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University of Connecticut

Hydrogen Technologies Research and Applications Initiatives

November 2, 2023

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Reducing Our Pawprint

OUTLINE

1. Potential Benefits
2. Pathways to Production
3. A Word about Carbon Capture
4. What is Green Hydrogen?
5. Challenges to Scalability
6. Why not? Why now?
7. UConn's plans…

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Reducing Our Pawprint

December 6, 2022 | Stephanie Reitz - UConn Communications

UConn Aims to Achieve Carbon Neutrality by 2030 and Become International Model of Sustainability

'There are unique things that we can do at this campus that no other campus is doing. We have the vision, interdisciplinary science, and technologies ready and have to start implementation'

President Radenka Maric gives U.S. Secretary of Energy Jennifer Granholm at tour of her lab during a visit to the Center for Clean Energy Engineering on May 20, 2022. (Peter Morenus/UConn Photo)

UConn Carbon Reduction Goals

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Fall 2022 Letter of Commitment for Carbon Reduction

“ We are putting our University on an accelerated path to net zero emissions for buildings and our energy supply as well as significantly reducing greenhouse gas emissions to become carbon neutral by 2030” - President Radenka Maric

U.S. Secretary of Energy Jennifer Granholm with UConn President Radenka Maric - hydrogen fuel cell & vehicle are featured.

Hydrogen Energy

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- **[Hydrogen is a] key player in the decarbonization efforts to**
  - **reduce emissions** of greenhouse gases (GHGs),
  - achieve carbon neutrality by 2050, and
  - reach the Paris Agreement targets to limit global warming to 1.5°C, compared to pre-industrial levels.

Source: U.S. Department of Energy

Hydrogen: Sector Decarbonization

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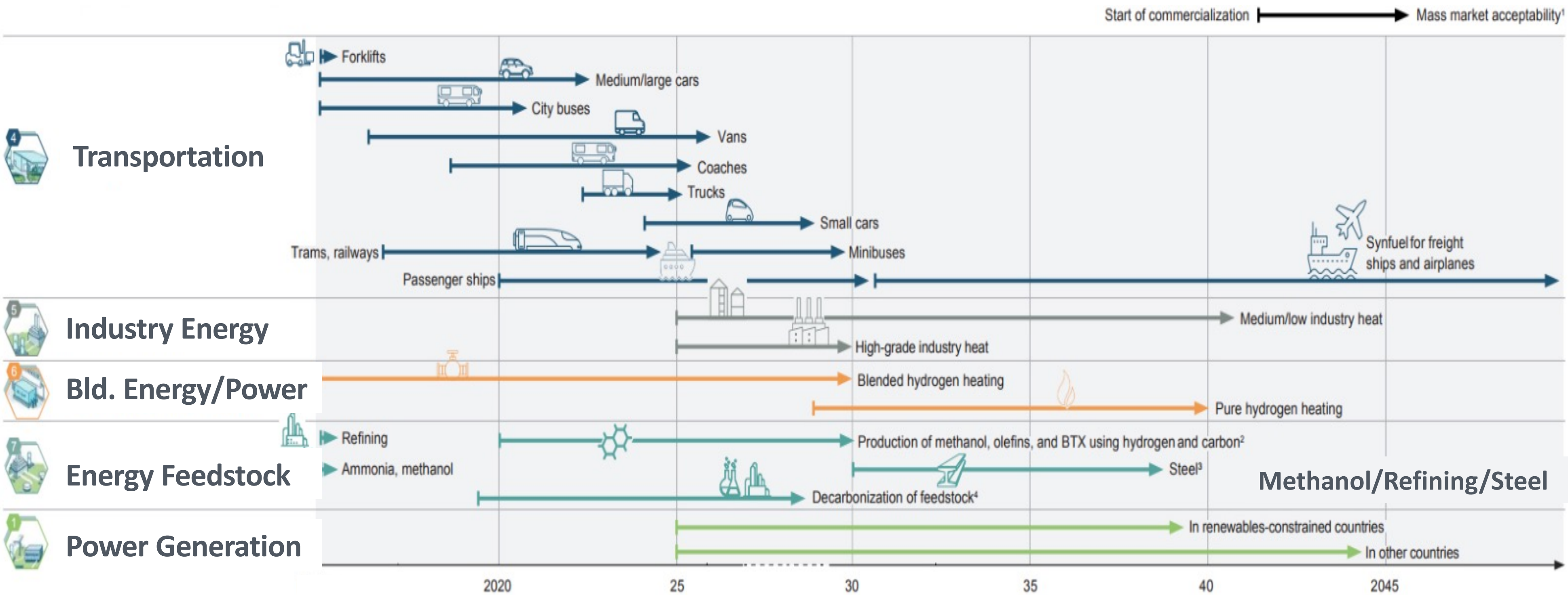
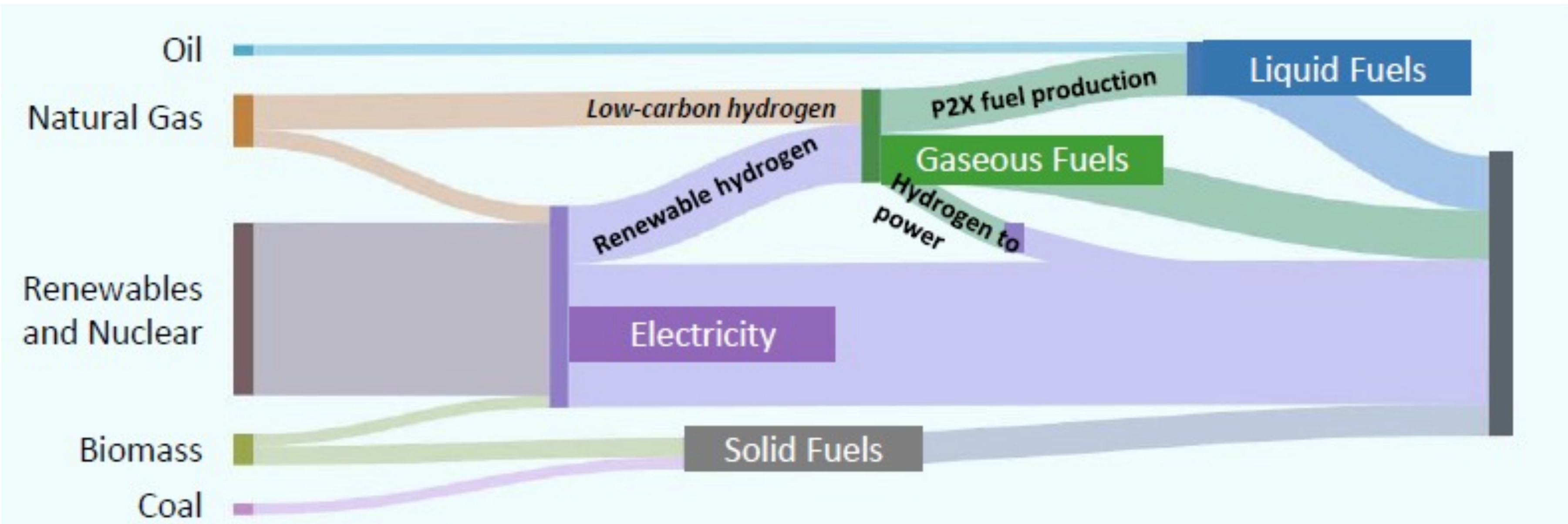


1 Defined as sales >1% within segment in priority markets
2 Market share refers to the amount of production that uses hydrogen and captured carbon to replace feedstock
3 DRI with green hydrogen, iron reduction in blast furnaces, and other low-carbon steel making processes using hydrogen
4 Market share refers to the amount of feedstock that is produced from low-carbon sources

SOURCE: Hydrogen Council

Source: Hydrogen Council

Hydrogen: Future Energy Systems



Source: Hydrogen in Decarbonized Energy Systems, Hydrogen Council, Baringa Partners, October 2023

Hydrogen Energy: Benefits

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"Electrolizers can offer a source of demand-side flexibility to power systems…"

Flexibility

- **Power system flexibility** - How will short term and seasonal fluctuations caused by large amounts of intermittent solar and wind be dealt with?
- **Regulation of supply and demand** - how do systems create the right incentives for rewarding system flexibility?

electrolyzers can offer a source of demand-side flexibility to power systems, provided they are free to respond effectively to market price signals and not isolated from the wider system through regulatory rules

*Source: Hydrogen in Decarbonized Energy Systems, **Hydrogen Council**, Baringa Partners, October 2023*

Hydrogen Energy: Benefits

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"...offers a form of long-duration energy storage at times... at time batteries will not be able to cover...."

Security and resilience

- **Resilience in isolated systems** - how will power systems deal with more acute supply/demand imbalances caused by weather events?
- **Import / export security** - how will regions with large net energy balances maintain security of supply and demand?
- **Price shocks** - How will systems deal with unexpected changes in commodity prices?

Hydrogen offers a form of long-duration energy storage where it can be burned to produce power at times where there is a prolonged supply shortage that batteries will not be able to cover cost-effectively

Hydrogen can be sourced from a variety of countries with strong renewable supply potential, reducing risk of energy cartels capable of controlling prices

"...sourced from a variety of countries... reducing risk of energy cartels...."

*Source: Hydrogen in Decarbonized Energy Systems, **Hydrogen Council**, Baringa Partners, October 2023*

Hydrogen Energy: Benefits

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"...produced from both renewable power and natural gas.... to hedge against shocks to either gas or power prices"

Affordability

- Optimal use of limited resources - how can systems with limited renewable resources keep the cost of decarbonized energy to a minimum?
- How does the system effectively link resources to demand?
- How do we reduce the risk of stranded assets used to serve fossil fuels and extend asset lifetime?

- Hydrogen can be produced from both renewable power and natural gas, offering opportunities to hedge against shocks to either gas or power prices
- Ammonia derived from hydrogen can provide a major source of power where there is low renewable resource
- Hydrogen pipelines can be an optimal means of moving energy across a region as well as a means of prolonging the lifetime of natural gas network and storage infrastructure

"Hydrogen pipelines can move energy across regions and prolong the lifetime of natural gas network and storage infrastructure"

*Source: Hydrogen in Decarbonized Energy Systems, **Hydrogen Council**, Baringa Partners, October 2023*

Hydrogen & Natural Gas Pipelines

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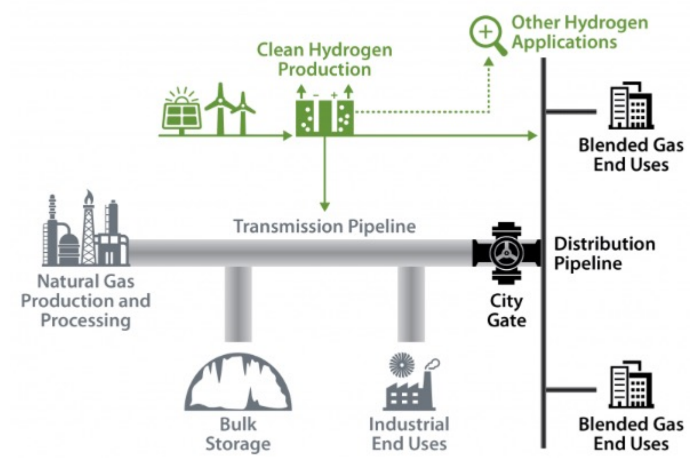
In 2021, the natural gas pipelines provide service for about:

- 32% of the nation's energy consumption
- 27.6 trillion cubic feet
- 7.77 million consumers



DOE's HyBlend initiative aims to address technical barriers to blending hydrogen in natural gas pipelines. Key aspects of HyBlend include materials compatibility R&D, techno-economic analysis, and life cycle analysis that will inform the development of publicly accessible tools that characterize the opportunities, costs, and risks of blending.

Source: Hydrogen Fuel Cell Technologies Office, Hyblend: Opportunities for Hydrogen Blending in Natural Gas Piplines

Hydrogen Blending in Florida

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FPL's Okeechobee Clean Energy Center,
a 3-on-1 combined-cycle plant with a capacity of approximately 1622 MW.

