Northeast Public Power Association

Hydrogen and the Clean Energy Transition

Annual Conference

August 24, 2021

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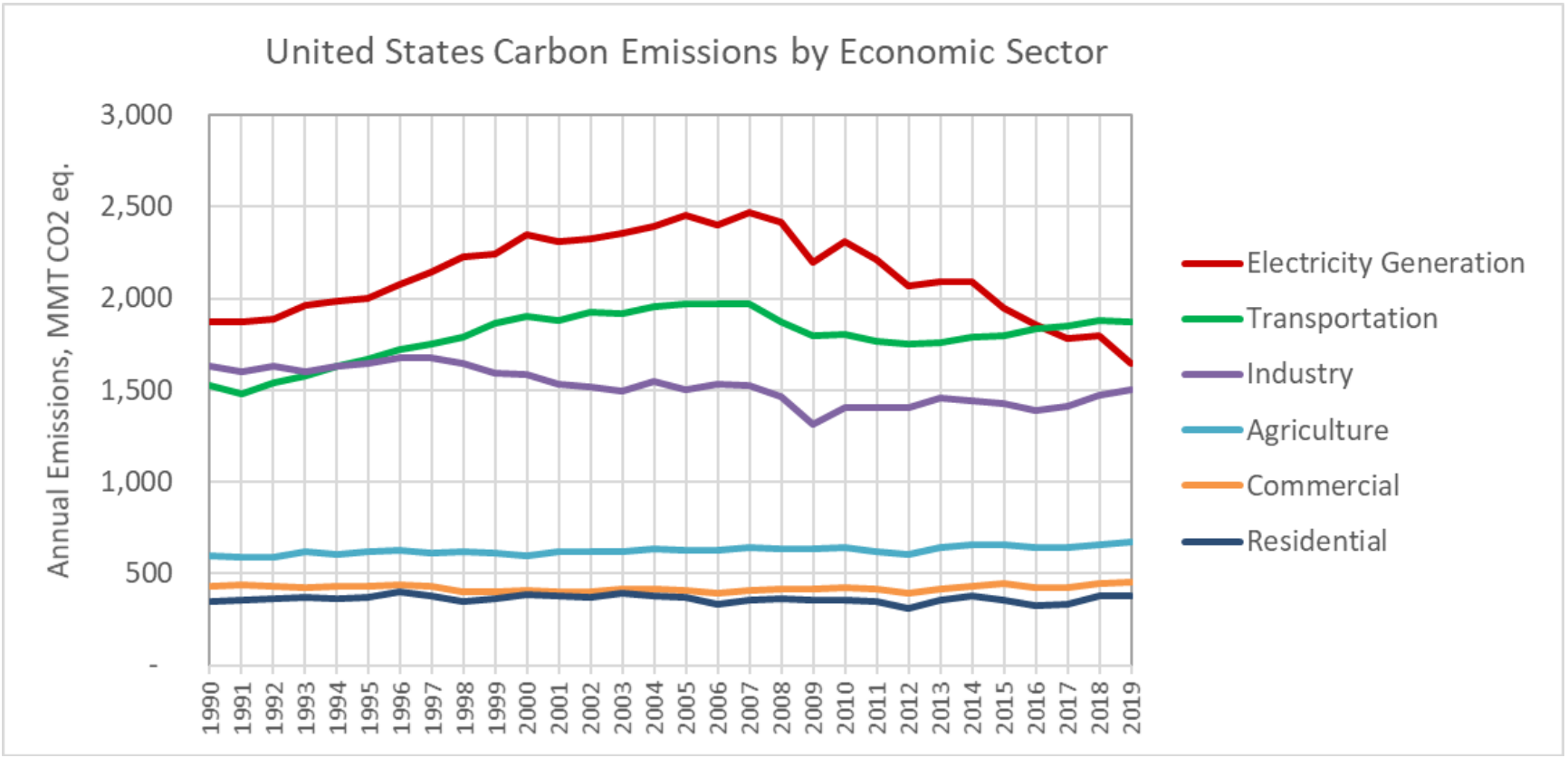
Agenda

- Energy Transformation
- Why Hydrogen Now?
- Hydrogen Review
- Hydrogen Use Cases
- Question & Answer

The United States electric power sector has led the reduction in carbon emissions among all the economic sectors



Source: Environmental Protection Agency, U.S. Greenhouse Gas Inventory Data Explorer (cfpub.epa.gov/ghgdata/inventoryexplorer/index.html)

