

The Ballard logo is displayed in white, bold, sans-serif capital letters within a dark blue rectangular box in the top-left corner of the slide. The background of the slide is a scenic photograph of a multi-lane highway curving along a rocky cliffside overlooking a large body of water, with mountains in the distance under a clear sky.

BALLARD™

FCEB LowNo Webinar Series

Webinar #2: Fuel and Permitting

March 8, 2023



Webinar Contributors



Kim Leach
Market Development
Manager, Ballard

**Fuel Cell Electric
Buses Today**



Sydney Kreuger
President, Kreuger
Transit Consulting

**Hydrogen Fuel
on the Buses &
at the Depot**



Timothy Sasseen
Market Development
Director, Ballard

**Hydrogen Safety
& Sustainability**



Hernan Henriquez
Vice President, Sales,
BayoTech

**First Deployments
and Gaseous
Hydrogen Options**



Stacey Grauer
Business Dev.
Director, Linde

**Liquid Hydrogen
& Fleet
Deployment at
Scale**



Nick Barilo
Executive Director,
Center for Hydrogen
Safety, AIChE

**Ensuring
Successful
Station Builds**

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Fuel Cell Electric Buses Today



Kim Leach

Market Development Manager, Ballard



Ballard by Numbers

44
YEARS


>1,100
employees


1,400
patents & applications

28 years

30 years

publicly listed company

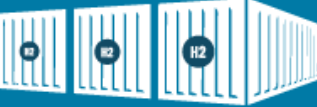
0 
2030
commitment to carbon neutrality



>1,400
transit buses


>2,300
trucks


7 TRAIN
projects


8 SHIPS
in development


8 MW
of stationary power projects


1 GW
fuel cell products delivered*


>5.3 MILLION
MEAs produced*


>175 MILLION
kilometers in operation*


1.6 GW
production capacity

4
PRODUCTION SITES
global footprint

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Hydrogen Fuel on the Bus and at the Depot



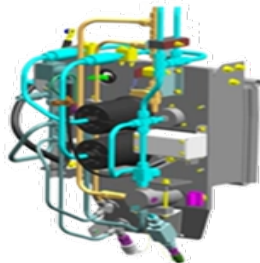
Sydney Krueger

Sales Representative for Ballard Power Systems

President of Krueger Transit Consulting (KTC)

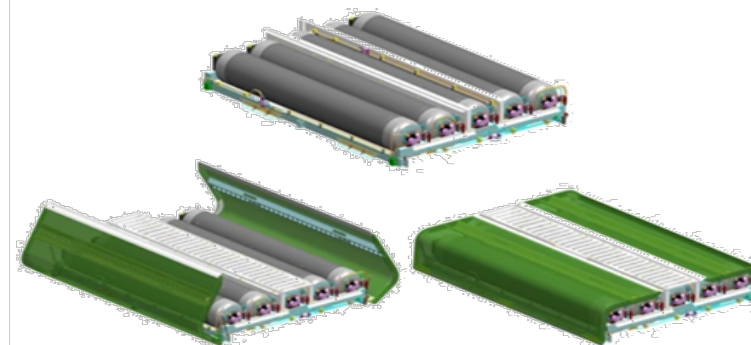
FCEB Tank Modules and Fueling Details

Fueling Tank Modules & Fill Panel



Fill Panel

- Dual H35 fill receptacles – TN1 and/or TN5
 - Inline Check Valves
- Prepared for IrDA communication w/ fill station or hardwired communication for fast fill @ smart stations
- Lower service panel
 - HP Defuel Port
 - LP Sample Port
 - LP Vent to Roof Stack
- HP & LP Analog Gauges & HP Digital Gauge



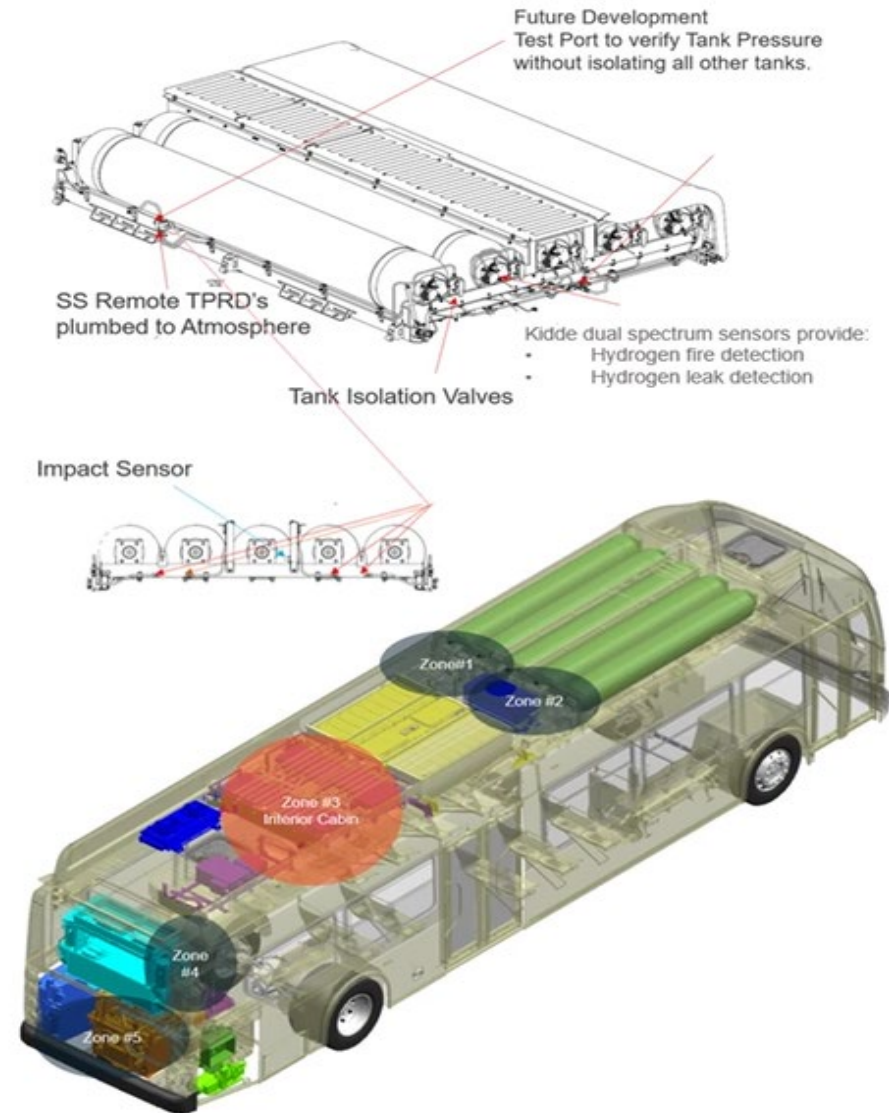
Tank Modules

- Lightweight Type 4 HGV2 tanks with 95% usable capacity
- All-composite (Hexagon)
- 7.5 kg H₂
- 350 bar (15 °C)
- 98 kg empty (excluding valve & mounting)
- Ø16.3" x 125" long
- HGV2 / EC79 certified
- 20-year service life

40'	60'
6 – 10 minutes*	12 – 20 minutes*

Hydrogen Safety


- **Fire detected** – shut off high voltage, shuts off all flow in the H2 system, turns off fans, turns off the fuel cell, alarm sounds
- **TPRD activated** – vent tank(s) to atmosphere
- **Excess flow valve activated** – tank(s) shut-off
- **Impact detected** – shuts off all flow in the H2 system
- **Proximity switch** – with fill box open ignition is disabled, high pressure hydrogen flow is stopped
- **Tank temperature reported to fill station** – fill station adjusts fill rate



Hydrogen Supply Solutions for Transit Agencies

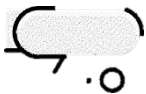
Off site production of hydrogen & delivery by trucks




Compressed gaseous hydrogen in tube trailers

Compression system, storage




Liquid hydrogen delivered on a LH2 trailer

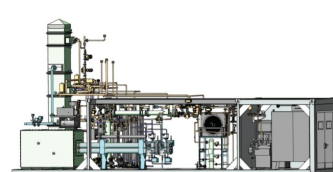
Vaporizer, pump, storage

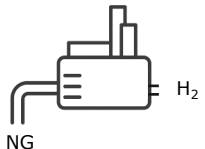


Considerations for transit agencies

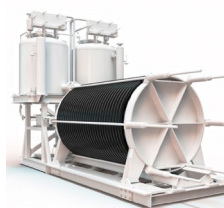
- Fuel supply resiliency
- Proximity to H2 production site
- Station footprint or site constraints
- Site modifications to support your transition
- Hydrogen carbon intensity
- Roll-out plan and long-term fleet conversion strategy
- Scalability of installation
- CAPEX and OPEX costs
- Technology developments
- Hydrogen cost

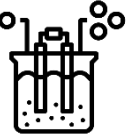
On-site production




Reforming of natural gas (SMR)

