valley vision
Community Inspired Solutions

Zero-Emission Hydrogen Locomotive Webinar

December 16th, 2022 - 9 AM - 10 AM PST

Webinar Logistics

Due to the large number of attendees, all participants will be muted for the duration of the webinar.

This webinar will be recorded and the recording will be on Valley Vision's website next week.

Use the Q/A function to ask a question at any time. If we don't have time for all questions, they will be addressed in the follow up email.

Agenda

1. Welcome & Webinar Logistics
2. Introduce Project and Project Team
3. History of Locomotives & Sierra Northern Railway's Local Operations
4. Hydrogen safety & technology
5. Operations, Life Cycle, & Data
6. Public Health Impacts & Improvements
7. Audience Q/A

GTI ENERGY

solutions that transform

GTI Energy – Sierra Northern H2 Locomotive

Bart Sowa
R&D Manager, Mobility
bsowa@gti.energy

December 2022

Need and funding background

- H2RAM Solicitation (Hydrogen in Rail and Marine Applications at Ports) issued by California Energy Commission (CEC)
- 4 projects awarded in 2021
- Funded by CEC Gas R&D Program (gas ratepayers)
- Developing science or technology, the benefits of which accrues to California citizens and are not adequately addressed by competitive or regulated entities
- Other co-funders
- Target hard to decarbonize applications, improve air quality

SoCalGas™

SACRAMENTO METROPOLITAN AIR QUALITY MANAGEMENT DISTRICT

Project Overview

- $4M CEC funding, $6M total project cost
- Awarded in 2021, completion in 2025
- 8 experienced project partners
- Start of testing and operation next year

We develop, scale and deploy solutions in the transition to low-carbon, low-cost energy systems

GTI ENERGY

SOURCE | MAKE | MOVE | STORE | USE

CLEAN – SAFE - AFFORDABLE

500 Enterprise Employees

TOP WORK PLACES 2019 Chicago Tribune

TOP WORK PLACES 2020 Chicago Tribune

TOP WORK PLACES 2021 Chicago Tribune

TOP WORK PLACES 2022 Chicago Tribune

We work collaboratively to address critical energy challenges impacting gases, liquids, efficiency and infrastructure

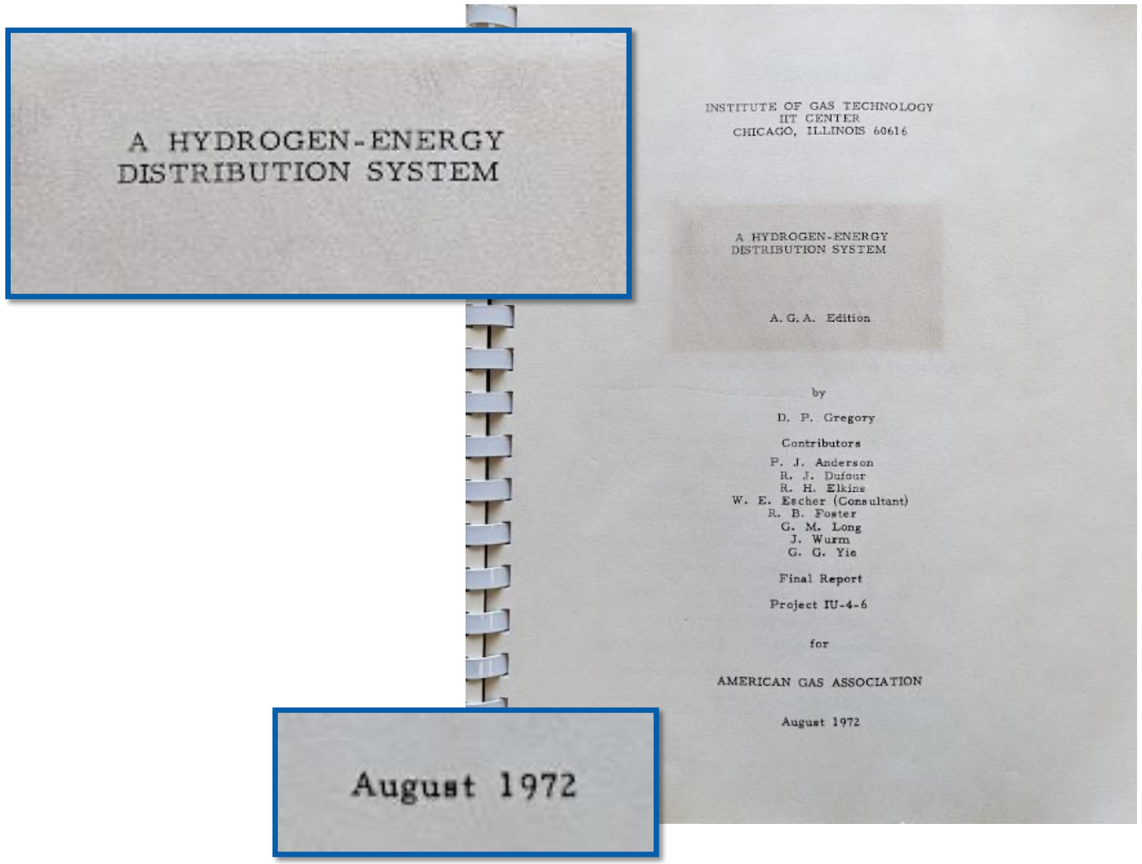
OTD Operations Technology Development

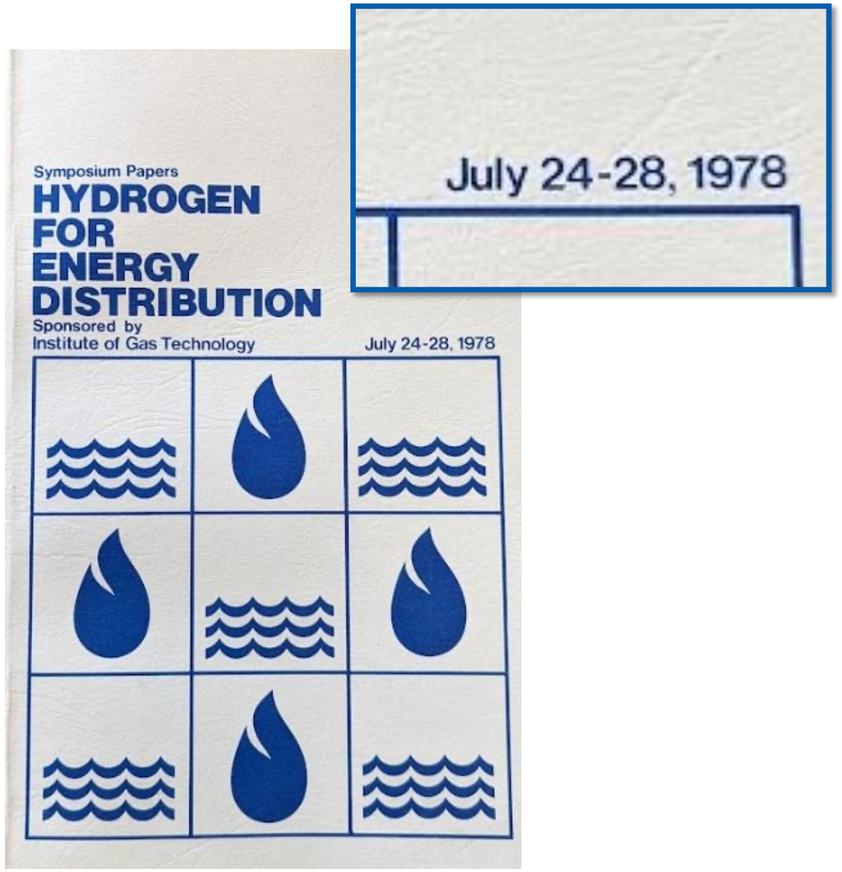
UTD Utilization Technology Development

ETP Emerging Technology Program

LCRI LOW-CARBON RESOURCES INITIATIVE

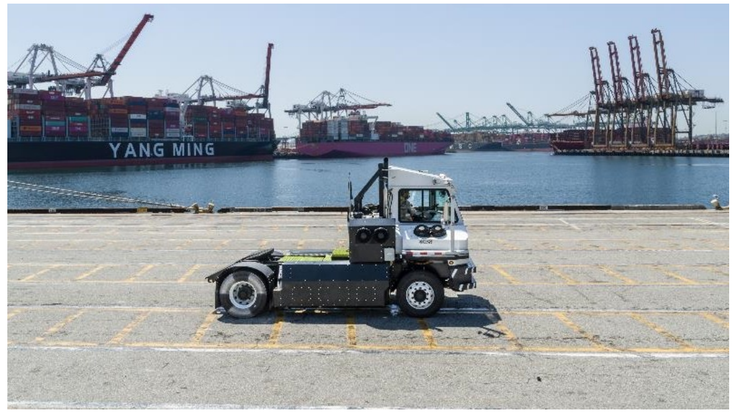
Hydrogen as energy carrier is not a new idea





Hydrogen in mobility : hands-on

- Endurance
- Weight
- Non-wires
- Refueling time



GTI ENERGY

solutions that transform

GTI Energy develops innovative solutions that transform lives, economies, and the environment

Hydrogen Switching Locomotive Project

GTI ENERGY
solutions that transform

The path forward to the future of zero-emission switching locomotives.

Zero Emission Hydrogen Locomotive Webinar

December 2022

What is a Switcher Locomotive?

