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

<table>
<thead>
<tr>
<th>Task / Event</th>
<th>Date(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public workshops to solicit stakeholder input on specific topic gaps</td>
<td>May – July 2021</td>
</tr>
<tr>
<td>Public workshop to get input and feedback on the CEC’s draft research initiatives being considered for the EPIC 4 Investment Plan</td>
<td>August 4, 2021</td>
</tr>
<tr>
<td>EPIC 4 Investment Plan considered at CEC Business Meeting for approval</td>
<td>September 2021 (tentative)</td>
</tr>
<tr>
<td>EPIC 4 Investment Plan submitted to CPUC</td>
<td>October 1, 2021 (tentative)</td>
</tr>
<tr>
<td>CPUC Decision on EPIC 4 Plan expected</td>
<td>Spring-2022 (tentative)</td>
</tr>
<tr>
<td>The first EPIC 4 solicitations released</td>
<td>Summer-Fall 2022</td>
</tr>
<tr>
<td>Workshop Title and Description</td>
<td>Date</td>
</tr>
<tr>
<td>---------------------------------------------------------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>Hydrogen Roadmap</td>
<td>Thursday, July 1, 2021 1:00 p.m.</td>
</tr>
<tr>
<td>Offshore Wind Energy R&amp;D Opportunities for EPIC 4</td>
<td>Wednesday, July 14, 2021 1:00 p.m.</td>
</tr>
<tr>
<td>Industrial Decarbonization</td>
<td>Friday, July 16, 2021 9:30 a.m.</td>
</tr>
<tr>
<td>Technology Advancements for Energy Storage</td>
<td>Tuesday, July 20, 2021 9:30 a.m.</td>
</tr>
<tr>
<td>Improving the Bankability of New Clean Energy Technologies</td>
<td>Thursday, July 22, 2021 10:00 a.m.</td>
</tr>
<tr>
<td>Draft Initiatives for EPIC 4</td>
<td>Wednesday, August 4, 2021 9:00 a.m.</td>
</tr>
</tbody>
</table>
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.
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
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
- Staff Collaboration
- Prior CEC research
- Information Sharing and Workshops
  - Expert Panels
  - EPIC- July 1
  - IEPR- July 28
  - Working Groups
    - Germany
    - Denmark

Green H2 Generation

Distribution & Storage Technology

Priority End Uses
H2 Roadmap

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

Distribution & Storage Technology
- Emerging Tech
  - Salt water
  - Non-water Electrolytes

Priority End Uses
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  - Non-water Electrolytes

Distribution & Storage Technology
- Current
  - Gaseous in Tanks
  - Pipelines
  - Geologic Storage
  - Liquid H2
  - Ammonia
  - Green CH4

Priority End Uses
- Eco System Examples
  - Land Base PV-H2
  - Offshore Wind - H2
H2 Roadmap

Data Gathering
- Staff Collaboration
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  - Pipelines
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  - 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 ($\text{H}_2$) is classified by color into three types according to the feedstock used and method of $\text{H}_2$ production: gray, blue, and green.

- **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** 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** 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.
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 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
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. All rights reserved.
Green H2 Ecosystem examples

CA Land Based PV + H2

CA Land Offshore Wind + H2

Example: North Sea Wind + H2
H₂ Supply Chain Map (2/2)

**Distribution**
- Pipelines
- Trucks
- Rail

**Applications**
- Electric Power
  - Gas-to-power
- Transportation
  - FC Cars, Buses, Trucks, etc.
- Syngas-based Synthesis
  - Fisher-Tropsch,
    Methanol Synthesis, etc.
- Mechanical Power
  - Engines for to Drive Pumps,
    Compressors, etc.
- H₂ as Feedstock
  - Hydrogenation,
    Ammonia Production, etc.