Energy transition is having impacts throughout the energy value chain

Renewable Energy Costs Continue to Fall	• Grid management becoming more challenging • Hydrogen production becoming cheaper
Increasing curtailment of variable renewable energy	• Solar and wind curtailment increasing • Project developers looking for opportunities to monetize stranded electrons
Expanding electrification of transportation and heat energy	• Demand for electricity to increase significantly • Not all end-uses can be electrified – the "hard to abate" end-uses
Declining Costs of Energy Storage	• Costs of storage continuing to fall • Storage still uneconomic for durations longer than six hours
Expanding distributed generation and microgrids	• Managing distributed resources are an important part of the power grid future
Expanding carbon mitigation policies and market mechanisms	• Multiple technologies will be brought to bear on addressing GHG throughout the energy value chain

Hydrogen has emerged as an important technology for accelerating carbon reductions and enabling increased variable renewable energy

Solar Power Purchase Agreements Are Approaching One Cents per kWh

- Marginal cost of hydrogen via electrolysis with one cent power is approximately $0.50/kg – lower than steam methane reforming

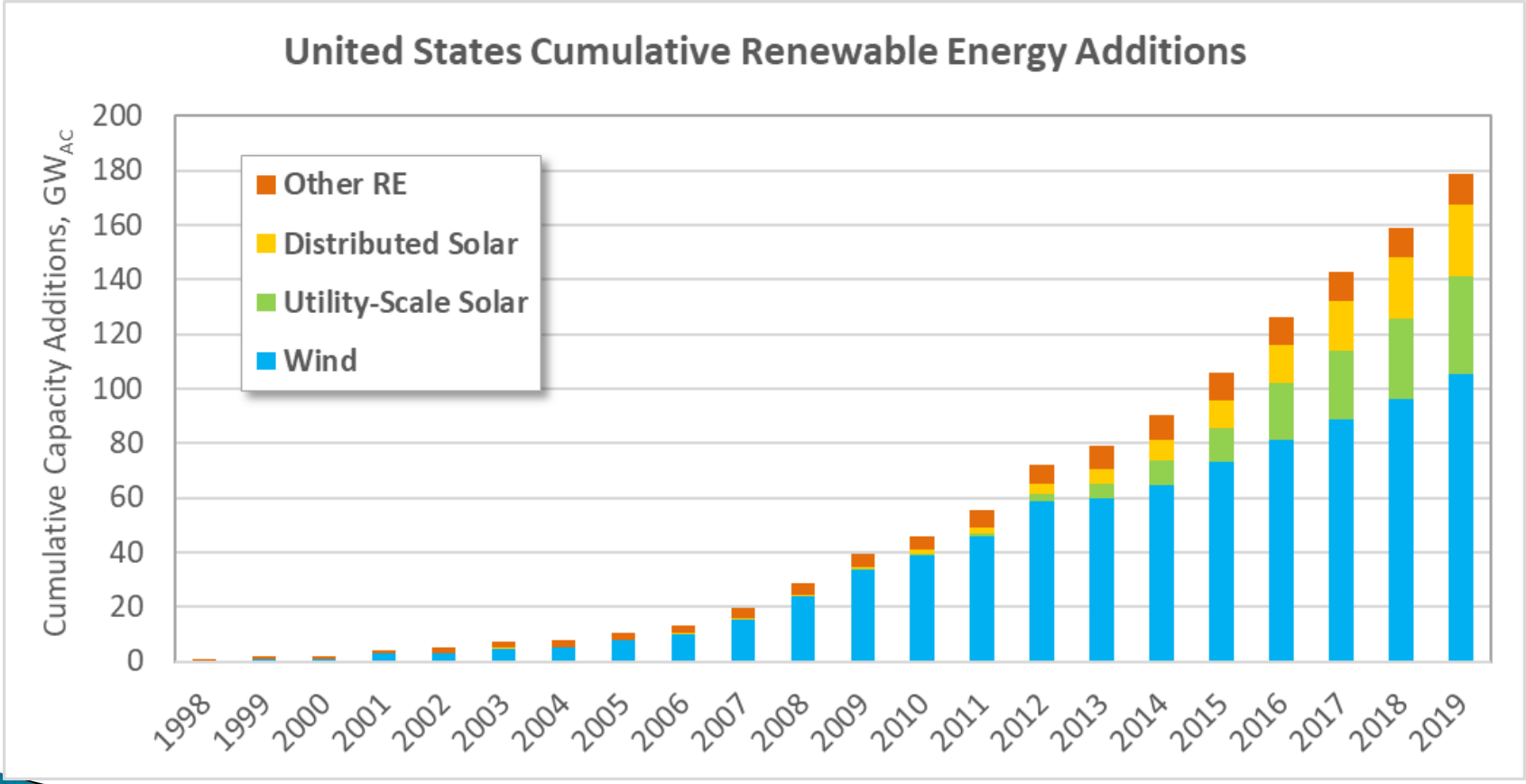
Curtailed wind and solar in California is approximately 1.5 million MWh/year