Compression system, storage

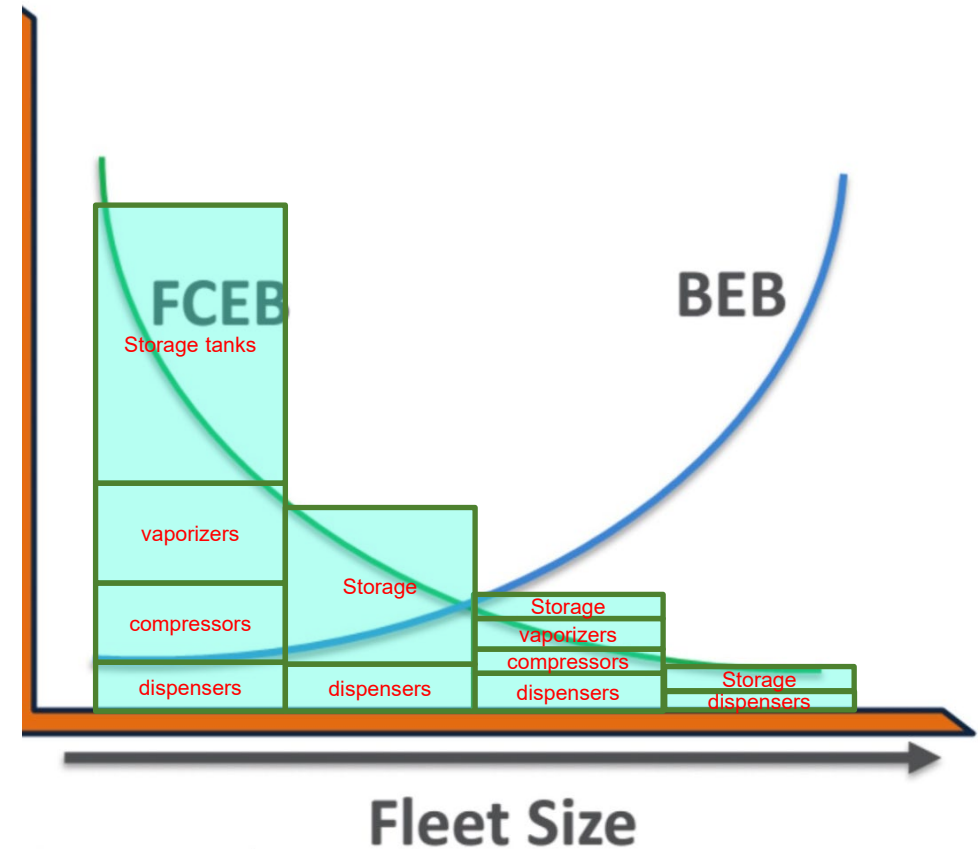
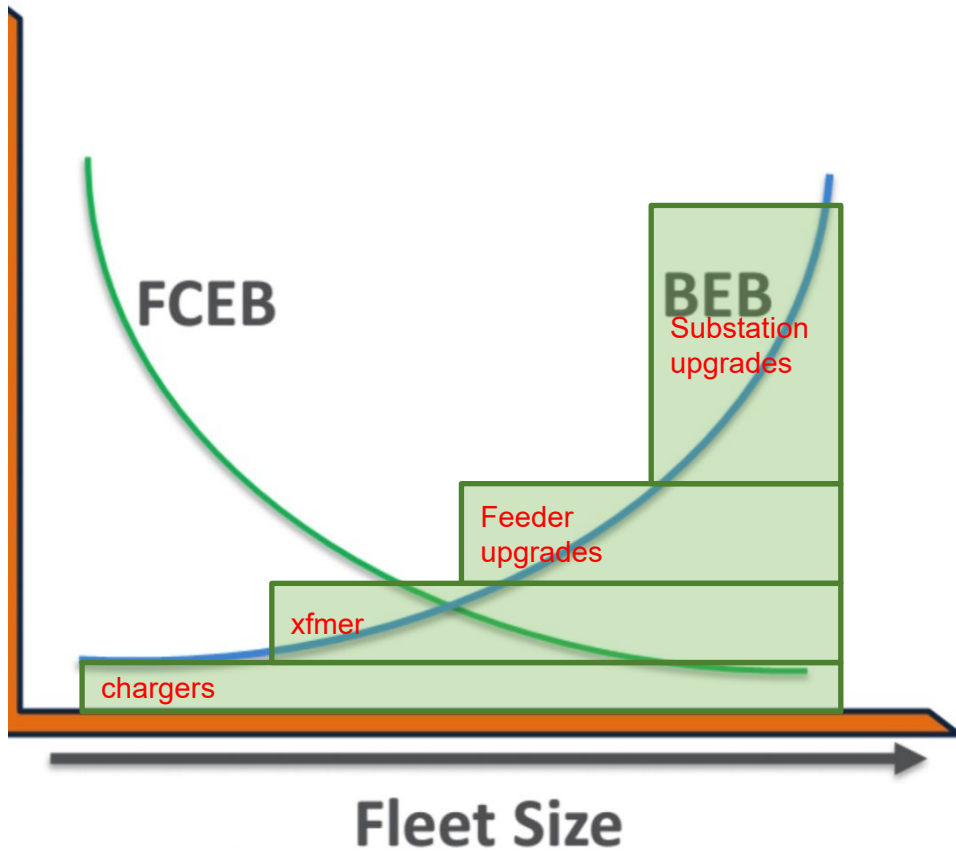



Electrolysis

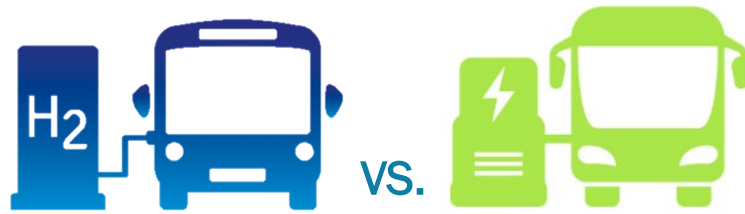
Compression system, storage



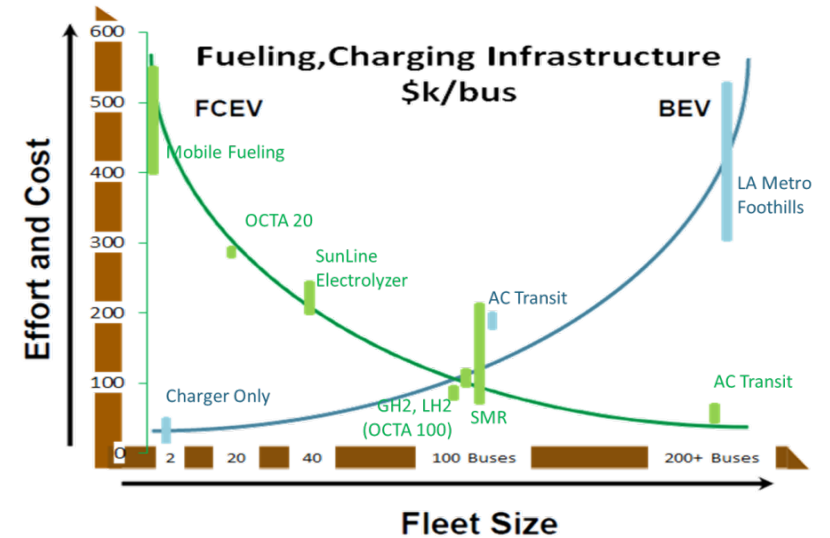
Infrastructure and Scalability



Infrastructure Costs



Infrastructure cost assessment reflects presumption that as fleet size increases, marginal costs for hydrogen decrease, while electrical infrastructure marginal costs increase, despite variability among agencies



Agency	FCEB	BEB
SunLine	\$231k/bus, 35 buses	\$64k/bus, 14 buses
Foothill Transit	\$133k/bus, 30 buses	\$322k/bus, 30 buses
Long Beach	\$108k/bus, 125 buses	\$209k/bus, 100 buses
AC Transit	\$90k/bus, 200 buses	\$560k/bus, 530 buses
NCTD	\$291k/bus, 158 buses	\$348k/bus, 158 buses

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Hydrogen Sustainability



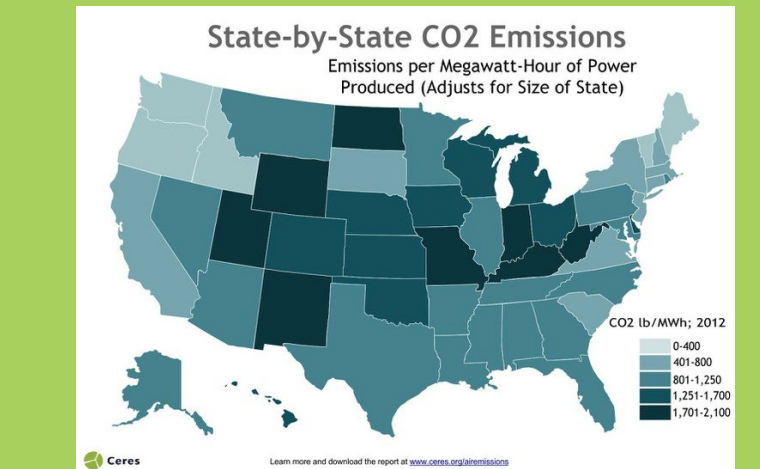
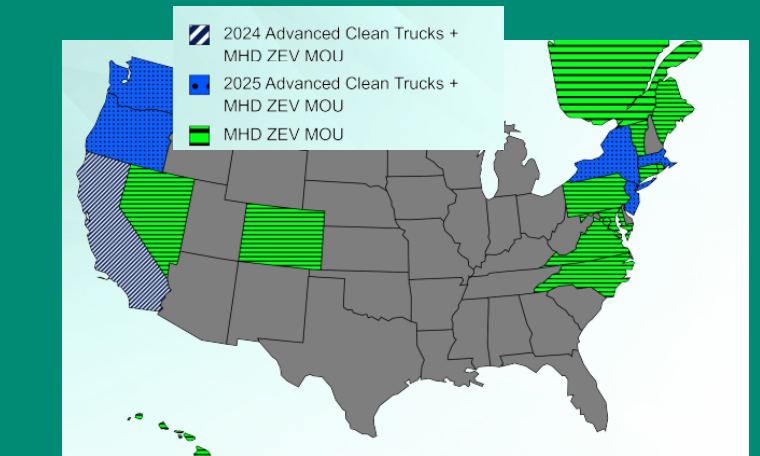
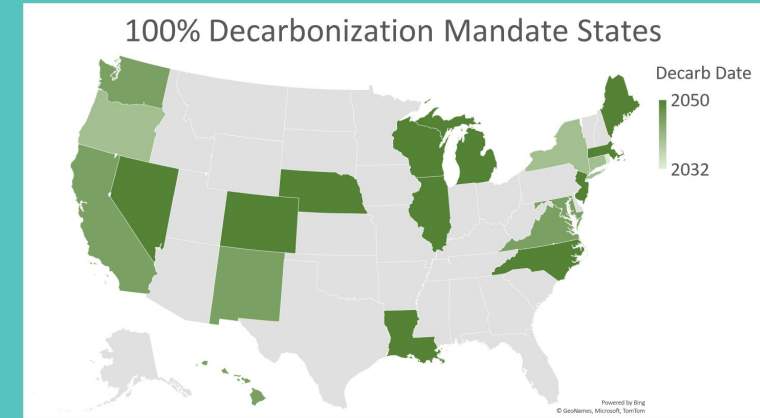
Timothy Sasseen

Director, Market Development and Public Relations, NA
Ballard

The Task Ahead for the Grid

Decarbonization Is Happening to Serve Today's Loads on the Grid

- At least **23 states** have decarbonization mandates
- Represents over 51% of population of US
- **17 States** have committed to adopting California's heavy duty trucking emissions regulations
 - Electrifying transport = **doubling the grid**
 - More than **3x new renewable sources** needed, requiring remote collection
 - Capturing renewables requires **storage**, on the order of **days or months**



GRIDLOCK is Coming!!

