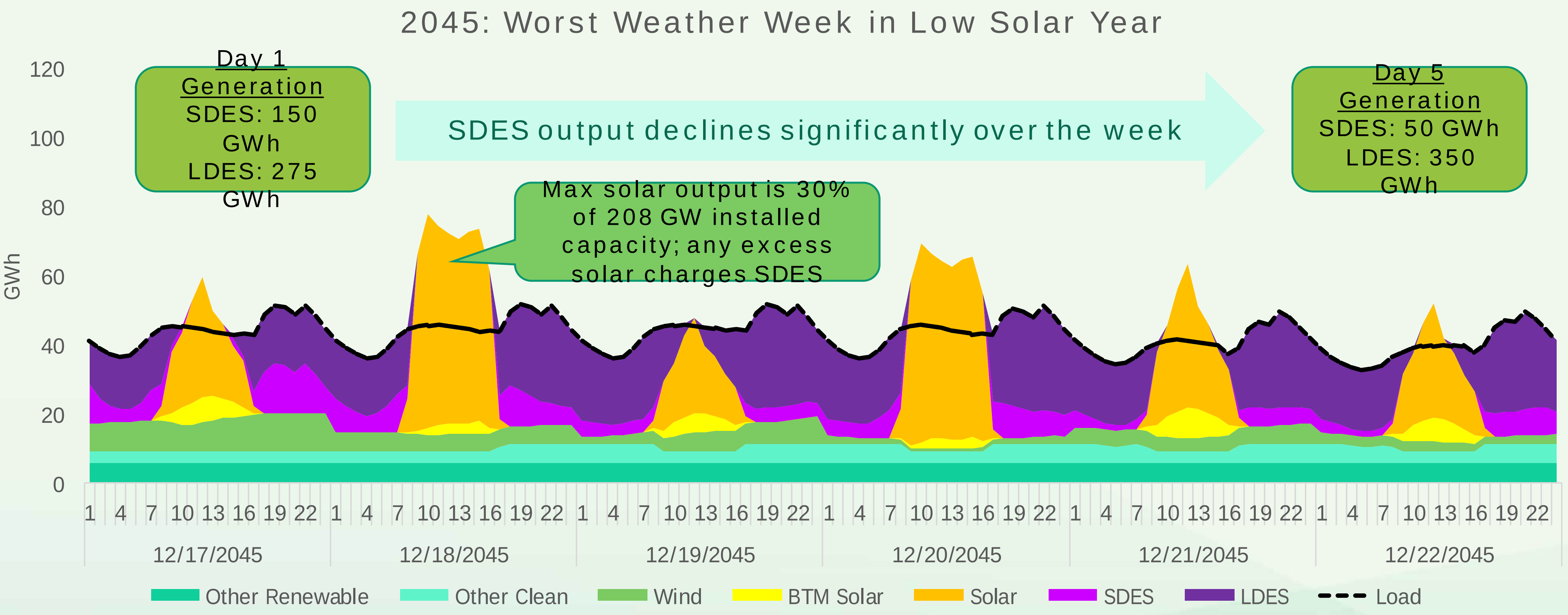
- Hydrogen one of many types of storage in CESA's 'Technology Neutral' approach
  - CESA championed SB 1369 (Skinner, 2018) to define green electrolytic hydrogen as energy storage

- Hydrogen storage applications likely could/should include:
  - Long-duration (8 hours +) storage solutions, including 'very-long' duration needs
  - Gas-Plant storage hybridization/augmentation

What will the future look like?

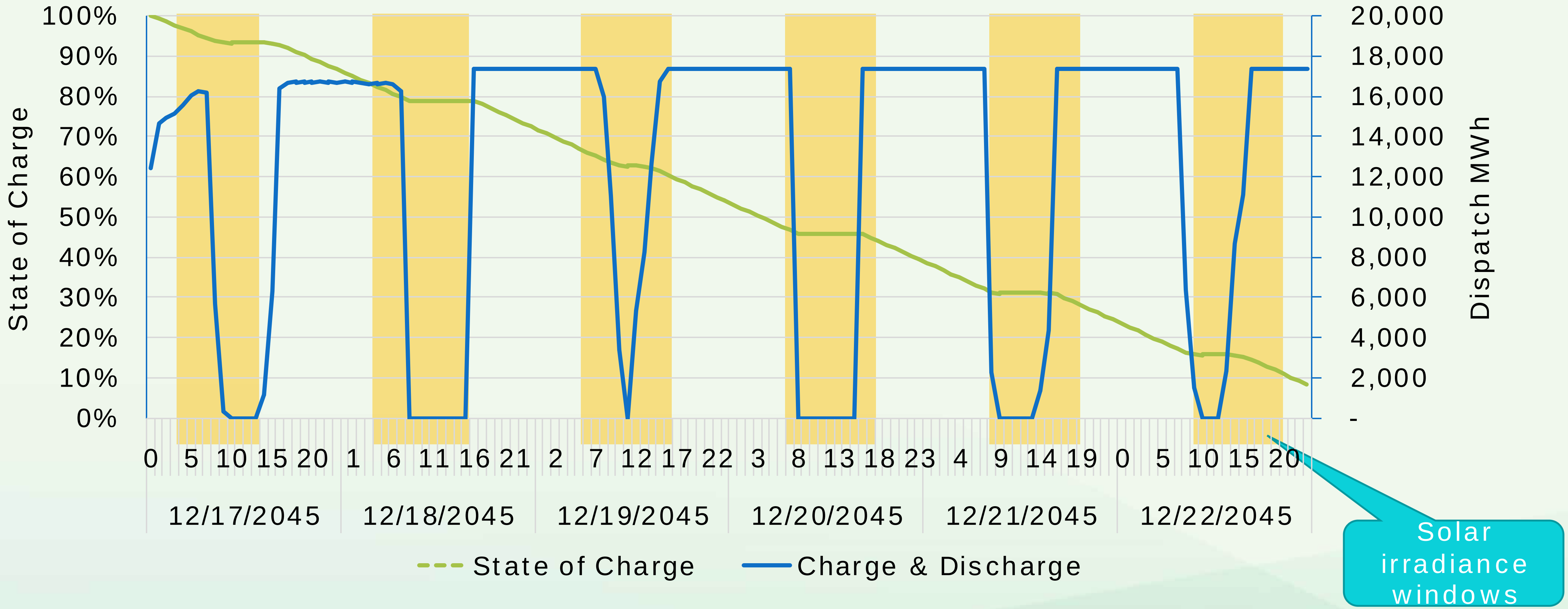


Long-Duration Storage is Critical for Weather Resilience



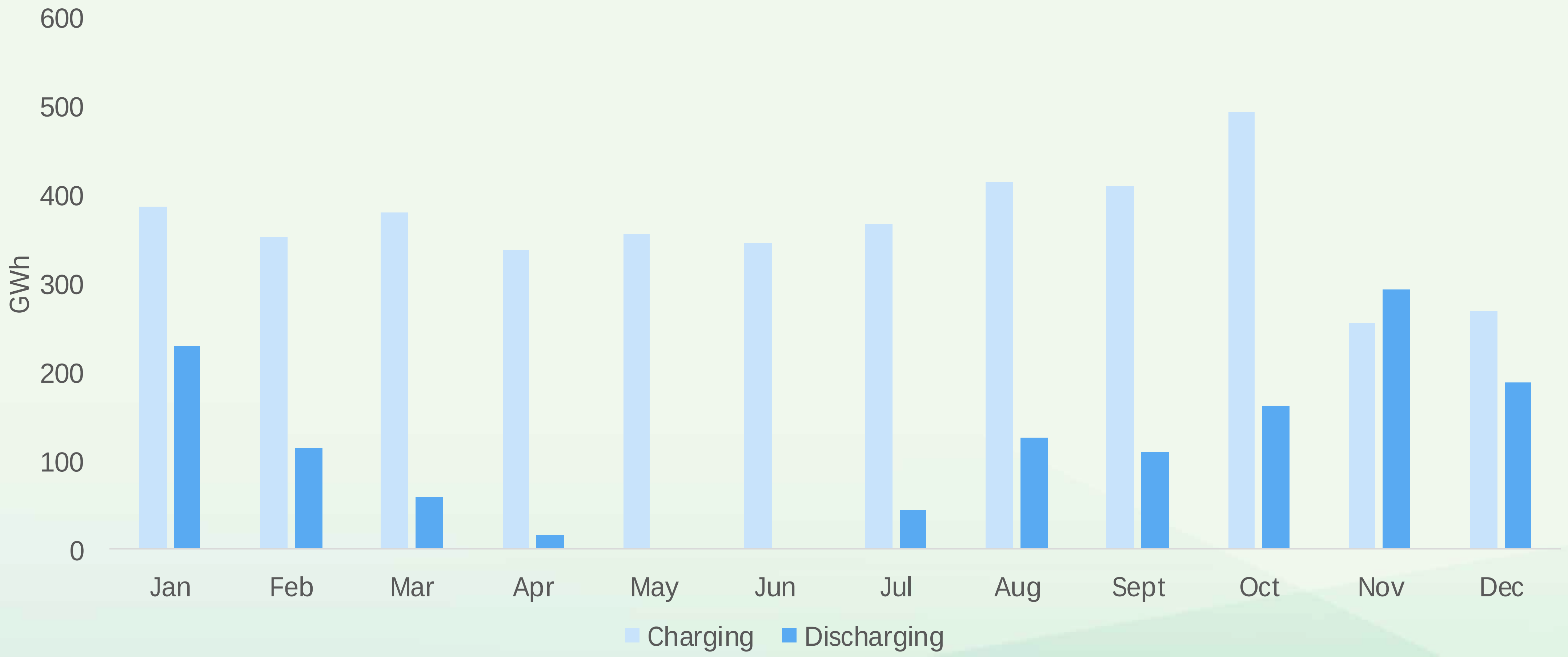
- During the worst weather week, long-duration storage supplies the majority of grid energy
- "Other Renewable" includes small hydro, geothermal, and biomass. "Other clean" includes hydro, nuclear, and demand

Worst weather drains seasonal storage reserves

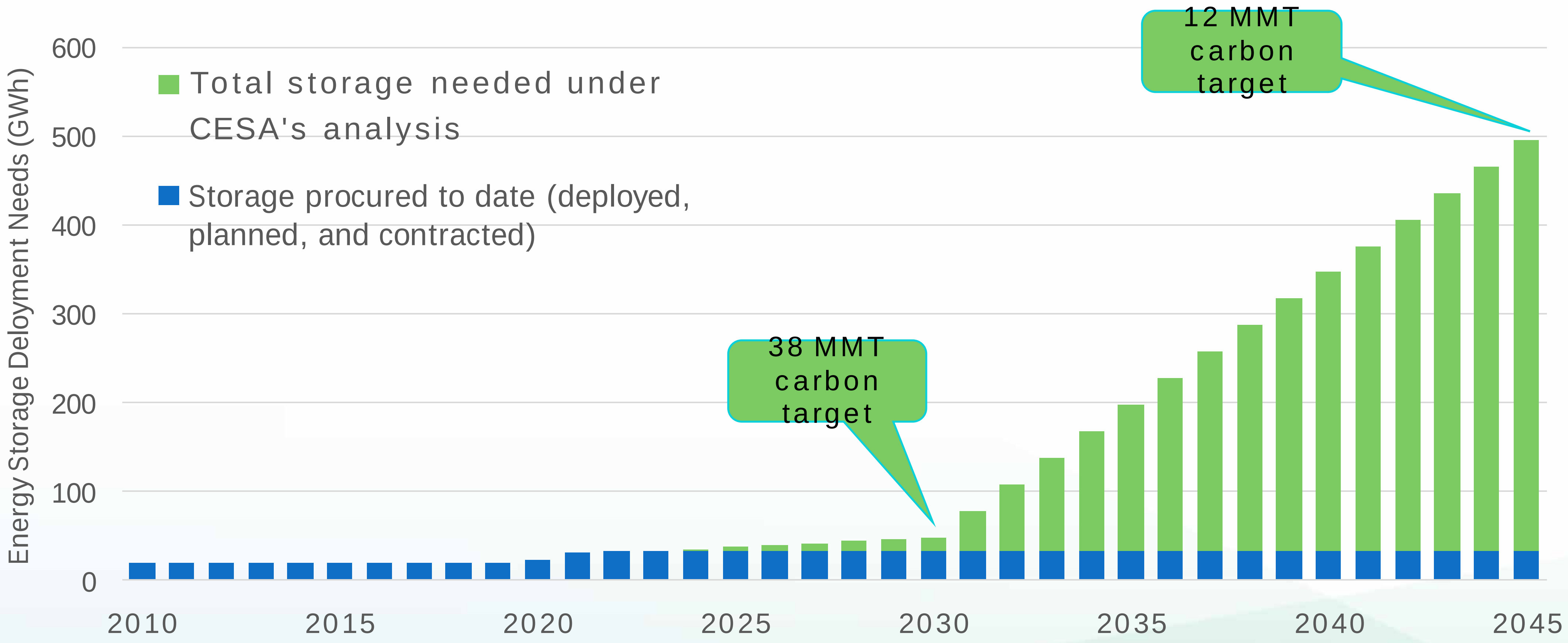


Worst weather week almost fully drains 100 hr. storage reserves

LDES Will be Necessary Every Month of the Year



Long-duration storage deployments accelerate significantly



What must we do?