Florida Power & Light Company (FPL)

- Solar power
- Series of electrolizers
- Natural Gas Turbine Generators
- 3 Solar Sites (75 MW each)
- 5% Blend Pilot
- 20% Blend Target
- "Real Zero" decarbonization by 2045

Blending hydrogen in natural gas infrastructure at rates higher the 5%

- **Raises chance of leakage**
- **Increases likelihood of pipe embrittlement**
- **Requires equipment modifications**

Sources:

CPUS Issues Independent Study on Injecting Hydrogen Into Natural Gas Pipelines, California Utilities Commission, July 18, 2022
FLP begins producing hydrogen with goal of decarbonizing gas turbines, POWER Engineering, October 11, 2023

Hydrogen – A bit more information

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- **Hydrogen** is the simplest and most abundant element on earth—it consists of only one proton and one electron.
  - **Green Hydrogen** is a zero-emission energy source
  - Hydrogen can store deliver usable energy (it is an "energy carrier')
  - Created from a variety of feedstocks (material sources)
  - Doesn't typically exist by itself in nature and must be produced from compounds that contain it

Source: U.S. Department of Energy

Hydrogen Energy Pathways

Hydrogen Production Pathways can be described by:

1. **Process** used for its production
    - **Thermochemical pathway** - from fossil fuel: Steam Methane Reformation (SMR): natural gas or coal gasification
    - **Electrolytic pathways –** from water-splitting using electricity
    - Biopathways **–** from reforming and pyrolysis of biogas to biomass gasification
    - Advanced solar pathways **–** from solar thermochemical hydrogen to photo-biological processes
2. **Feedstock** (source material)
3. **Energy Source –** fossil fuel / renewable energy
4. **Resulting Emissions** – lifecycle carbon intensively

Source: (Re)Defining Clean Hydrogen: From Colors to Emissions, Ahmet Kusoglu 2022 Electrochem. Soc. Interface 31 47

Hydrogen Production – Thermochemical Pathway

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- **Most hydrogen is produced through steam methane reforming (SMR)**
  (***about 76%*** according to the Center on Global Energy Policy, June 17, 2022)
  - mature production process
  - high-temperature steam (700°C–1,000°C) is used to produce hydrogen from a methane source, such as **natural gas**
  - methane reacts with steam under 3–25 bar pressure (1 bar = 14.5 psi) in the presence of a catalyst
  - hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide is produced

Source: U.S. Department of Energy

Steam Methane Reforming (SMR)

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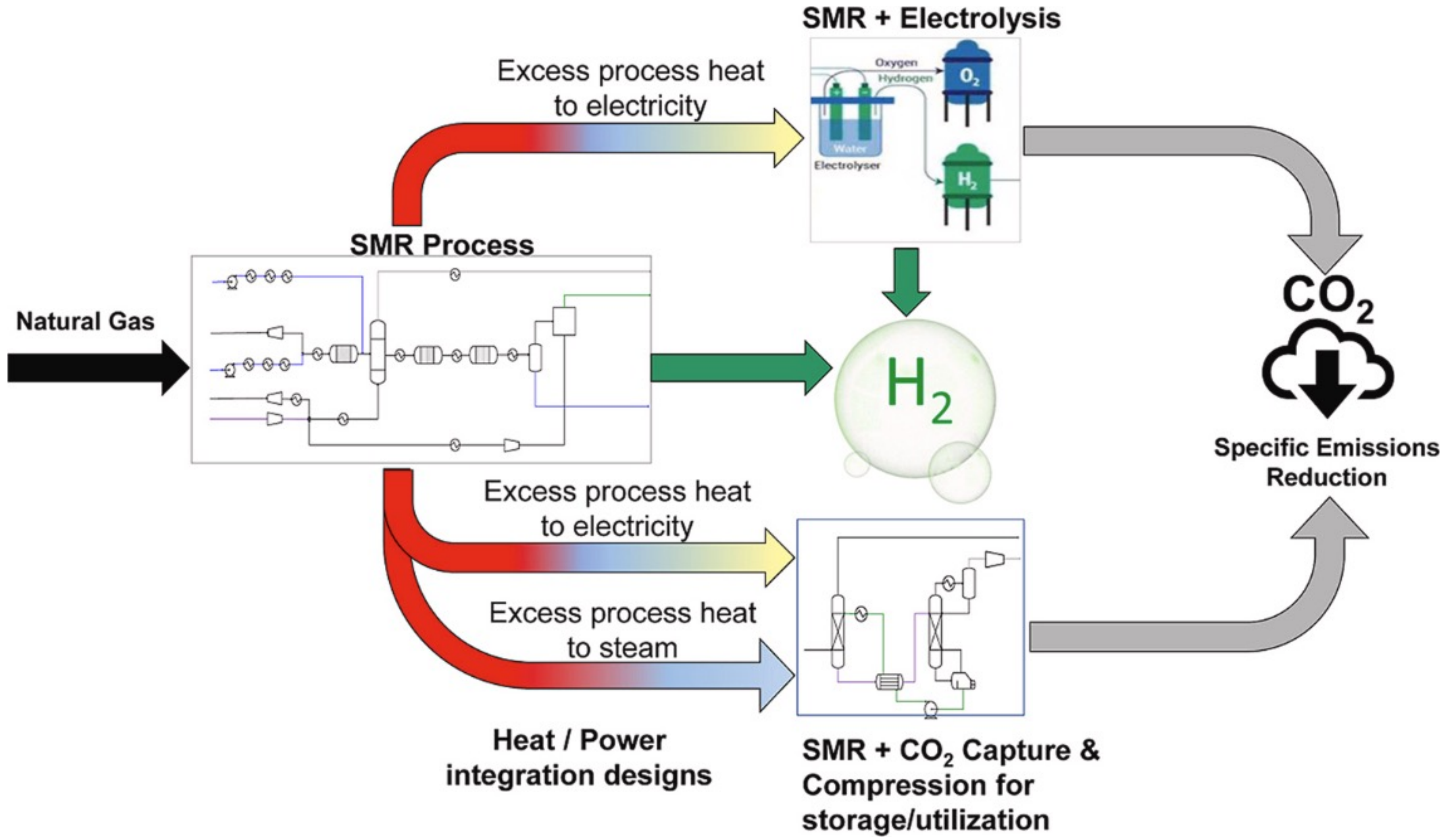

Source: Analysis of hydrogen production costs in Steam-Methane Reforming considering integration with electrolysis and CO_2 capture, Katebah, Al-Rawashdeh, Linke, Cleaner Engineering and Technology, Volume 10, October 2022, 1000552

Production of Hydrogen

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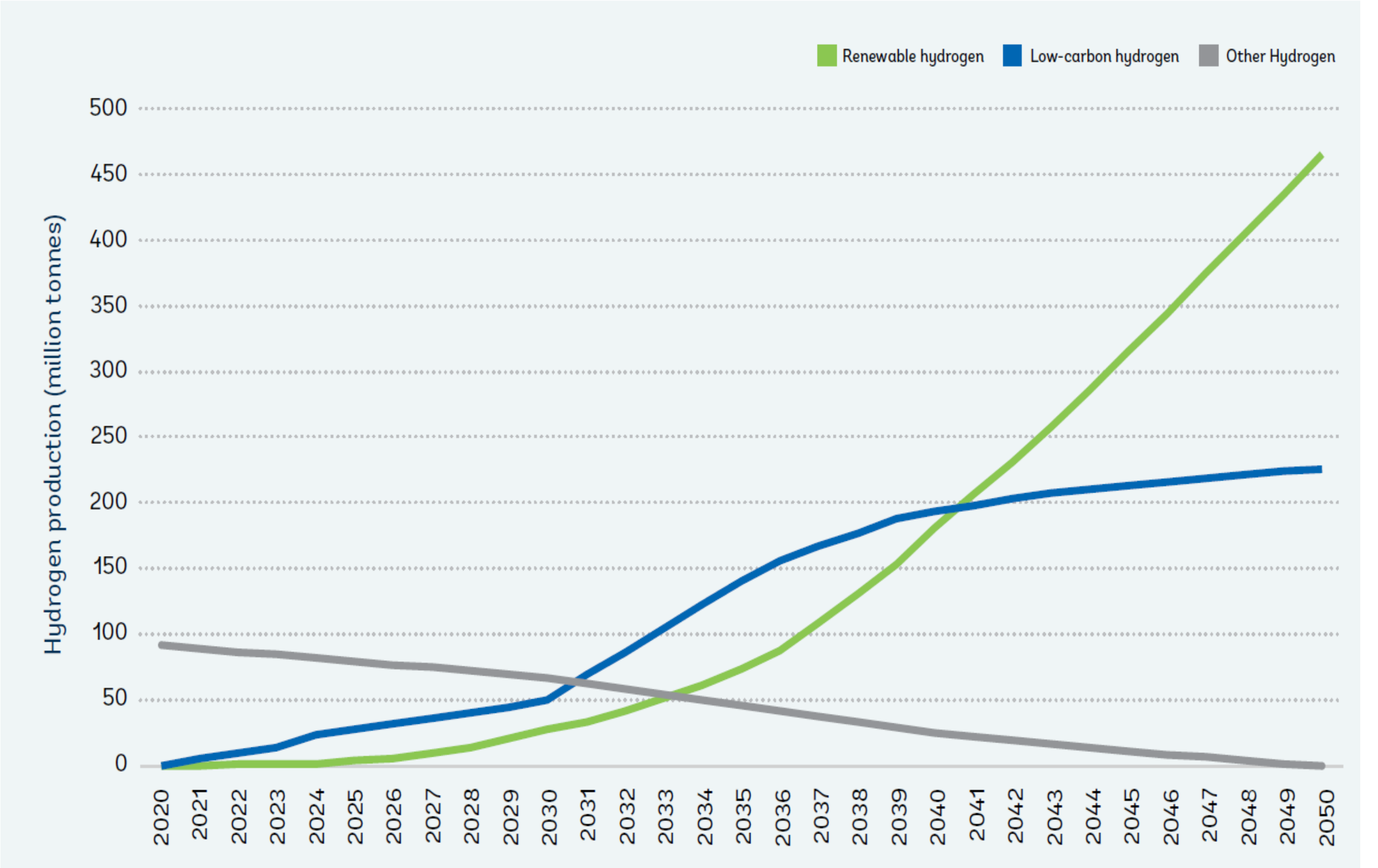
- **GREEN** Hydrogen via electrolysis requires the use of Renewable Electricity
- Steam Methane Reforming (SMR) hydrogen requires CCUS to be **BLUE**



Carbon Capture Using Sequestration (CCUS)