Renewables Installations Struggle Today, Yet Expansion Is Needed to Serve New Decarbonized Loads

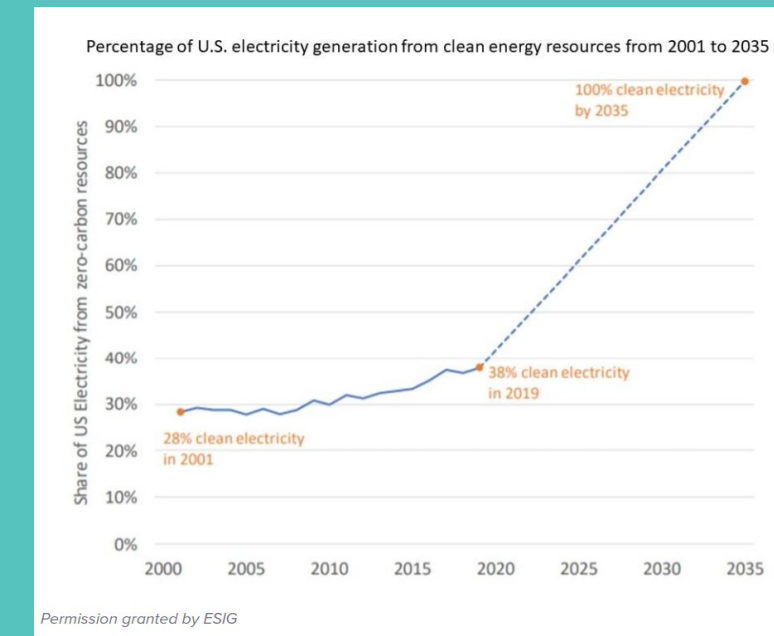
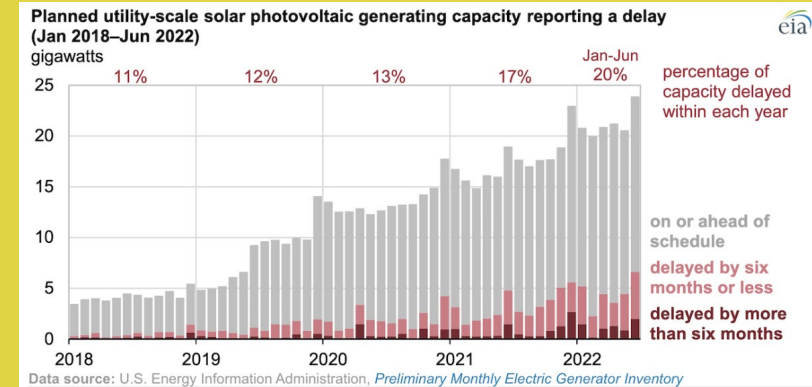
- **95% of the renewables needed in 2035** are backlogged today for transmission
- 20% of planned capacity for utility-scale solar projects was delayed in the first half of 2022
- Less than a quarter of the projects that enter interconnection queues around the U.S. will make it through to completion.

U.S. transmission's 1% annual growth must more than double to an average of about 2.3% to meet federal climate goals

- EV's from passenger cars, commercial freight
- Decarbonization of heating and industrial processes

13 [recent analysis](#) from the U.S. Energy Information Administration, [Utility-scale solar capacity delays hit 20% in first 6 months of 2022: EIA | Utility Dive](#)

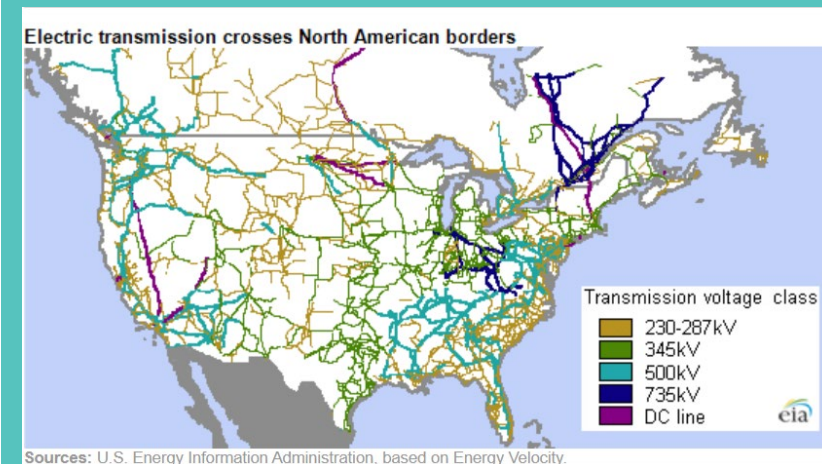
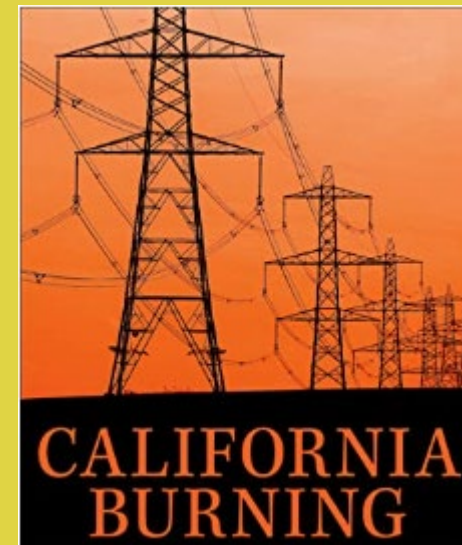
• Princeton University's September report, [Electricity Transmission is Key to Unlock the Full Potential of the Inflation](#)



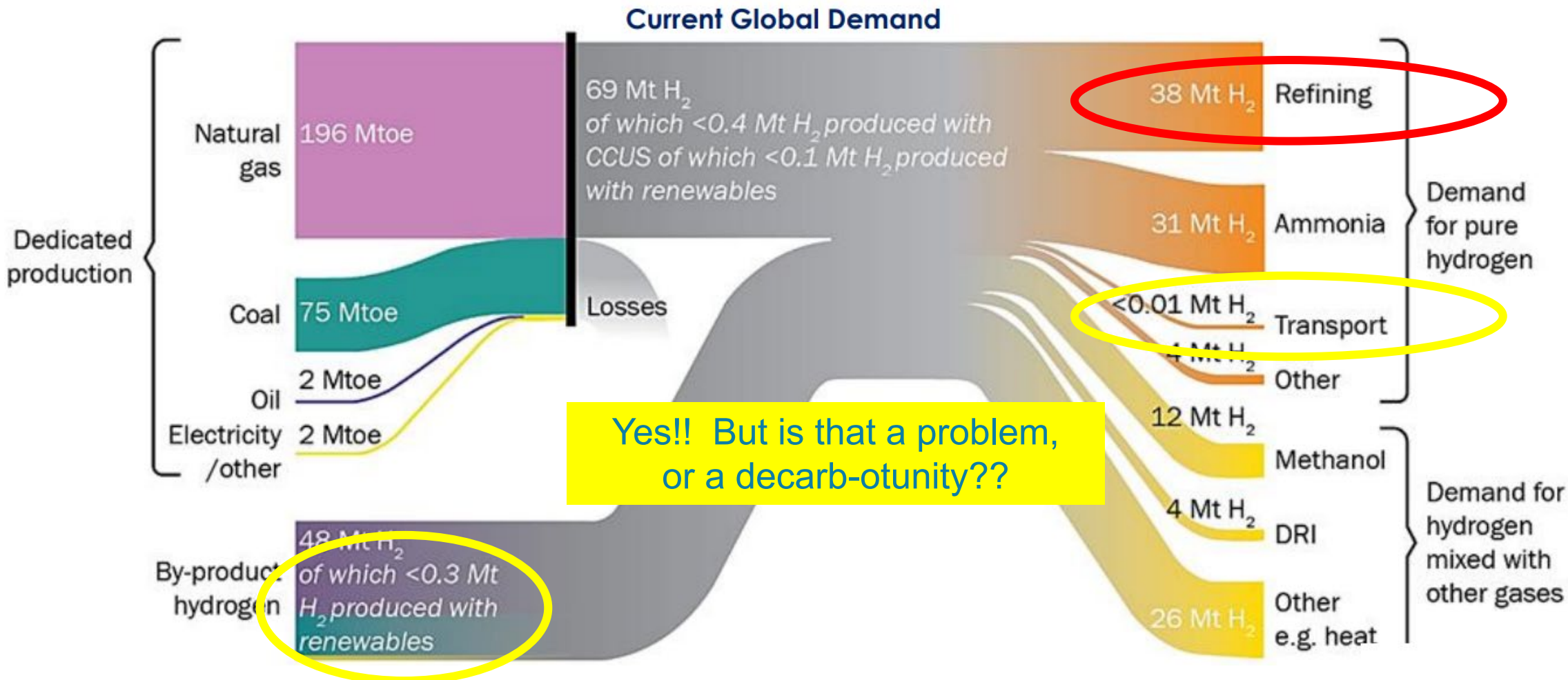
Adaptation

Strengthening is Required for Adaptation to Climate Change

- **California wildfires** in 2019 created more **CO2** than **EV's** had saved to that point, cumulatively.
- Overloaded grids in California now shut down intentionally during excessive loads for **“Public Safety Power Shutoffs”**
- ERCOT in Texas struggled this summer with **low winds** and expensive fuel during **high heat**, requiring customers to drop loads to **avoid rolling blackouts**