Near-term, no-regrets procurement	More procurement, construction, and contracting for a diverse energy storage portfolio is appropriate for many reasons
Ready our Toolkit Now	Further readying our energy-storage fleet, including with RD&D and commercializing viable technologies, is prudent. Diversifying our fleet lowers risks.
Properly Value Long-Duration Storage	Update our rules and regulations to reflect the increased reliability benefits of a diverse and long-duration storage fleet

2045

Image: iStock/MrJub

THANK YOU

Please contact us at: info@storagealliance.org | www.storagealliance.org

AB
COGENERATION WORLD

American biogas Council

Anaergia
Breaking Barriers to Sustainability

ARIES CLEAN ENERGY

City of Bakersfield California

Biogas Energy

BIOGAS ENGINEERING

Bloomenergy

BRAD THOMPSON company

BRIGHTMARK
REIMAGINE WASTE

CALIFORNIA BIOENERGY

California Waste Haulers Council

CATERPILLAR

Clean Energy RENEWABLES

CALGREN Renewable Fuels

CASA

Camptonville Community Partnership

COBIA CAPITAL
Infrastructure Development & Management

CORTUS ENERGY

CR&R

DTE Energy
DTE Biomass Energy

Edgar & Associates

Cummins

Westport

Delta Diablo

EAST BAY MUNICIPAL UTILITY DISTRICT

City of FRESNO

GSNGS
GOLDEN STATE NATURAL GAS SYSTEMS

GENERATE CAPITAL

GREENLANE BIOGAS

gna GLADSTEIN, NEANDROSS & ASSOCIATES

Bioenergy Association of California

JRMA
ARCHITECTS ENGINEERS

Las Gallinas
VALLEY SANITARY DISTRICT

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

LIVE OAK BANK

gti

GREEN HYDROGEN COALITION

Hitachi Zosen INOVA

Irvine Ranch
WATER DISTRICT

MAAS ENERGY WORKS

MOMENTUM

North State Hulling Cooperative, Inc.

NOWON
See the future. Change the present.

OC Waste & Recycling

LOS ANGELES COUNTY SANITATION DISTRICTS
Converting Waste Into Resources

W. M. LYLES CO.
CONTRACTOR

Mariposa Biomass Project
Clean Energy Healthy Forests Public Safety

Since 1951
Service, Stewardship and Sustainability

San Joaquin Renewables
NATURAL GAS FROM BIOMASS

PW Public Works
LOS ANGELES COUNTY

ReFuel
by ATLAS DISPOSAL

RESOURCE RECOVERY
COALITION OF CALIFORNIA

CITY OF SAN JOSE
CAPITAL OF SILICON VALLEY

PHOENIX ENERGY

Placer County
AIR POLLUTION CONTROL DISTRICT

SalinasValleyRecycles.org

SMUD

City of San Diego
PUBLIC UTILITIES
Water & Wastewater

SIERRA ENERGY

STOEL RIVES LLP
ATTORNEYS AT LAW

StormFisher
BIOGAS

SEVANA BIOENERGY

Sierra Institute
for Community and Environment

RAVEN SR

SYNTECH BIOENERGY LLC

TNRE

TruStar Energy

tss consultants

SoCalGas
A Sempra Energy utility

UNIVERSITY OF CALIFORNIA

WATERSHED CENTER
HAYFORK, CALIFORNIA

WEST BIOFUELS

WUD
WESTERN UNITED DAIRIES

WESTERN ENERGY SYSTEMS
Power Systems Specialists

WCH
WESTHOFF, CONE & HOLMSTEDT

WE
WISEWOOD ENERGY

Wonderful
renewable energy

ZeroWaste
ENERGY, LLC.
Recovery and Energy with Zero Waste

WHY H_2 FROM ORGANIC WASTE?

- Climate Change
- Air quality
- Landfill reduction
- Wildfire reduction
- Local energy supplies
- Community resilience

Climate Priorities

IPCC: We have < 10 years left to slow climate change or face catastrophic changes

ARB: SLCP Reduction and carbon sequestration are the only ways to immediately reverse climate change and its impacts

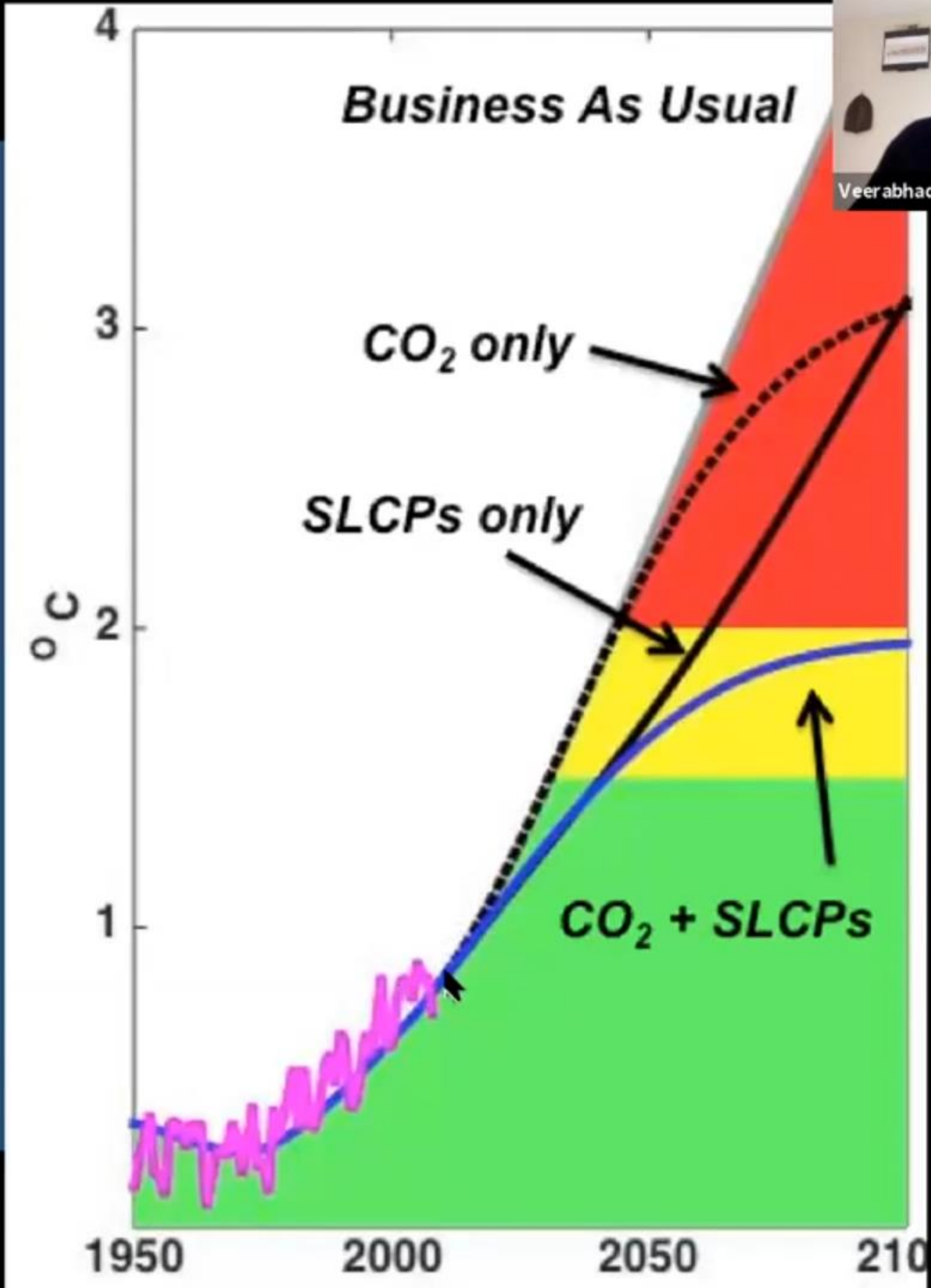
SLCP's are tens to thousands of times more damaging to the climate than CO_2

SLCPs Reductions can bend the warming curve:

0.6 C by 2050

&

1.2 C by 2100

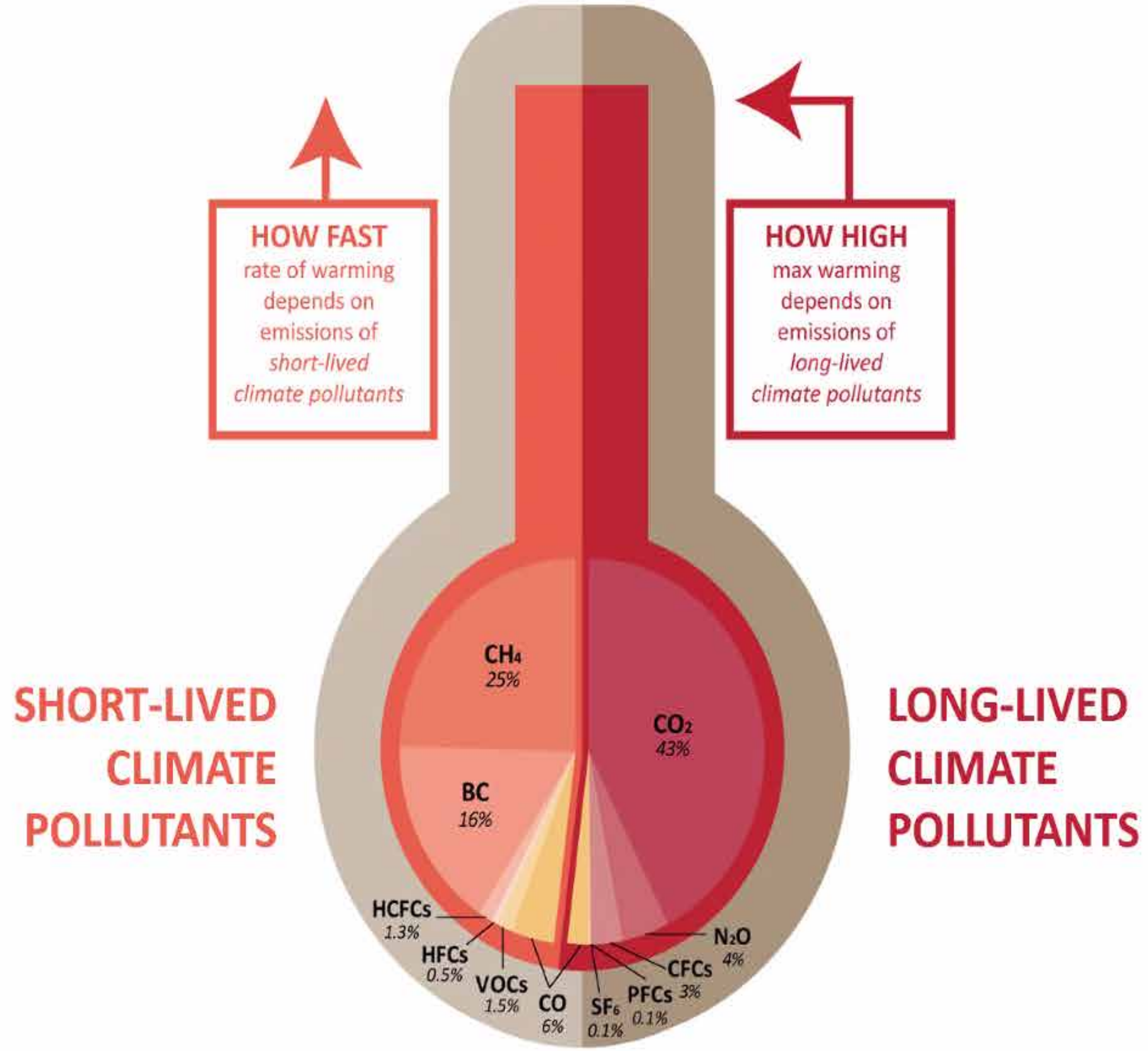


EDF ENVIRONMENTAL DEFENSE FUND

Finding the ways that work

CO_2 accounts for ~**half** of today's warming

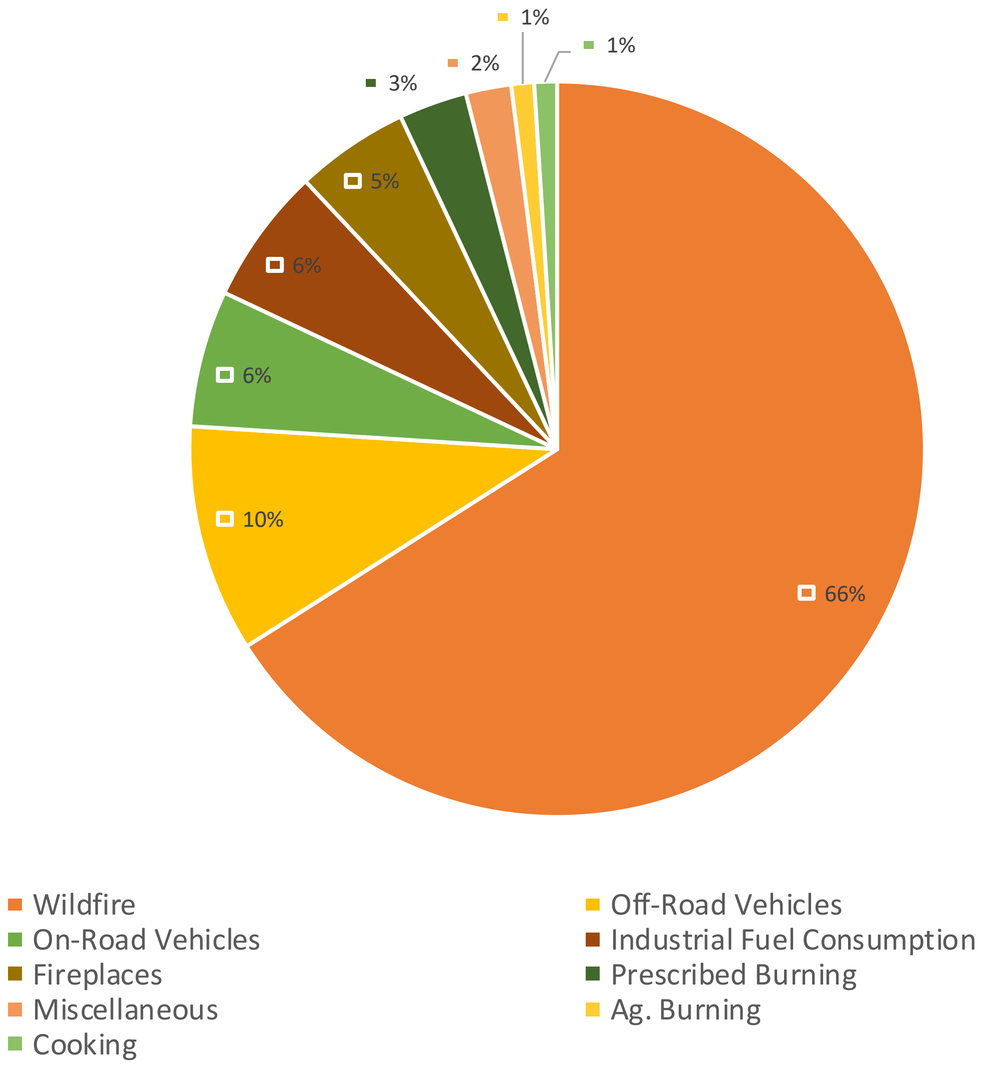
SLCPs other half!



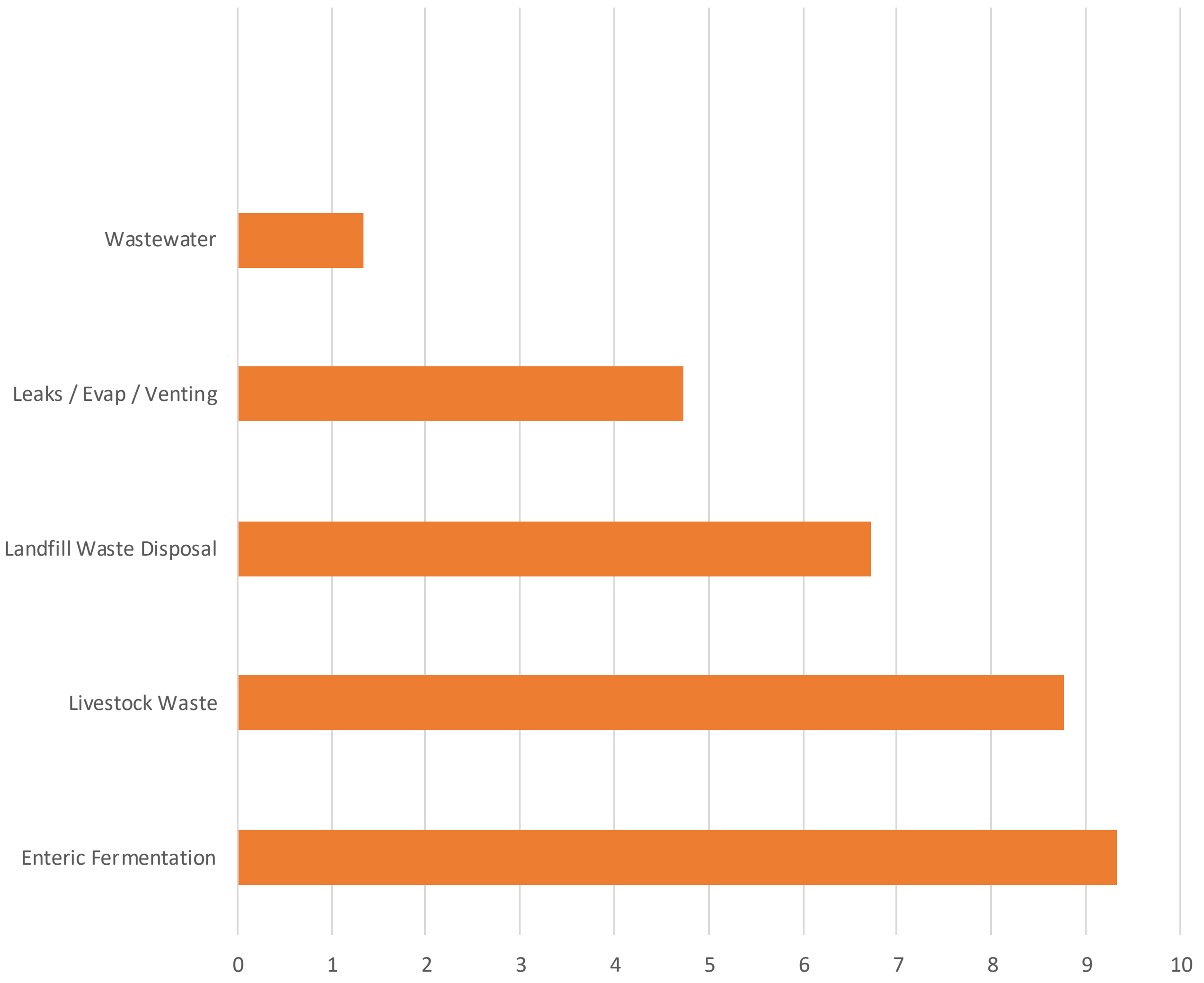
CONTRIBUTION OF EMITTED POLLUTANTS TO TODAY'S WARMING

data from IPCC AR5 WGI 2013 using positive radiative forcing as a proxy for warming

Black Carbon Sources in CA

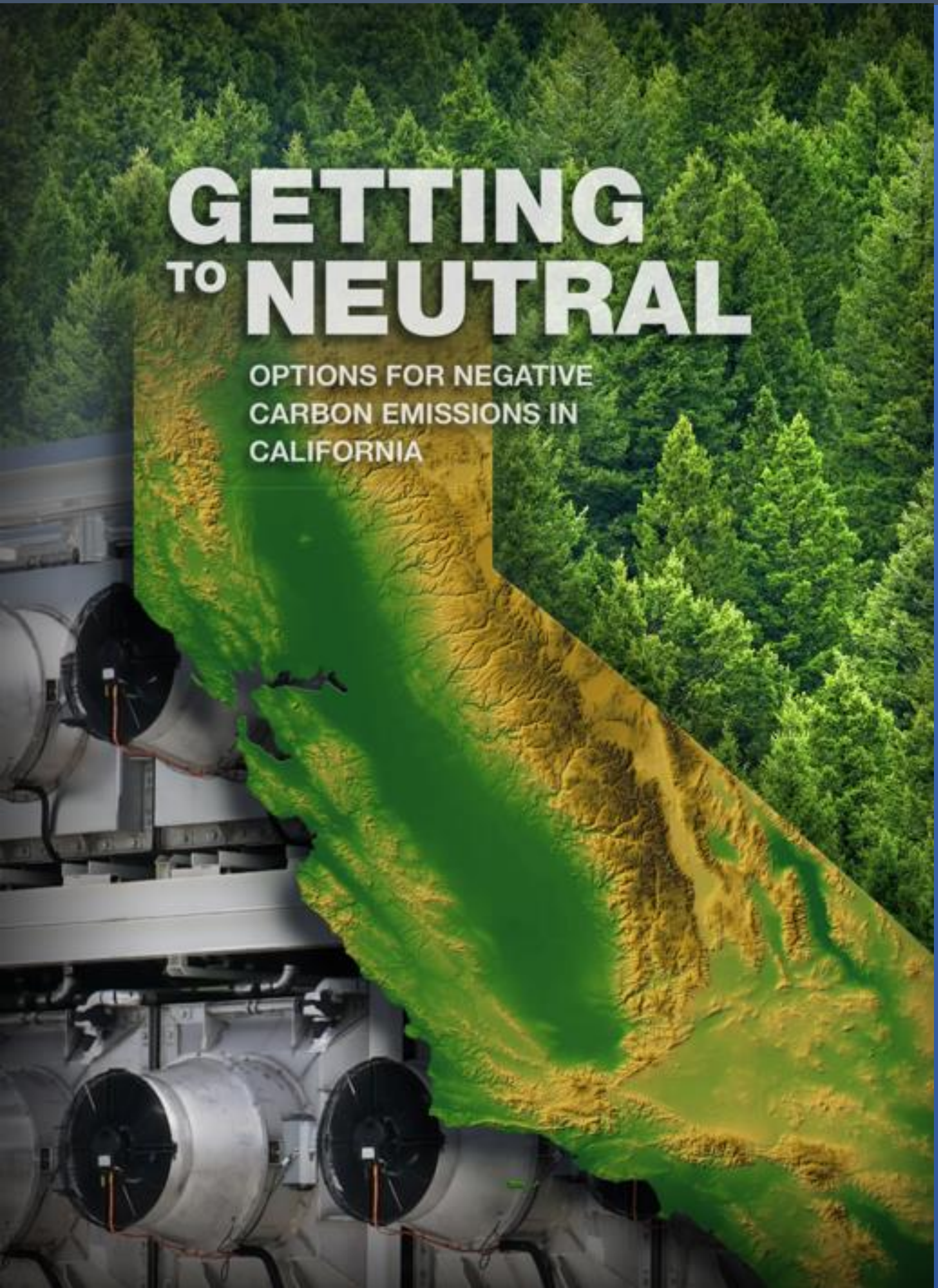


California's Top 5 Methane Sources



BC is 3,200x more damaging to climate than CO2

CH4 is 75x more damaging to climate than CO2



THE LLNL CARBON INITIATIVE

California Negative Emissions

LLNL-PRES-795982

Lawrence Livermore National Lab: "Getting to Neutral – Options for Negative Emissions in California"