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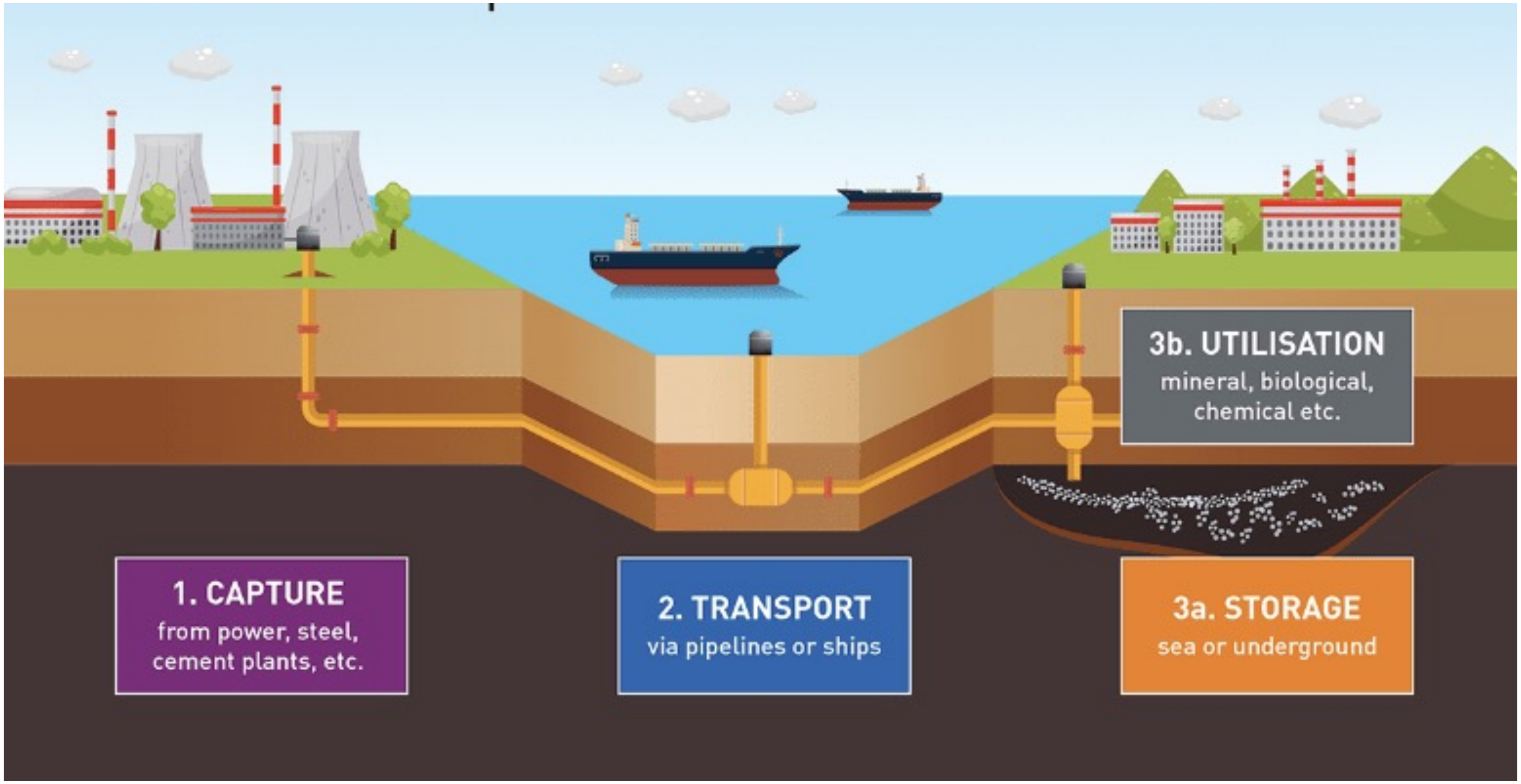
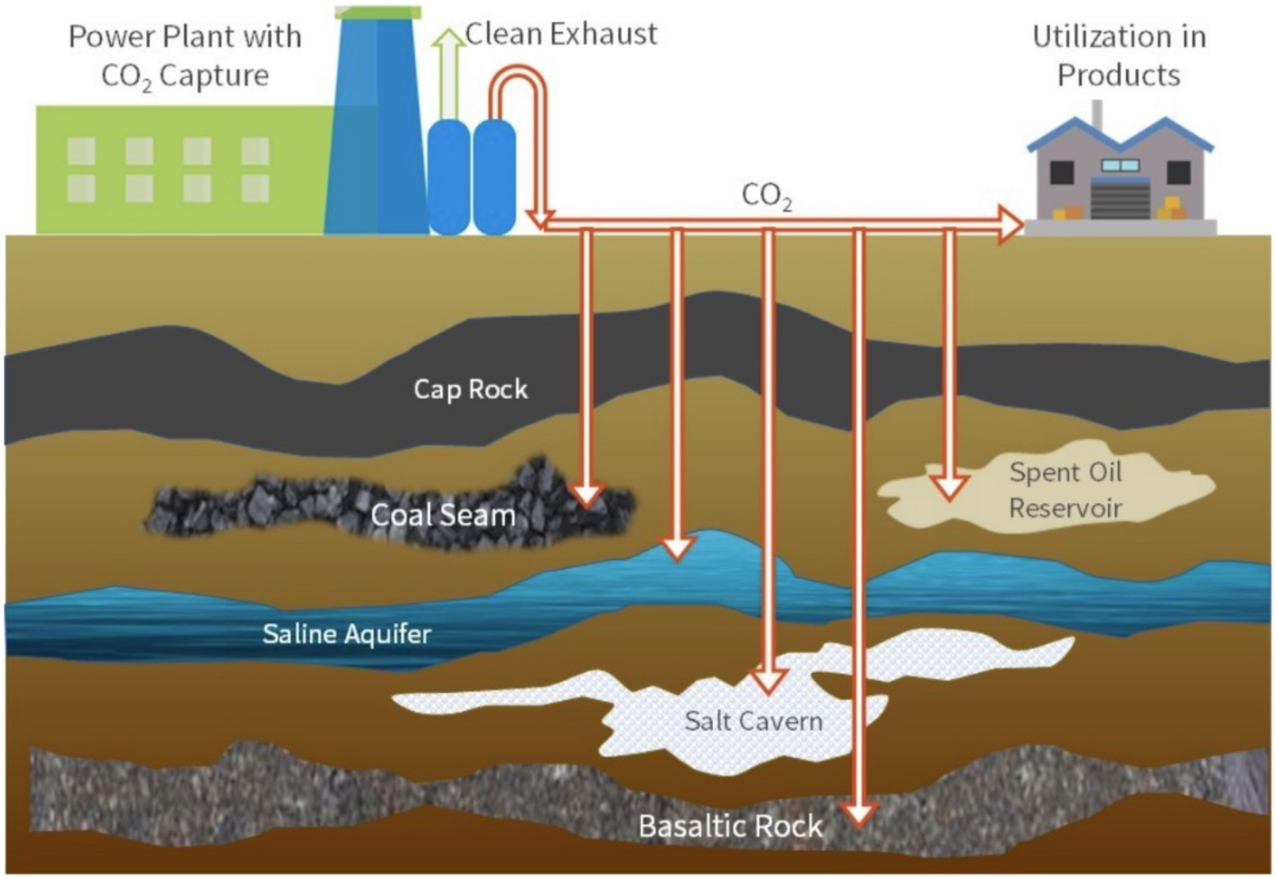


Source: "CCUS: A key technology for a lower carbon future, International Association of Oil & Gas Producers

Geologic Carbon Sequestration



Source: "[The role of carbon capture in climate change policy](#)," Citizens' Climate Lobby, Rick Knight, April 18, 2023.

Capture and Sequestration Global Projects

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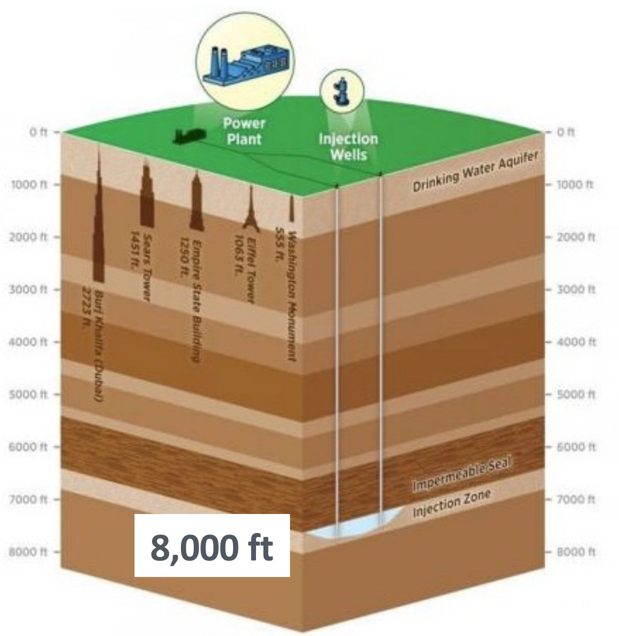

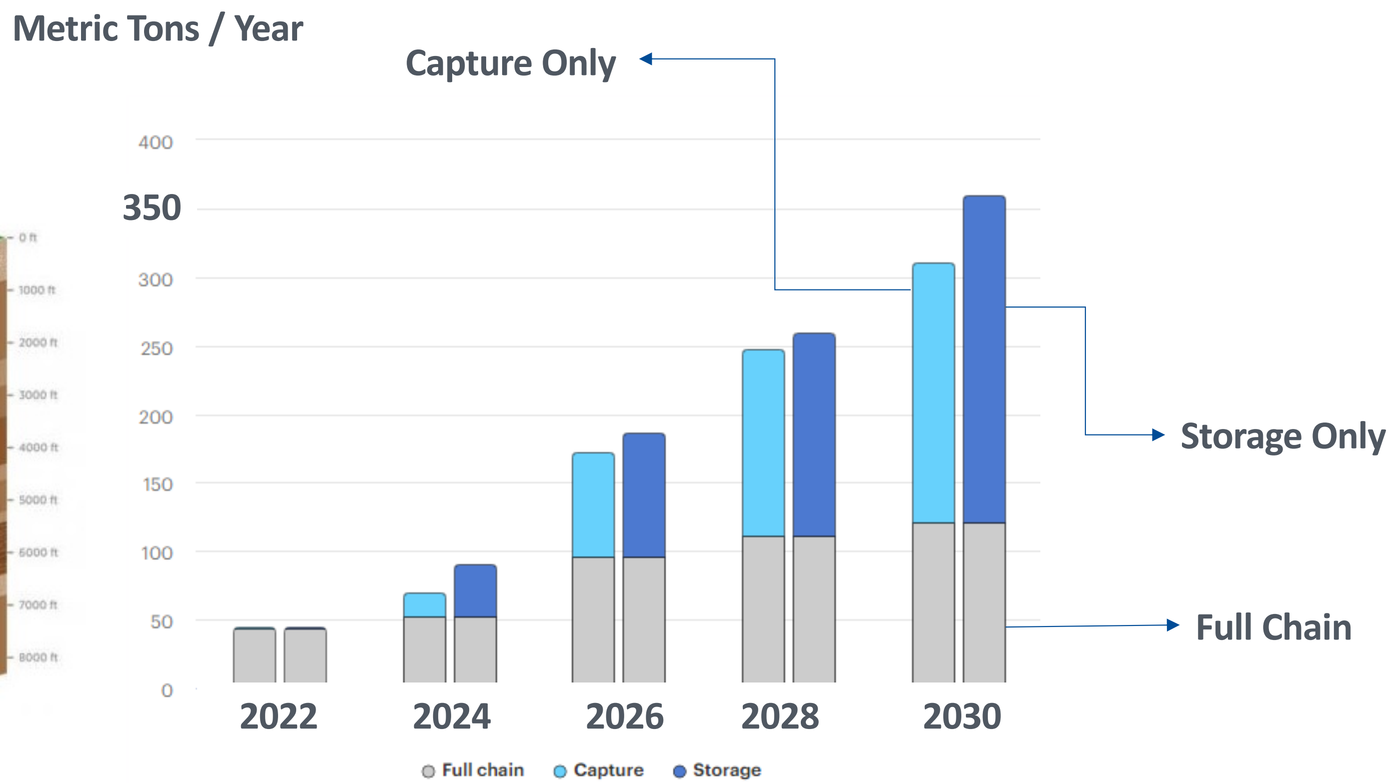

Planned Operational CO_2 Storage Capacity

Sources: Carbon Dioxide Capture and Sequestration: Overview, U.S. EPA
CCSU Projects Explorer, International Energy Agency, March 24, 2023

What is Green hydrogen???

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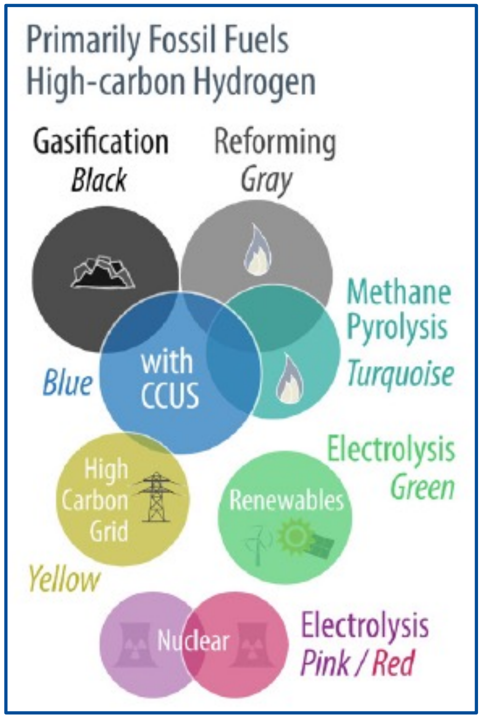
Isn’t all hydrogen Green?