Definition of Class I, II & III Railroads

Railroads are classified based on their annual operating revenues.

- Class I - $447+/- Million or more.
- Class II - Less than $447+/- Million to $35+/- Million
- Class III - Less than $35+/- Million

Class I Freight Railroads In California

- BNSF
- Union Pacific Railroad Company

Class II Railroads

- These railroads are also known as a “regional railroads.”

Class III Railroads

- These railroads are also known as a “short line railroads.”
- In California there are 24+/- Class III Railroads including SERA

- 73 feet long
- 15 feet high
- Weighs 480,000 pounds +/-
- Holds 5,000 gallons of diesel fuel

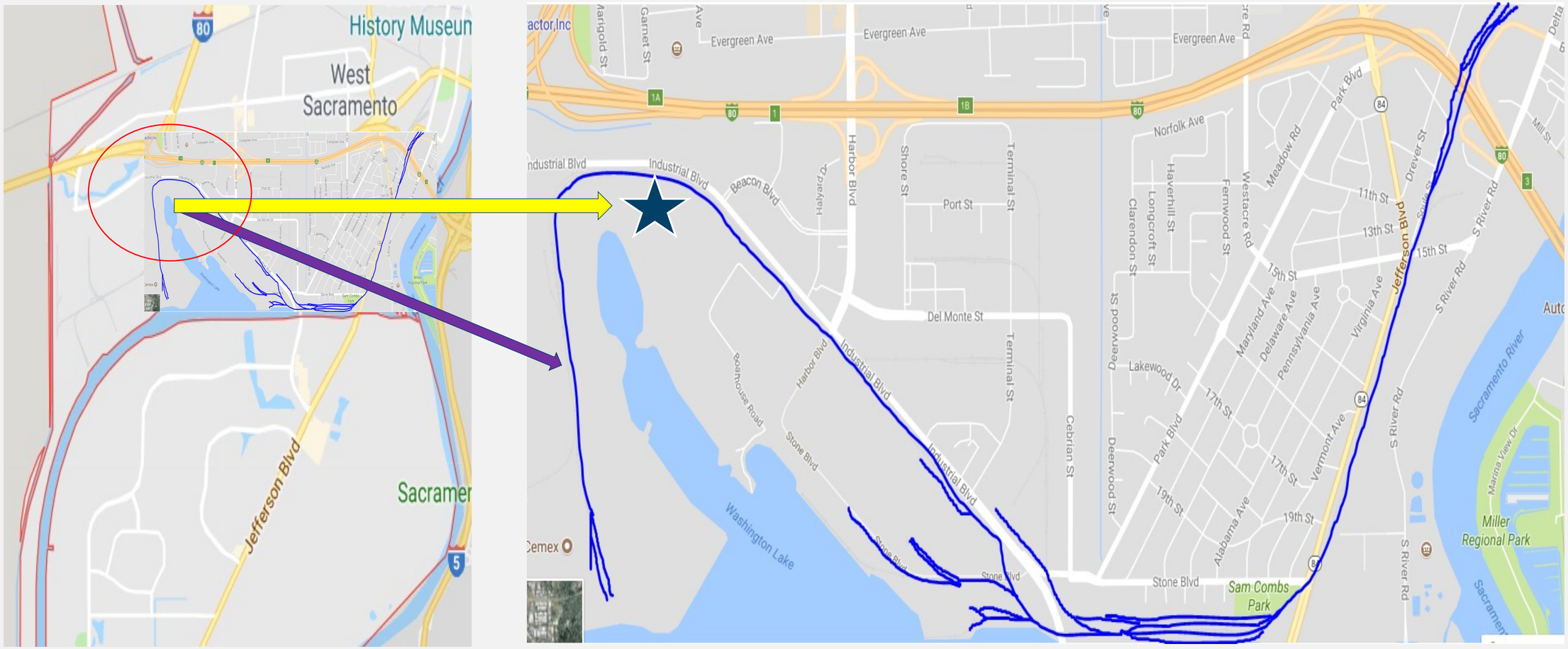
- 62 feet long
- 15.5 feet high
- Weighs 275,000 pounds +/-
- Holds 0 gallons of diesel fuel

SERA Local Operations

- Short line operations in California since 1897.
- First miles/last miles for clients connected to national freight network - BNSF and the Union Pacific Railroad (UP).
- Sierra Northern Railway (SNR) operates and owns 41 switcher locomotives.
- Sierra Northern Railway was formed in August 2003 through the merger of two Northern California shortline railroads: the Sierra Railroad Company and the Yolo Shortline Railroad.
- Sierra Northern currently operates Sierra Northern Railway (SNR) operates 160+ miles of track in California, through the heart of a number of California's prime industrial areas, serving a wide variety of customers, and interchanging with both the Burlington Northern Santa Fe Railway and the Union Pacific Railroad. Sierra Northern's employees strive to help its customers with all their railroad transportation needs.
- Sierra Northern Railway's alpha code (reporting mark) is SERA.

SERA West Sacramento Operations

Sierra Northern Railway serves rail customers in the City and Port of West Sacramento.
Sierra is building and will test the zero-emission switching locomotive in it's Railyard in the Port of West Sacramento and on the rail lines it operates on



Sierra Northern Railway Hydrogen Switching Locomotive Project

The path forward to the future of zero-emission switching locomotives.

Ken Beard
CEO and President
kbeard@sierrarailroad.com

Michael Faust
Sierra Northern Railway Project Consultant &
President, Velocity Strategies
mfaust@mefcllc.com