- Curtailed power may reach 5% to 20% of US power production – creating an opportunity for producing between 4 and 16 billion kg of hydrogen per year at zero marginal cost

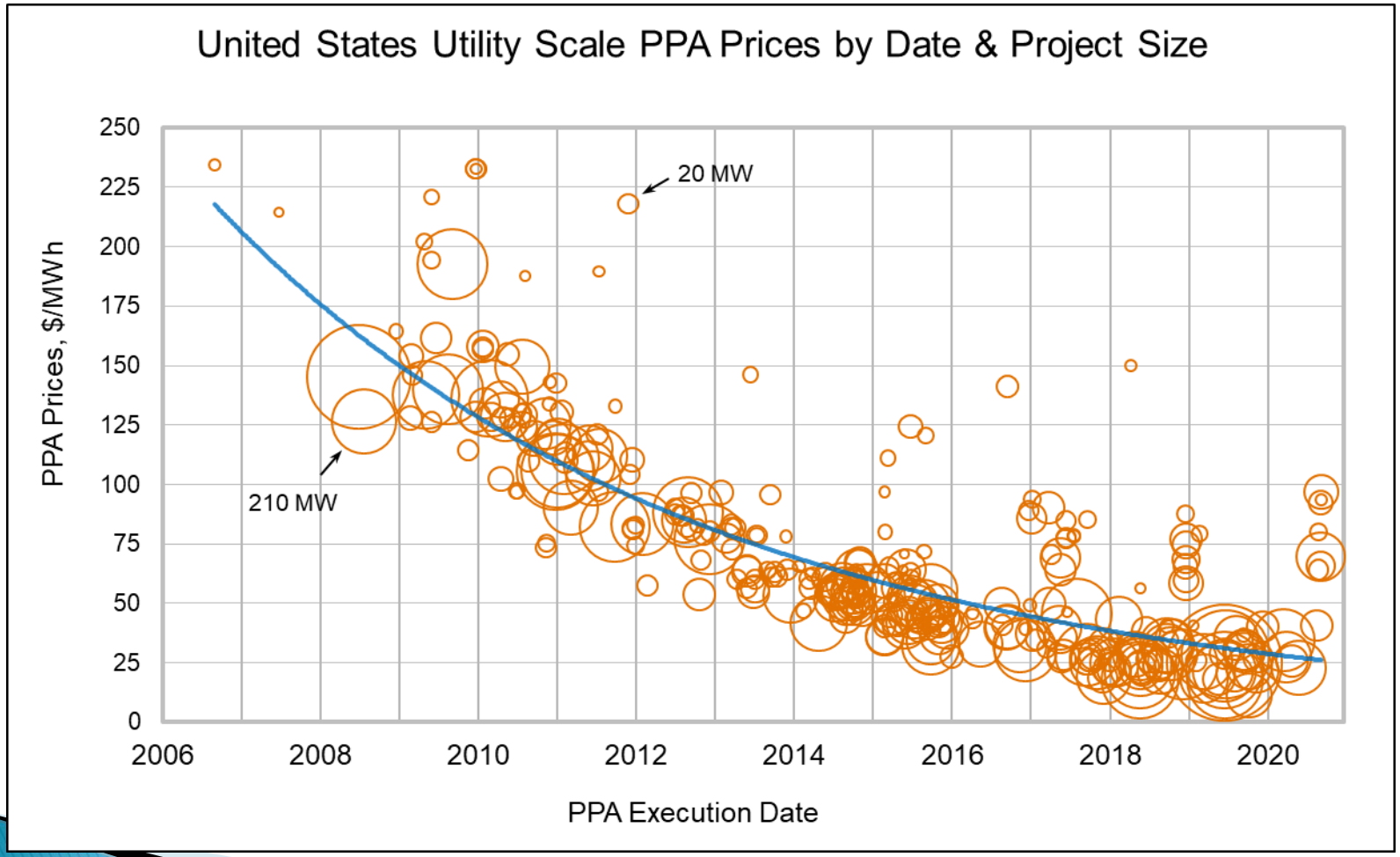
Hydrogen Has Emerged as a Candidate for Multiple Applications