Photo: Saul Loab/AFP/Getty Image

Color of Hydrogen Energy

Black	**Gasification – Coal**
Grey	**Reforming – Natural Gas**
Turquois	**Methane Pyrolysis – Natural Gas & Biopathways**
Blue	*All of above with Carbon Capture Using Sequestration (CCUS)*
Yellow	**High Carbon Grid Electricity**
Pink / Red	**Nuclear (Electrolysis)**
Green	**Renewable Energy Sources (Hydro, Wind, Solar)**



Source: (Re)Defining Clean Hydrogen: From Colors to Emissions, Ahmet Kusoglu 2022 Electrochem. Soc. Interface 31 47

Color of Hydrogen Energy

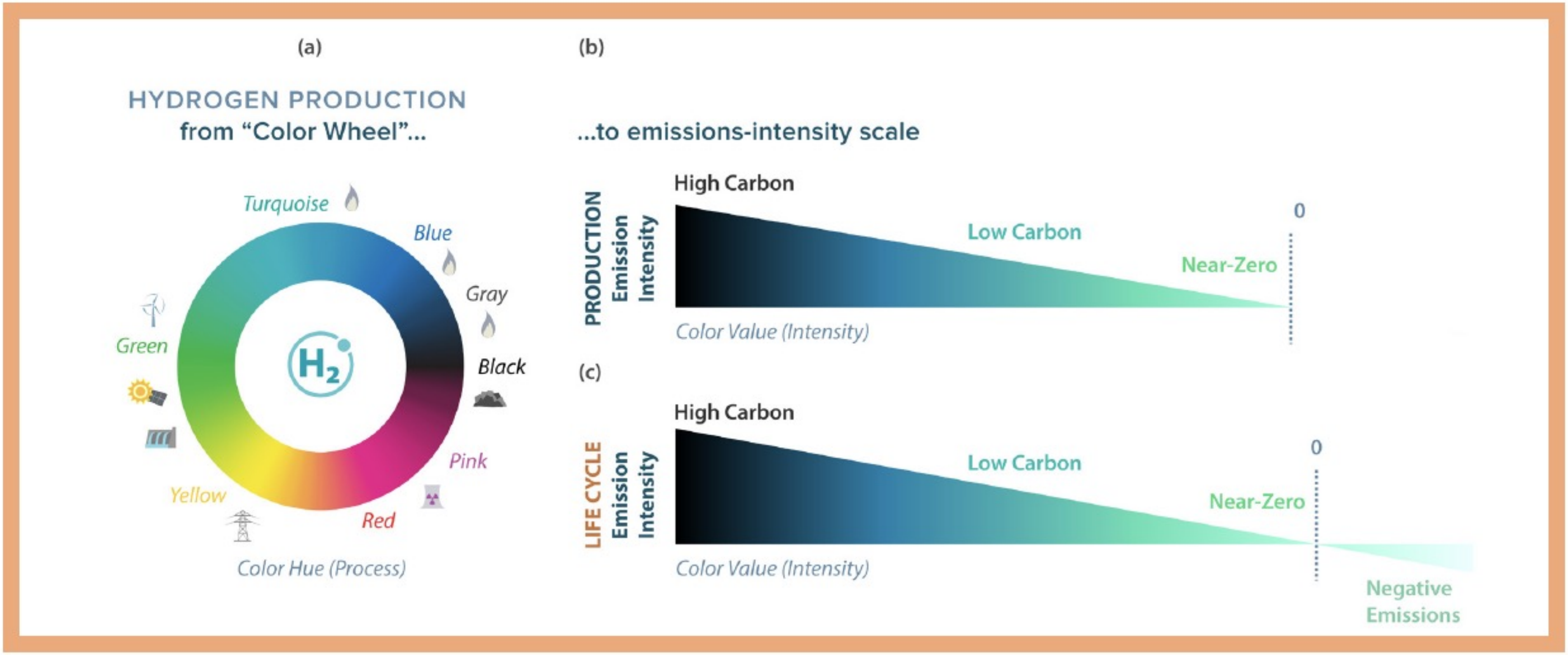


FIG. 6. *A conceptual illustration of the transition from (a) the traditional "color wheel" concept for hydrogen to (b) an alternative representation of carbon emissions-based definition of hydrogen "intensity wedge."*

Source: (Re)Defining Clean Hydrogen: From Colors to Emissions, Ahmet Kusoglu 2022 Electrochem. Soc. Interface 31 47

Hydrogen Production – Fuel Cells

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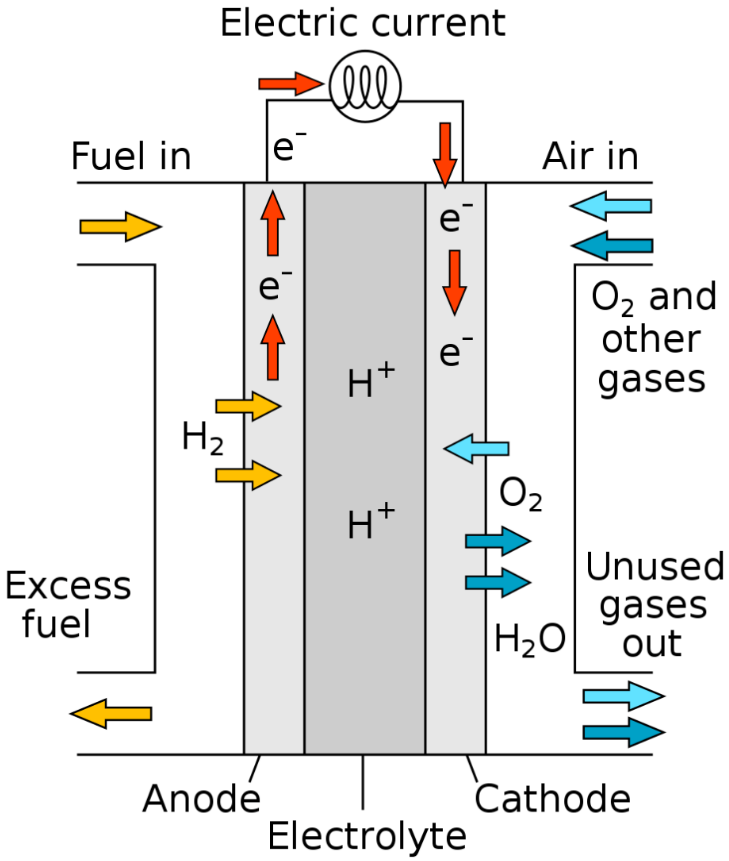
- **1838-1842: The First Fuel Cells**
  The first The first fuel cells were invented by Welsh physical scientist Sir William Grove which he termed a "gas voltaic battery"
- **1932 Scale Up Lab to Application**
  English engineer Francis Thomas Bacon developed a 5-kW stationary fuel powering a welding machine
- **1959: Commercial Success**
  GE/NASA/McDonnell used a Grubb-Niedrach fuel cell to power the Gemini spacecraft.



Hydrogen Production – Electrolytic Pathway

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- **Low-emission hydrogen production is <1% of global hydrogen production (2022)**
- **Getting on track with the Net Zero Scenario (by 2050)** requires:
  - ➢ a rapid scale-up of low-emission hydrogen (50% of total) by 2030
    - 50 Mt of hydrogen electrolysis production
    - 30 Mt produced from fossil fuels using CCUS
    - >550 GW of installed electrolysers capacity
  - ➢ rapid scale-up of electrolyser manufacturing capacity
  - ➢ significant deployment of renewable energy capacity for production
  - ➢ enhancement of the power grid

Source: Global Hydrogen Review 2021, International Energy Agency, Report, October 2021

Bottlenecks on Current Trajectory

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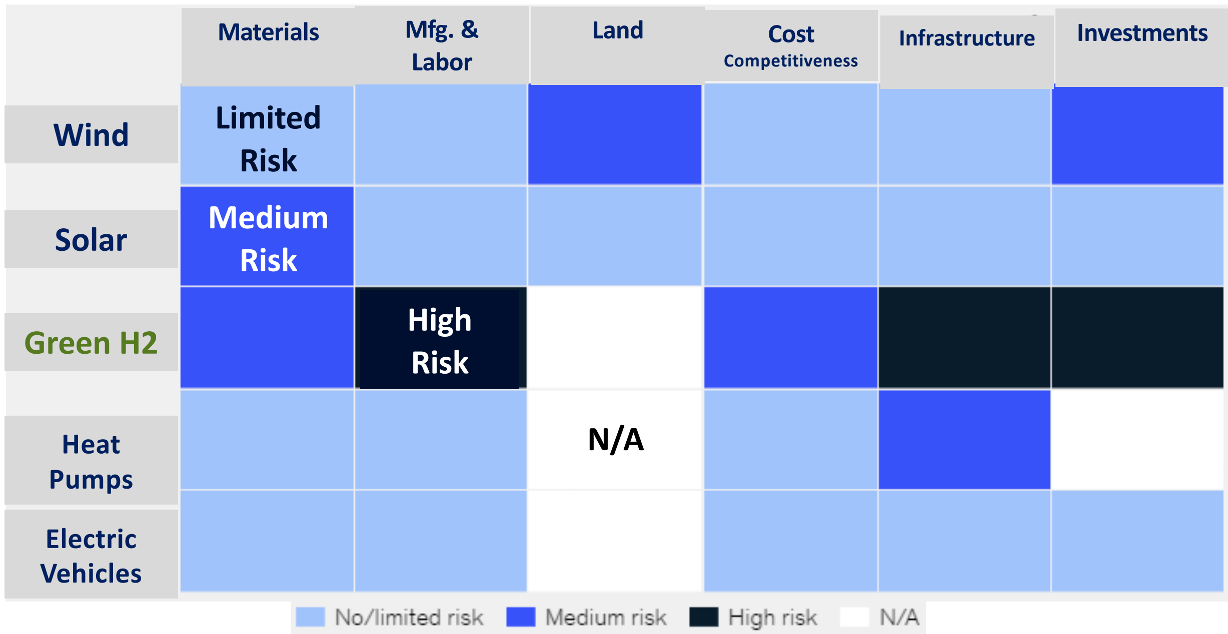

"**Green hydrogen** faces high risk mainly due to infrastructure needs and the high investments required to achieve large-scale deployment."

Source: Global Energy Perspective Report 2023, McKinsey & Company, October 18, 2023.

Hydrogen: The chicken and the egg

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High
Infrastructure
Costs

&

Limited
Incentives
&
Few
Offtakers

Supply-side economics

Demand-side economics

Why Now? The Hydrogen Shot

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- **DOE launched the Hydrogen Shot** as the first of the Energy Earthshots in **2021** – with the goal to cut the cost of clean hydrogen by 80% to $1 per 1 kilogram in 1 decade ("1-1-1")
- If the Hydrogen Shot goal is achieved, there is an opportunity for a 5-fold increase in clean hydrogen and to attain a 16% reduction in CO2 by 2050
- Technology advancements and newly identified pathways enable projected costs of hydrogen production, delivery, and dispensing for 700-bar fueling to be reduced to about $5 - $7/kg
- In Fiscal Year 2022, DOE budgeted $400M for hydrogen activities, up $115M from the previous year

Source: U.S. Department of Energy, Energy Earthshots, Hydrogen Shot: An Introduction (August 2021)

Infrastructure Investment and Jobs Act of 2021

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AKA: **the Bipartisan Infrastructure Law (BIL)**, Section 40315

- The Bill authorizes $**9.5 billion** for the development of hydrogen as a clean energy source.
  - establishment of **technology cost goals** oriented toward achieving clean hydrogen production;
  - **production** of clean hydrogen from diverse energy sources;
  - use of clean hydrogen for use as a fuel source for other residential, commercial, industrial…
  - sale and efficient **delivery** of hydrogen or hydrogen-carrier fuels;
  - **advanced vehicle**, locomotive, maritime vessel or plane technologies;
  - **storage** of hydrogen or hydrogen-carrier fuels…
  - domestic clean hydrogen **commercial equipment manufacturing**
  - **use of clean hydrogen in the transportation sector**, including in light, medium and heavy-duty vehicles, rail transport, available and maritime applications.

Source: U.S. Department of Energy, Energy Earthshots, Hydrogen Shot: An Introduction (August 2021)

Infrastructure Investment and Jobs Act of 2021

UCONN

AKA: the Bipartisan Infrastructure Law (BIL), Section 40315

- Additional elements
  - **Regional Hydrogen Hubs** ***(up to $8 billion over 4 years)***
  - **National Energy Strategy for Hydrogen** - national energy strategy and roadmap to facilitate widescale production, processing, delivery, storage and use of clean hydrogen;
  - **Grants for Research and Development** *($500 million over 4 years)*

    for the production, processing, delivery, storage and use equipment manufacturing technology
  - **Clean Energy Electrolysis Program** ***($1 billion)***

    Grant program for research, development, commercialization, & deployment of clean hydrogen electrolyzers.

    (i) reduce the cost of hydrogen produced using electrolyzers to less than **$2 per kilogram of hydrogen by 2026**
  - **Coordination of the National Renewable Energy Laboratory (NREL) and institutions of higher education**, and research institutes.