- Natural and Working Lands

25 MT/year

- Waste Biomass Conversion to energy with CO_2 Storage

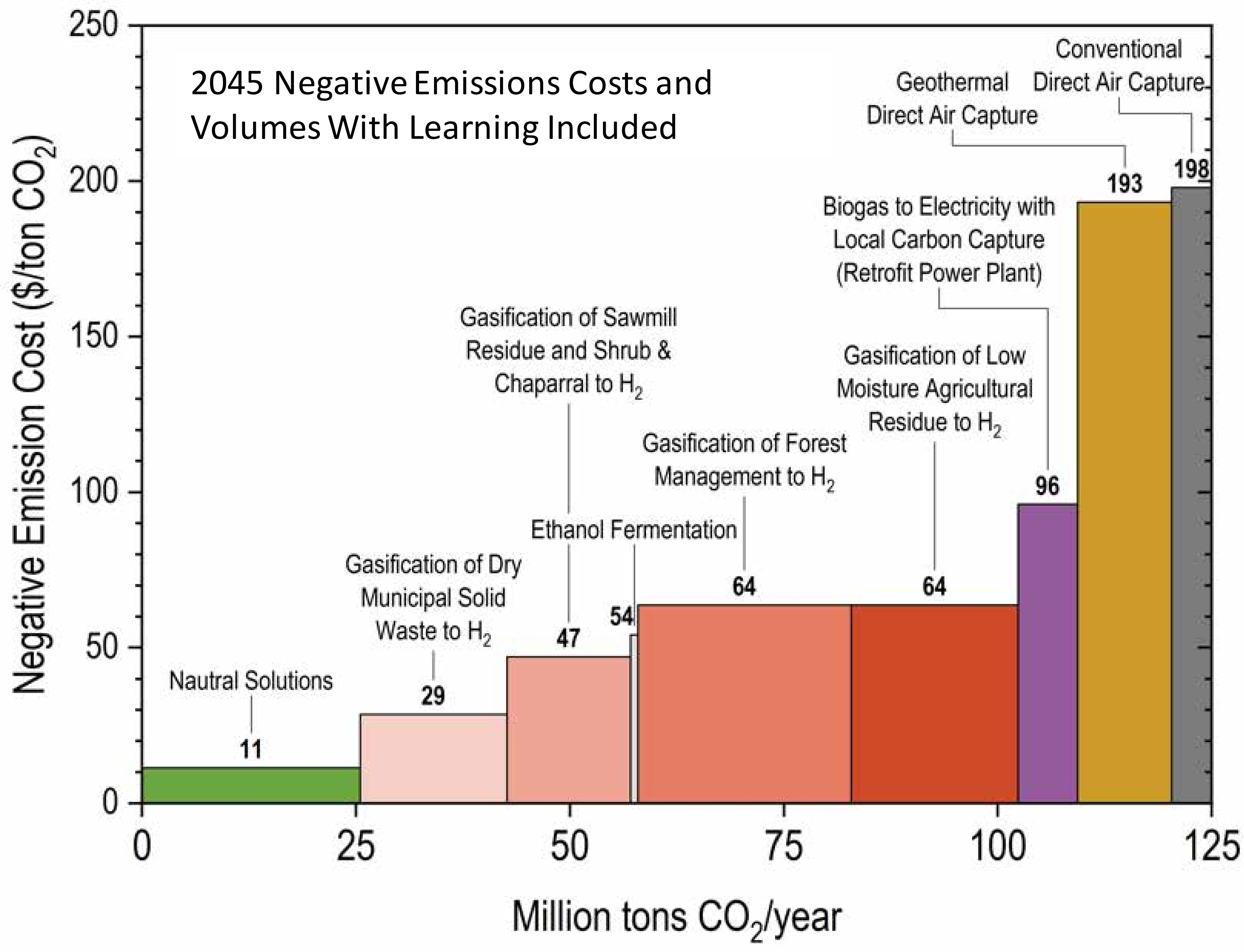
83 MT/year

- Direct Air Capture with CO_2 Storage

17 MT/year

Technological readiness: mid-to-high – no new breakthroughs required

The least-cost path to 125 MT/year uses natural solutions, gasification of biomass to H_2, and some direct air capture.



Biogas from San Diego Wastewater Treatment Plant Used to Produce Hydrogen for 3 MW Fuel Cell at UCSD

THANK YOU

Julia Levin, Executive Director

jlevin@bioenergyca.org

510-610-1733

www.bioenergyca.org

Bioenergy Association of California

Panel 1: Some Key Questions to Answer Along the Road Ahead?

- How much of the energy storage capability planned for the state should be green hydrogen?
- The SB100 report shows that about 15 GW of firm dispatchable generation is needed- depending on trade offs with LDS- how much of this should be H2?
- What is the capacity need for seasonal energy storage that green H2 could be well suited to address?
- What is the current price of H2 what trajectory do you expect it to take over time? The DOE Earth shot goal is to reduce the price of H2 to $1/kg in a decade.
- What is the rough cost/efficiency of electrolyzers?
- What is the ideal size paring of an electrolyzer and the RE generating asset to ensure optimal utilization of each?
- What is the rough cost/efficiency of an H2 Turbine- what is the cost/kWh for electricity generated from an H2 Turbine? What are issues w NOx?
- What are industry plans for H2 Turbines, when will 50% and 100% turbines be available?
- What is an H2 eco-system likely to look like for land based PV and off shore wind
- Should H2 sources from organic sources such as reforming Green CH4 be considered Renewable H2? Is it decarbonized?
- Can Green CH4 be used for grid support generation? What are the trade offs with Green H2? Can Storage be used with Green CH4 generation to reduce criteria pollutants?

Panel 1: Green Hydrogen for Grid Reliability- Firming and Shaping Intermittent Renewables in the Grid of the Future

- Moderator: Mike Petouhoff, CEC

A. Janice Lin, Green Hydrogen Coalition
B. Peter J. Sawicki, Pacific West Mitsubishi Power Americas, Inc.
C. Mårten Lunde, Hydrogen Pro
D. Alex Morris, California Energy Storage Association
E. Julia Levin, BioEnergy Association of CA

Panel 2: The Role of Green Hydrogen in the Decarbonization of the Transportation System as FCV and BEV's Evolve

- Peter Chen, CEC Energy Generation Research Office
- Jane Berner, CEC Advanced Vehicle Infrastructure Office

Panel 2: Some Key Questions to Answer Along the Road Ahead?

- What H2 transportation research has CEC done in the past and planned in this area?
- What is the current status of FCV and BEV adoption?
- As the transportation sector decarbonizes, what volume and type of vehicles will likely be based on H2 Fuel Cell Technology?
- How would this impact the annual H2 budget in CA?
- Though it may be outside of EPIC- is there a role for Hydrogen in ship and air travel- would it likely be in the form of NH4?

Hydrogen in the Context of Transportation Electrification

Energy Research and Development Division

Peter Chen, Mechanical Engineer

July 1, 2021

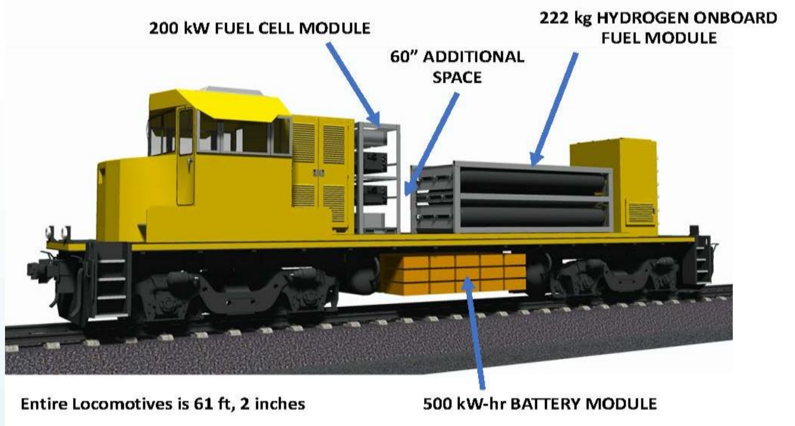
Green H2 - a Complementary ZEV Pathway for the Transportation Sector

- EO N-79-20 sets ambitious targets to transition light-, medium-, and heavy-duty vehicles and off-road equipment to ZE, where feasible.
  - ZEVs include both plug-in electric vehicles and hydrogen fuel cell electric vehicles.
  - Ensure that ZEV adoption is providing direct air quality benefits to communities burdened by mobile source emissions.
  - Embrace all viable pathways to ZE and design for resilience, reliability, and renewable energy penetration.

H2 Fuel Cells for Decarbonizing Challenging Transportation End-Uses

- Advance the use of H2 fuel cells to decarbonize challenging transportation applications such as heavy transport, rail, marine, and off-road:
  - ✓ Long range or high onboard energy requirements
  - ✓ Limited refueling opportunities
  - ✓ High payload capacity needs