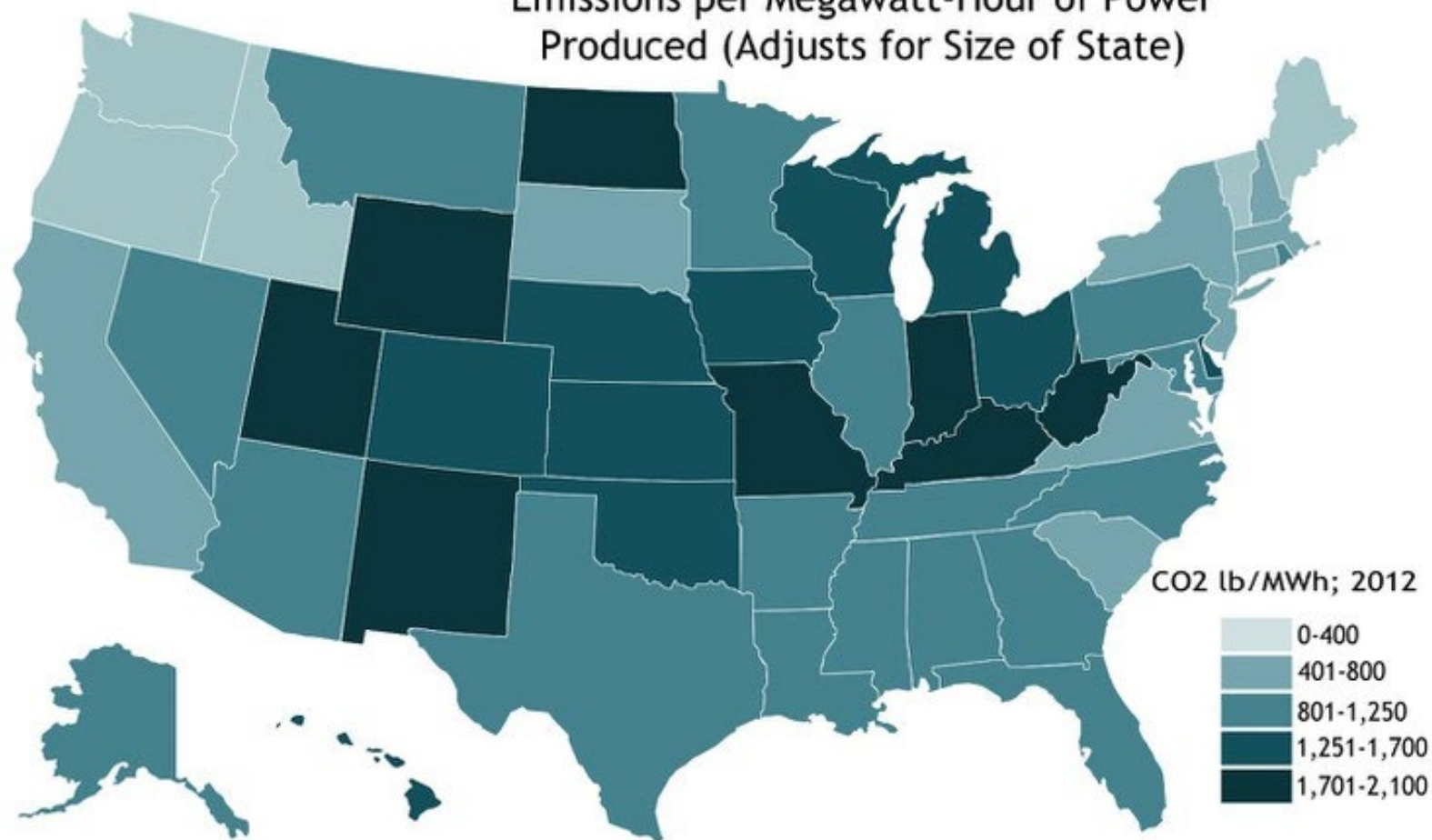
But Doesn't Most Hydrogen Come from Fossil?



State-by-State CO2 Emissions

Emissions per Megawatt-Hour of Power Produced (Adjusts for Size of State)

Not all electricity sources are equal

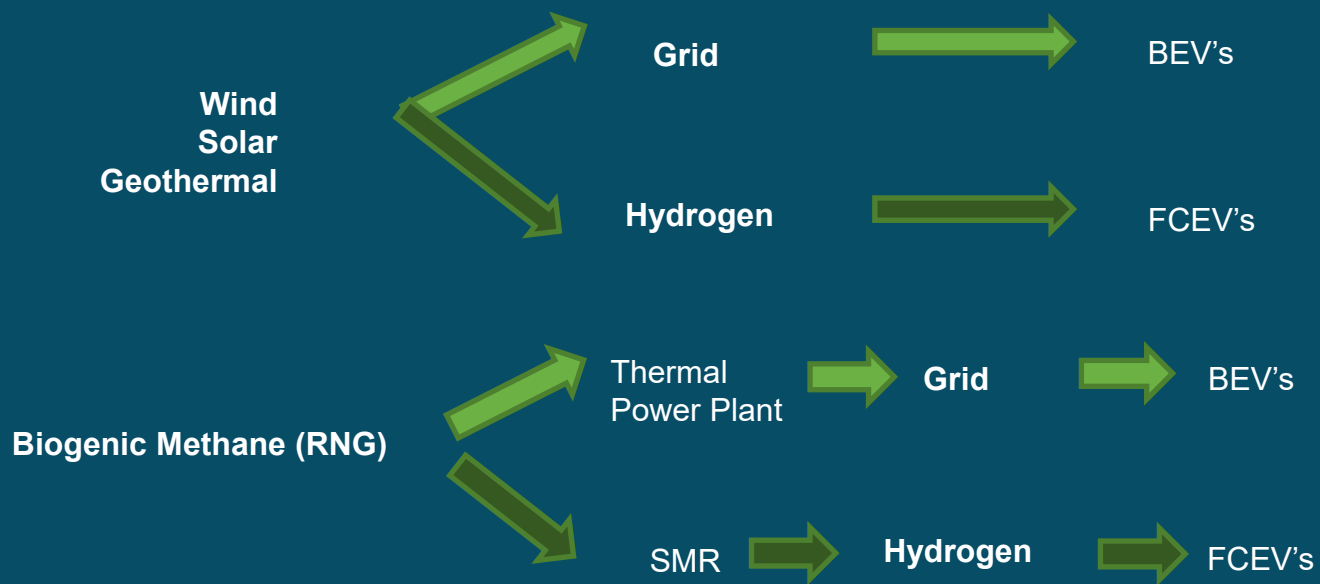


Learn more and download the report at www.ceres.org/airemissions

State-by-state power production CO2 emissions – source Ceres

Carbon-Free Renewable Power Depends on the SOURCE

Carbon content is decided before the electron hits the grid, or hydrogen enters the pipe