- Long duration energy storage
- Blending with natural gas to reduce carbon emissions
- Transportation fuel for trucks and ships
- Zero carbon solution for hard to abate applications

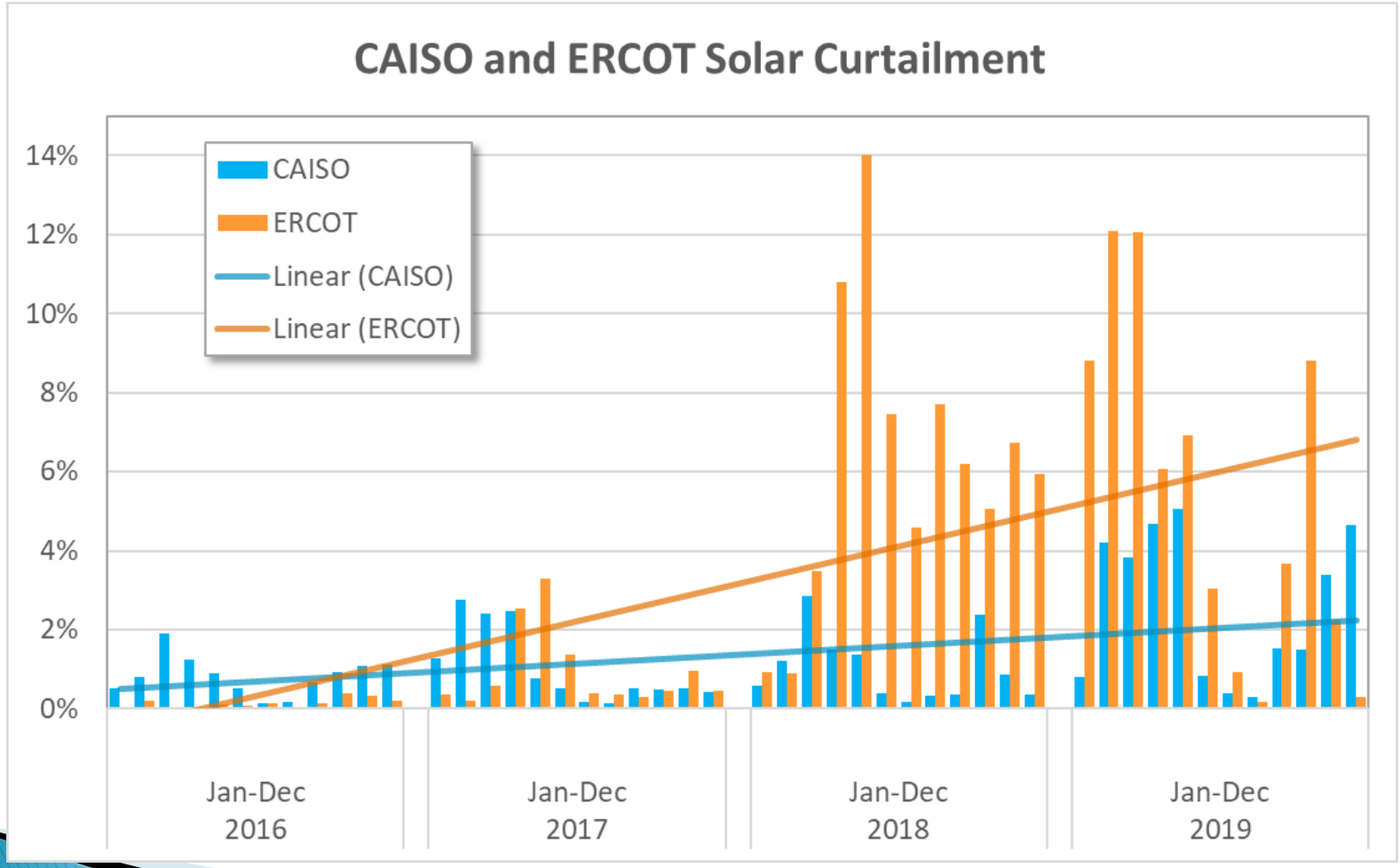
Variable renewable energy continues to climb, with calls for accelerating deployment



A fundamental driver creating an opportunity for hydrogen is the extraordinary drop in PPA prices



The issue of growing curtailment is impacting RE project economics and creating an opportunity for electrolytic hydrogen production



Hydrogen background
What color is your hydrogen?