Source: CALSTART

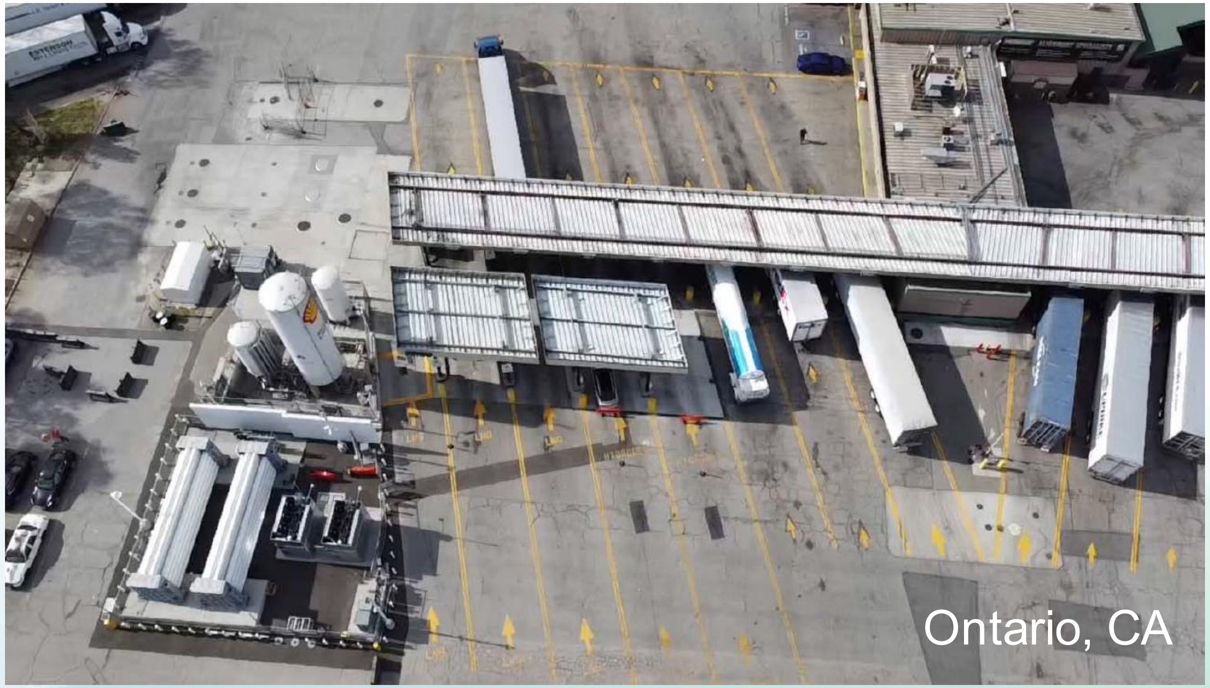


Source: Gas Technology Institute

Source: Port of Los Angeles

H2 Fuel Cells as Distributed Generation to Support HDV Electrification

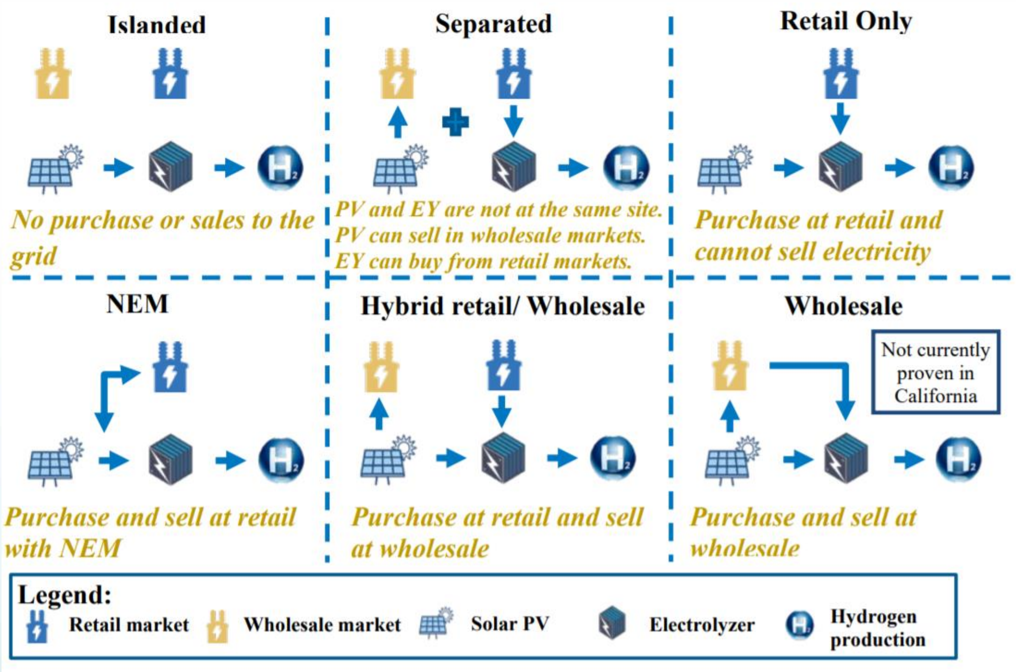
- Leverage H2 fuel cells as DG to minimize grid impacts of heavy-duty vehicle charging infrastructure and improve resiliency.
  - ✓ Supplement PV and batteries to ensure 24/7 generating capacity
  - ✓ Extend islanding capabilities to support critical loads
  - ✓ Leverage H2 supply chains for co-located hydrogen fueling



Source: Port of Los Angeles

Grid-integrated Electrolysis for Green H2 Transportation Fuel

- Determine optimal methods for producing green H2 from grid-integrated electrolysis to reduce costs and support grid needs.
  - ✓ Avoid or defer transmission investments
  - ✓ Enable green H2 production at scale to meet transportation demand
  - ✓ Leverage load flexibility while providing a reliable supply of green H2



Source: NREL

Contact: Peter Chen

peter.chen@energy.ca.gov

Thank you!

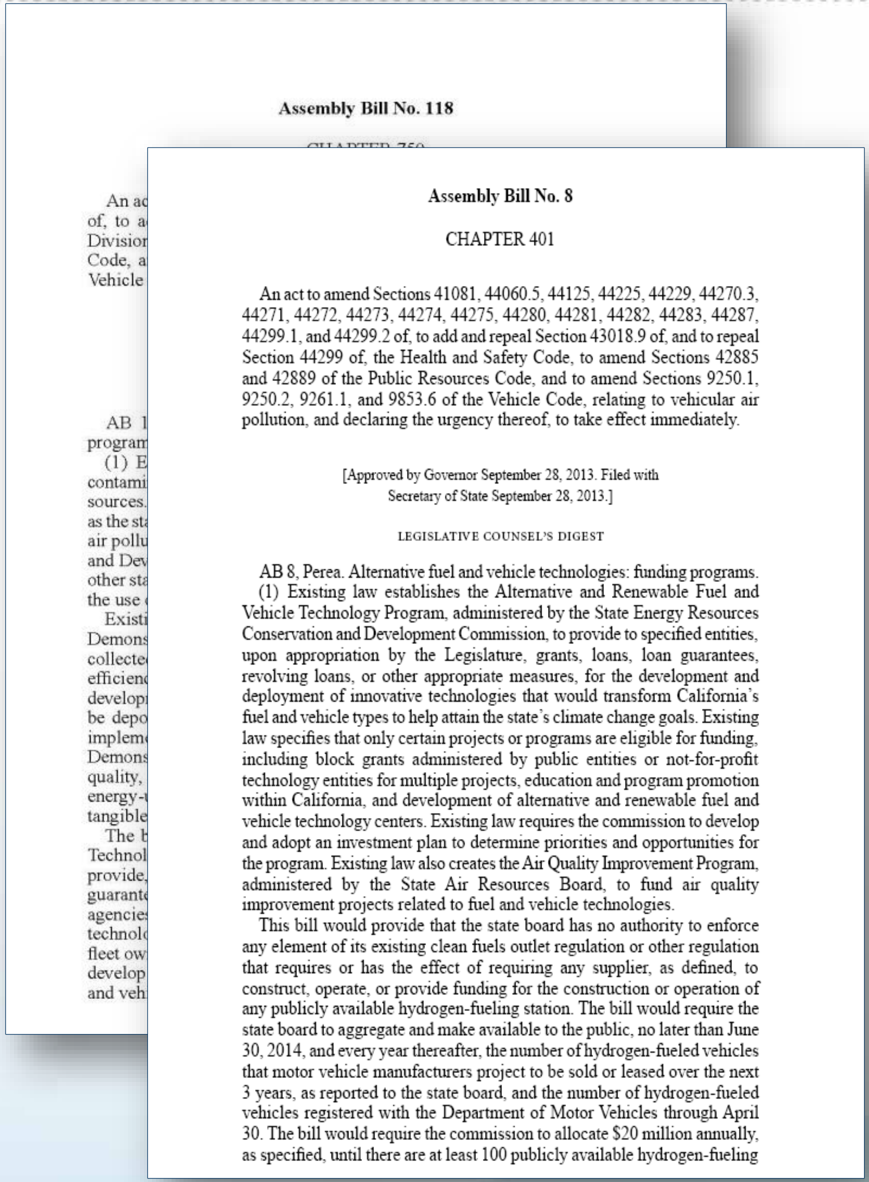
California Energy Commission

Fuels and Transportation Division Hydrogen Activities

Jane Berner

July 1, 2021

Clean Transportation Program



Assembly Bill No. 118

Assembly Bill No. 8

CHAPTER 401

An act to amend Sections 41081, 44060.5, 44125, 44225, 44229, 44270.3, 44271, 44272, 44273, 44274, 44275, 44280, 44281, 44282, 44283, 44287, 44299.1, and 44299.2 of, to add and repeal Section 43018.9 of, and to repeal Section 44299 of, the Health and Safety Code, to amend Sections 42885 and 42889 of the Public Resources Code, and to amend Sections 9250.1, 9250.2, 9261.1, and 9853.6 of the Vehicle Code, relating to vehicular air pollution, and declaring the urgency thereof, to take effect immediately.

[Approved by Governor September 28, 2013. Filed with Secretary of State September 28, 2013.]

LEGISLATIVE COUNSEL'S DIGEST

AB 8, Perea. Alternative fuel and vehicle technologies: funding programs.

(1) Existing law establishes the Alternative and Renewable Fuel and Vehicle Technology Program, administered by the State Energy Resources Conservation and Development Commission, to provide to specified entities, upon appropriation by the Legislature, grants, loans, loan guarantees, revolving loans, or other appropriate measures, for the development and deployment of innovative technologies that would transform California's fuel and vehicle types to help attain the state's climate change goals. Existing law specifies that only certain projects or programs are eligible for funding, including block grants administered by public entities or not-for-profit technology entities for multiple projects, education and program promotion within California, and development of alternative and renewable fuel and vehicle technology centers. Existing law requires the commission to develop and adopt an investment plan to determine priorities and opportunities for the program. Existing law also creates the Air Quality Improvement Program, administered by the State Air Resources Board, to fund air quality improvement projects related to fuel and vehicle technologies.

This bill would provide that the state board has no authority to enforce any element of its existing clean fuels outlet regulation or other regulation that requires or has the effect of requiring any supplier, as defined, to construct, operate, or provide funding for the construction or operation of any publicly available hydrogen-fueling station. The bill would require the state board to aggregate and make available to the public, no later than June 30, 2014, and every year thereafter, the number of hydrogen-fueled vehicles that motor vehicle manufacturers project to be sold or leased over the next 3 years, as reported to the state board, and the number of hydrogen-fueled vehicles registered with the Department of Motor Vehicles through April 30. The bill would require the commission to allocate $20 million annually, as specified, until there are at least 100 publicly available hydrogen-fueling

Formerly known as the Alternative and Renewable Fuel & Vehicle Technology Program

Established in 2007 by Assembly Bill 118 (Núñez, 2007)

Extended through January 1, 2024 by Assembly Bill 8 (Perea, 2013)