Source: U.S. Department of Energy, Energy Earthshots, Hydrogen Shot: An Introduction (August 2021)

Regional Hydrogen Hubs ($7 Billion)

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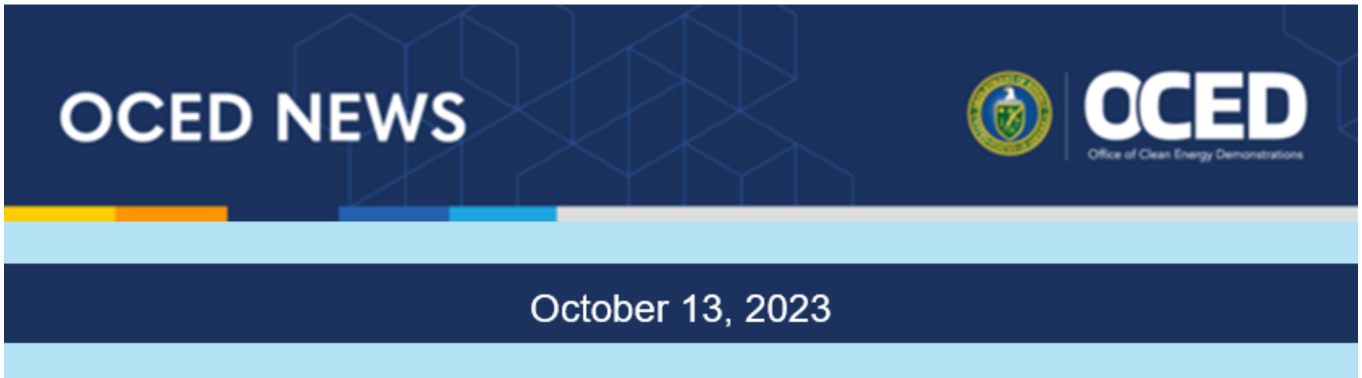

Seven Regional Clean Hydrogen Hubs will Create Thousands of High-Quality Jobs, Strengthen the Nation's Energy Security, and Combat the Climate Crisis

- **Appalachian** (VA, OH, PA)
- **California** (CA)
- **Gulf Coast** (TX)
- **Heartland** (MN, ND, SD)
- **MidAtlantic** (PA, DE, NJ)
- **Midwest** (IL, IN, MI)
- **Pacific Northwest** (WA, OR, MT)

Not selected…

Northeast (NY, CT, MA, NJ, RI, ME)

Regional Hydrogen Hubs ($7 Billion)

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S&P Global
Market Intelligence

Hydrogen hubs reveal brings more questions than answers for environmental groups

US President Joe Biden announces the winners of up to $7 billion in hydrogen infrastructure grants at the Tioga Marine Terminal in Philadelphia on Oct. 13.
Source: Mark Makela/Stringer/Getty Images News via Getty Images North America

4 of the selected Hubs use Blue Hydrogen.

Biden administration picks 7 hydrogen hub proposals for up to $7B in grants

1. **Appalachian Regional Clean Hydrogen Hub** – Ohio, West Virginia, Pennsylvania
2. **Alliance for Renewable Clean Hydrogen Energy Systems** – California
3. **HyVelocity Hub** – Texas
4. **Heartland Hydrogen Hub** – Minnesota, North Dakota, South Dakota
5. **Mid-Atlantic Clean Hydrogen Hub** – Pennsylvania, Delaware, New Jersey
6. **Midwest Alliance for Clean Hydrogen** – Illinois, Indiana, Michigan
7. **Pacific Northwest Hydrogen Hub** – Washington, Oregon, Montana

Data accessed Oct. 13, 2023.
Map credit: Jonathan Paul Lalgee.
Sources: US Department of Energy; stakeholder announcements.

Carbon Reduction: Chess, not checkers

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Source: The Queen's Gambit. Photo by Netflix.

Alternate Fuel Corridors: Hydrogen, Pending

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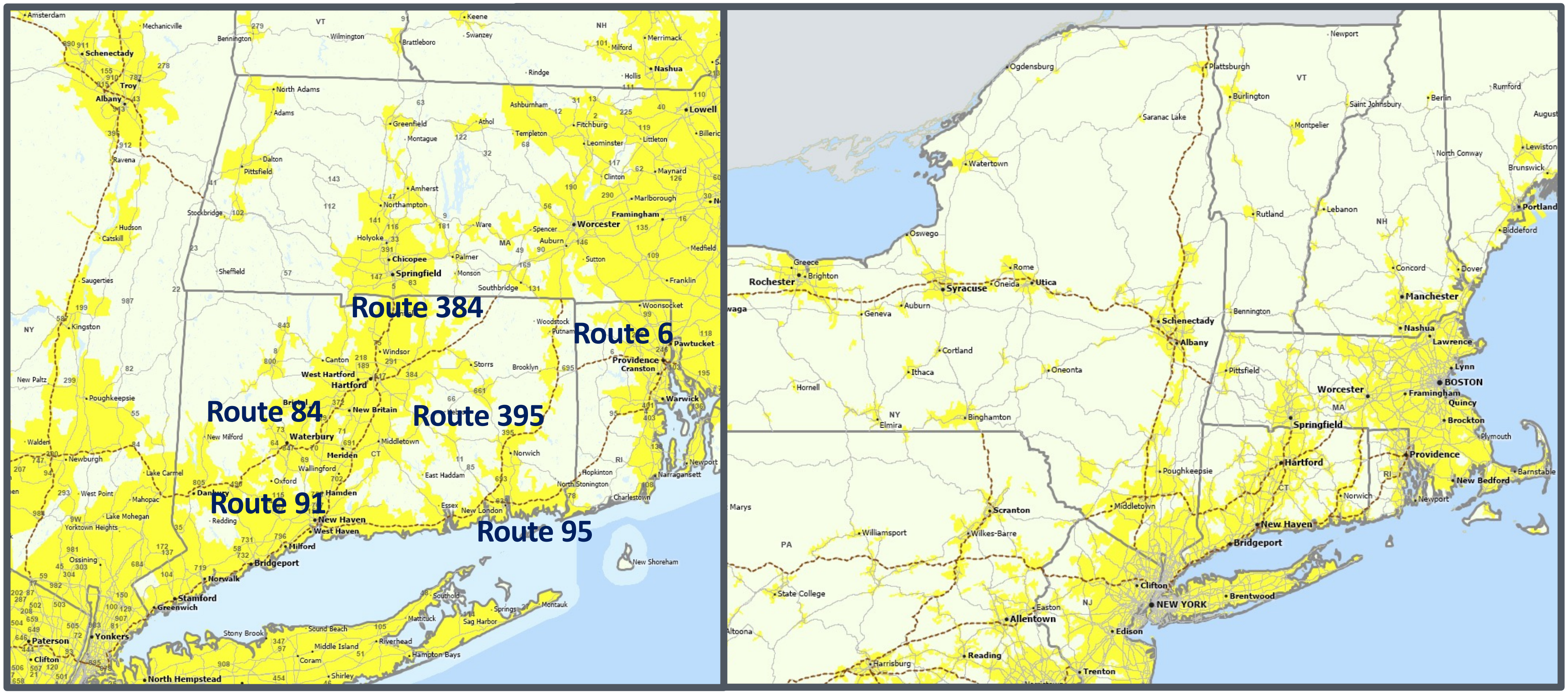

Source: U.S. DOT, Federal Highway Administration, Alternative Fuel Corridors, Office of Planning, Environment, & Reality

Hydrogen Fueling Stations

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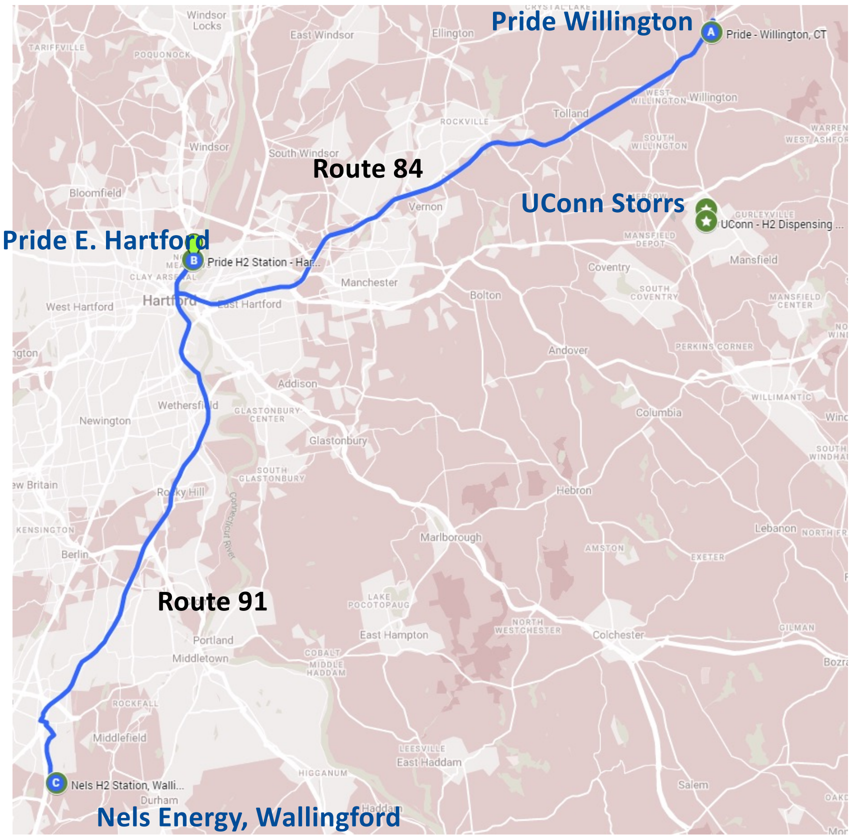
H2 Fueling Locations

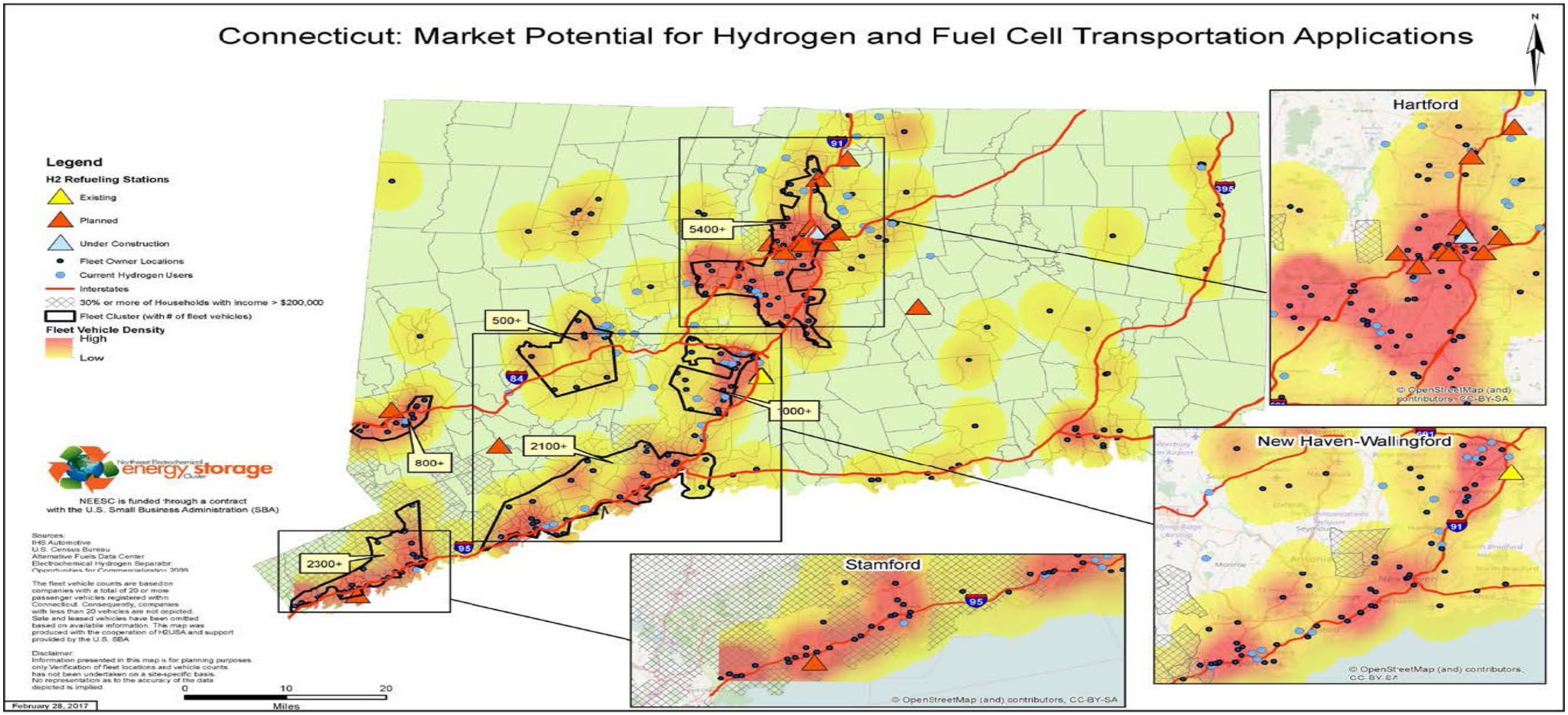
- IPB Fueling Station (UConn)