Green hydrogen

Technology: Electrolyser

Input: Renewable electricity

Process: Splitting water into hydrogen and air

GHG emissions: Depends on the GHG emissions from electricity supply

Blue hydrogen

Technology: (1) Steam Methane Reforming (SMR) plant with Carbon Capture and Storage (CCS); (2) Coal gasification plant with CCS

Input: (1) Natural gas; (2) Coal

Process: Converting (1) natural gas/(2) coal into hydrogen and CO_2

GHG emissions: Low, CO_2 stored and/or reused

Turquoise hydrogen

Technology: Methane pyrolysis plant with Carbon Capture and Utilisation (CCU)

Input: Mainly natural gas

Process: Splitting methane into hydrogen and solid carbon

GHG emissions: Depend on the input to generate the necessary heat

Grey hydrogen

Technology: (1) Steam Methane Reforming (SMR) plant; (2) Coal gasification plant

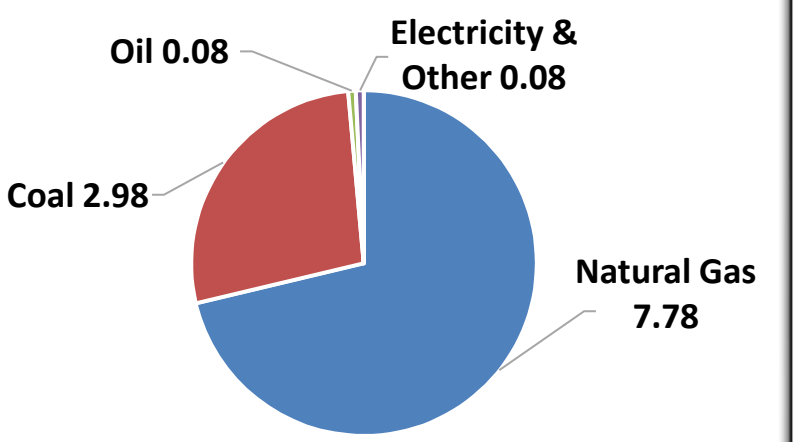
Input: (1) Natural gas; (2) Coal

Process: Converting (1) natural gas/(2) coal into hydrogen and CO_2

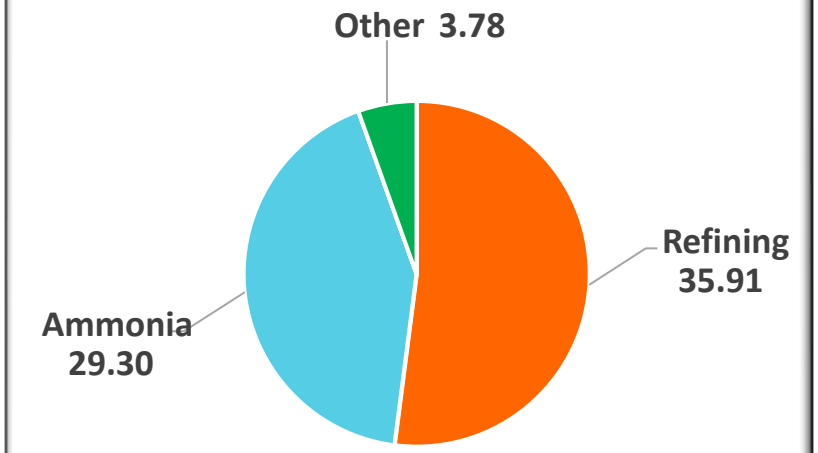
GHG emissions: Yes

The global market consumes close to 100 billion kilograms of hydrogen per year

Global Energy Use for Hydrogen Production – 10.9 billion MMBtu

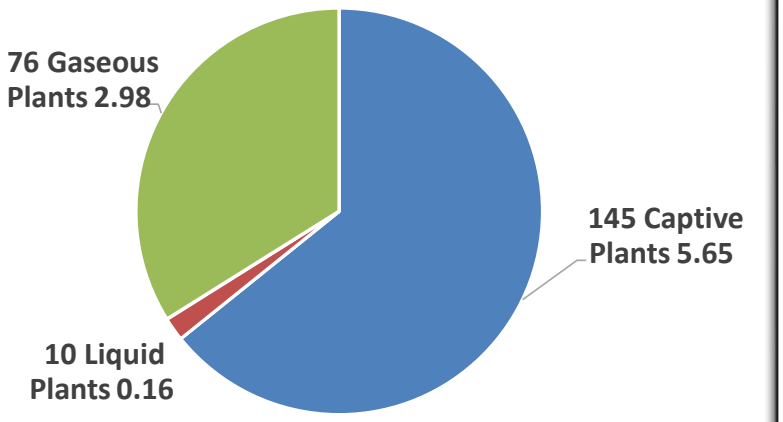


Global Hydrogen Use 95.18 billion kg

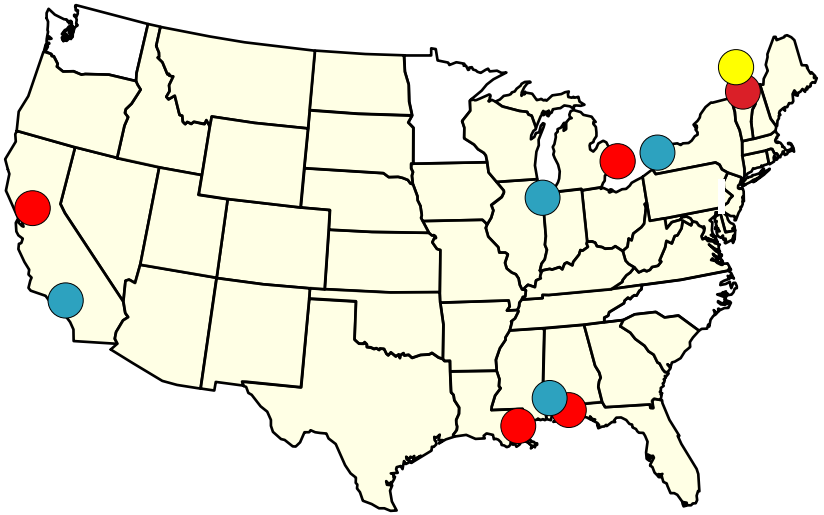


The United States has a well-developed hydrogen production and distribution infrastructure focused mostly on oil refining and ammonia production

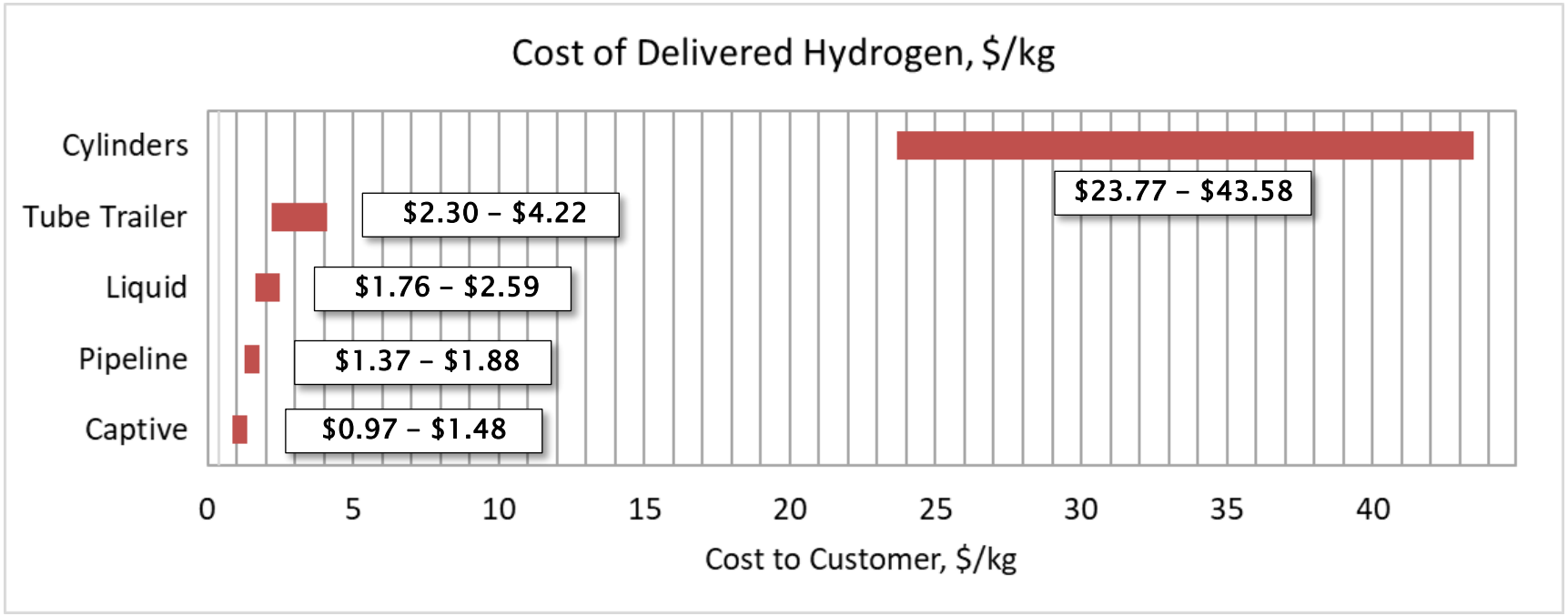
US Hydrogen Production Approximately 8.8 billion kg/year



