DOCKETED	
Docket Number:	21-IEPR-05
Project Title:	Natural Gas Outlook and Assessments
TN #:	239050
Document Title:	Presentation - Introduction of EPIC Initiative - The Role of Green Hydrogen in a Decarbonized CA - A Roadmap and Strategic Plan
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Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	7/27/2021 8:48:49 PM
Docketed Date:	7/28/2021

California Energy Commission

Panel Moderator: Mike Petouhoff, Manager, Energy Systems Research Office, ERDD

Introduction of EPIC Initiative: The Role of Green Hydrogen in a Decarbonized CA- A Roadmap and Strategic Plan

Panel: National and International Applications

H2 Roadmap

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

- Staff Collaboration
- Prior CEC Research
- Information Sharing and Working Groups
  - Denmark
  - Germany
  - Finland
- In State Collaboration
- Workshops
  - EPIC- July 1
  - IEPR- July 28

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Green H2 Generation

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

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Distribution & Storage Technology

Technology Options

- Gaseous in Tanks
- Tube Trucks
- Pipelines
- Geologic Storage

Other Forms of H2

- Liquid H2
- Ammonia NH3
- Green CH4

- Eco System Examples
  - Land Base PV-H2
  - Offshore Wind - H2

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Some Priority End Uses

- Electric generation and storage
  - Firm Dispatchable Decarbonized 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
- Follow on 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.

Key Driver: H2 for Grid Reliablity

- SB100 Scenarios show up to 15 GW of Firm Dispatchable Generation May be needed (p13) – Trade offs with Long Duration Storage

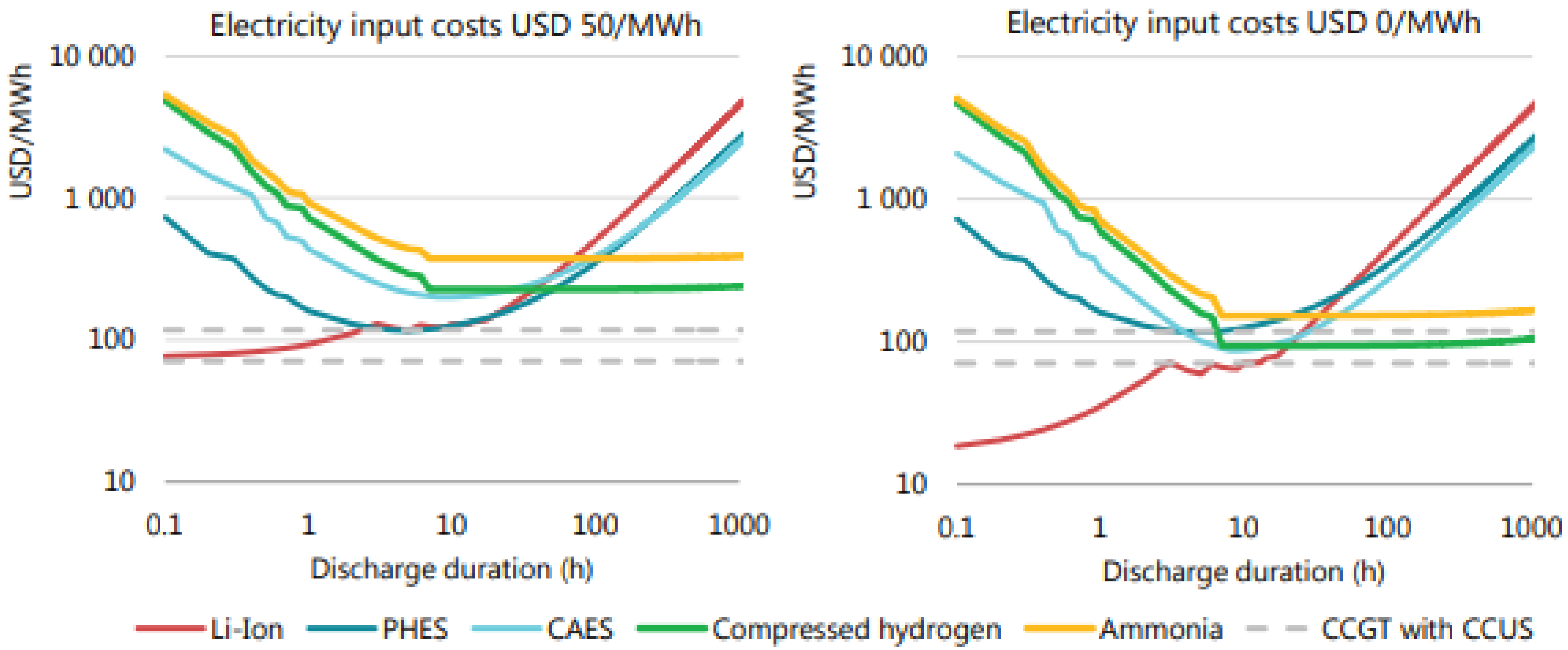
- Modelling included SB100 “Core” option and “Study” (no combustion) options- w incremental cost of “no combustion” option of $8Billion/Year

- H2 Generation may have less land use impacts than other sources

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 and Pumped Hydro

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.