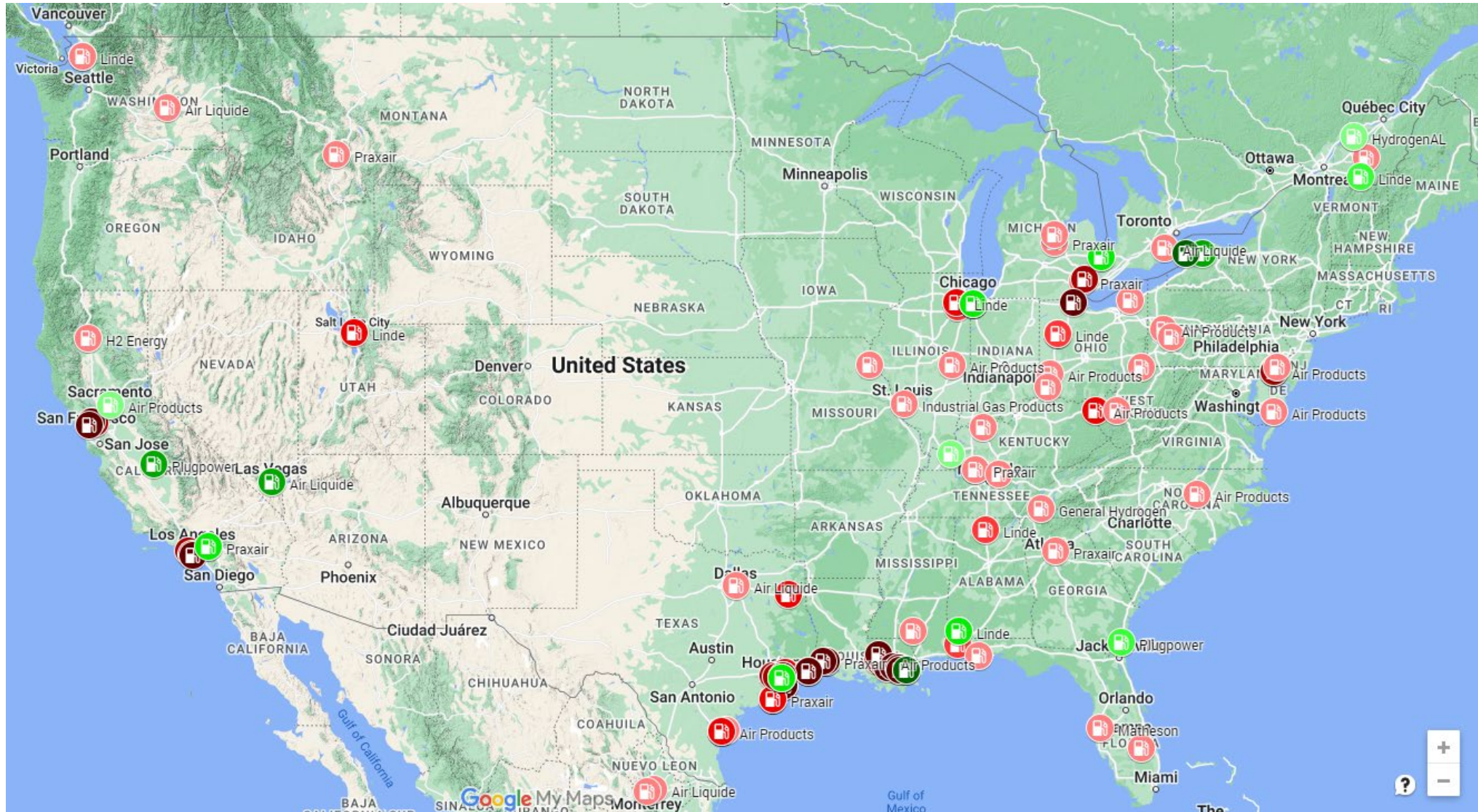


~~VHS vs BetaMax~~

Solar Power + Wind Power
Batteries + Fuel Cells
Diesel or Gasoline
Hydrogen or Grid Power

Hydrogen Fuel in the US, before IIJA / IRA

- H2 Gas
 - Styled by Capacity (tons/day)
 - 0 - 18 (55)
 - 19 - 61 (18)
 - 65 - 125 (24)
 - 145 - 253 (23)
 - 265 - 627 (20)
- H2 Liquid
 - Styled by Capacity (tons/day)
 - 6 - 10 (3)
 - 14 - 15 (2)
 - 20 - 28 (5)
 - 30 - 45 (3)
 - 54 - 63 (2)



Source: H2tools.org, project press releases

US Federal Hydrogen Cost Reduction Programs



Bipartisan Infrastructure Law - Hydrogen Highlights



- Covers **\$9.5B** for clean hydrogen:
 - **\$8B** for at least four regional clean hydrogen hubs
 - **\$1B** for electrolysis research, development and demonstration
 - **\$500M** for clean hydrogen technology manufacturing and recycling R&D



President Biden Signs the Bipartisan Infrastructure Bill on November 15, 2021.
Photo Credit: Kenny Holston/Getty Images

- Aligns with **Hydrogen Shot priorities** by directing work to reduce the cost of clean hydrogen to **\$2 per kilogram by 2026**
- Requires developing a **National Hydrogen Strategy and Roadmap**

Hydrogen Energy Earthshot

“Hydrogen Shot”

“1 1 1”
\$1 for 1 kg clean hydrogen
in 1 decade

Launched June 7, 2021
Summit Aug 31-Sept 1, 2021



A wide ecosystem to support your FCEB deployments with complete hydrogen fueling solutions



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First Deployments and Gaseous H2 Options

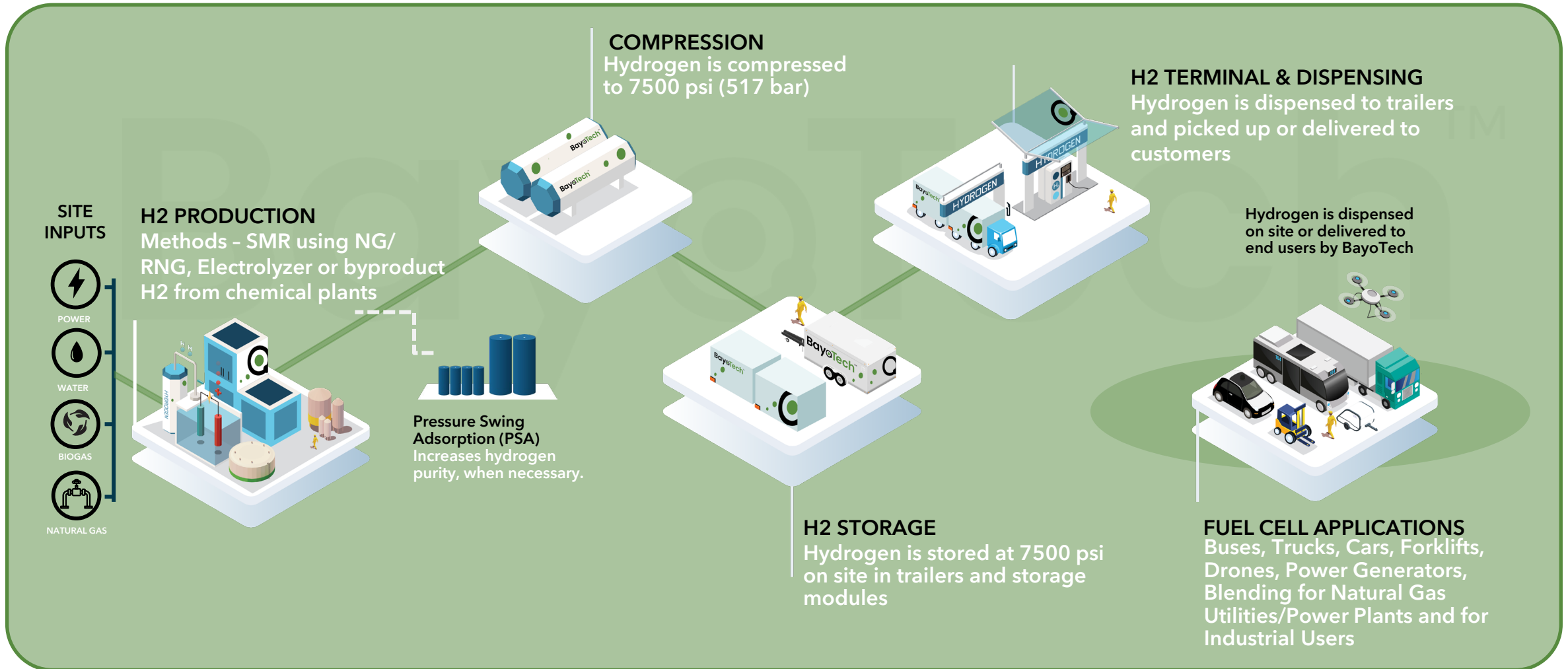


Hernan Henriquez

Vice President of Sales

BayoTech

How Does a BayoTech Distributed Hydrogen Hub Work?



Fuel Cell Transit Bus Fleet Fueling Solutions



Pilot Programs

Direct fill trucks from BayoTech's gas transport modules. Pay for hydrogen by the kilogram with no capital overhead.



Demonstration Fleets:

Hydrogen delivery, storage and dispensing via high-pressure, high-capacity HyFill™ transport trailers and skid-based dispenser.



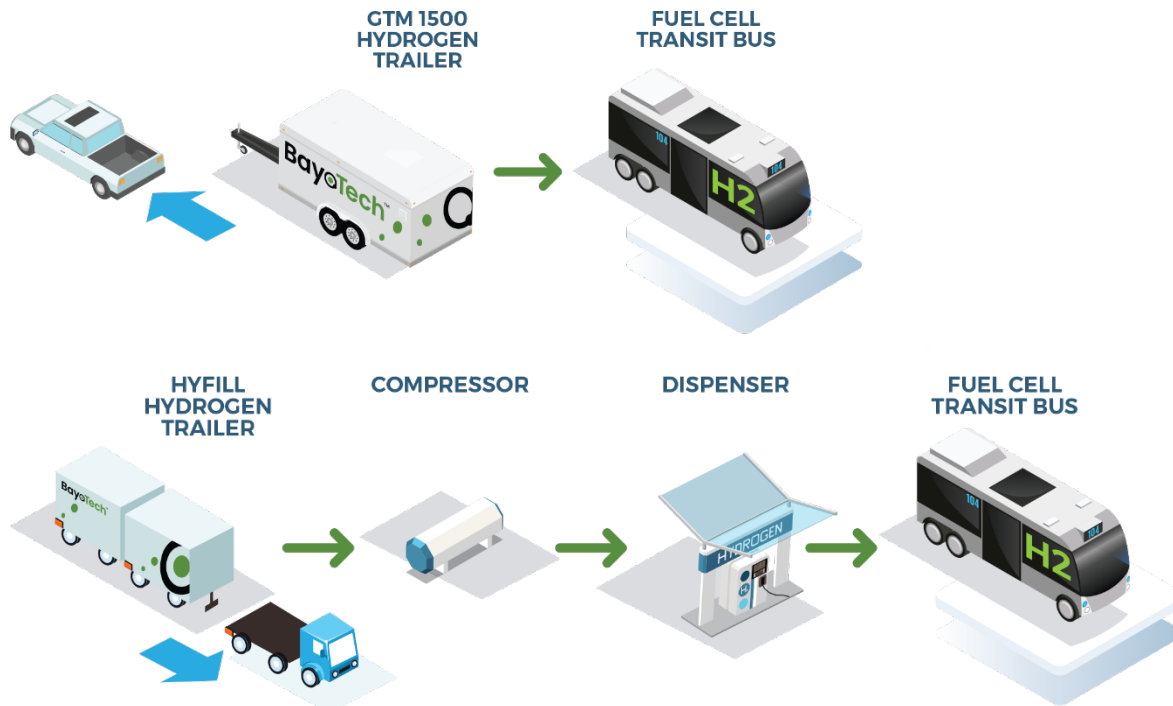
Full Fleet Conversion

Onsite hydrogen production with BayoTech's highly efficient, compact & scalable hydrogen hubs.