DECEMBER 2022

HYDROGEN FUEL CELL PARTNERSHIP

1/12/23

Hydrogen basics and safety

Zero-Emission Hydrogen Locomotive Webinar

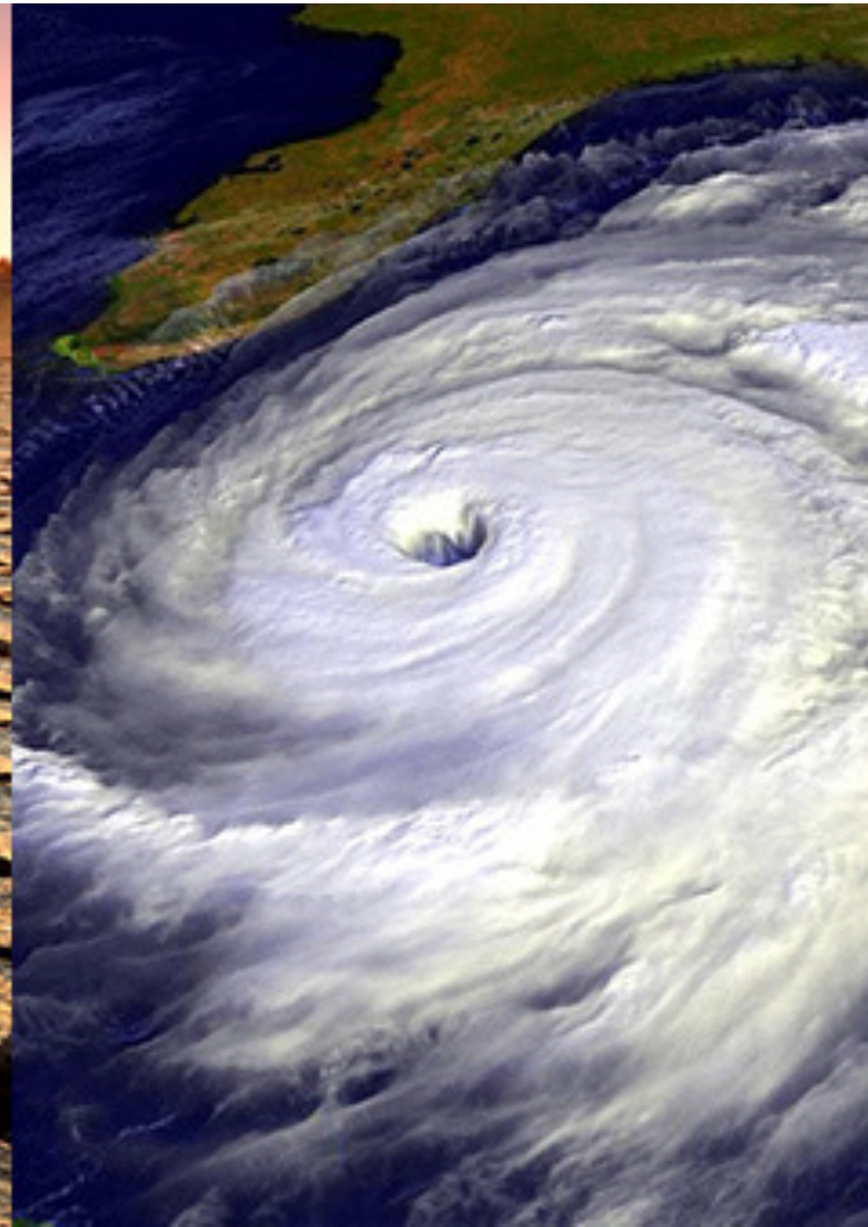
Jennifer Hamilton, Technical Director

H2FCP Members

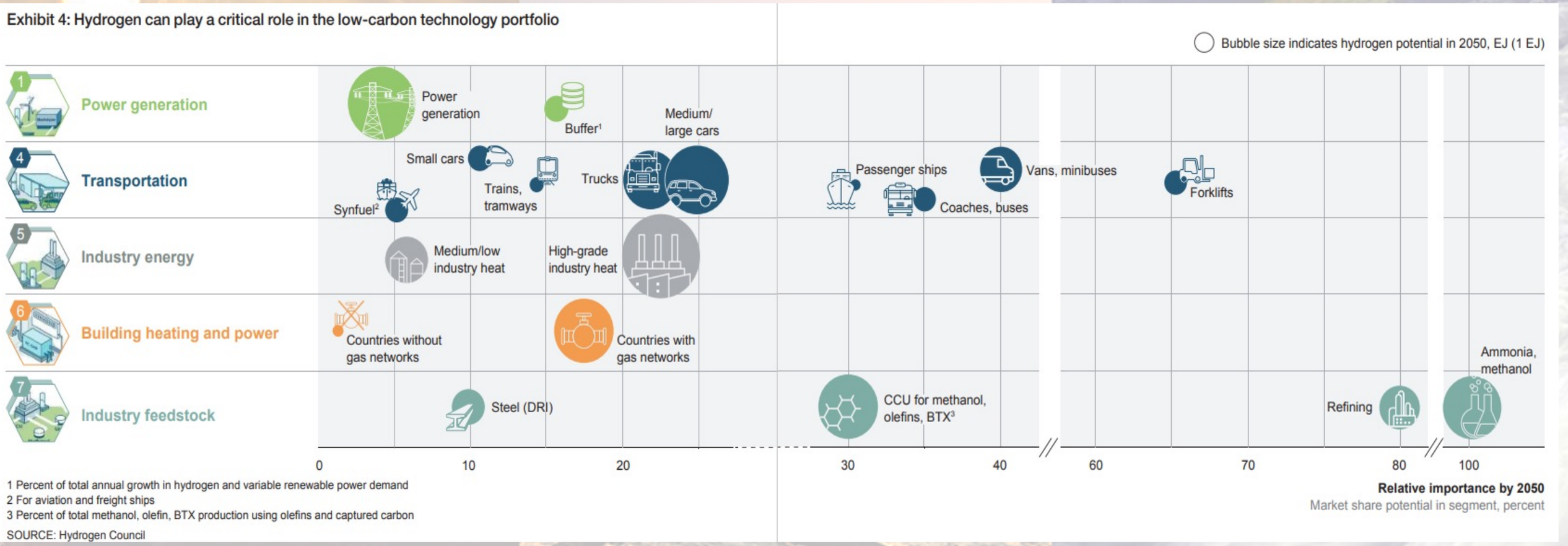
— 20+ years of collaboration —

Hydrogen in California

Energy & Transportation Systems are Transitioning Globally…



Hydrogen has a Significant Role in Global Decarbonization



https://hydrogencouncil.com/en/

Hydrogen Fuel Cell Vehicles – Light-Duty

Honda Clarity

Hyundai NEXO

Toyota Mirai

Toyota Mirai

BMW

Hopium

Hyperion

Hyundai

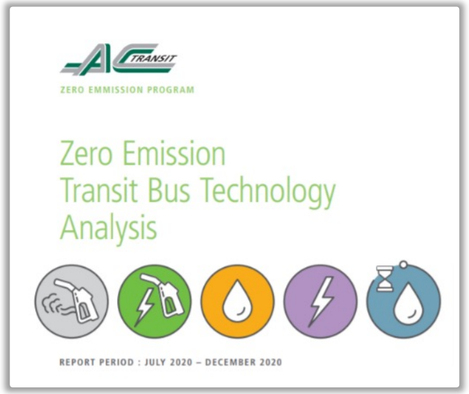
Riversimple

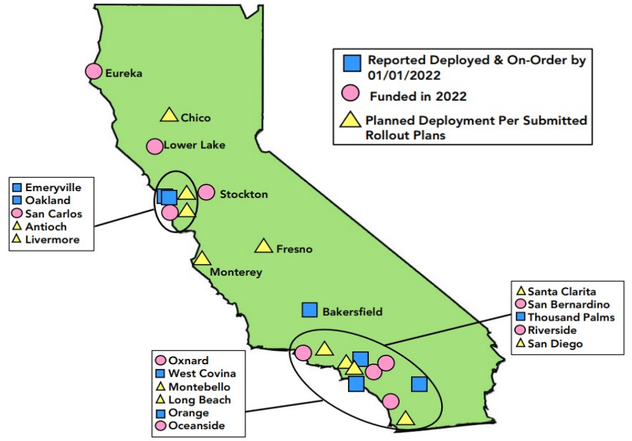
Stellantis

Hydrogen Fuel Cell Vehicles – Transit Buses

California Transit Agencies with fuel cell electric buses on the road and initial pipeline

- AC Transit (East Bay)
- Eastern Contra Costa Transit Authority (East Bay)
- North County Transit (San Diego)
- OCTA (Orange County)
- Riverside Transit Agency
- SunLine Transit (Coachella Valley)
- UC Irvine





Alameda-Contra Costa Transit District	Oakland & Emeryville	Large
Butte Regional Transit	Chico	Small
City of Santa Clarita	Santa Clarita	Large
Eastern Contra Costa Transit Authority	Antioch	Small
Foothill Transit	West Covina	Large
Fresno Area Express	Fresno	Large
Gold Coast Transit District	Oxnard	Small
Golden Empire Transit District	Bakersfield	Large
Humboldt Transit Authority	Eureka	Small
Lake Transit Authority	Lower Lake	Small
Livermore/Amador Valley Transit Authority	Livermore	Small
Long Beach Transit	Long Beach	Large
Montebello Bus Lines	Montebello	Large
Monterey-Salinas Transit District	Monterey	Small
North County Transit District	Oceanside	Large
Orange County Transportation Authority	Orange	Large
Omnitrans	San Bernardino	Large
Riverside Transit Agency	Riverside	Large
San Diego Metropolitan Transit System	San Diego	Large
San Joaquin Regional Transit District	Stockton	Large
San Mateo County Transit District	San Carlos	Large
Sunline Transit Agency	Thousand Palms	Small

Hydrogen Fuel Cell Vehicles – Trucks & more

- BAE
- Ballard
- Bosch
- Cellcentric
- Cummins
- Daimler Truck
- Hino
- Hyundai
- Hyzon
- International/GM
- Loop Energy
- Kenworth
- Nikola
- Quantron
- Siemens
- Toyota
- Volvo

Many more HD FCVs…

California Environmental Goals

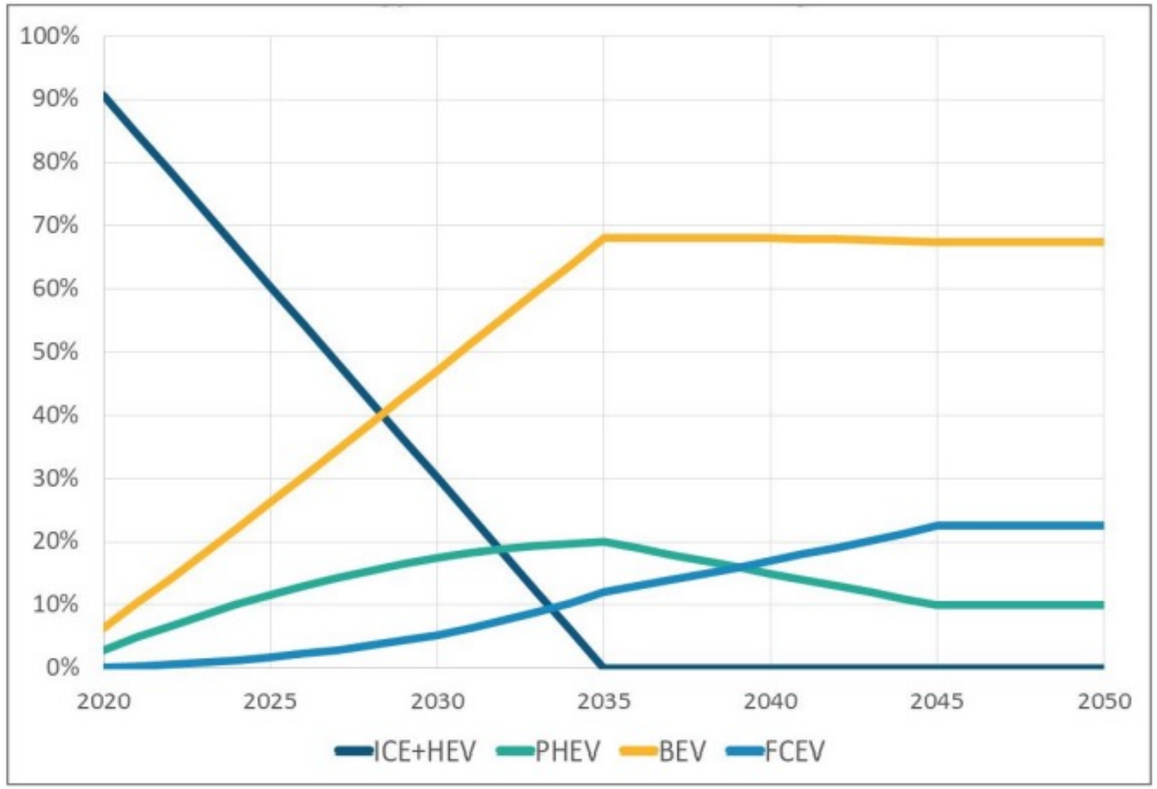
Legislation and Executive Orders are driving the state towards 100% zero-emission transition