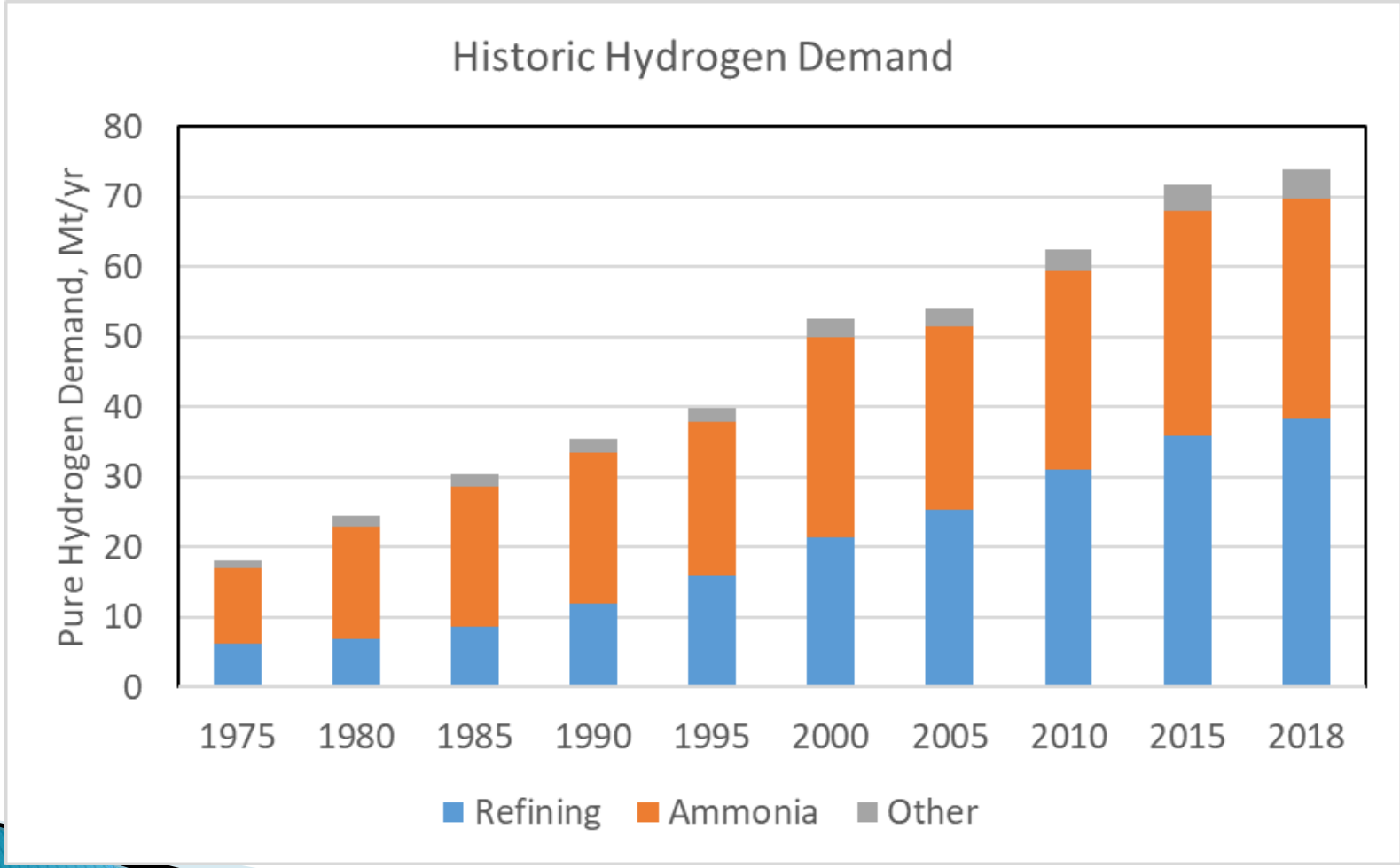
Liquid Hydrogen Facilities



The economics of hydrogen vary significantly depending on the form, quantity and location of delivery