Scalable Fuel Cell Bus Fueling Solutions

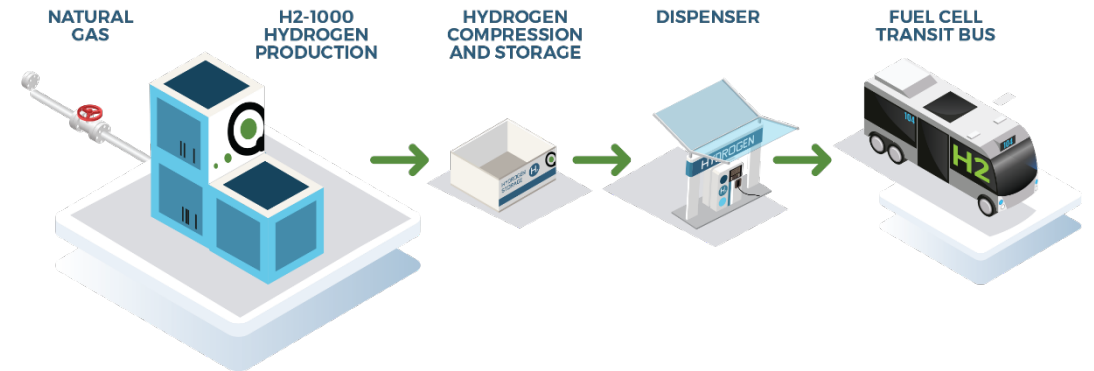
Delivered Hydrogen: <10 buses

- Hydrogen delivered to the bus depot via high-pressure transport trailers
- Capacity of up to 750kg per trailer is sufficient for 25-30 bus fills
- Depleted trailer swapped with full trailer by BayoTech as required



Onsite Production: >10 buses

- BayoTech owned and operated SMR hydrogen production hub installed at transit depot
- Hydrogen is produced on site or close by and dispensed directly to buses
- Scalable infrastructure produces 2,000+ kilograms per day



Customer Case Study: Champaign-Urbana Mass Transit District

Challenge:

- When it became clear that the completion of hydrogen station would lag behind the delivery of new fuel cell buses, MTD needed a temporary hydrogen fueling solution.

Solution:

- To ensure timely & reliable delivery, BayoTech was selected to provide hydrogen fuel and fueling infrastructure to bridge the gap.
- BayoTech's gas transport module was deployed to provide hydrogen within a tight deadline. The stanchion was customized to meet MTD's specific requirements.

Result:

- The easy-to-use system paired with BayoTech's unbridled customer support, let MTD complete the commissioning and training process.
- Even with the completion of MTD's onsite hydrogen production station, the partnership between MTD and BayoTech is expected to continue for reliable secondary hydrogen supply.

"Launching a start-up hydrogen project is complicated. **BayoTech really saved the day** in providing their temporary fueling stanchion and trailers. They were a pleasure to work with and their accommodations were much appreciated."

Karl Gnadl, Managing Director, CUMTD



MTD

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Liquid H2 and Fleet Deployments at Scale