Climate	• 2045 – 100% zero carbon electricity (SB 100) • 2045 – Carbon neutral economy (EO B-55-18)
Air Quality	• 2031 – 80% reduction in smog-forming Nox
Zero Emission Vehicles (ZEVs)	• *ZEV regulation* – increasing ZEV sales requirement for LD automakers • *Innovative Clean Transit* – 100% new bus purchases ZEV by 2029, and 100% of all operating buses ZEV by 2040 • *Advanced Clean Trucks* – increasing sales requirement for MHD manufacturers starting 2024, and 100% ZEV sales by 2045 • 2025 – 1.5 million ZEVs (EO B-16-12) • 2030 – 5 million ZEVs (EO B-48-18) • 2035 – 100% in-state passenger vehicle sales are ZEV (EO-N-79-20) • 2045 – 100% in-state M-HD vehicle sales are ZEV (EO-N-79-20)
ZEV infrastructure and fuels	• 2025 – 200 hydrogen stations and 250,000 chargers (EO B-48-18) • Low Carbon Fuel Standard – sets carbon intensity standard for fuels, with fuel producers producing and selling credits around the standards

California's environmental challenge – and ZEV actions

- 1990 zero emission vehicle regulation (ZE to curb tailpipe emission
- Requires automakers sell ZEVs in Californ and other states
- Complimentary nature of BEVs & FCEVs
  - Hydrogen and electricity system enables larger decarbonized energy transition in all sectors
- Provides consumer choice

Figure 13 – Light-Duty Vehicle Sales Fractions by Technology Type



Source: CARB's Mobile Source Strategy

Both ZEV technologies needed to reach environmental goals

Envisioning the Transition : *CA Fuel Cell Revolution*

100 BY **2020**

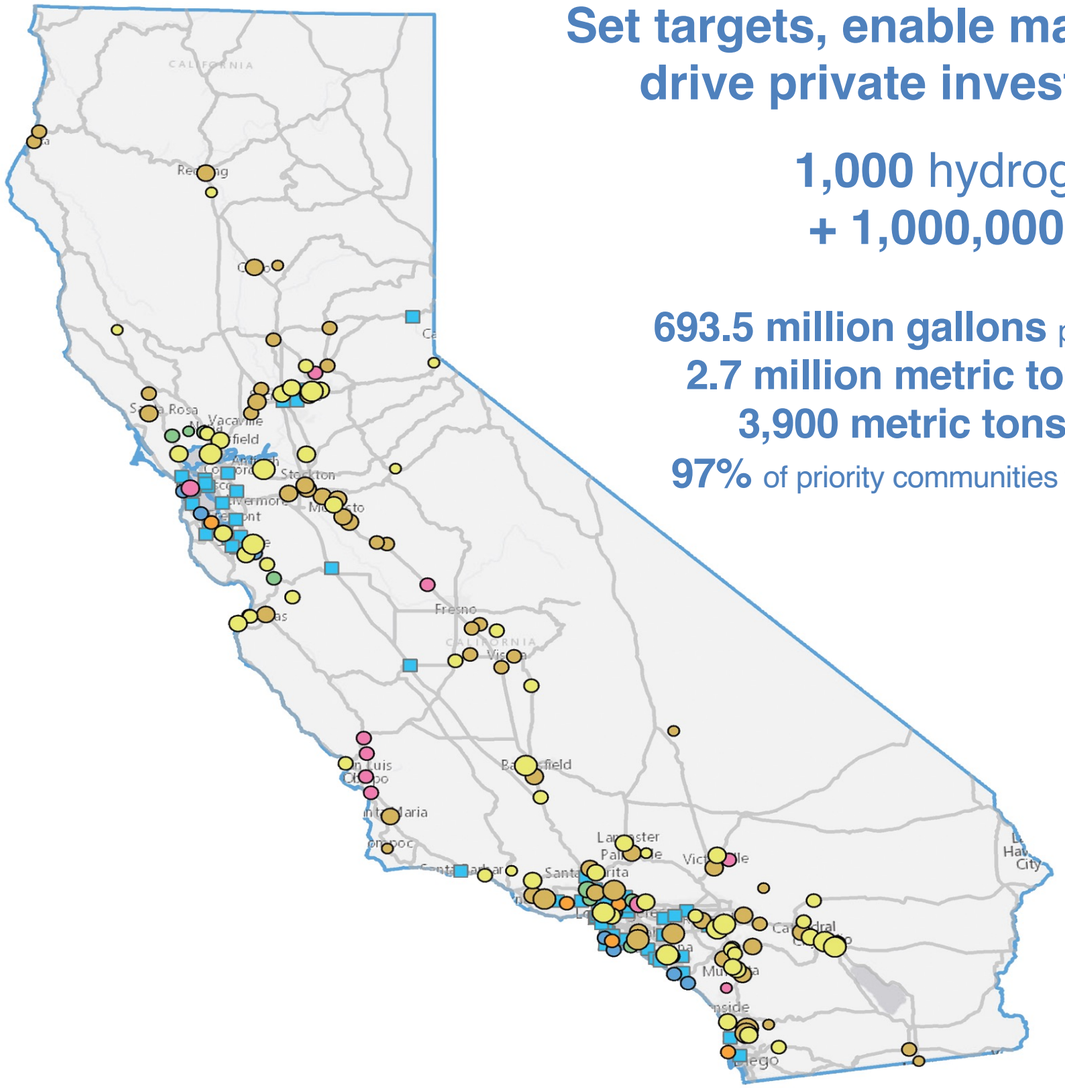
hydrogen stations by ***2020***.
Funded by Assembly Bill 8 (2013).

200 BY **2025**

hydrogen stations by ***2025***,
pursuant to the Governor's 2018
ZEV infrastructure Proposal.

1000 BY **2030**

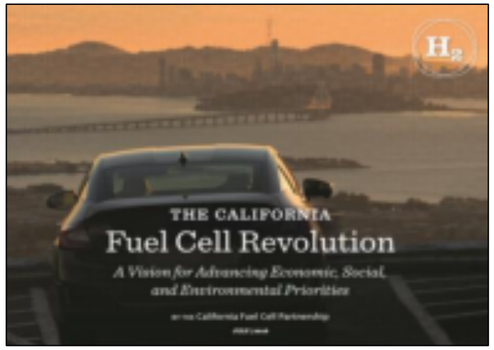
hydrogen stations by ***2030*** with favorable market conditions and state policies pursuant to the CAFCP 2030 vision. Will support 1,000,000 fuel cell electric vehicles.



Set targets, enable market conditions, and drive private investment to support:

1,000 hydrogen stations
+ 1,000,000 vehicles **=**

693.5 million gallons per year of gasoline displaced
2.7 million metric tons per year GHG avoided
3,900 metric tons per year NOx avoided
97% of priority communities within the network coverage



Achieving the Transition: *CA Self-sufficiency Study*

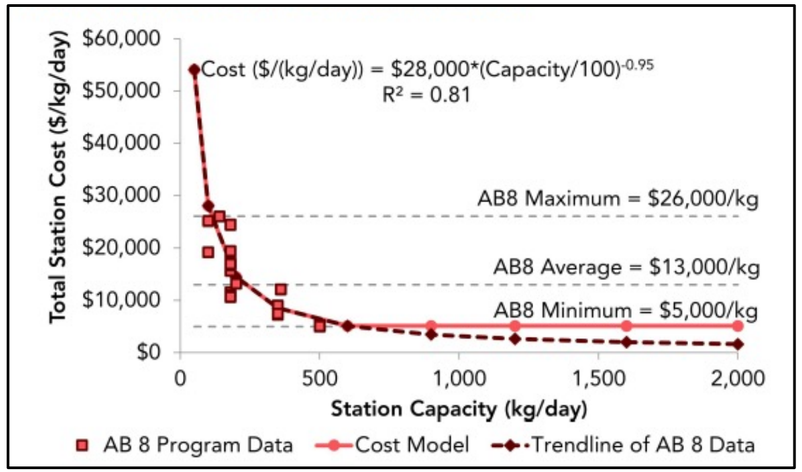
Self-Sufficiency Achieved by:

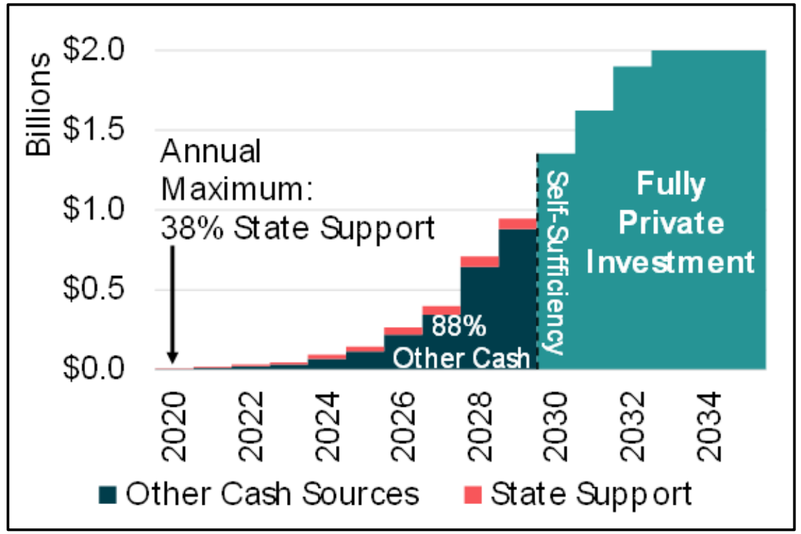
2030

With State Support up to:

300M

- Self-sufficiency is possible with State support
- Industry supports the majority of network growth
- California's network growth rate drives its own economies of scale
- Stations and FCEV deployments need to grow together to gain full benefit
- State support offers benefits to the consumer and may be sufficient to accelerate reductions in price at the pump





http://ww2arb.ca.gov/resources/documents/self-sufficiency-report

Envisioning the Transition: *Fuel Cell Truck Vision*

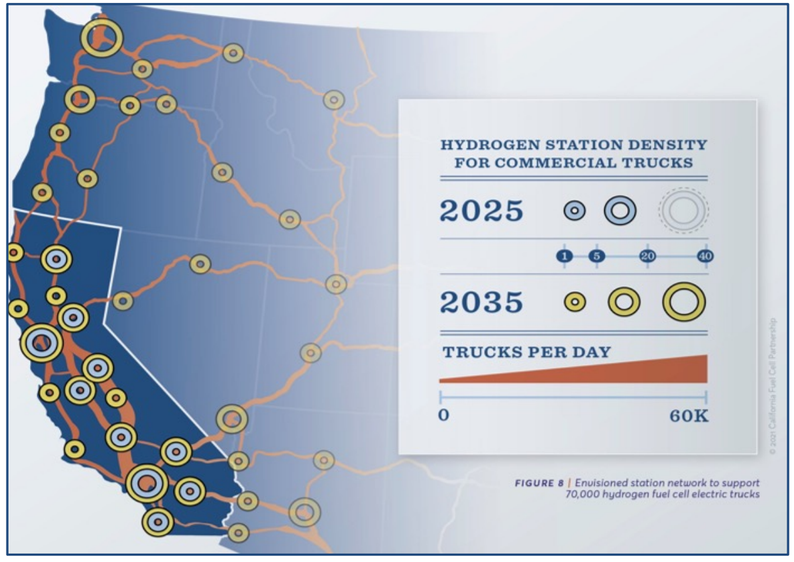


FIGURE 8 | Envisioned station network to support 70,000 hydrogen fuel cell electric trucks

—Fuel Cell Electric Truck Vision—

Enable market conditions to support:

200 hydrogen stations
+ 70,000 trucks =

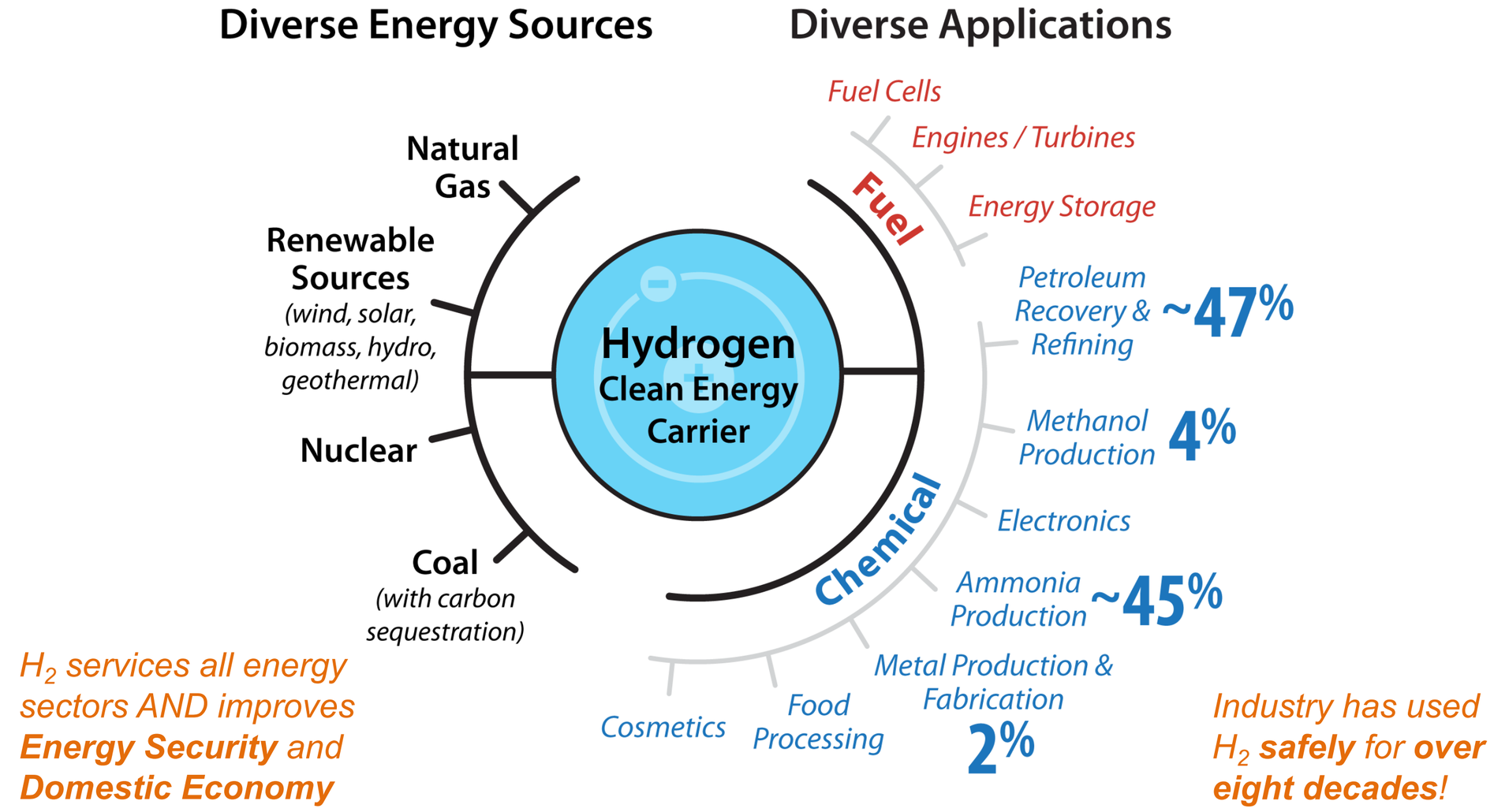
541.8 million gallons per year of diesel displaced
6.7 million metric tons per year GHG avoided
18,100 metric tons per year NOx avoided

Alliance for Renewable Clean Hydrogen Energy Systems

ARCHES is California's public-private hydrogen (H_2) hub consortium to accelerate the development and deployment of clean, renewable H_2 projects and infrastructure. Clean H_2 can supplement renewable energy sources to reduce greenhouse gas emissions and advance a zero-carbon economy. The US Department of Energy will award $8 billion to up to 10 regional H_2 hubs to build self-sustaining H_2 economies of producers, infrastructure, and users. In partnership with the Governor's Office of Business and Economic Development (GO-Biz), ARCHES unites key public and private stakeholders to build the framework for a California renewable, clean H_2 hub.

Hydrogen properties and safety

Hydrogen – A Clean, Flexible Energy Carrier



*H_2 services all energy sectors AND improves **Energy Security** and **Domestic Economy***

*Industry has used H_2 **safely** for **over eight decades**!*

Source: DOE, NREL, Hydrogen and Fuel Cell Program

Why Hydrogen Fuel?

- Most abundant element in the universe
- Excellent energy carrier
- Ultra-low/Zero emissions
- Economically competitive
- Safe and secure
  - *More than 80 years of industrial use*
  - *Can be used as safely as gasoline*
  - *Domestically produced from a variety of sources*

H2 fuel dispenser
(Photo :California Fuel Cell Partnership)

Hydrogen Uses

The use of hydrogen is not new; private industry has used it safely for many decades. Nine million tons of hydrogen are safely produced and used in the United States every year; 56 billion kg/yr are produced globally. For example, H_2 is used for:

- Petroleum refining
- Glass purification
- Aerospace applications
- Fertilizers
- Annealing and heat treating metals
- Pharmaceutical products

The Air Products and Chemicals hydrogen production facilities in Port Arthur, Texas, is funded by the Energy Department through the 2009 Recovery Act. | Photo credit Air Products and Chemicals hydrogen production facilities.

- Petrochemical manufacturing
- Semiconductor industry
- Hydrogenation of unsaturated fatty acids in vegetable oil
- Welding
- Coolant in power generators

How is Hydrogen Stored and Transported?

Well-established industrial supply system

Gaseous (GH_2)

- Thick walled metallic (Type I) or composite reinforced cylinders (Type II or III)
- 2,400-8,000 psi
  - *No liquid phase in compressed gas H_2 storage*
  - *Compression does not liquefy*

How is Hydrogen Stored and Transported?