- Reclaimed Water Facility (UConn)

- **Pride Hartford, H2 Station**
  10 Jennings Road, Hartford, CT 06120
- **Nels Energy, H2 Station**
  10 Technology Drive, Wallingford, CT 06492
- **Pride Willington, Truck Stop**
  327 Ruby Road, Willington, CT 06279



Hydrogen Research & Development



Source: Northeast Electrochemical Energy
Storage Cluster, 2018 www.neesc.org

UConn Research Capability

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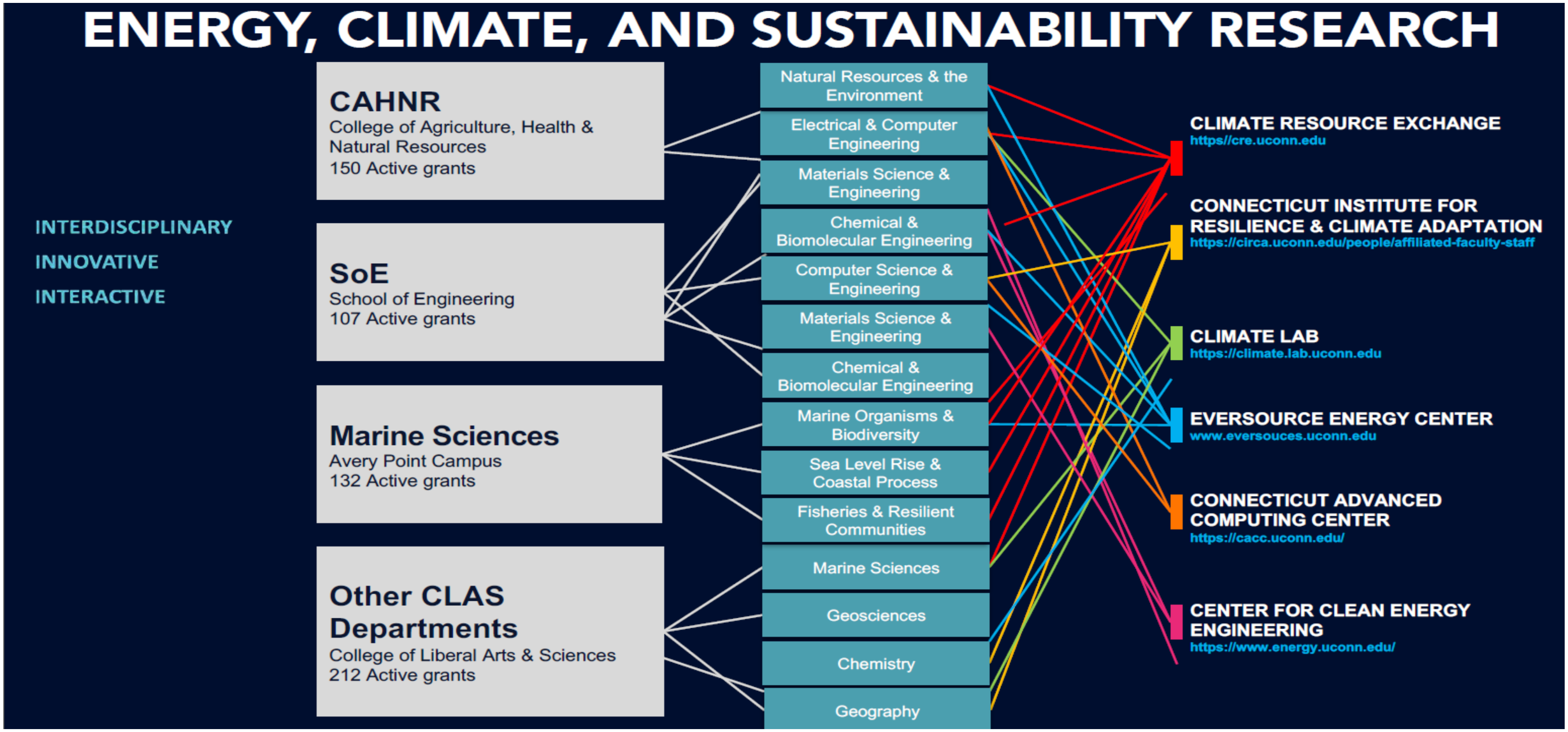

Hydrogen Storage Research

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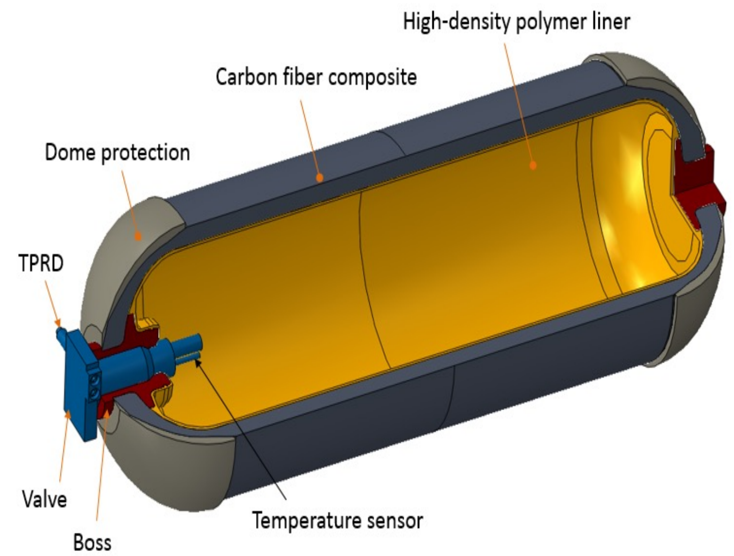
Areas include:

- High Density Storage
- Advanced storage container materials
- Cryo-compressed storage.

Targets include:

- 300-mile range
- 1.5 kWh/kg system (4.5 wt.% hydrogen)
- 1.0 kWh/L system (0.030 kg hydrogen/L)
- $10/kWh ($333/kg stored hydrogen capacity).



TPRD = Thermally Activated Pressure Relief Device

Credit: Process Modeling Group, Nuclear Engineering Division. Argonne National Laboratory (ANL)

Hydrogen: Stationary Power

Fuel Cell

UConn Depot Campus

Annual Environmental Benefits

- **CO_2** = 1.1Million lbs. saved or 116 acres of trees
- **NOx** = 3,300 lbs. saved or 87 cars
- **H_2O** = 1.4Million gallons saved or 2.2 Olympic pools

➢ **Two Additional Fuel Cell Installations are Expected**

- 500 kW Solid Oxide Fuel Cell (SOFC)
- 2.3 MW Power Purchase Agreement

Hydrogen: Fuel Cell Flu Gas

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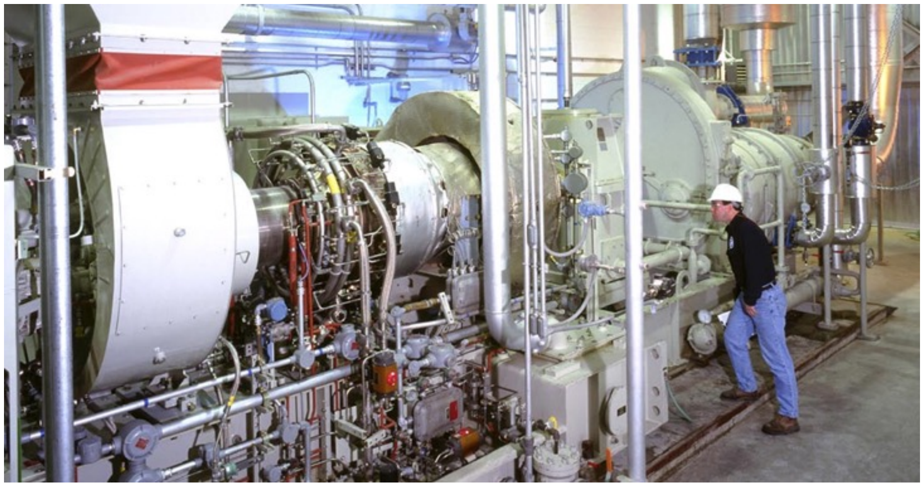
GHG Conversion

- **Converts problematic greenhouse gases** like waste carbon dioxide, into usable and valuable fuels such as:
  - methanol
  - formic acid
- 50% less than the cost of conventional manufacturing methods
- Advanced Prototype

Central Heating Plant Applications



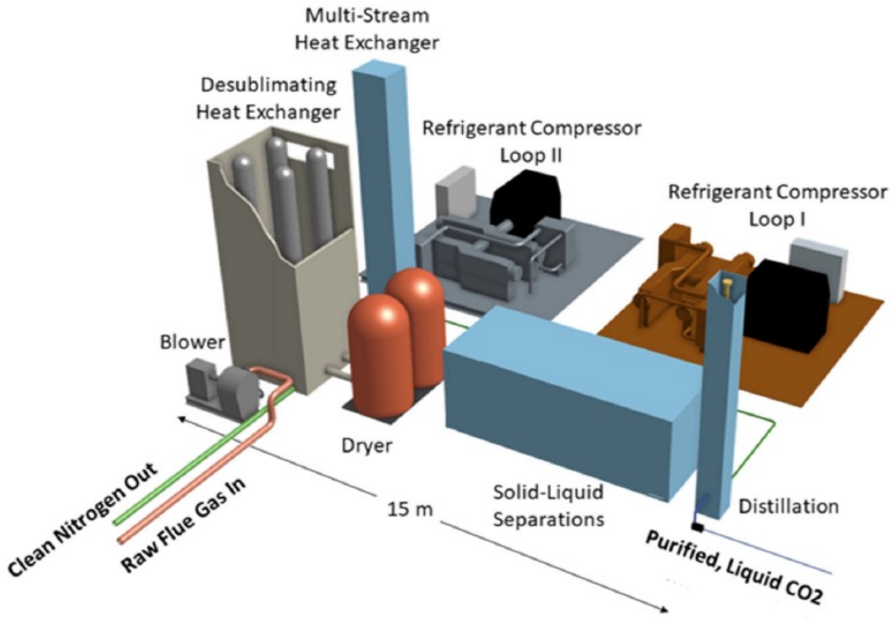
Caterpillar Solar Turbines

- **SoLoNOx** utilizes lean-premixed combustion technology to ensure an extremely uniform air/fuel mixture and stringently control the combustion process to prevent undesirable emissions from forming; particularly nitric oxide.
  - Up to 20% SoLoNOx mix (100% conventional)
  - Goal of 100% SoLoNOx by 2030
- **4% Hydrogen blending** without significant equipment retrofit
- **Up to 70% blending** possible following 2024 turbine swapout

Source: SoLoNOx Dry Low Emissions Technology, Solar Turbines, A Caterpillar Company 2007