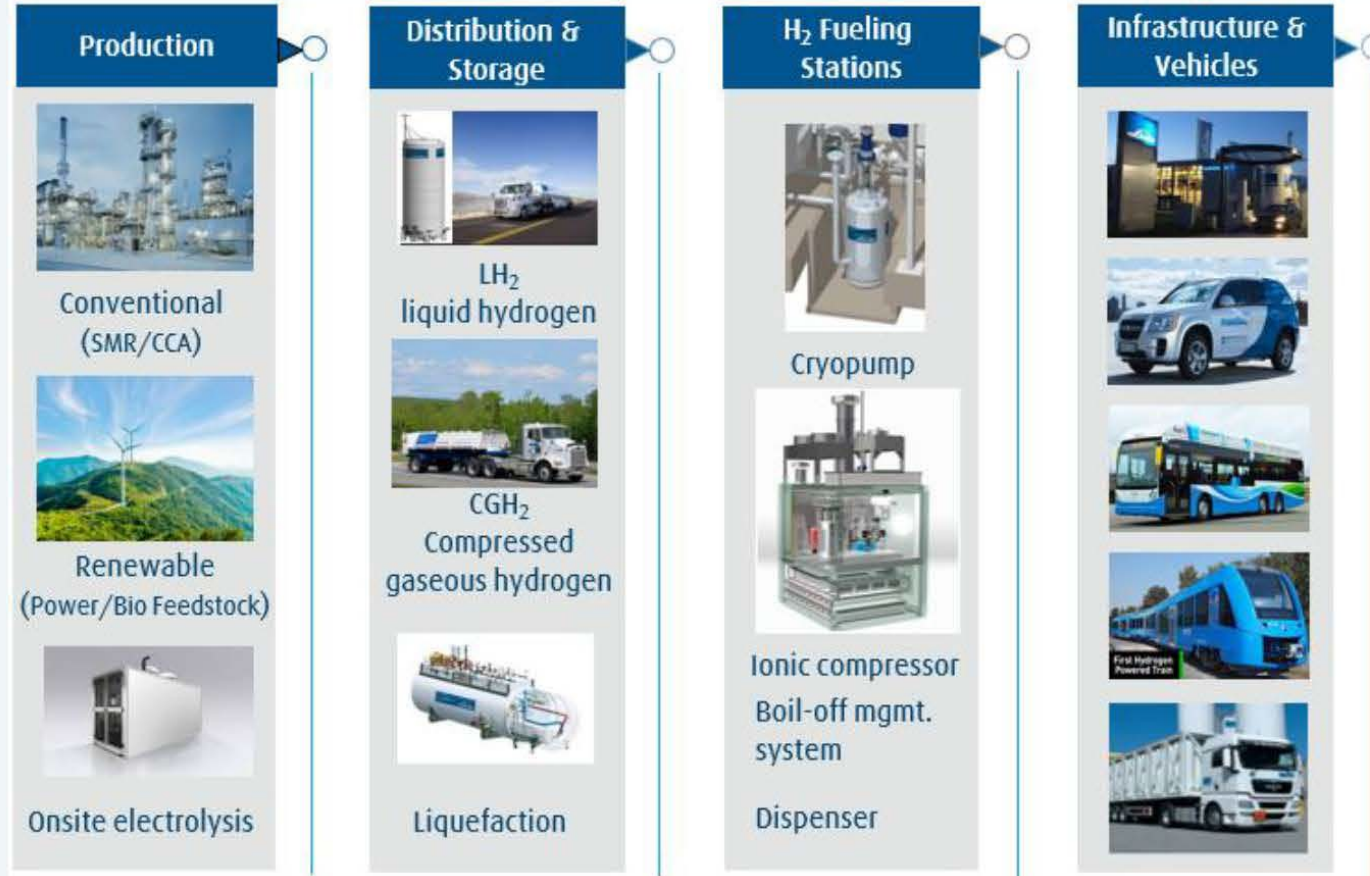


Stacey Grauer

Business Development Director, Clean Hydrogen

Linde Inc

Linde's Hydrogen Value Chain for H₂ Mobility

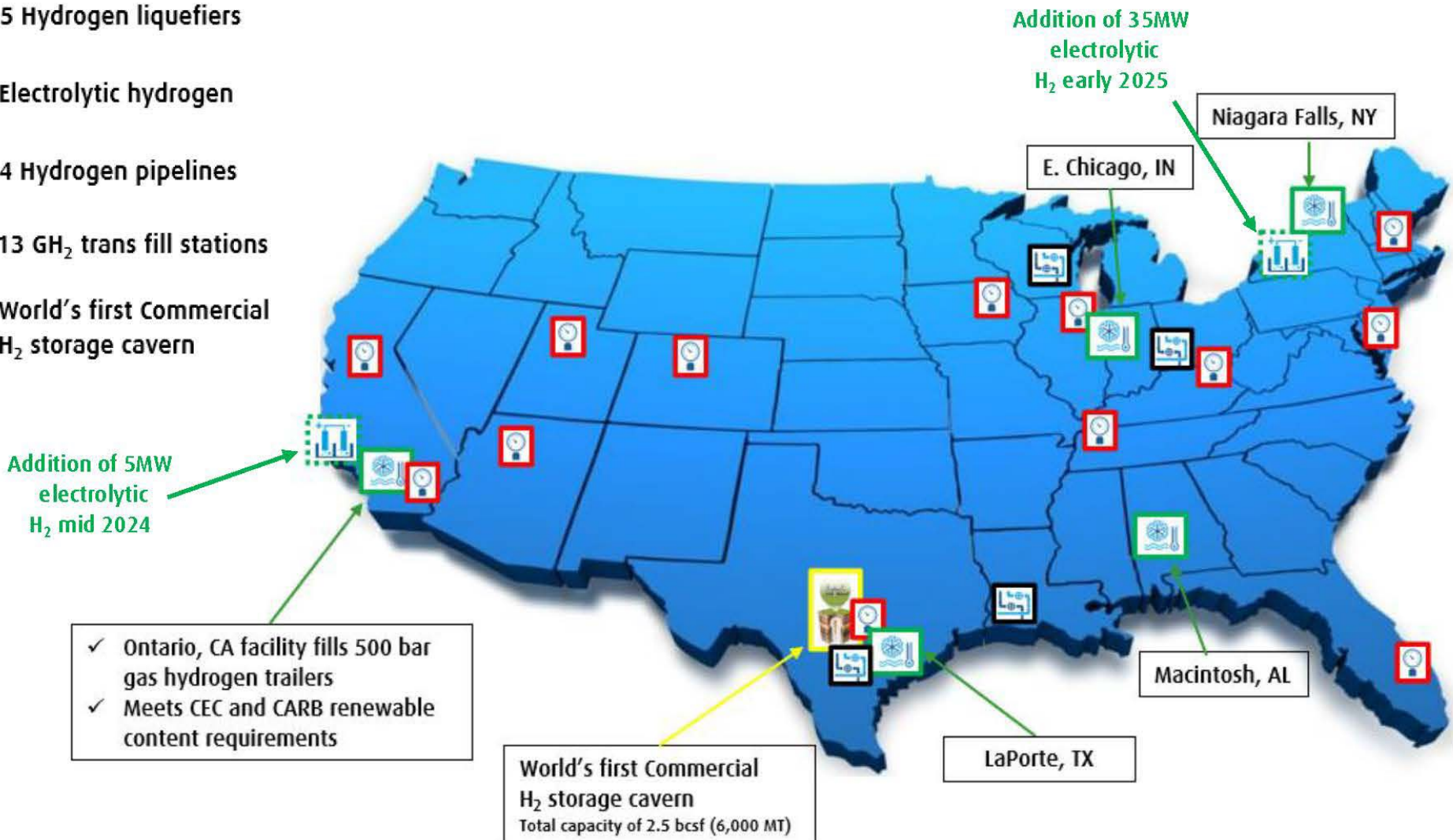


- ✓ Experienced
 - >200 H₂ stations
 - >1.5MM successful H₂ fuelings
- ✓ Customized design
 - Liquid, gas and on site solutions
- ✓ Turn key installation
- ✓ 24/7 Customer service
- ✓ System maintenance
- ✓ Certified green hydrogen documentation

North America's Largest Merchant Hydrogen Supplier



-  5 Hydrogen liquefiers
-  Electrolytic hydrogen
-  4 Hydrogen pipelines
-  13 GH₂ trans fill stations
-  World's first Commercial H₂ storage cavern



Distribution and Storage Gas and Liquid Hydrogen



Liquid



~3,370 kg



LHY Cryogenic Tank

Gas



180 bar ~280 kg
500 bar ~400 kg



GHY Receiver Bank

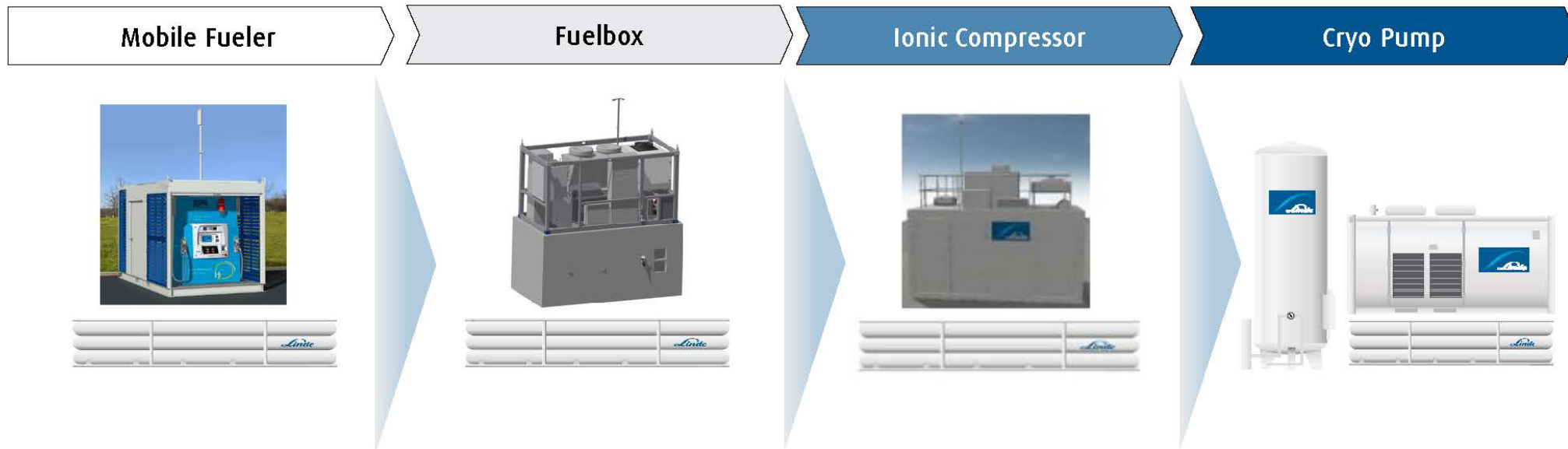


GHY Pipeline

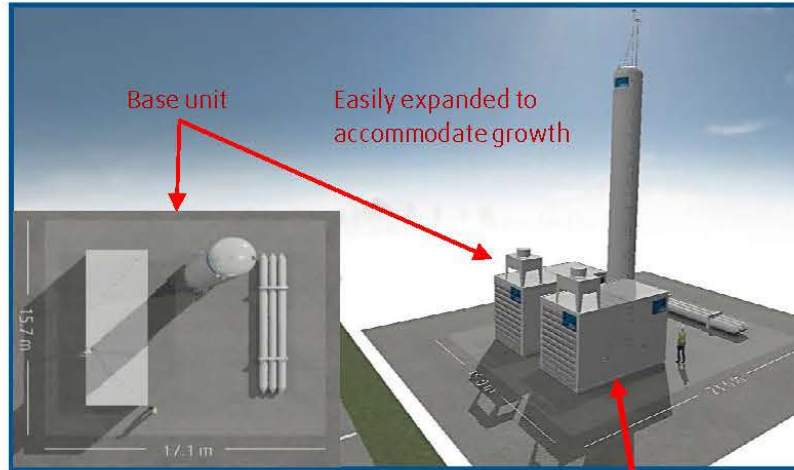
Linde Technology Solutions



Small	Medium	Medium/Large	Large
GHY feed supply	GHY feed supply	GHY feed supply	LHY feed supply
Integrated dispenser	Integrated dispenser	Parallel fueling supported	Parallel fueling supported
Minimal utilities, installed in 1 day	Minimal utilities & infrastructure	Modular & easily expandable	Modular & easily expandable
350 bar	350 or 700 bar	350 or 700 bar, parallel fueling	350 or 700 bar, parallel fueling
Mobile	Semi-Mobile	Permanent	Permanent

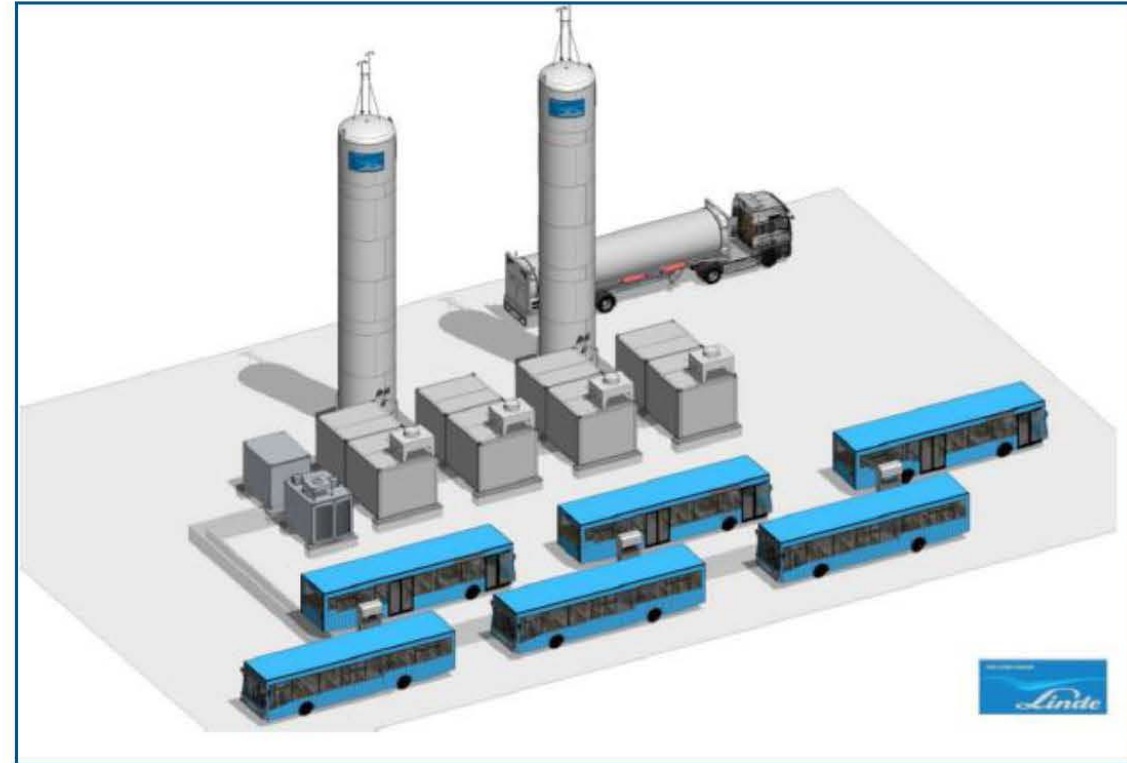


Linde Cryo Pump Solution: Large Scale Refueling with LH2



Benefits:

- Modular design
- Easy to install and relocate
- 2 chamber submersible pump
- LH₂ compressed to 100 Mpa and -40C
- High purity maintained
- More energy efficient than conventional compressor
- No external cooling required



- ✓ Fueling capacity: 2,400 kg in 6 hours
- ✓ Core technology: 4x CP 90 (100 kg/hour each)
- ✓ High pressure storage capacity: 500 kg
- ✓ 6x 350 bar dispensing lines

- ✓ LH₂ storage capacity: 2x 4,500 kg
- ✓ Total footprint station: 85'3" (length) x 39'4" (width)
- ✓ Electrical connection power: 400 kW

Making our world more productive



For more information
Please contact:
Stacey Grauer
Director of Business Development
stacey.grauer@linde.com



**Thank You
for Your Attention**

BALLARD™

Ensuring Successful Station Builds



Nick Barilo

Executive Director, Center for Hydrogen Safety, AIChE

Comparing Hydrogen and Gasoline

All fuels contain energy and can pose a hazard if not properly handled. Just like gasoline, diesel, and natural gas, it is important to know the properties and follow established rules to safely handle hydrogen.