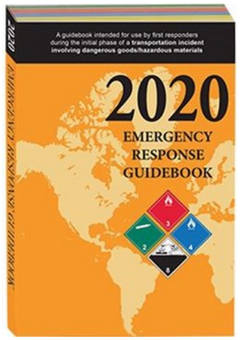
Well-established industrial supply system

Liquid (LH_2)

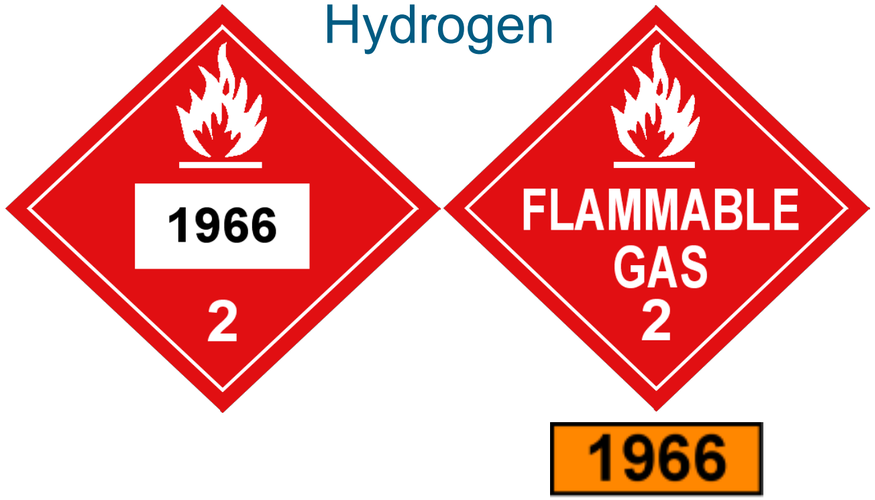
- Cryogenic: -423°F (-253°C)
- Double walled, vacuum insulated tanks with burst disks, vents, and pressure relief devices
- Low pressure - 50 psi

Transporting Hydrogen Today

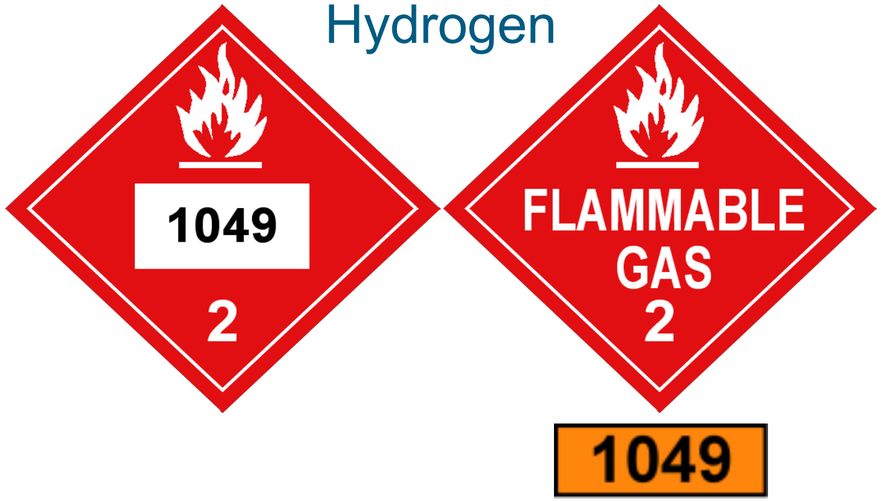
DOT placards for commercial transport of hydrogen



Liquid
Hydrogen

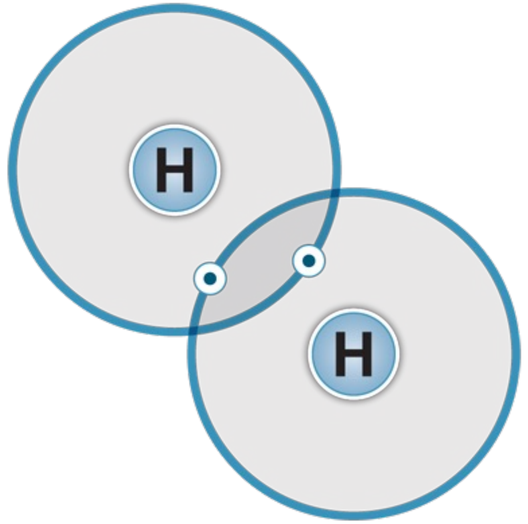


Gaseous
Hydrogen



Hydrogen Properties and Behavior

- **Gas** at ambient conditions
  - Rises and disperses rapidly (14x lighter than air)
  - Flammable range 4-75% in air
- **Liquid** at -423°F (-253°C) – a *cryogen*
  - LH_2 stored at 50 psi in vacuum insulated tanks
  - No liquid phase in compressed gas H_2 storage
- **Energy content comparison** :
  - 1 kg of hydrogen ~ 1 gallon gasoline
  - 33.3 kWh/kg hydrogen vs. 32.8 kWh/gal gasoline



Molecular Hydrogen Model:
2 protons (H+) sharing 2 electrons (e-)

Hydrogen Properties: A Comparison

	Hydrogen	Natural Gas	Gasoline
Color	No	No	Yes
Toxicity	None	Some	High
Odor	Odorless	Mercaptan	Yes
Buoyancy Relative to Air	14X Lighter	2X Lighter	3.75X Heavier
Energy by Weight	2.8X > Gasoline	~1.2X > Gasoline	43 MJ/kg
Energy by Volume	4X < Gasoline	1.5X < Gasoline	120 MJ/gallon

Source: California Fuel Cell Partnership

General Station Safety Systems

- Pressure relief systems
  - Burst disks
  - Pressure relief valves/devices (PRV/PRD)
  - Safety vents
- Fire and leak detection systems
  - Remote system monitoring
  - Hydrogen gas detectors (dispenser)
  - UV/IR flame detectors
  - Fueling line leak check on nozzle connect

ASME steel and composite stationary storage tubes

General Station Safety Systems

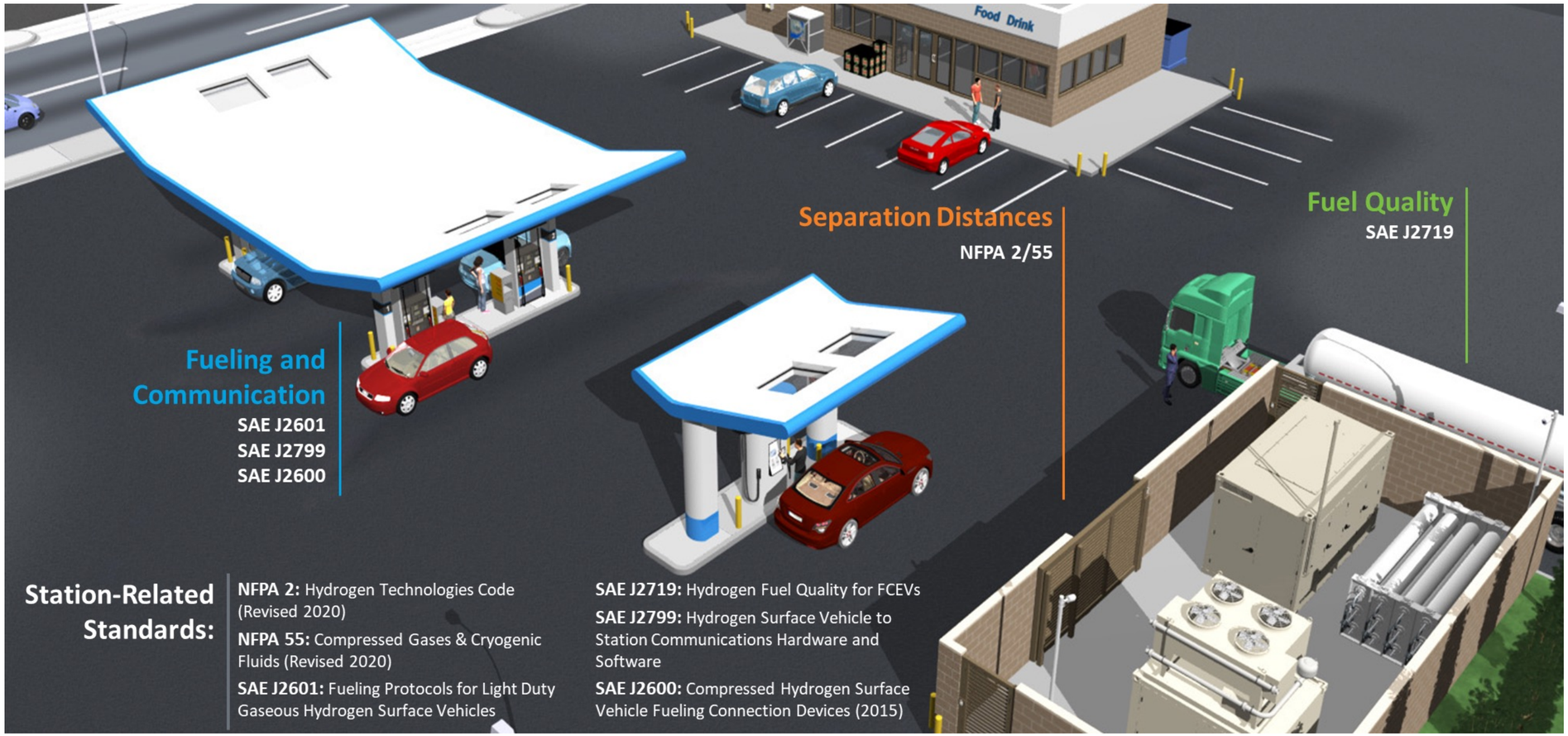
- Design elements
  - Engineering safety margins and risk analysis (HAZOP, FMEA, etc.)
    - Hydrogen Risk Assessment Model (HyRAM) available on h2tools.org
  - Hydrogen compatible materials
    - Prevents hydrogen embrittlement
  - Siting to established regulations
    - IFC and NFPA 2
- Other systems
  - Emergency stops
  - Dispenser hose break-away devices
  - Impact sensors at dispenser
  - Leak detection with automatic shut-off
  - Redundant isolation of systems