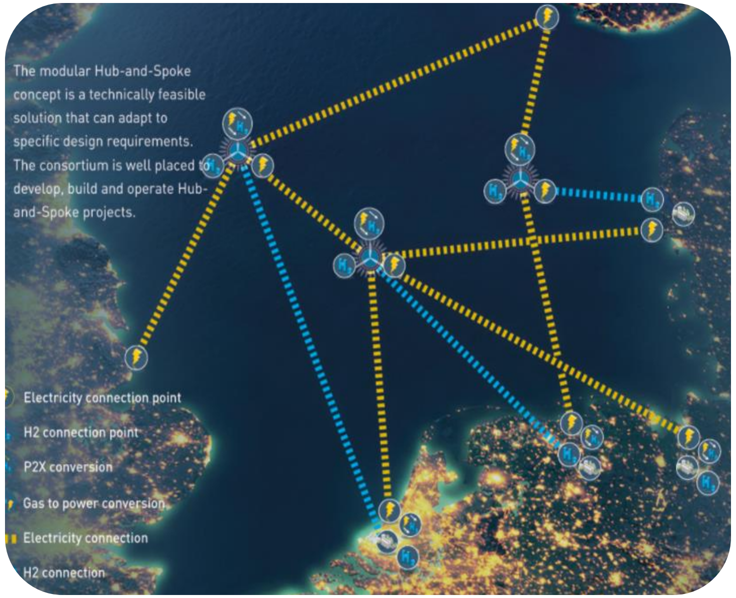
Source: IEA 2019.