**Storage or Pipelines**

**Co-located H₂ Generation**

Chemical Products
- Synthetic Kerosene,
  Methanol, etc.
Electricity input costs dominate the economics for electrolysis

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

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 H₂
- The two bars on the right are for centrally produced H₂

Relevant to
- Curtailed Clean PV or Wind
- Optimizing Purpose Built PV or Wind
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 H₂ 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 H₂ tanks** will continue to be the most visible form of H₂ storage, including for onsite systems generating H₂ and users in remote locations.
- **Pipelines**, Pure H₂ or blending into NG pipelines, provide efficient movement of gaseous H₂ 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 H₂ in the long term.
- **Liquid H₂ (LH₂)** 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 H₂.
- **Methanol**, another chemical with existing industrial application, is considered a representative of a group called Liquid Organic H₂ Carriers (LOHCs) that can be stored at ambient temperatures.
End Use Pain Points (1/2)

Cost of H₂ 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 H₂-capable turbines available commercially from major manufacturers may carry a price premium relative to incumbent systems designed for NG.
- Initial H₂-capable reciprocating engines available commercially from major manufacturers may carry modest (<10%) price premiums relative to incumbent NG or diesel systems.

H₂ in Natural Gas Pipelines

- H₂ is limited in natural gas pipelines to blending of 20% by volume and 7% by weight due to metallurgical embrittlement and related issues.
- H₂ 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\textsubscript{x} management via Dry Low Emissions (DLE) is a major area of R&D by NG turbine manufacturers, having H\textsubscript{2} blending impacts. (See graphic below)

### System/Procedures

<table>
<thead>
<tr>
<th>H\textsubscript{2} Volume Impact on DLE Combustion Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
</tr>
</tbody>
</table>

- Burners and combustion chamber
- No change
- Modified burner may be required
- New burner design

*Percentage varies from GT model to model and emission limit requirements*

Figure 7: Hydrogen fuel volume impacts on DLE combustion systems

# Accelerating Hydrogen Research in ERDD

<table>
<thead>
<tr>
<th>Investment Area</th>
<th>$19M invested</th>
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<tbody>
<tr>
<td><strong>Generation and storage</strong></td>
<td></td>
</tr>
<tr>
<td>• Wind to H2 storage for load shifting when prices are high</td>
<td></td>
</tr>
<tr>
<td>• Solar to H2 for 100-hour storage in metal hydrides</td>
<td></td>
</tr>
<tr>
<td>• Lowering the energy and cost of electrolysis with advanced non water electrolytes</td>
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<tr>
<td><strong>Mobile H2 for PSPS</strong></td>
<td></td>
</tr>
<tr>
<td>• Mobile H2 production and energy storage, emergency power &amp; PSPS resiliency</td>
<td></td>
</tr>
<tr>
<td><strong>Transportation</strong></td>
<td></td>
</tr>
<tr>
<td>• Fuel Cell Railway switcher locomotive</td>
<td></td>
</tr>
<tr>
<td>• Fuel Cell Tugboat</td>
<td></td>
</tr>
<tr>
<td>• Fuel Cell Harbor craft and mobile refueling system</td>
<td></td>
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</table>
# Upcoming Research for ERDD

<table>
<thead>
<tr>
<th>Investment Area</th>
<th>Details</th>
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<tbody>
<tr>
<td>Generation</td>
<td>• Cost Reduction and Efficiency Improvement for Renewable H2 Production&lt;br&gt;• Developing and Demonstrating H2 Power Generation Systems</td>
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<tr>
<td>Delivery &amp; Storage</td>
<td>• Green Hydrogen, A Roadmap and Strategic Plan for a Decarbonized CA&lt;br&gt;• Hydrogen Roadmap for the Natural Gas System&lt;br&gt;• Hydrogen Blending Validation</td>
</tr>
<tr>
<td>Transportation</td>
<td>• H2 Fuel Cell Truck and Bus Tech, Integration and Demonstration&lt;br&gt;• Advanced Hydrogen Refueling Infrastructure Solutions for Heavy Transport</td>
</tr>
<tr>
<td>Buildings and Industrial</td>
<td>• Effects of Hydrogen in end use Appliances for Large Commercial Buildings and Industrial Applications&lt;br&gt;• Likely Industrial Candidates for Hydrogen Adoption</td>
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## Fuels and Transportation Investments

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<td>Fueling Infrastructure</td>
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<tr>
<td>Hydrogen Production</td>
<td>$7.9M</td>
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<tr>
<td>Fuel Standards and Equipment Certification</td>
<td>$3.9M</td>
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<tr>
<td>Light-Duty ZEV Deployment (CVRP support)</td>
<td>$0.7M</td>
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<tr>
<td>Medium- &amp; Heavy- Duty Advanced Vehicle Technology Demonstration</td>
<td>$11.9M</td>
</tr>
<tr>
<td>Regional Alternative Fuel Readiness and Planning</td>
<td>$0.8 M</td>
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</table>
"Detailed Technical Analysis needs to be completed 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 Roadmap and Strategic Plan"
The project statement requires that we consider alternatives to H2 for each end use.