Gasoline Characteristics	Hydrogen Characteristics
Combination of various hydrocarbons and additives with varying toxicity.	Pure hydrogen with no toxicity.
Stored as a liquid in sealed containers at atmospheric pressure.	Generally stored as a gas in sealed cylinders at high pressure.
Harder to ignite.	Easier to ignite (high pressure releases often autoignite).
Leaks result in pools that accumulate at low points. If ignited, will result in pool fires.	Leaks result in gas jets that disperse quickly. If ignited, will result in directional jet fires like a blow torch.
Vapors accumulating in an enclosed space with air can explode if ignited.	Gas accumulating in an enclosed space with air can explode if ignited. The hydrogen explosion occurs more rapidly because hydrogen burning velocity is so high.
Generally, not corrosive to common materials of construction for components.	Will embrittle some common materials used for components, so selection of compatible materials is important.



Comparing Common Fuels

	Hydrogen Gas	Natural Gas	Gasoline
Color	No	No	Yes
Toxicity	None	Some	High
Odor	Odorless	Yes (mercaptan)	Yes (benzene)
Buoyancy <i>Relative to Air</i>	14X Lighter	2X Lighter	Vapor is 3.75X Heavier
Autoignition Temperature (C)	585°	539°	232°
Energy by Weight	2.8X > Gasoline	~1.2X > Gasoline	43 MJ/kg
Energy by Volume	4X < Gasoline	1.5X < Gasoline	120 MJ/Gallon



State of Hydrogen Safety

Safety issues can be a 'deal breaker' and must be addressed for successful hydrogen technology acceptance and deployment

Its Use as a Fuel is New to Many

- ▶ Users may lack experience or expertise for its safe use
- ▶ Some users have misconceptions... and may not know that they don't know



Stable Foundation

- ▶ Hydrogen can be used safely... It has been for nearly a century by industry
- ▶ Safety knowledge and best practices exist

Dangerous Assumptions

- ▶ "We already know how to use hydrogen safety" (apathy - established users)
- ▶ "Hydrogen is like any other flammable gas" (misconceptions - new players)
- ▶ "Hydrogen is too dangerous" (fear - general public/AHJ's)

Failing to address the knowledge gaps can result in impactful incidents and industry setbacks

Resources for Hydrogen Safety



An online hydrogen information portal

- ✓ Best Practices
- ✓ Lessons Learned
- ✓ Compatibility of Materials
- ✓ Bibliographic Database
- ✓ Codes and Standards
- ✓ Analysis Resource Tools



An expert resource for reviewing projects and facilities



A global non-profit community dedicated to promoting hydrogen safety and best practices worldwide

- ▶ **Collaborate** in a hydrogen safety community of more than 100 members
- ▶ Access resources to **remove barriers** and manage risk
- ▶ **Increase knowledge** and expertise
 - Training courses, credentialing, and webinars
 - Conferences and workshops
 - Incident resources
 - Technical bulletins

Hydrogen Tools: <https://h2tools.org>

Hydrogen Safety Panel: <https://h2tools.org/hsp>

Center for Hydrogen Safety: www.aiche.org/chs



Hydrogen Safety Panel (HSP)

THE HSP PROMOTES SAFE OPERATION, HANDLING, AND USE OF HYDROGEN

Background

- ▶ Formed in 2003
- ▶ 22 members with 600+ yrs combined experience
- ▶ Hydrogen safety reviews – hydrogen fueling, auxiliary power, backup power, CHP, portable power, and lab R&D
- ▶ White papers, reports, and guides
- ▶ Provides support on the application of hydrogen codes and standards

20 Years

606 Reviews

436 Projects

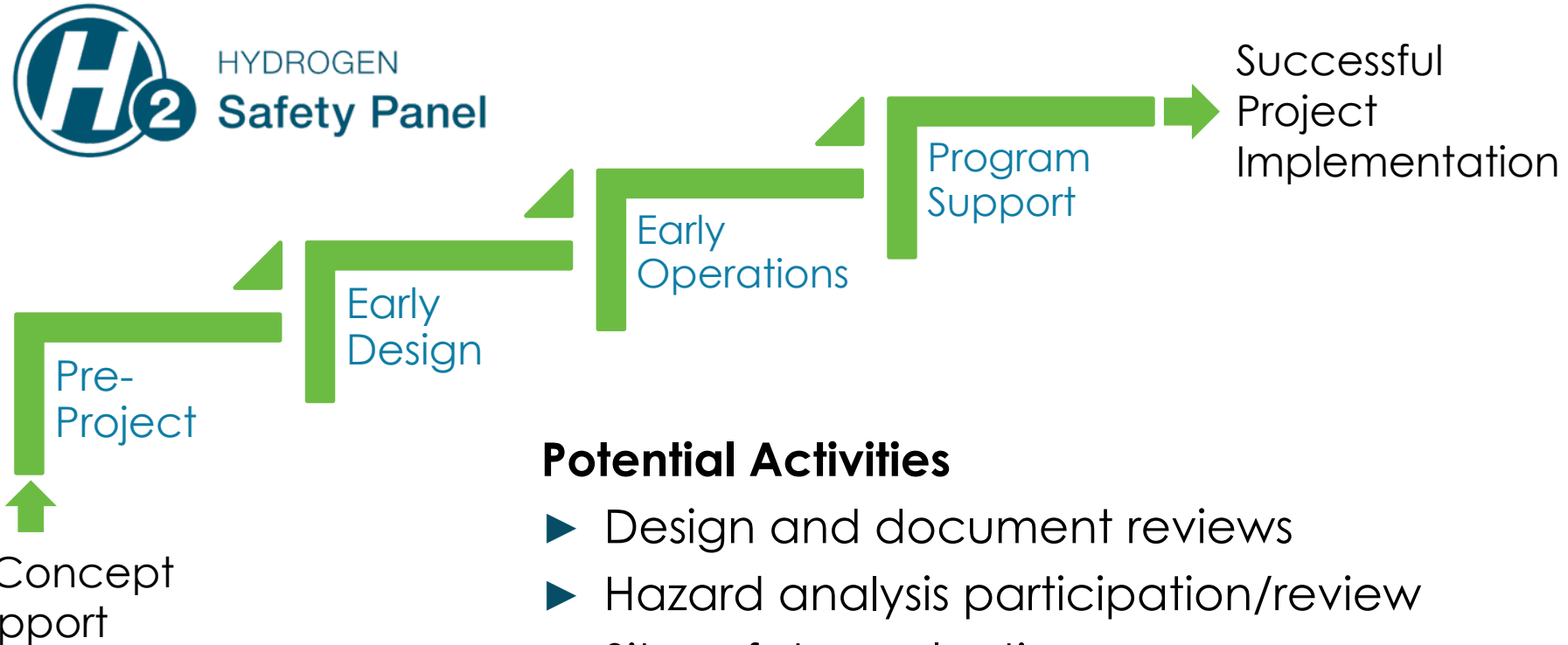
200+ Presentations

15 Guides

Impact

- ▶ Non-regulatory, objective, and neutral
- ▶ Helps reduce costs
 - Costs from over-engineering
 - Delayed approvals
 - Missed safety considerations/features
- ▶ Provides a balanced solution to questions and problems
- ▶ Helps projects avoid safety incidents
- ▶ Helps establish stakeholder and public confidence

CHS Use of the Hydrogen Safety Panel



Potential Activities

- ▶ Design and document reviews
- ▶ Hazard analysis participation/review
- ▶ Site safety evaluations
- ▶ Safety training and webinars
- ▶ Outreach
- ▶ Incident investigation

The HSP Provides Review Services



Education and Training



<https://tinyurl.com/CHS-Course>

Fundamental Hydrogen Safety E-Courses

- Hydrogen as an Energy Carrier
- Properties and Hazards
- Safety Planning
- Facility Design
- Equipment and Components
- Liquid Systems
- Material Compatibility
- System Operation
- Inspection & Maintenance

New Free eLearning Course

- Hydrogen Laboratory Safety



First Responder Hydrogen Safety E-Courses

- Introduction to Hydrogen Safety for First Responders
- First Responders Micro Training Learning Plan
- Introduction to Hydrogen Fuel Cell Vehicles for Incident Response
- Fire Response & Extrication of a Hydrogen Fuel Cell Vehicle
- Transport of Hydrogen Fuel
- Hydrogen Fueling Station Incident Response

Other Training Resources

Recorded webinars:

- Safety of Water Electrolysis
- Global Hydrogen Safety Codes and Standards
- Ventilation Considerations for Hydrogen Safety
- Material Compatibility Considerations for Hydrogen
- Overview of Hazard Analysis for Hydrogen Applications
- Safety for the Transportation and Delivery of Hydrogen
- Liquid Hydrogen: Safety and Design Considerations

Questions for Consideration

We must recognize that with the promise of hydrogen comes the responsibility of safety

- ▶ How will you ensure that hydrogen safety is a demonstrated value in your project and activities?
- ▶ How will you identify and address hydrogen safety vulnerabilities?
- ▶ How will you ensure that your staff are trained and equipped to identify and address hydrogen safety questions, concerns, and challenges?

Be prepared and avoid having to deal with the consequences of an incident

 **BALLARD™**

Thank you

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