Renewable Electricity – Storrs Campus

Co-Generation Facility



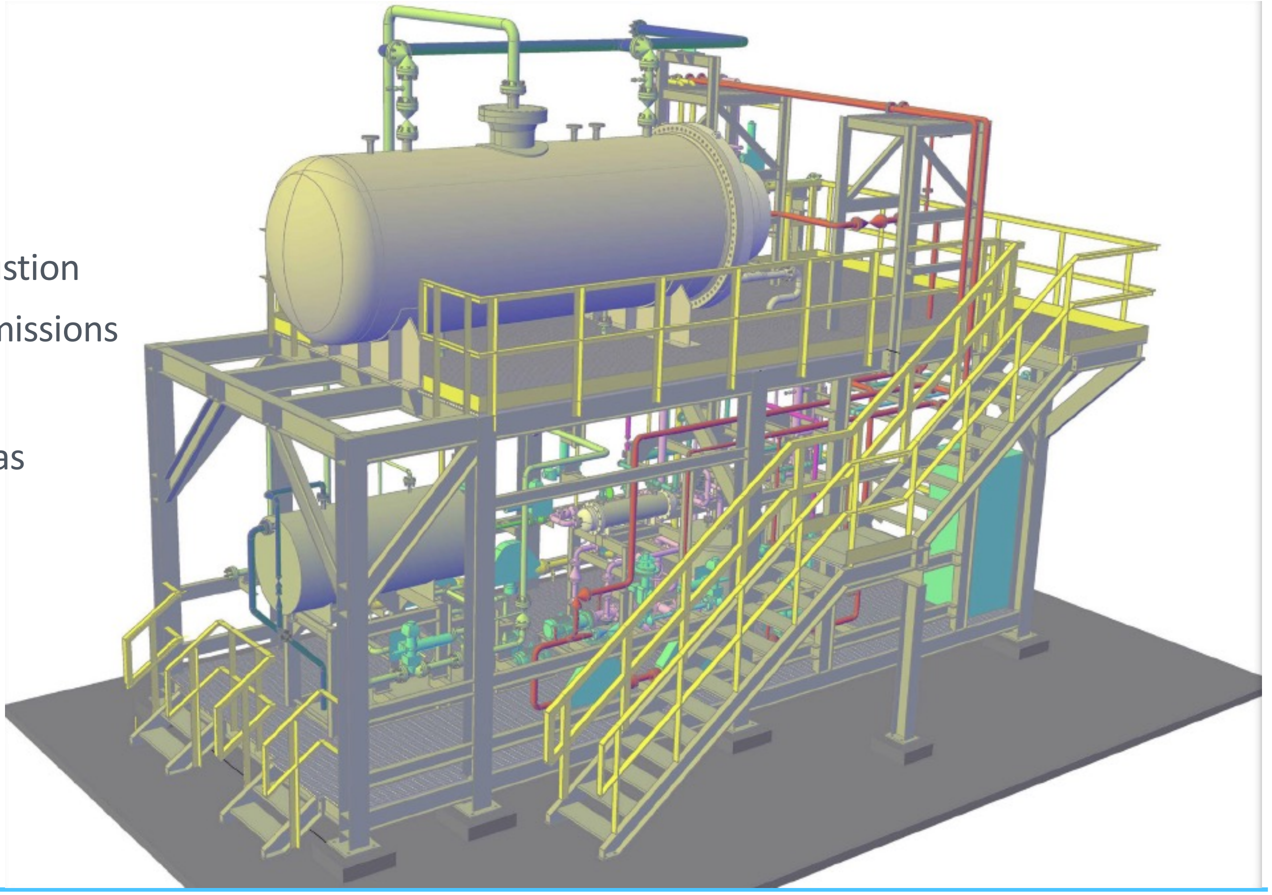
Cryogenic Carbon capture

Hydrogen Boilers

Utility-Scale

Hydrogen Boiler

- Does not use atmospheric air for combustion
- There is no fuel stack, no NOx or CO2 emissions
- Combustion water is recovered
- Operating costs equivalent to Natural Gas
- Zero emissions



Hydrogen Boilers

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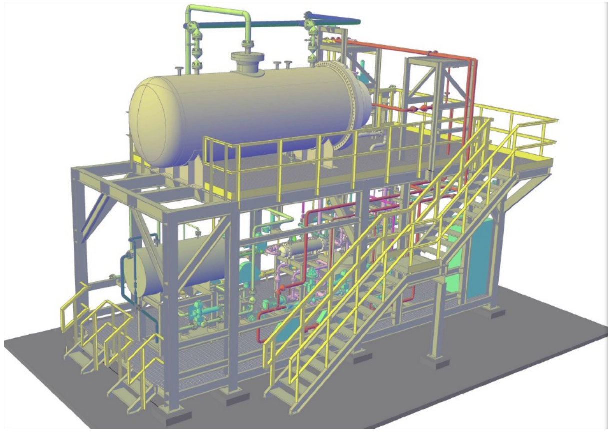
Utility-Scale Boiler

	UNITS	DCC™ 3000	DCC™ 6000	DCC™ 3000 HP	DCC™ 6000 HP	DCC ™ 28K*
STEAM OUTPUT RATE	kg/hr lb/hr tonnes/hr	3,000 6,600 3	6,000 13,200 6	3,000 6,600 3	6,000 13,200 6	28,000 62,000 28
UTILIZATION HORSEPOWER	BHP	265	530	315	630	2,500
HEAT OUTPUT	MMBTU/hr	8.9	17.8	10.6	21.2	83.1
OUTLET PRESSURE	PSIG	165	165	600	600	600
STEAM TEMPERATURE	°C / °F	200 / 400	200 / 400	300 / 570	300 / 570	400 / 570
H_2 FUEL CONSUMPTION	kg/hr lb/hr	62 137	123 270	62 137	123 270	615 1,350
O_2 CONSUMPTION	kg/hr lb/hr	496 1,096	984 2,160	496 1,096	984 2,160	4,900 10,800
DIMENSIONS (LxWxH)	meters feet	8 x 5 x 7 26 x 16 x 22	8 x 5 x 7 26 x 16 x 22	8 x 5 x 7 26 x 16 x 22	8 x 5 x 7 26 x 16 x 22	TBD



Hydrogen Boilers

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Residential / Building-Scale

Hydrogen Boiler / Electricity Generator

User applications include Domestic Hot Water (DHW), Hydronic and Radiant Heating, and Forced Air Heating; 95% (HHV) Heating Efficiency; Low NoX; Black Start

Fuel type	NG/LP
Fuel pressure	3.5"-14" WC
Fuel consumption	88 kW (300,000 BTU/hour)
Thermal output	78 kW (265,000 BTU/hour)
Electrical output	6 kW(e)
Voltage output	240 / 208 single phase *
Power input	120 VAC
Weight	1,150 lbs
Noise at max load	60 dBA
NOx class	7-15 ppm

Hydrogen Storage & Dispensers

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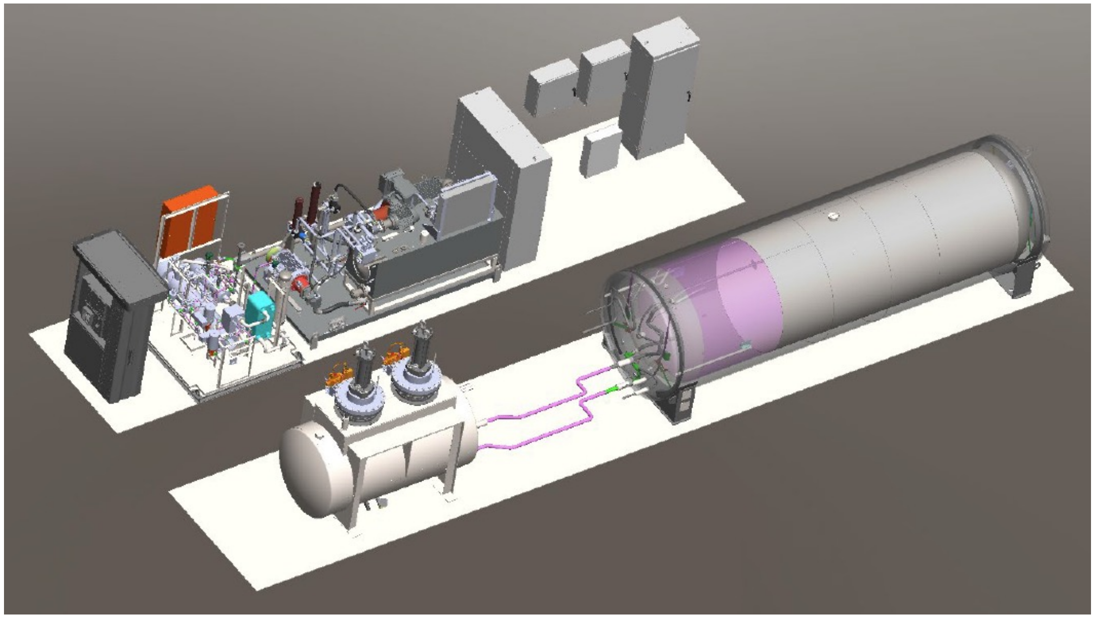
Transportable

Hydrogen Fueling & Storage

- 1,300 Kg LH2 Storage.
- (1) Sump with (2) H70 pumps.
- Capable of 4.2 Kg/min flowrate at pressure to the dispenser.
- Allows for back-to-back fills
- (1) HPU
- (1) HEX
- (1) OEM Dispenser
- Vacuum insulated piping
- High-pressure piping
- Footprint: 63 ft. x 8 ft.
- Full station controls



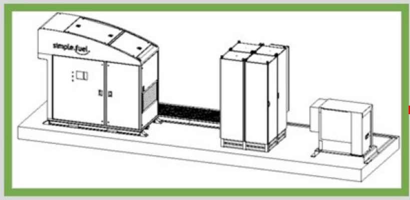
Hydrogen Fueling Stations

UCONN

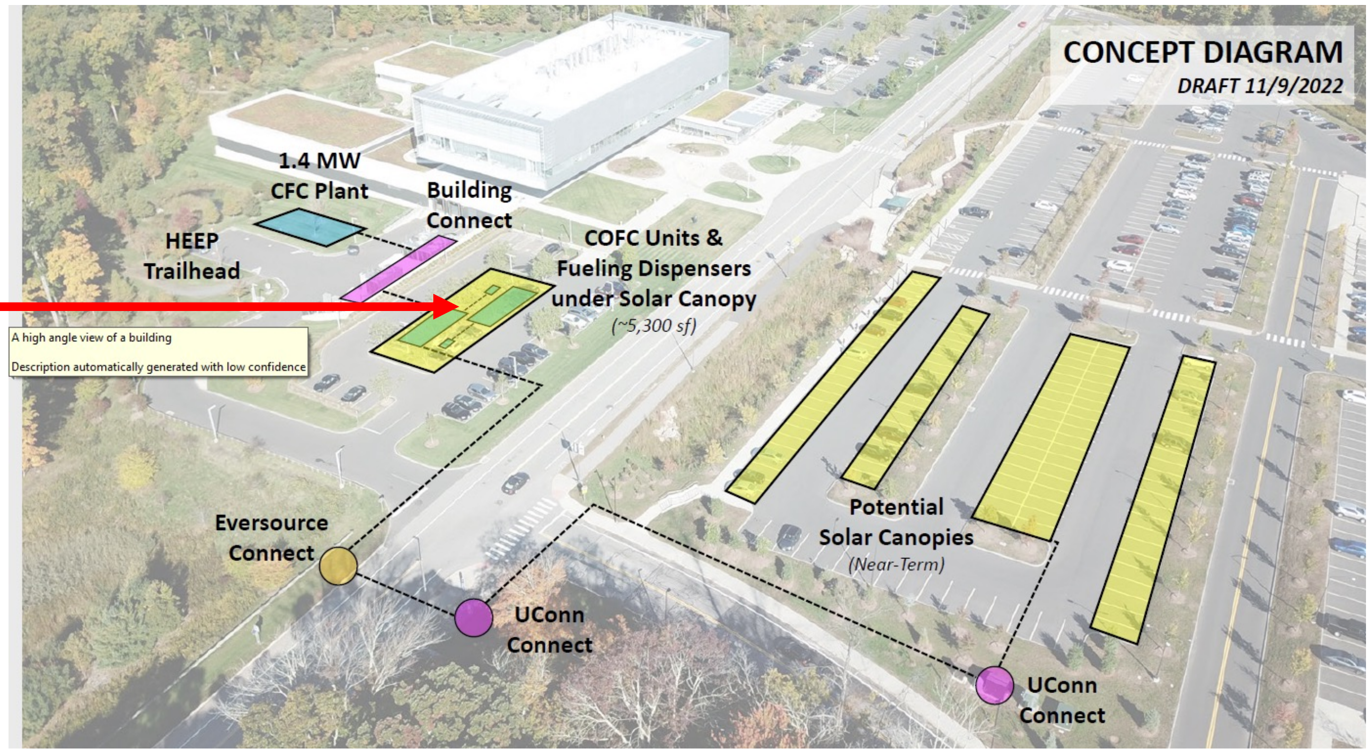
Innovation Partnership Building

H2 Fueling Appliance

350 bar: 2-3 min / kg
700 bar: 8-10 min / kg



Material Handling	Light Duty Vehicles
SF35-20 350 bar dispensing PEM electrolyzer 20 kg/day production 5 kg storage	SF70-20 700 bar dispensing PEM electrolyzer 20 kg/day production 5 kg storage