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

- 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 electrolysers?
- What is the ideal size pairing 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
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

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

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

Data Source: CAISO, Compiled April 2021

Data Source: Armonk Cohen Testimony

Information Source: Mitsubishi Power Americas
Green hydrogen is commercially viable now and on trajectory for lowest cost

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

<table>
<thead>
<tr>
<th>Explanation</th>
<th>Variable</th>
<th>Units</th>
<th>2028</th>
<th>2035</th>
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<tbody>
<tr>
<td>Hydrogen Cost Assumptions</td>
<td>Delivered GH2 Commodity Cost(^a)</td>
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<td>$1.50</td>
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<td></td>
<td>Green Hydrogen Levelized Cost, (a)</td>
<td>$/MWh</td>
<td><strong>$116</strong></td>
<td><strong>$87</strong></td>
<td><strong>$58</strong></td>
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<td>IPP Plant at 100% Green Hydrogen</td>
<td>% Hydrogen Plant Consumption</td>
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<td>Power Plant Capacity Factor(^d)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Blended GreenH(_2) + PPA cost to achieve 24x7 100% renewable electricity</td>
<td>25%(a+b+c) + 75%(d)</td>
<td>$/MWh</td>
<td><strong>$42</strong></td>
<td><strong>$35</strong></td>
<td><strong>$28</strong></td>
</tr>
</tbody>
</table>

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 transportation, 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 can repurpose existing infrastructure & jobs

Enabling an affordable & responsible transition

Source: DNV GL

Source: LADWP
What’s the barrier to our green hydrogen economy?

Infrastructure and Economies of Scale

Cost of Green Hydrogen
HyDeal Los Angeles

Architecting the Green Hydrogen Ecosystem For a Deeply Decarbonized LA
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
- LAWQ Power Plants
- Wind Resource
- Solar Resource
- Urban Areas of LA and LA County
- Oil Refineries
- Cement Plants
- Airport
  - Backup Generators
  - Hydrogen Fuel Stations
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
### 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
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)

Hydrogen Demand

Production Costs ($/kg) vs Capacity Factor for Various Sized Facilities (metric tonnes/day)

Production Facility Capacity Factor

- 10 TPD
- 50 TPD
- >50 TPD
- >>50 TPD
- >>>50 TPD

Hydrogen Demand

- 5 TPD
- 75 TPD
- 600 TPD

Power Plant
- 30% H2 Demand
- 100% H2 Demand

Transportation Only
High Utilization Rates
Smaller Facility

Power Industry Only
Low Utilization Rates
Large Facility

Transportation + Power Industry
High Utilization Rates
Larger Facility

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

**Salt Cavern**
- On cavern can hold as much hydrogen as 50 Saturn V rockets (not to scale)
- Empire State Building shown for scale
- Diameter: 150' to 300'
- Salt done
- Height: 1,000 to 1,500

**Per 1 Cavern Stats**
- >100,000 MWh
- 5,500 tonnes $H_2$
- 10 days to 1 month

**Hydrogen Pipeline Pack**
- Assumptions:
  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

**Pressurized Vessels**

**Per 10-mile Stats**
- >1,000 MWh
- 45 tonnes $H_2$
- 2 hours to 16 hours

**Per 10-Bullet Stats**
- >200 MWh
- 10 tonnes $H_2$
- 0.5 hours to 4 hours
WECC Analysis – Power Systems With and Without Hydrogen Storage

➢ 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

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Low NO₂ tech</th>
<th>Status</th>
<th>H₂ density (volume %)</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1: Diffusion</td>
<td>N₂ dilution, Water / Steam injection</td>
<td>Available</td>
<td>0 - 100%</td>
<td>1970 Cogen/IGCC Operation</td>
</tr>
<tr>
<td>Type 2: Pre-Mix (DLN)</td>
<td>Dry</td>
<td>Available</td>
<td>0 - 30%</td>
<td>1982 DLN Operation</td>
</tr>
<tr>
<td>Type 3: Multi-Cluster (DLN)</td>
<td>Dry</td>
<td>Final Development and Validation</td>
<td>0 - 100%</td>
<td>2017 IGCC Operation 2025 Validation Complete</td>
</tr>
</tbody>
</table>