$100 million per year with funds collected from vehicle registration fees

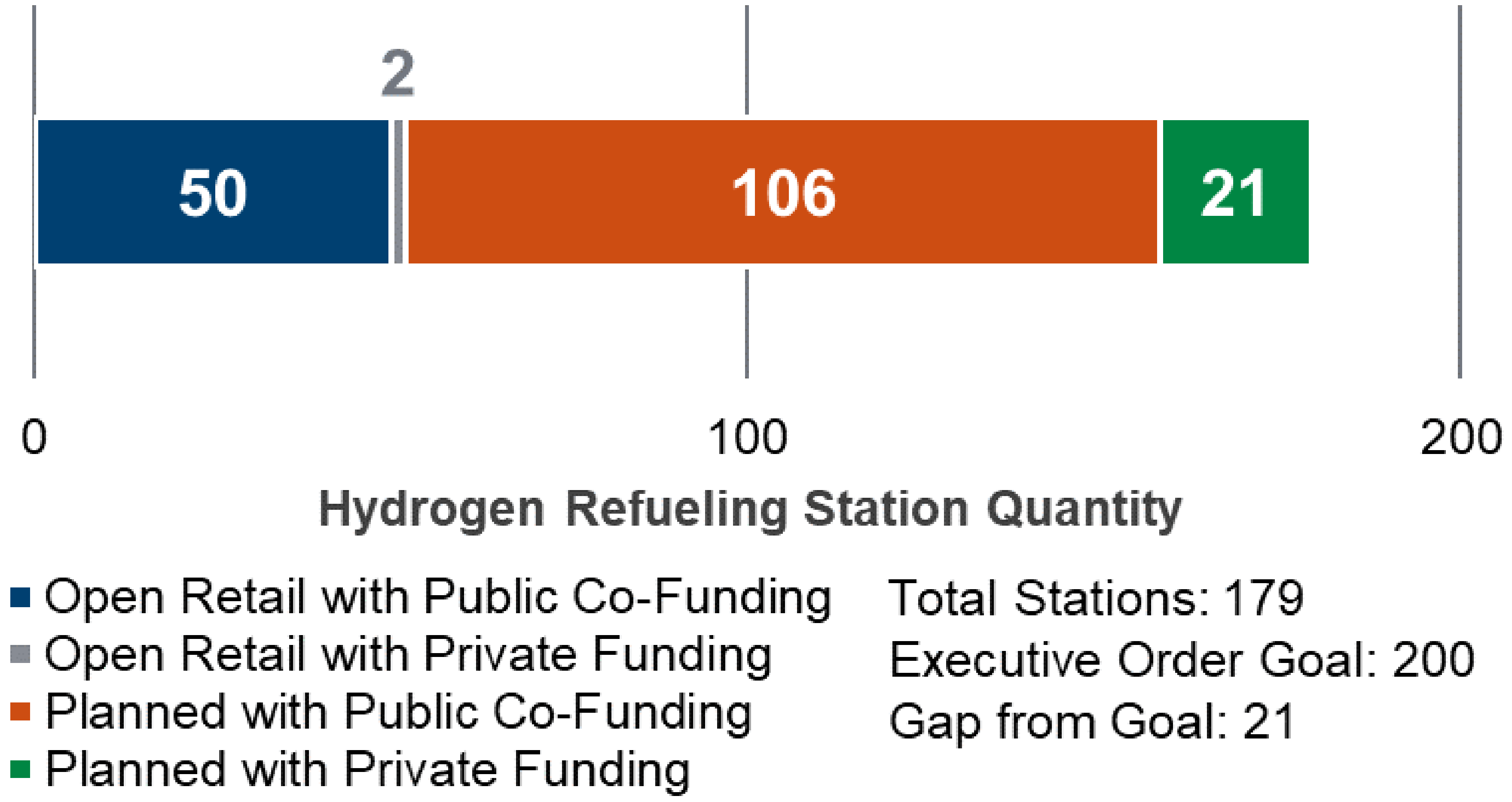
$20 million per year for hydrogen stations to establish at least 100 stations

California Goals

- AB 8: 100 publicly available stations
- Governor Edmund G. Brown Jr.'s [Executive Order B-48-18]
  - 200 hydrogen stations by 2025
  - 5 million zero-emission vehicles by 2030
- Governor Gavin Newsom's [Executive Order N-79-20]
  - 100 percent of new-passenger-vehicle sales be zero-emission by 2035
  - 100 percent of medium- and heavy-duty vehicle operations be zero-emission by 2045 where feasible

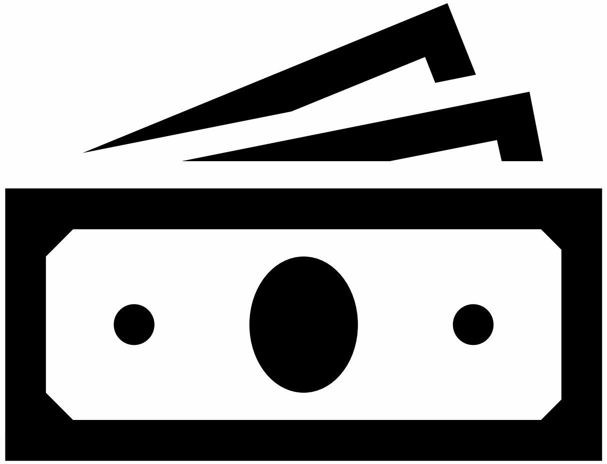
Picture of a station from FirstElement Fuel

H2 Retail Station Development



Total Stations: 179
Executive Order Goal: 200
Gap from Goal: 21

Clean Transportation Program Investment



Public Hydrogen Refueling Stations

~$170 M

Medium / Heavy-Duty Refueling Stations

~$30 M

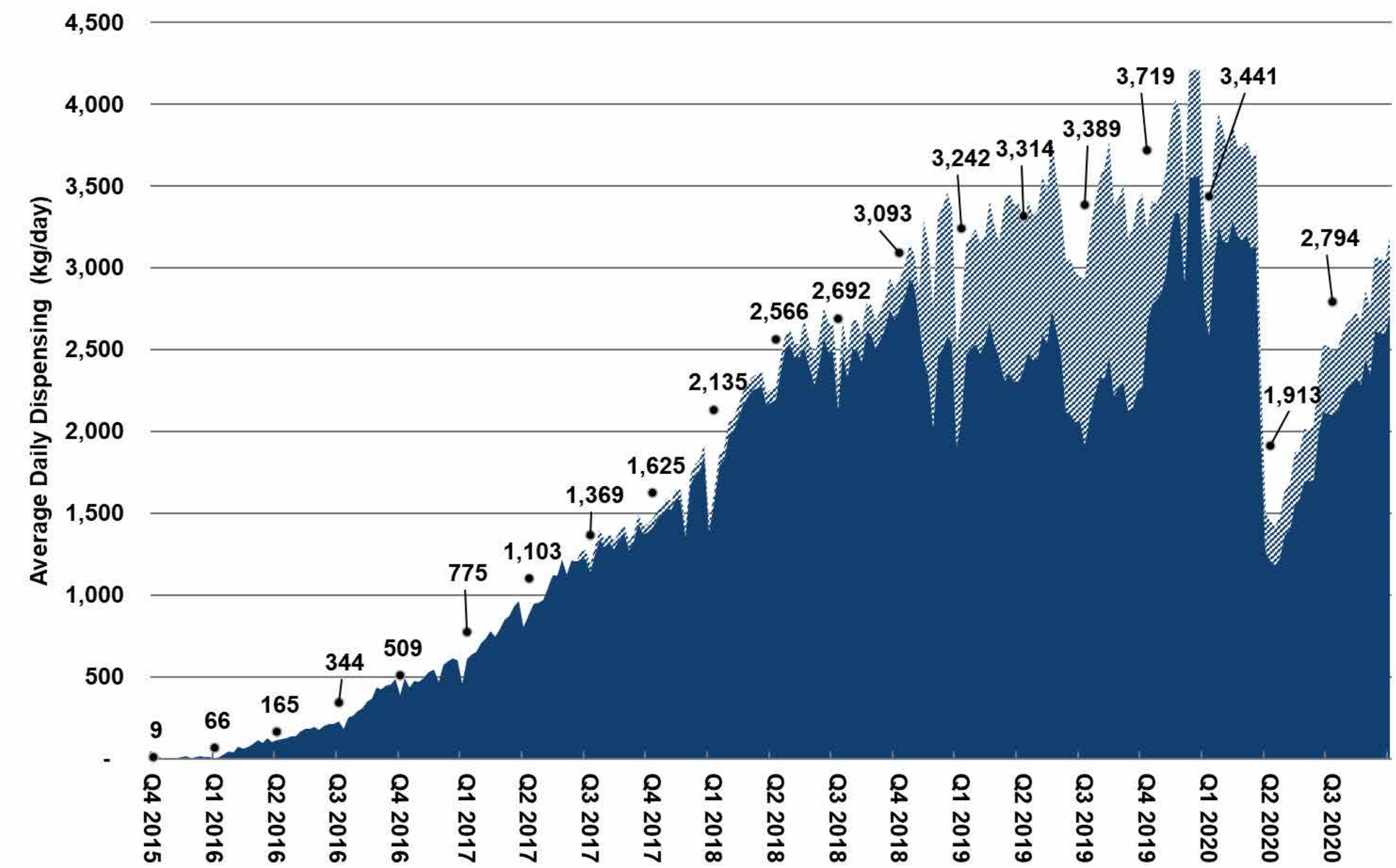
Renewable Hydrogen Production

~$8 M

Medium- and Heavy-Duty (MD/HD) ZEV Infrastructure Investments

- Block Grant for MD/HD ZEV Infrastructure Incentive Projects
- Blueprints for MD/HD ZEV Infrastructure
- Zero-Emission Transit Fleet Infrastructure Deployment
- Zero-Emission Drayage Truck and Infrastructure Pilot Project
- School Bus Replacement Program
- Hydrogen Fuel Cell Demonstrations in Rail and Marine Applications at Ports (H2RAM)

Hydrogen Fuel Dispensed 2015-2020



Renewable Hydrogen Requirement:

33.3%
SB 1505
(Lowenthal, 2006)

40%
Low Carbon Fuel Standard Hydrogen Refueling Infrastructure Program

Future Hydrogen Fuel Need

Today: ~10,000 FCEVs

179 Stations:

~160,000 kg/day Capacity → ~230,000 Light-Duty FCEVs

Tank Capacity

5 kg

10 - 60+ kg

New Hydrogen Production

- Clean Transportation Program
  - GFO-20-609 will fund new green hydrogen production projects for transportation uses in California
- Air Liquide
  - New 30 ton/day liquid hydrogen production plant is under construction in North Las Vegas, Nevada, to serve the California mobility market and will have the capacity to fuel 42,000 light-duty FCEVs.
- Air Products
  - Investing in 650 ton/day green production plant in Saudi Arabia to serve the global transportation market.
- Linde PLC
  - Is upgrading and expanding its hydrogen plant in Ontario, California, to add a high-pressure filling system and be able to supply green hydrogen for up to 1,600 FCEVs daily.

Contact: Jane Berner
jane.berner@energy.ca.gov

Thank You!

Panel 2: Some Key Questions to Answer Along the Road Ahead?

- What H2 transportation research has CEC done in the past and planned in this area?
- What is the current status of FCV and BEV adoption?
- As the transportation sector decarbonizes, what volume and type of vehicles will likely be based on H2 Fuel Cell Technology?
- How would this impact the annual H2 budget in CA?
- Though it may be outside of EPIC- is there a role for Hydrogen in ship and air travel- would it likely be in the form of NH3?

Panel 2: The Role of Green Hydrogen in the Decarbonization of the Transportation System as FCV and BEV's Evolve

- Peter Chen, CEC Mechanical Engineer
- Jane Berner, CEC Fuels and Transportation Division Green Hydrogen Activities

Panel 3: California End Use Applications of Green Hydrogen

- Moderator: Kevin Uy, CEC Energy Efficiency Research Office

A. Bill Zobel, California Hydrogen Business Coalition

B. Dr. Jack Brouwer, UC Irvine

Panel 3: Some Key Questions to Answer Along the Road Ahead?

Overarching questions

- Most beneficial applications of H2 for stationary end uses a
- What are the obstacles and how does that inform the research?
- What are the use cases or deployment strategies where green hydrogen is most promising in California?

Industrial questions

- What industrial sub sectors are best suited for green H2?
- What technical or economic challenges are there to utilizing green hydrogen in this sub sector and how could research help address these challenges?
- What is the price goal that need to be achieved to make industrial use of green hydrogen competitive to hydrogen produced via conventional steam methane reforming (with and without carbon capture)?
- What are some green hydrogen production technologies that could have favorable economics in the industrial sector (for instance, by reuse of byproducts)?