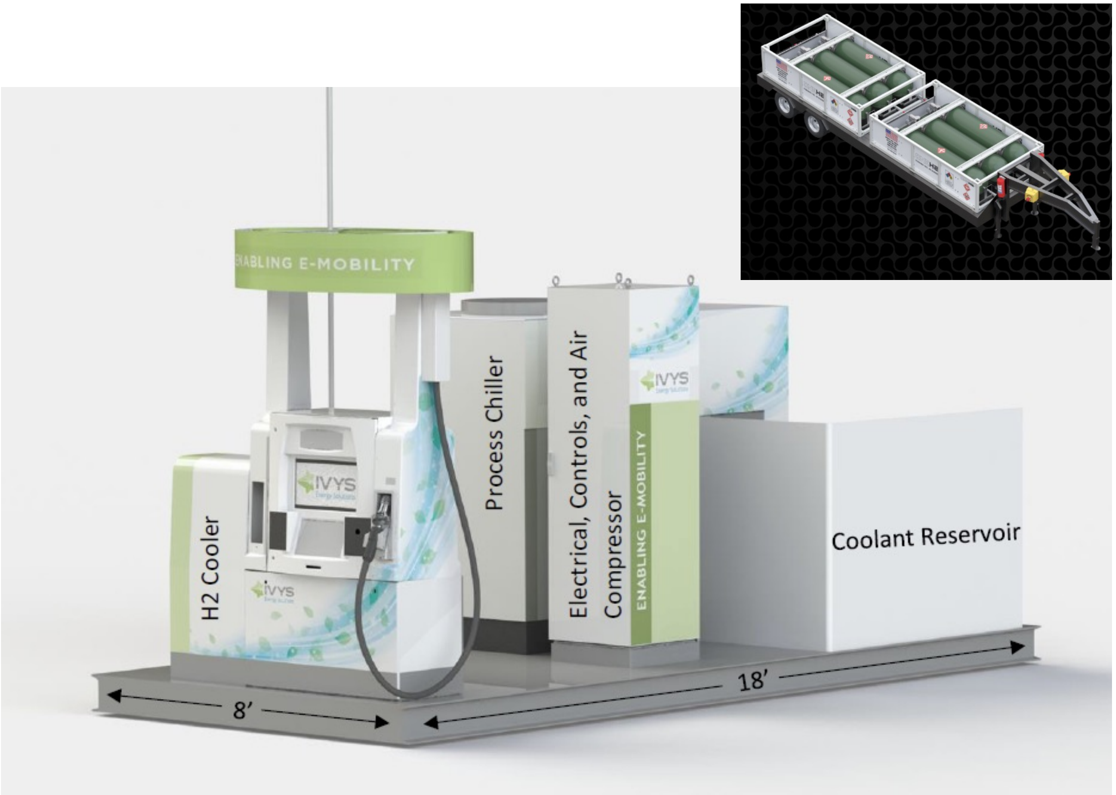
Hydrogen Fueling Stations

UCONN

Reclaimed Water Facility

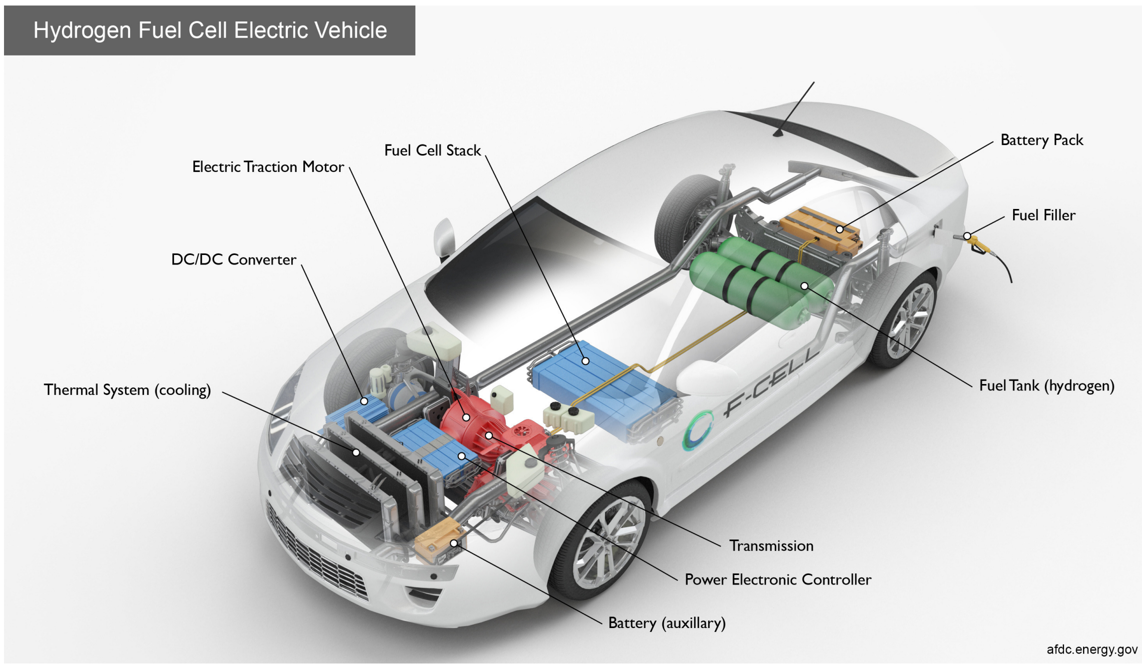
H2 Fueling Dispenser

- 350 or 700 bar dispensing
- Hydrogen Electrolyzers and Gaseous or Liquid hydrogen supplies can be integrated
- Diminutive mobile footprint, flexibility, and capacity
- Delivered hydrogen supply (~20kg/day)



Hydrogen Vehicles

UCONN



- Hydrogen gas is compressed for fueling
  - 5,000 pounds per sq. inch (H35 – 350 bar)
  - 10,000 pounds per sq. inch (H70 - 700 bar)
- Hydrogen may be pre-cooled to speed fueling
  - Pre-chilled (-40 C) vs ambient temperature fueling
- Appliance typically communicates with vehicle
  - SAE J2601 (3 – 5-minute target)
- Hydrogen Prices
  - U.S. Department of Energy (DOE) – Hydrogen Shot (June 7, 2021)
  - Reduce the cost of clean H2 by 80% by 2031 to $1 per kilogram (1-1-1)
  - California – February 1st – prices is $26 per kilogram ($108 for fill-up)
- 59 The number of H2 fueling stations in the US

Source: afdc.energy.gov

Hydrogen Vehicles

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Hyundai Nexo

380-mile driving range

MPGe 65 City/54 Hwy/ 61 Combined

System Power 135 KW

95 kW stack & 1.56 kWh Battery

H2 Tank Capacity 6.33 kg

Hydrogen Vehicles

UCONN

Toyota Marai

402-mile driving range

- MPGe 76 City/71 Hwy/ 74 Combined

System Power 134 KW

- 80 kW stack & 1.24 Kwh Battery

H2 Tank Capacity 5.6 kg

Hydrogen – Delivery and Portability

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Hydrogen Transport Refueler

- 1,000 kg Hydrogen (minimum)
- 700 bar Hydrogen tanks
- Built-in compression and chilling
- Compression and chilling services are Hydrogen Fuel Cell powered
- Environment - Temperature: -40 °C to +45 °C. Humidity: 0-95 % (non-condensing). Altitude: <1,500 m above sea level

Mobile Hydrogen Refueler and Rapid EV Charger

- 80 kW Fuel Cell
- 180 kW Inverter
- 180 kWh Lithium-ion battery array
- Up to 70 kg Hydrogen gas
- 180 kW DC EV fast charger
- Can connect to a facility for backup power
- Can connect to utility for grid services
- Outputs can be paralleled
- On-board Hydrogen gas for refilling other tanks
- Inline vehicle battery management
- Refill from any Hydrogen fueling station

Hydrogen Mobile Power Generator (MPG)

- 80 kW Hydrogen Fuel Cell
- 180 kW Inverter
- 180 kWh Lithium-ion battery array
- 40 kg Hydrogen gas
- 180 kW DC EV fast charger
- Can connect to a facility for backup power
- Can connect to utility for grid services
- Outputs can be paralleled
- Environment - Temperature: -40 °C to +45 °C. Humidity: 0-95 % (non-condensing). Altitude: <1,500 m above sea level

Empower Hydrogen Rapid EV Charger

- 700 kg Hydrogen (minimum)
- 700 bar Hydrogen tanks
- 500 kW up to 700 kW power
- 4 dual port DC EV fast chargers with point-of-sale option
- Utility interface for backup or bi-directions utility connection
- Optional canopy
- Optional lighting package
- Environment - Temperature: -40 °C to +45 °C. Humidity: 0-95 % (non-condensing). Altitude: <1,500 m above sea level

Hydrogen Demonstration: Earth Day 2023

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Hydrogen-Powered
Fuel Cell Generator
used to charge electric vehicles

Hydrogen Demonstration: Earth Day 2023

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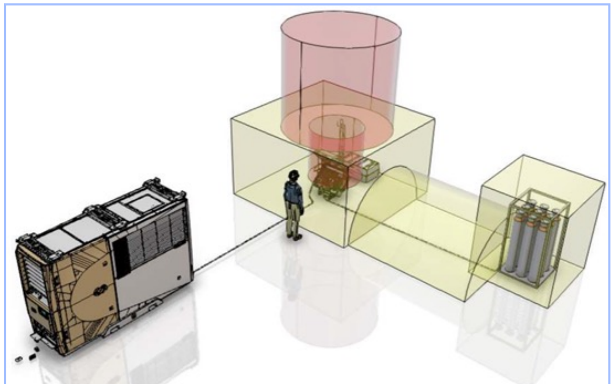
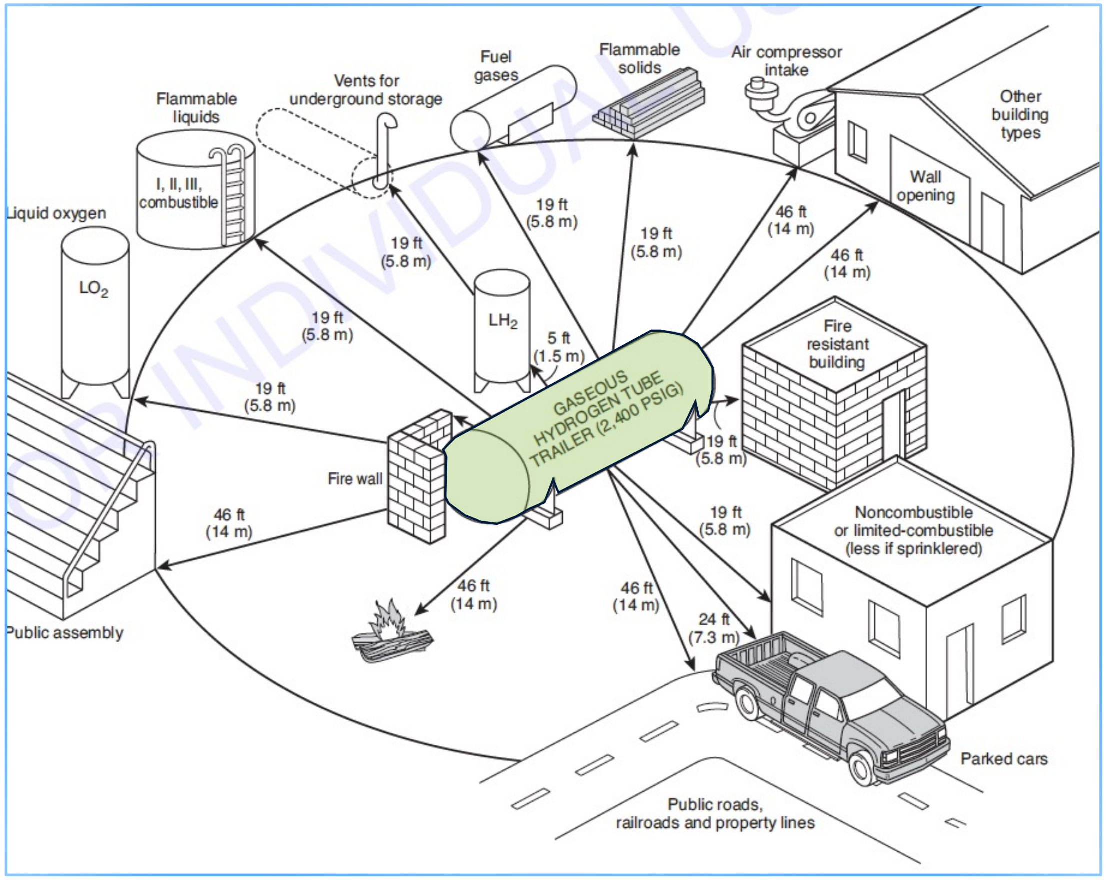
National Fire Protection Agency

Hydrogen Technologies Code (NFPA 2)



Explosive Atmosphere (ATEX) Zones



Renewable Electricity – Storrs Campus

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Parking Lot

Solar Canopies

- Approximately 1.6 Million Sq. Ft.
- Approximately 7 MW
- 11 Parking Lots
- Reviewing RFP results

Questions

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