Typical Station Configurations

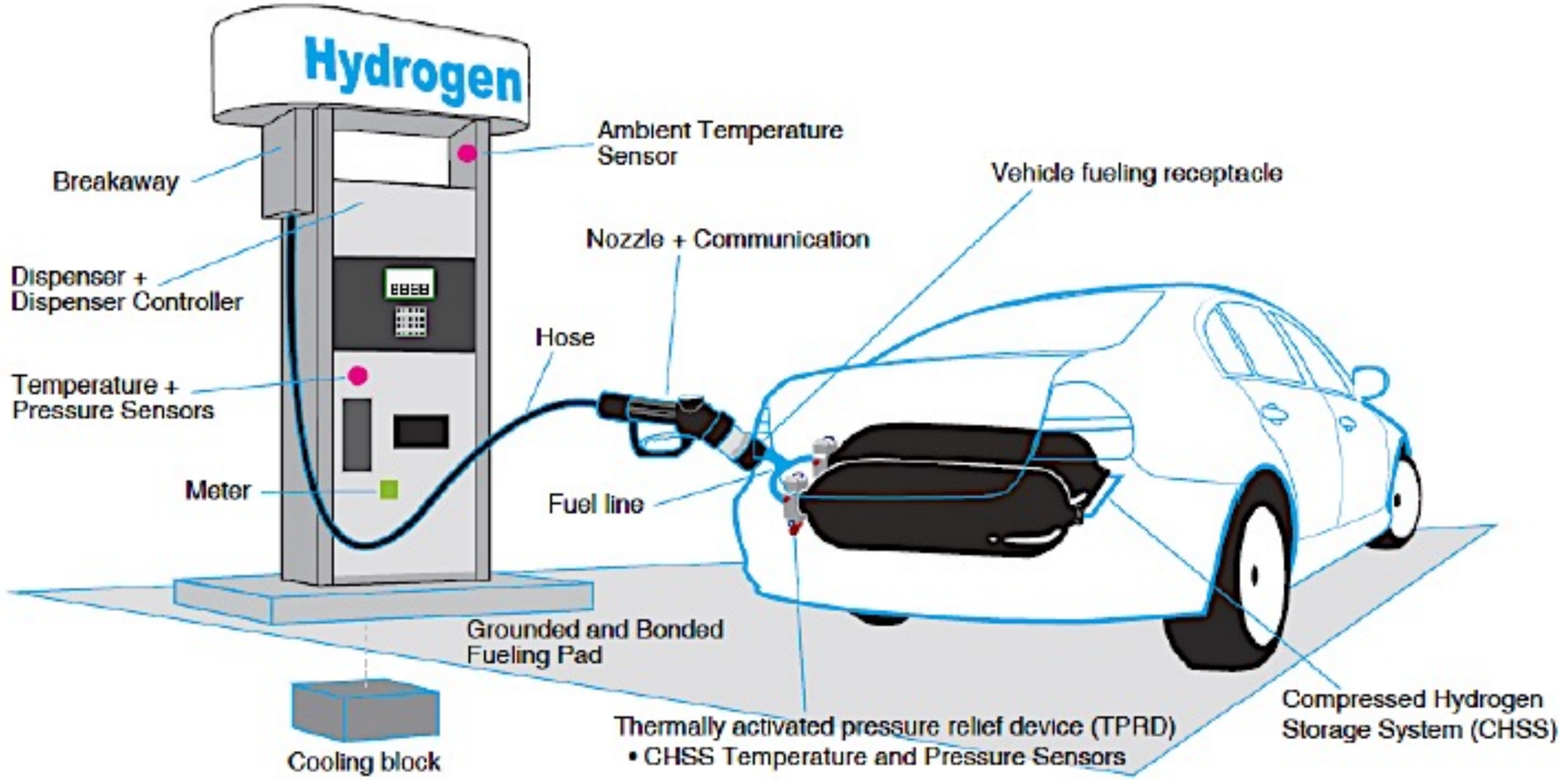
- Hydrogen can be produced at a central plant and delivered or made on site
- Delivered hydrogen
  - Liquid – refill bulk storage tank
  - Gaseous – tube trailer swap or refill
  - Pipeline
- On-site production
  - Natural gas (steam methane reformer-SMR)
  - Electrolysis of water
- Final product = gaseous hydrogen dispensing

North American-Based Codes & Standards

- Examples of Standards Impacting Refueling Infrastructure



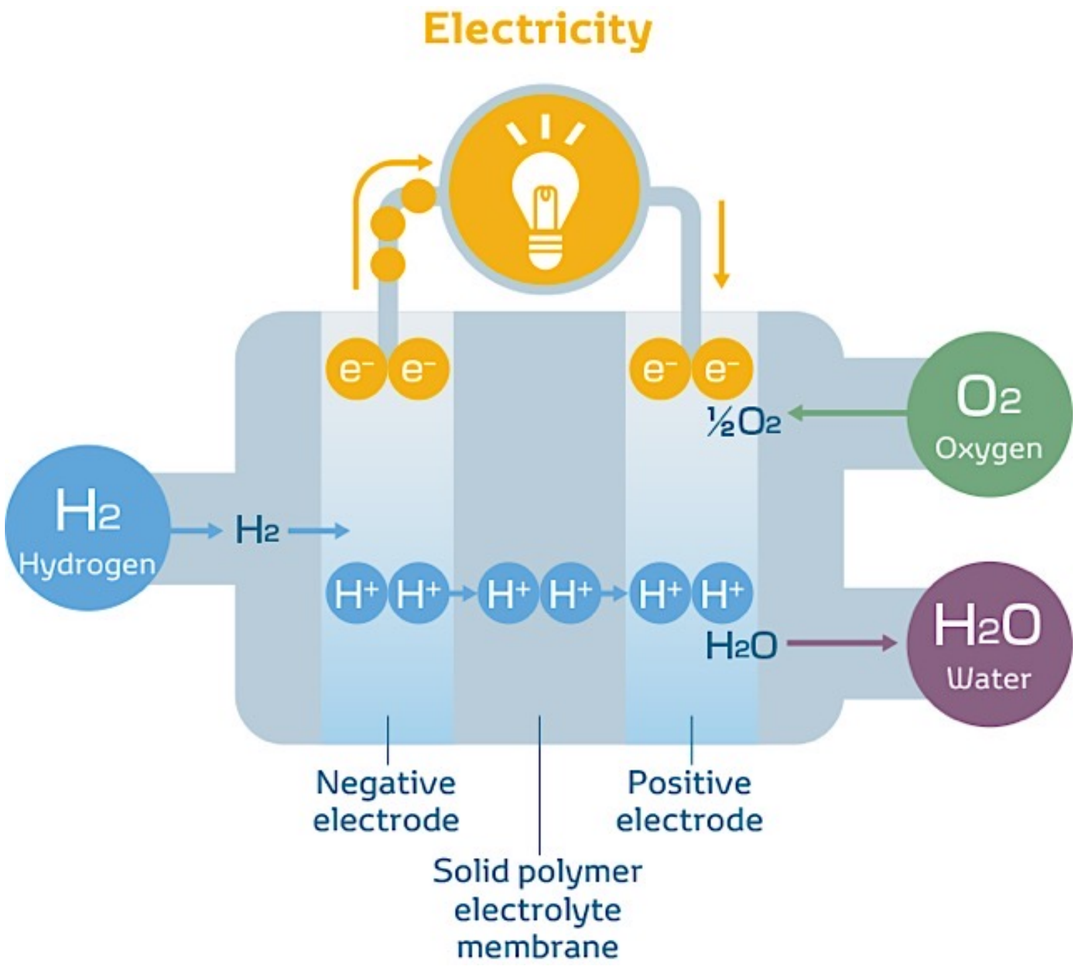
Hydrogen Fueling Diagram



High-pressure Hydrogen Cylinder Testing

- In accordance with latest proposed hydrogen vehicle fuel storage system standards (SAE J2579, CSA HGV2, GTR 13)
- Tests conducted as part of the design qualification testing for new cylinders
- Vent only, no rupture

How a PEM* Hydrogen Fuel Cell Works:



*(*Proton exchange membrane)*

1. **Hydrogen** (H_2) to anode side (*negative electrode*)
2. H_2 molecules react at anode, release ***electrons*** (**e-**)
3. Electrons travel external circuit toward cathode (*positive electrode*), as **electrical current,** to do **work**
4. Hydrogen ions (**H+,** *protons*) exchange through *solid polymer electrolyte membrane (PEM)* to cathode
5. Hydrogen ions react with airborne **oxygen** (O_2) and electrons at the cathode electrode to form **water**

Resources

- Hydrogen Fuel Cell Partnership: https://h2fcp.org
  - By the numbers
  - FAQ’s
  - Reports
  - Events
  - Station Map

- Center for Hydrogen Safety: https://www.aiche.org/chs
  - Hydrogen Tools (h2tools.org)
  - Emergency Responder Training resource
  - Lessons Learned
  - Best Practices
  - Hydrogen Safety Panel

We’re creating transformative change for a brighter, healthier future.

Join the revolution.