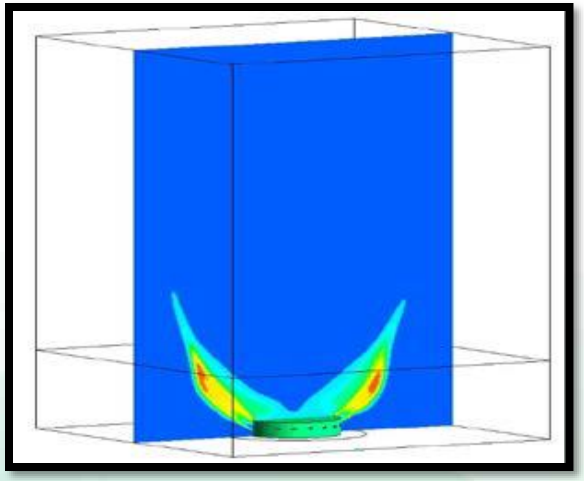
Buildings questions

- In what building types would green hydrogen be best utilized? (Ex. large campuses with cogeneration facilities)
  - Are there specific appliances that would be good candidates for green hydrogen but need additional research to enable existing models to use the fuel?
  - What technical or economic challenges are there to utilizing green hydrogen in this application and how could research help address these challenges?
- What are some potential non-energy benefits green hydrogen offer building occupants or owners? (resiliency, low GHG emissions, and etc.,)
- *Are there any infrastructure challenges to transport green hydrogen to residential or commercial buildings? (lower priority question – may overlap with infrastructure panel)*

EPIC 4 Workshop - The Role of Green Hydrogen in a Decarbonized California - A Roadmap and Strategic Plan

- **Project Highlight:** PIR-16-017, Implications of Increased Renewable Natural Gas on Appliances
- **Research Goal:** evaluate the stability, operational, and emissions implications of operating dual fuel appliances (natural gas + CO_2 or H_2)
    - Experimentally tested **4 appliances** and applied simulation methodologies to 9
- **Key Findings:**
    - For these un-modified appliances, when H_2 concentration increases above 10% by volume, probability of combustion instability increases (e.g. flashback)
    - At 10% H_2 level, NO_x and CO level decrease in general
    - Modelling approach shows a lot of variance—needs to be anchored in more experimental testing
    - There is a need for more standardized testing procedures

(a) Photograph of experiment setup.



(b) Figure from 3-D model for cooktop burner

Planned Research Initiative (Natural Gas Research Program):

Examining the Effects of Hydrogen in End-Use Appliances

- Establish criteria to define “safe” in the context of a hydrogen-blended natural gas supply
- Evaluate fuel composition that reduces emissions (e.g. NOx, CO) and maximizes efficiency
- Estimate the cost of retrofitting appliances to accommodate higher blends of hydrogen
- Quantify the impact of varying levels of hydrogen blends on the carbon intensity of natural gas-fueled appliances and its overall contribution to state climate and energy goals

Bill Zobel

California Hydrogen Business Coalition

UCI

NATIONAL FUEL CELL RESEARCH CENTER

Hydrogen for Industry & Agriculture

Jack Brouwer

July 1, 2021

California Energy Commission
EPIC Hydrogen Technology Workshop

Hydrogen for Industry and Agriculture

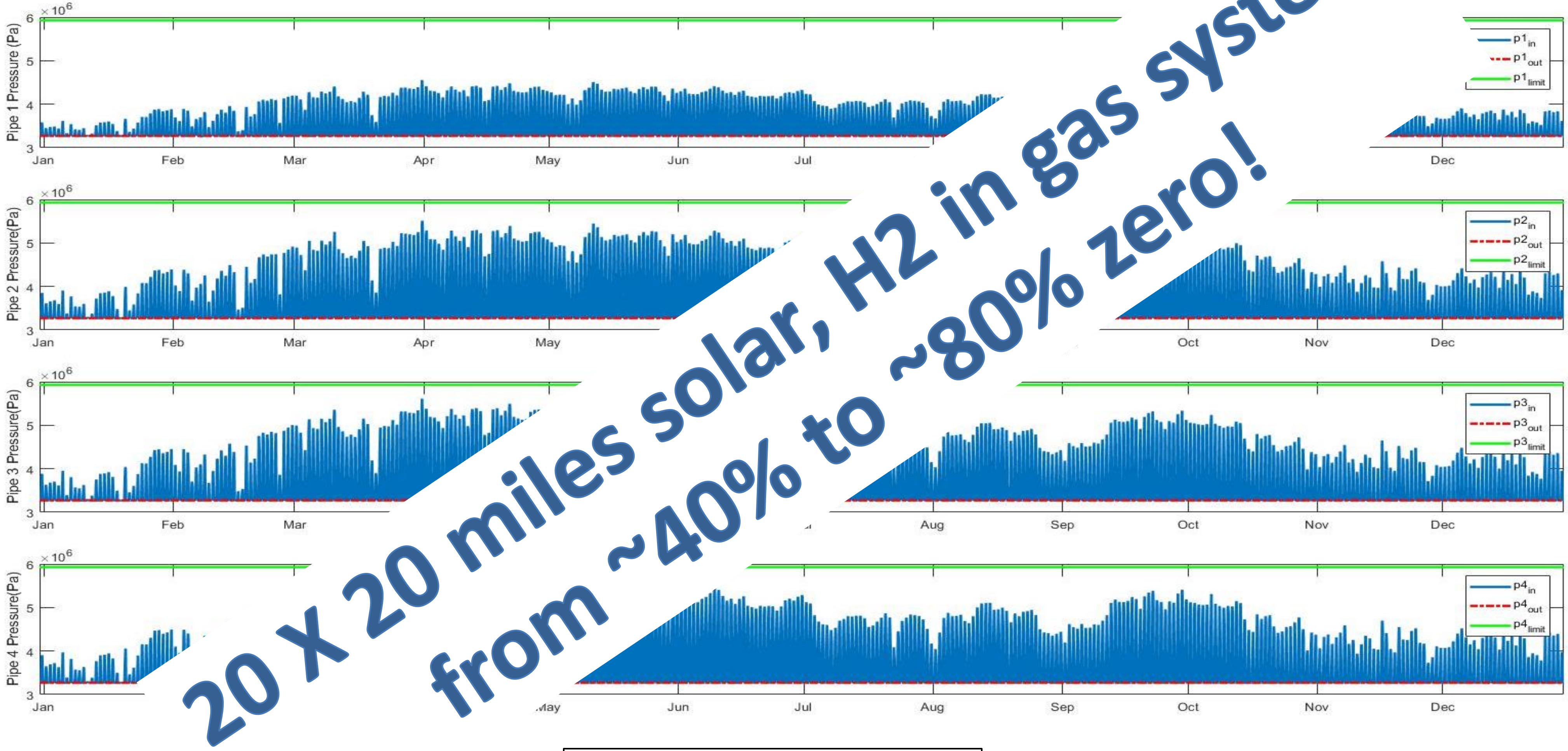
- **Begin overall industrial decarbonization by transforming gas system**
  - Support renewable electricity generation investment
- **Begin transformation of massive storage facilities**
  - Enable resilient 100% renewable electric grid & industry
- **Integrate production and use of renewable hydrogen in various end uses**
  - Heavy duty transport
  - Cement
  - Steel production & recycling
  - Ammonia – main agriculture connection
  - Food processing with combined heat & power
  - Refining
  - Plastics
  - Pharmaceuticals
  - Computer chip fabrication
  - …

Gas System – MASSIVE Resource for Zero Emissi...

- First mix up to X% – ADD grid renewables & transportat... ...cation
- Then piecewise conversion to pure hydrogen

Gas System – MASSIVE Resource for Zero Emissions

- 40% of all electric demand – 20 sq. miles of solar, only gas system u… for H_2 storage AND all T&D



Heydarzadeh, Zahra, PhD Dissertation, UC Irvine, J. Brouwer advisor, 2020.

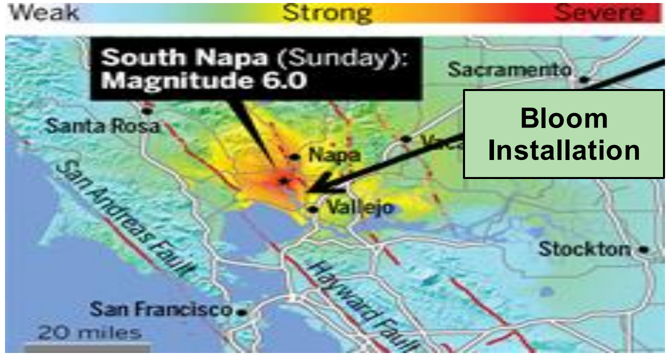
Demonstrated Resilience of Fuel Cells and Gas System

San Diego Blackout, 9/28/11

Winter Storm Alfred, 10/29/11

Hurricane Sandy, 10/29/12

CA Earthquake, 8/24/14

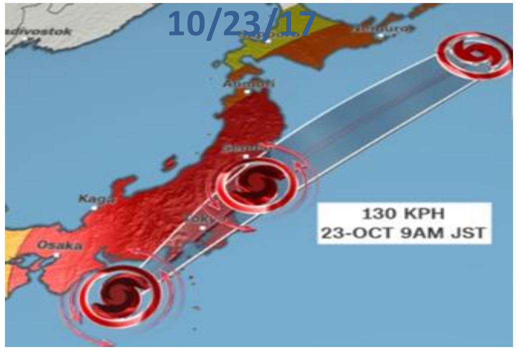


Data Center Utility Outage, 4/16/15

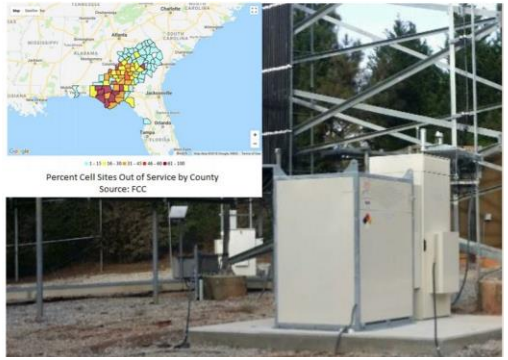
Hurricane Joaquin, 10/15/15

Napa Fire, 10/9/17

Japanese Super-Typhoon, 10/23/17

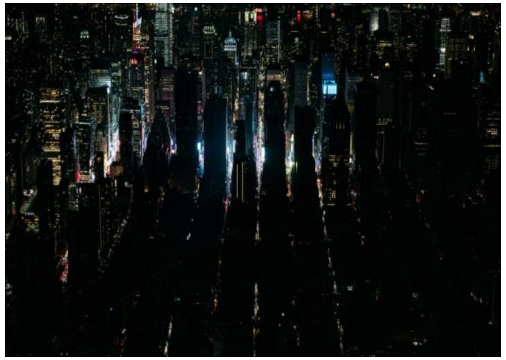


Hurricane Michael, 10/15/18



Ridgecrest Earthquakes, 7/4-5/19

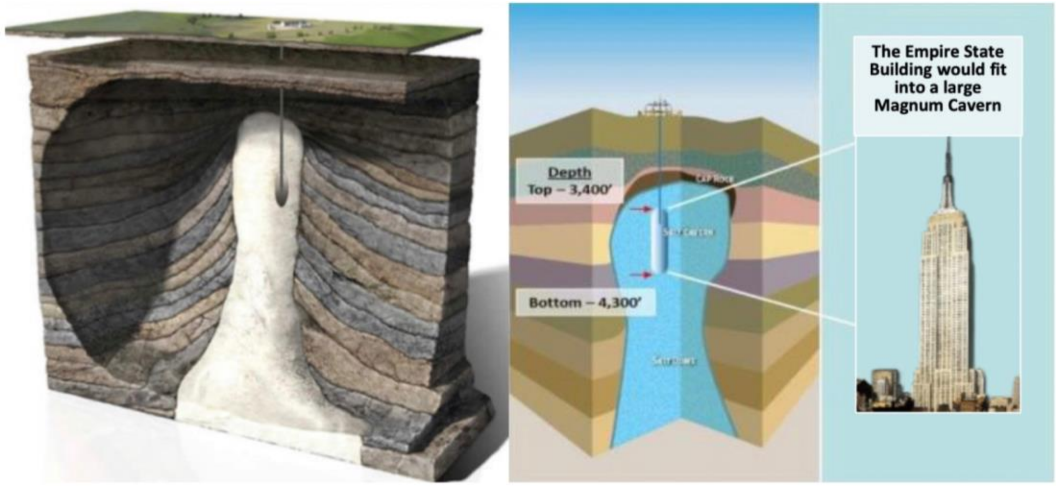
Manhattan Blackout, 7/13/19



> 99.999% available

Gas Technology Institute, Assessment of Natural Gas ... Service Reliability, 2018.