*DLN: Dry Low NOₓ*
NOx In Focus

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
- CO₂, 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

- Coal Fired Power Plant (900 MW): 16.0 MMGD
- Gas Turbine Combined Cycle (1,000 MW): 5.1 MMGD
- Desert Golf Course: 1.5 MMGD
- Water Requirements for Agriculture (One [1] Center Pivot): 1.0 MMGD
- Green Hydrogen for 30%-H2 GTCC (1,000 MW): 0.1 MMGD
- Green Hydrogen for 100%-H2 GTCC (1,000 MW): 1.1 MMGD
- 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 electrolysis is an old, well proven technology (> 100 years)

The electrolyzer technology has never been industrialized and scaled
Maturing the electrolyzer technology

**Market drivers**

- Price of renewable power
- Decarbonization

**HydrogenPro response and focus**

- Improved efficiency – HydrogenPro targeting 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**

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 electrolysers consume 4.4 MW to produce 90 kg H₂/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 electrolyzer for the US market

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

Further innovation and improvement
Summary features of the high pressure alkaline electrolyzer technology

- Ideal for large scale applications
- High efficiency
- Less cooling water
- No noble metals
- No use of polyfluorinated 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).
Long-Duration Storage and Roles for Hydrogen

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

July 1, 2021
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.
Our CESA Members
• 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?

- **Existing**: 77 GW
- **2030**: 100 GW
- **2045**: 44.4 GW
- **2045 Retirements**: 50 GW
- **Total**: 47.9 GW

- **Other**
- **Renewable**
- **Non-storage**
- **Clean**
- **Wind**
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 response.

Max solar output is 30% of 208 GW installed capacity; any excess solar charges SDES.

SDES output declines significantly over the week.
Worst weather drains seasonal storage reserves

Worst weather week almost fully drains 100 hr. storage reserves

Solar irradiance windows
DES Will be Necessary Every Month of the Year
Long-duration storage deployments accelerate significantly

- Total storage needed under CESA’s analysis
- Storage procured to date (deployed, planned, and contracted)

- 12 MMT carbon target
- 38 MMT carbon target
| **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 |
THANK YOU

Please contact us at: info@storagealliance.org | www.storagealliance.org
WHY H₂ FROM ORGANIC WASTE?

- Climate Change
- Air quality
- Landfill reduction
- Wildfire reduction
- Local energy supplies
- Community resilience
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 CO₂
SLCPs Reductions can bend the warming curve:

- 0.6°C by 2050
- 1.2°C by 2100
CO₂ accounts for ~half of today’s warming
---
SLCPs other half!
Black Carbon Sources in CA

- Wildfire: 66%
- Off-Road Vehicles: 6%
- On-Road Vehicles: 5%
- Industrial Fuel Consumption: 3%
- Fireplaces: 6%
- Prescribed Burning: 1%
- Miscellaneous: 2%
- Ag. Burning: 1%

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

California's Top 5 Methane Sources

1. Livestock Waste: 9
2. Landfill Waste Disposal: 7
3. Leaks / Evap / Venting: 4
4. Wastewater: 1
5. Enteric Fermentation: 0

CH4 is 75x more damaging to climate than CO2
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 CO₂ Storage: 83 MT/year
- Direct Air Capture with CO₂ 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 H₂, 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
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 with 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

Legend:
- Retail market
- Wholesale market
- Solar PV
- Electrolyzer
- Hydrogen production

Source: NREL
Contact: Peter Chen
peter.chen@energy.ca.gov

Thank you!
Clean Transportation Program

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
H2 Retail Station Development

Hydrogen Refueling Station Quantity

- Open Retail with Public Co-Funding: 50 stations
- Open Retail with Private Funding: 106 stations
- Planned with Public Co-Funding: 21 stations

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)
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)
• **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\textsubscript{2} or H\textsubscript{2})
  - Experimentally tested 4 appliances and applied simulation methodologies to 9

• **Key Findings:**
  - For these un-modified appliances, when H\textsubscript{2} concentration increases above 10% by volume, probability of combustion instability increases (e.g. flashback)
  - At 10% H\textsubscript{2} level, NO\textsubscript{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
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
Hydrogen for Industry and Agriculture

• Begin overall industrial decarbonization by transforming gas system
  o Support renewable electricity generation investment

• Begin transformation of massive storage facilities
  o Enable resilient 100% renewable electric grid & industry

• Integrate production and use of renewable hydrogen in various end uses
  o Heavy duty transport
  o Cement
  o Steel production & recycling
    o Ammonia – main agriculture connection
    o Food processing with combined heat & power
  o Refining
  o Plastics
  o Pharmaceuticals
  o Computer chip fabrication
  o ...