Compare H2 cost and performance to other forms of LDS as they both evolve

Green H2 Ecosystem examples

CA Land Based PV + H2

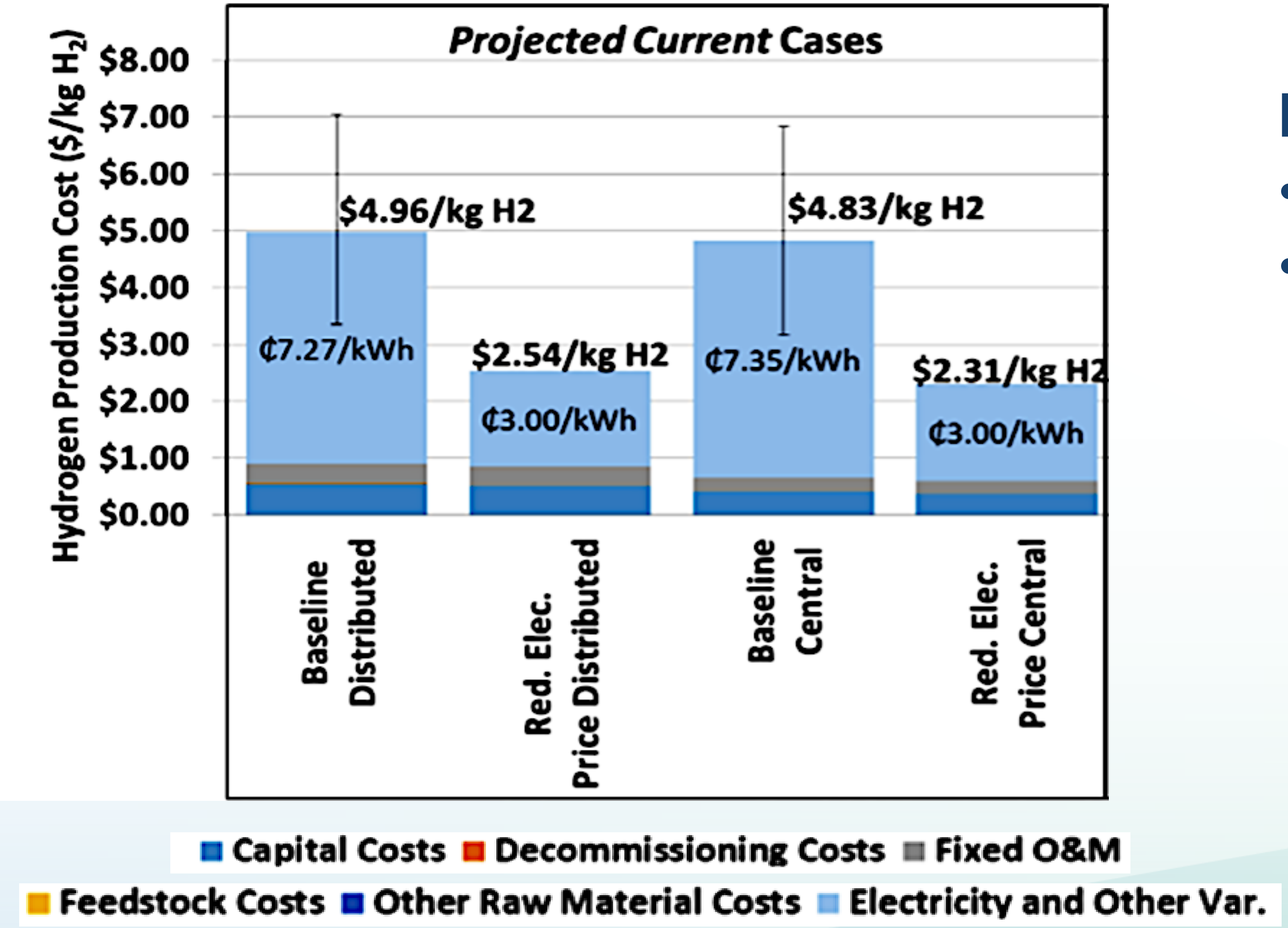
CA Land Offshore Wind + H2



Example: North Sea Wind + H2

Clean Electricity input costs dominate the economics for electrolysis

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



Relevant to

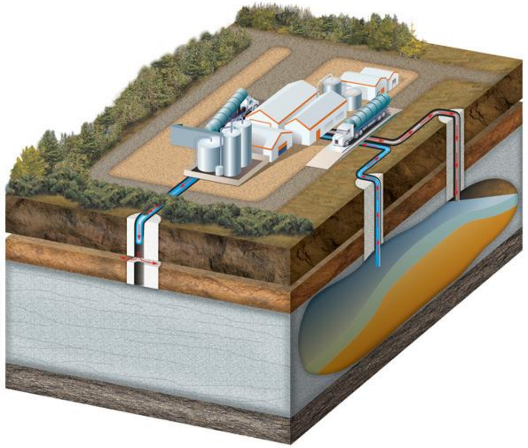
- **Curtailed Clean PV or Wind**
- **Optimizing Purpose Built PV or Wind**

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

End Use Main Points

For Grid Scale H_2 Power Solutions-

- H2 Turbines generally more cost effective than H2 Fuel Cell
- Local Criteria Pollutants (NOx) are an issue for turbines

H_2 in Natural Gas Pipelines

- **H_2** is limited in natural gas pipelines to blending of 20% by volume or 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 fossil sourced natural gas, but its decarbonized

H_2 Behaves differently than Fossil Sourced CH4 in end use appliances

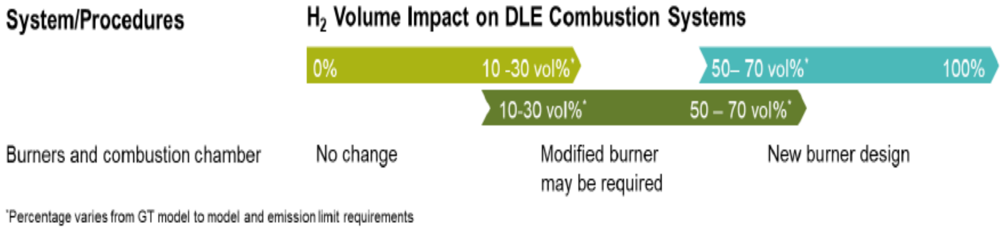


Figure 7: Hydrogen fuel volume impacts on DLE combustion systems

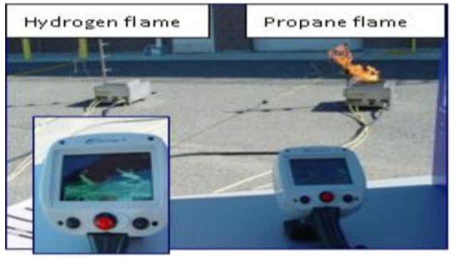


Figure 5 - Hydrogen and Propane Flames in Daylight (Photo courtesy of HAMMER)

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

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

Electrolyzers (3 x 2 MW) Methanation Unit

Green CH4 can be both a by clean product of Green H2, and also a competing decarbonized fuel from Biogas

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

Evaluation of Green H2 End Uses & Alternatives

The H2 Roadmap 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 Duration Energy Storage	1. Can use existing Generation and pipeline 2. Compare Costs to Long Duration Energy Storage
Transportation Uses *(contextualize with BEVs)*	Fuel cell vehicles (*As FCV and BEVs evolve*)	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

Accelerating Hydrogen Research in ERDD

Investment Area	$19M invested
Generation and storage	• Wind to H2 storage for load shifting • 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 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

Panels

And now for our panelists!