Massive Storage Facility Transformation



Plan for storing hydrogen in Utah salt caverns

Images: Los Angeles Department of Water and Power

<u>Salt Caverns already widely used and proven</u>

- Air Liquide & Praxair operating H2 salt cavern storage in Texas since 2016
  - Very low leakage rate
  - Massive energy storage
  - Safe & Low cost storage
- Similar success in Europe
- Magnum working with LADWP to adopt similar salt cavern H2 storage in Utah

<u>Current CA depleted oil and gas fields not yet used or proven for H_2 use</u>

- Several research and development needs
  - H2 leakage
  - H2 reaction with petroleum remnants
  - H2 biological interactions
  - H2 storage capacity
  - H2 safety

Low Fuel Utilisation Solid Oxide Fuel Cell System for CO_2-free Hydrogen Production in Oil Refineries

Luca Mastropasqua[*,a], Andrea Pegorin[b], … Campanari[b]

[a] Advanced Power and En… of California, Irvine, CA 9…

[b]Group of Energy Conversi… di Milano, Via Lambruschini 4…

e-mail: lm1@apep.uci.edu

*Corresponding author

Especially attractive in short-term w/ access to LCFS credits

Contents lists available at ScienceDirect

Journal of Power S…urces

journal homepage: www… …/jpowsour

ELSEVIER

Low fuel utilisation solid oxi… …e hydrogen production in oil refineri…

Luca Mastropasqua[a,*], A…

[a] Advanced Power and Energy P…

[b] Group of Energy Conversi… …an, Italy

H I G H…

…ies main processes.
…ctor are proposed.
…hydrogen generation is achieved.
…pared to conventional SMR technology.
…g^{-1} can be obtained without carbon tax.

…uel cell
…gen production
… refinery
Steam methane reforming
Carbon capture and storage

A B S T R A C T

Oil refining sector contributes for 4% of the overall anthropogenic CO_2 emissions and it is recognised as important industrial sector for the implementation of carbon capture and storage technologies. This work focu… on the investigation of oil refinery emission sources and the specific development of a multi-energy SOFC-ba… system for the combined production of hydrogen, electricity and process steam with carbon capture. The syst… is sized to satisfy the fraction of refinery hydrogen demand, i.e., 22,500 Nm^3 h^{-1} – conventionally covered… natural gas fired steam methane reformers. Four plant layouts are designed for this purpose featuring differ… levels of integration with the refinery process. The thermodynamic analysis shows the potentialities in terms… primary energy savings compared to separate production with conventional technologies. CO_2 emissions can… reduced by 85% compared to reference cases, reaching zero or negative overall emissions due to the expor… steam and electricity. A preliminary economic analysis is performed to establish the value of the levelised cos… hydrogen, to define its dependence on the carbon tax value and compare its value with difference hydrog… production technologies. This works shows the possibility of producing hydrogen at 3.3 € kg^{-1} in a current c… scenario.

Value of H_2: Zero Emissions Fuel

- **Provide zero emissions fuel to difficult end-uses**

Anything that requires: (1) long range, (2) fast fueling, (3) heavy payload

Why Hydrogen? Industry Requirements for Heat, Feedstock, …

- Many examples of applications that cannot be electrified

Steel Manufacturing & Processing

Cement Production

(Photo: ABB Cement)

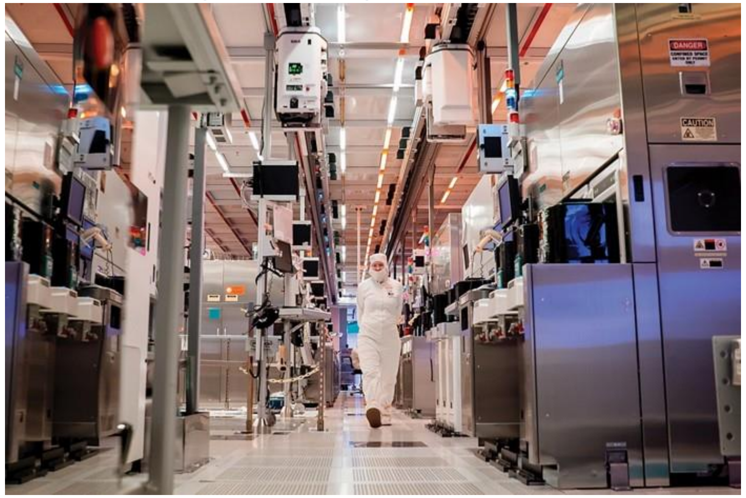
Plastics

(Photo: DowDuPont Inc.)

Ammonia & Fertilizer Production

(Photo: Galveston County Economic Development)

Computer Chip Fabrication



(Photo: American Chemical Society)

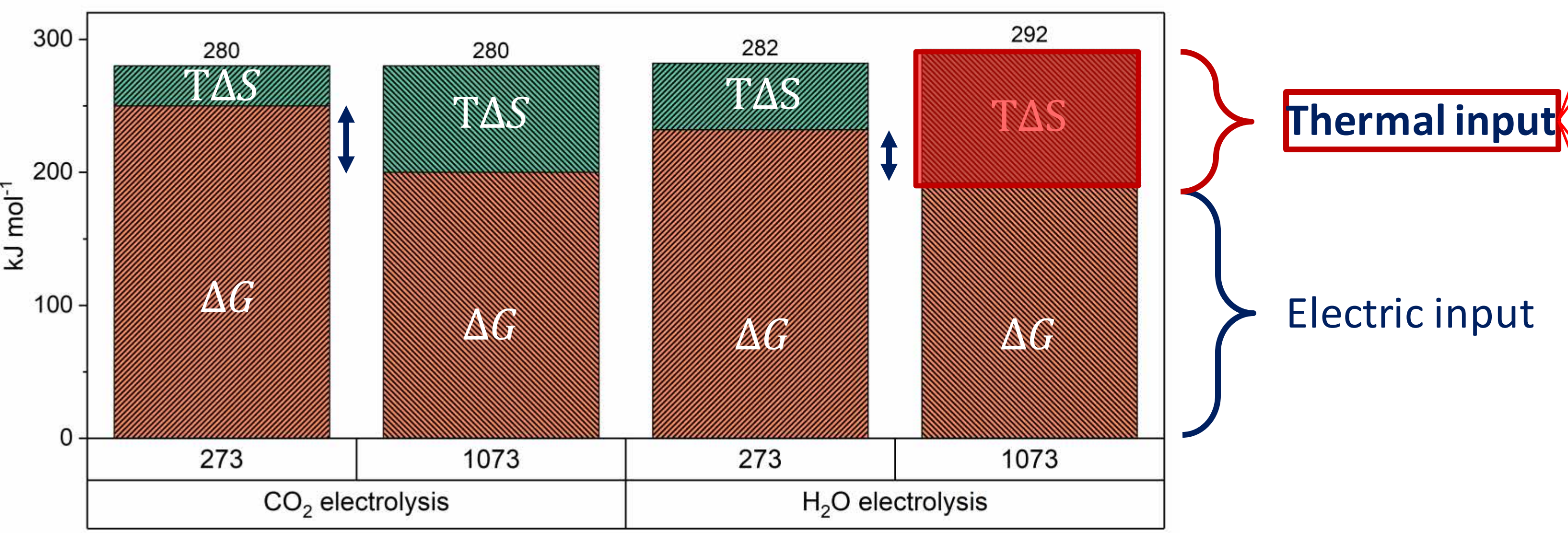
Pharmaceuticals

(Photo: Geosyntec Consultants)

Integration w/ Various Industrial Applications

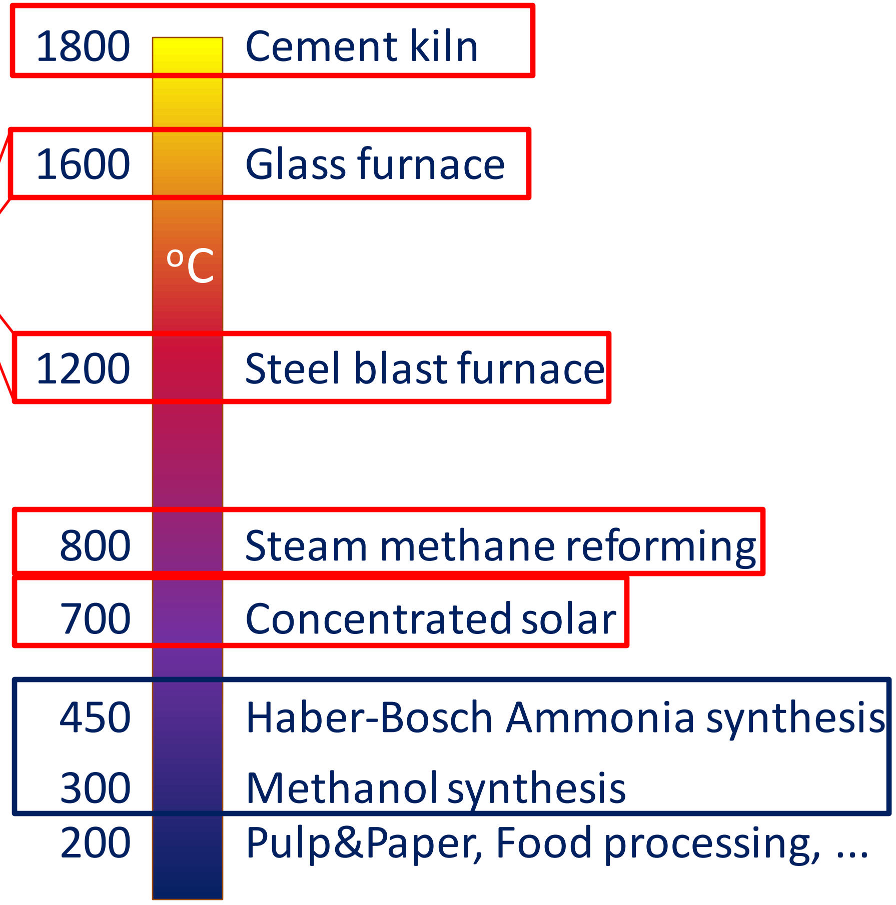
- **The hotter the better – solid oxide electrolysis ~ 1073K (800°C)**

$$\Delta G^{\circ} = -nFE^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ}$$



$$CO_2 \rightarrow CO + 0.5O_2 \qquad H_2O \rightarrow H_2 + 0.5O_2$$

$$\frac{\eta_{el}^{HOT}}{\eta_{el}^{COLD}} = 125\% \qquad \frac{\eta_{el}^{HOT}}{\eta_{el}^{COLD}} = 121\%$$



Panel 3: California End Use Applications of Green Hydrogen

- Moderator: Kevin Uy, CEC Energy Efficiency Research Office

A. Bill Zobel, California Hydrogen Business Coalition

B. Dr. Jack Brouwer, UC Irvine

Presentation: DOD Activities in Green Hydrogen Research

- Mike Gravely, Military Advisor to CEC Chair David Hochschild
- Ben Richardson, Portfolio Director, Advanced Energy & Materials, Defense Innovation Unit

PUBLIC INPUT SESSION

Stakeholder Comments on the Scope of the EPIC 4 Investment Plan

- 3 minutes per commenter, 1 commenter per organization
- Please clearly state your name and affiliation
- Use the raise hand function in Zoom and wait to be called upon to unmute
- Type questions/comments into the Q/A window

https://www.online-stopwatch.com/full-screen-stopwatch/

Next Steps

To stay involved in EPIC 4:

Visit **www.energy.ca.gov/epic4.**

Submitting Written Comments and EPIC 4 Plan Concepts:

Please use CEC's **e-commenting** system: https://efiling.energy.ca.gov/Ecomment/Ecomment.aspx?docketnumber=20-EPIC-01

See **notice** for **e-mail and U.S. Mail** commenting instructions: https://efiling.energy.ca.gov/getdocument.aspx?tn=238093

Workshop Comments are due July 15, 2021.

Thank You