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Gas System – MASSIVE Resource for Zero Emissions

- First mix up to X% – ADD grid renewables & transportation electrification
- Then piecewise conversion to pure hydrogen

650 GWh if stored at 5% H2 in natural gas
$130 billion battery (DOE future cost)

© National Fuel Cell Research Center, 2020
Gas System – MASSIVE Resource for Zero Emissions

- 40% of all electric demand – 20 sq. miles of solar, only gas system used for H₂ storage AND all T&D

20 x 20 miles solar, H₂ in gas system from ~40% to ~80% zero!

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**
  - 23 Doosan Units
  - Bloom Installation at Brookside, DE
- **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**
- **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

Salt Caverns already widely used and proven
- 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

Current CA depleted oil and gas fields not yet used or proven for H2 use
- 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 Pegorinb, Stefano Campanari

*a Advanced Power and Energy Program, University of California, Irvine, CA 92697, USA
bGroup of Energy Conversion Systems, Politecnico di Milano, Via Lambruschini, e-mail: lm1@apep.uci.edu
*Corresponding author

Abstract

Oil refining sector contributes for 4% of the overall anthropogenic CO$_2$ emissions and it is recognised as an important industrial sector for the implementation of carbon capture and storage technologies. This work focuses on the investigation of oil refinery emission sources and the specific development of a multi-energy SOFC based system for the combined production of hydrogen, electricity and process steam with carbon capture. The system is sized to satisfy the fraction of refinery hydrogen demand, i.e., 22,500 Nm$^3$ h$^{-1}$ – conventionally covered by natural gas fired steam methane reformers. Four plant layouts are designed for this purpose featuring different levels of integration with the refinery process. The thermodynamic analysis shows the potentialities in terms of primary energy savings compared to separate production with conventional technologies. CO$_2$ emissions can be reduced by 85% compared to reference cases, reaching zero or negative overall emissions due to the export of steam and electricity. A preliminary economic analysis is performed to establish the value of the levelised cost of hydrogen, to define its dependence on the carbon tax value and compare its value with difference hydrogen production technologies. This work shows the possibility of producing hydrogen at 3.3 € kg$^{-1}$ in a current scenario.
Value of H₂: 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
- Plastics
- Ammonia & Fertilizer Production
- Computer Chip Fabrication
- Pharmaceuticals

(Images: Galveston County Economic Development, ABB Cement, DowDuPont Inc., Geosyntec Consultants, American Chemical Society)
Integration w/ Various Industrial Applications

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

\[ \Delta G^\circ = -nF E^\circ = \Delta H^\circ - T\Delta S^\circ \]

\[
\begin{array}{c|c|c|c|c}
\text{kJ mol}^{-1} & \text{273} & \text{1073} & \text{273} & \text{1073} \\
\hline
\Delta G & \text{280} & \text{280} & \text{282} & \text{282} \\
\Delta S & \text{1200} & \text{1200} & \text{1200} & \text{1200} \\
\end{array}
\]

\[
\begin{array}{c|c|c|c|c}
\text{CO}_2 \rightarrow \text{CO} + 0.5\text{O}_2 & \text{H}_2\text{O} \rightarrow \text{H}_2 + 0.5\text{O}_2 \\
\eta_{el}^{\text{HOT}} & \eta_{el}^{\text{COLD}} = 125% & \eta_{el}^{\text{HOT}} & \eta_{el}^{\text{COLD}} = 121% \\
\end{array}
\]

- 1800°C Cement kiln
- 1600°C Glass furnace
- 1200°C Steel blast furnace
- 800°C Steam methane reforming
- 700°C Concentrated solar
- 450°C Haber-Bosch Ammonia synthesis
- 300°C Methanol synthesis
- 200°C Pulp&Paper, Food processing, ...

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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
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:

Submitting Written Comments and EPIC 4 Plan Concepts:
Please use CEC’s e-commenting system:

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