Jennifer Hamilton
jhamilton@h2fcp.org
h2fcp.org

UC Riverside Life Cycle Analysis (LCA)

Valley Vision Webinar

December 16, 2022

Presented By:

Georgios Karavalakis
Adjunct Professor & Research Engineer
gkaraval@cert.ucr.edu
www.cert.ucr.edu
(951) 781-5786

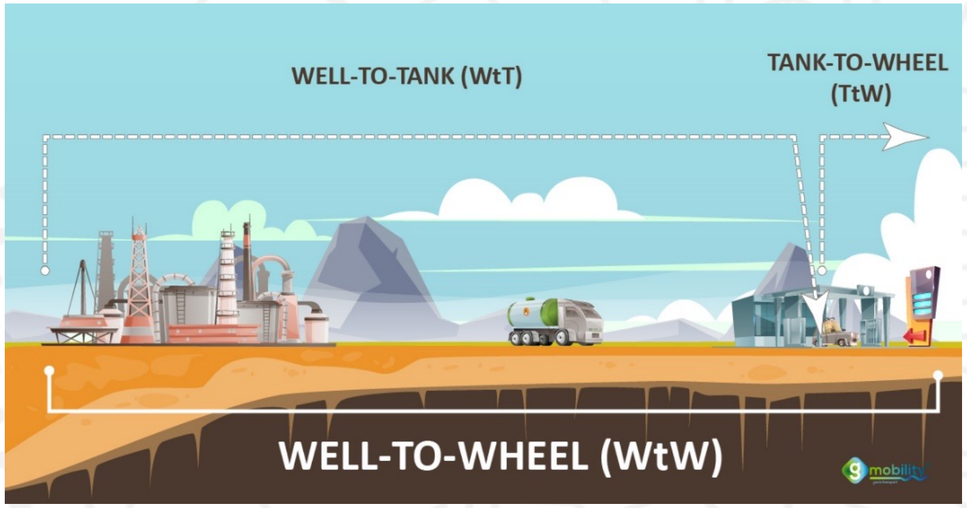
University of California, Riverside
Center for Environmental Research and Technology
(CE-CERT)

www.cert.ucr.edu

Life Cycle Assessment (LCA)

- Life cycle assessment is a technique for assessing the environmental aspects associated with a product over its life cycle.
- The final full life cycle emissions and energy consumption information, i.e., Well-to-Wheels (WtW), is obtained by summing up the two parts:
  - The Well-to-Tank section accounts for all the fuel production steps such as resource extraction, fuel production, transport, storage, distribution, and marketing.
  - The Tank-to-Wheels part takes into account the emissions during the vehicle operation.

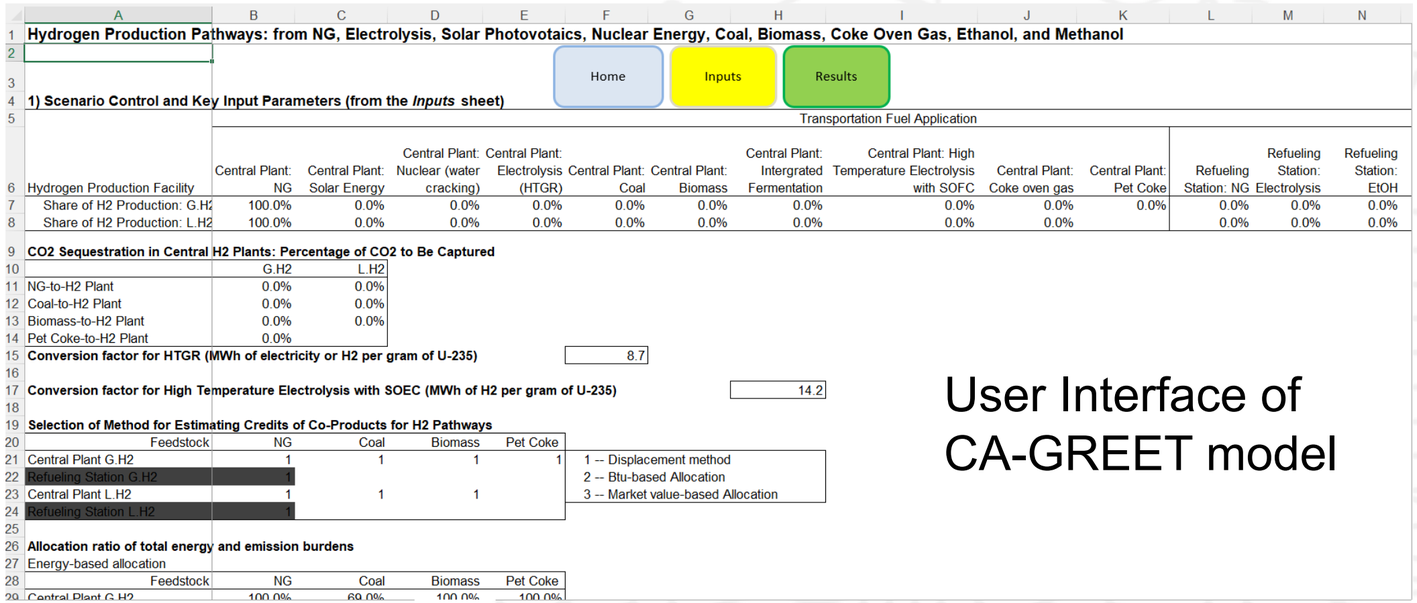
- A life cycle assessment for H2/fuel cell switcher trains and more broadly for these types of locomotives in CA will be conducted in this project.



Source: gmobility.eu (2022)

California Analysis Model (CA-GREET)

- The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model is widely used in LCA studies, especially in the United States.
- The CA-GREET model is a modified version of the GREET model consisting of California specific assumptions. We use CA-GREET 3.0, the latest CA-GREET model in this project.
  - Well-to-Tank: focusing on raw material extraction, hydrogen production and distribution
  - Tank-to-Wheels: using locomotive activity data to collect operation and mileage information



Hydrogen Production Pathways: from NG, Electrolysis, Solar Photovotaics, Nuclear Energy, Coal, Biomass, Coke Oven Gas, Ethanol, and Methanol

Home | Inputs | Results

1) Scenario Control and Key Input Parameters (from the *Inputs* sheet)

Transportation Fuel Application

Hydrogen Production Facility	Central Plant: NG	Central Plant: Solar Energy	Central Plant: Nuclear (water cracking)	Central Plant: Electrolysis (HTGR)	Central Plant: Coal	Central Plant: Biomass	Central Plant: Intergrated Fermentation	Central Plant: High Temperature Electrolysis with SOFC	Central Plant: Coke oven gas	Central Plant: Pet Coke	Refueling Station: NG	Refueling Station: Electrolysis	Refueling Station: EtOH
Share of H2 Production: G.H2	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Share of H2 Production: L.H2	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%

CO2 Sequestration in Central H2 Plants: Percentage of CO2 to Be Captured

	G.H2	L.H2
NG-to-H2 Plant	0.0%	0.0%
Coal-to-H2 Plant	0.0%	0.0%
Biomass-to-H2 Plant	0.0%	0.0%
Pet Coke-to-H2 Plant	0.0%	

Conversion factor for HTGR (MWh of electricity or H2 per gram of U-235) 8.7

Conversion factor for High Temperature Electrolysis with SOEC (MWh of H2 per gram of U-235) 14.2

Selection of Method for Estimating Credits of Co-Products for H2 Pathways

Feedstock	NG	Coal	Biomass	Pet Coke
Central Plant G.H2	1	1	1	1
Refueling Station G.H2	1			
Central Plant L.H2	1	1	1	
Refueling Station L.H2	1			

1 -- Displacement method
2 -- Btu-based Allocation
3 -- Market value-based Allocation

Allocation ratio of total energy and emission burdens

Energy-based allocation

Feedstock	NG	Coal	Biomass	Pet Coke
Central Plant G.H2	100.0%	69.0%	100.0%	100.0%

User Interface of CA-GREET model

Baseline locomotive activity data

GPS traces from the locomotive activity data

Public Health Impacts and Improvements

December 16th 2022

valley vision
Community Inspired Solutions

Grace Kaufman
Project Manager
Valley Vision

What is Diesel Exhaust?

Diesel exhaust is made up of Particulate Matter (PM) and various gases. Diesel is a complex mixture and includes over 40 substances that are listed by the US EPA as hazardous air pollutants

Chemical reactions in the atmosphere combine with emitted gases in diesel exhaust, resulting in the formation of harmful ozone that impacts human and wildlife health


Existing route of the switcher locomotive

Impact to the surrounding community

The Impact

Immediate improvement of regional air quality

Reduction of greenhouse gas emissions, noise, and odor

Long term reduction of ozone levels

The potential market for hydrogen locomotives in California includes **more than 260 switcher locomotives**. Sierra Northern Railway wants to convert their entire fleet to zero-emission hydrogen

Thank you!

Grace Kaufman
Grace.Kaufman@ValleyVision.org

Audience Q/A

Bart Sowa
R&D Manager, GTI Energy
BSowa@gti.energy

Michael Faust
Sierra Northern Railway Project Consultant &
President, Velocity Strategies
mfaust@mefcllc.com

Grace Kaufman
Project Manager, Valley Vision
Grace.Kaufman@ValleyVision.org

ALL MATERALS presented in this document are proprietary.

LEGAL NOTICE

This document was prepared as a result of work sponsored by the Gas Technology Institute and the California Energy Commission. It does not necessarily represent the views of GTI, the Energy Commission, nor their employees, or the State of California. Neither GTI, the Commission, the State of California, nor GTI or the Commission's employees, contractors, or subcontractor makes any warranty, express or implied, or assumes any legal liability for the information in this document; nor does any party represent that the use of this information will not infringer upon privately owned rights. This document has not been approved or disapproved by the Commission, nor has the Commission passed upon the accuracy of the information in this document.