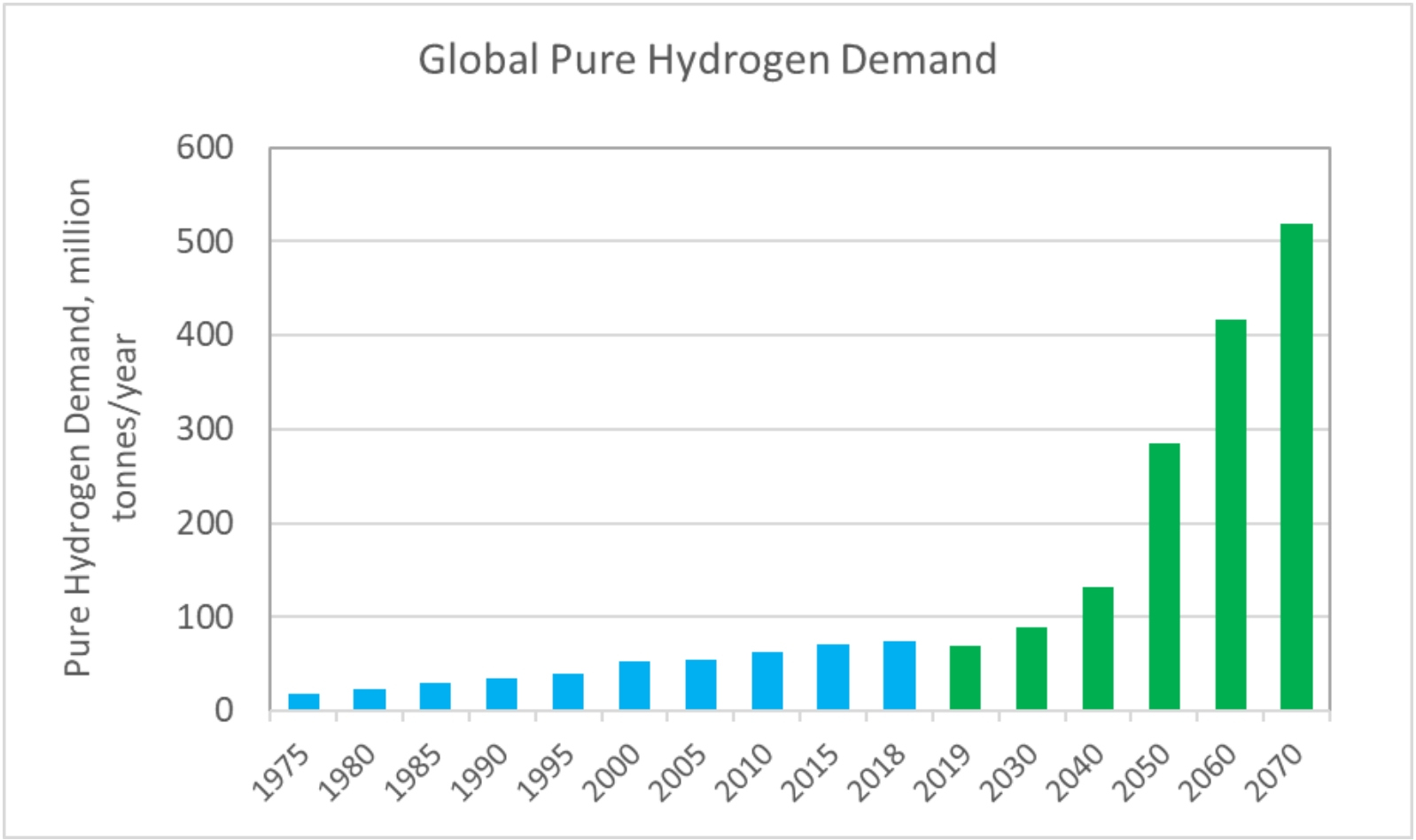


Historic global hydrogen demand



Source: IEA

Projected clean hydrogen demand dwarfs historic demand



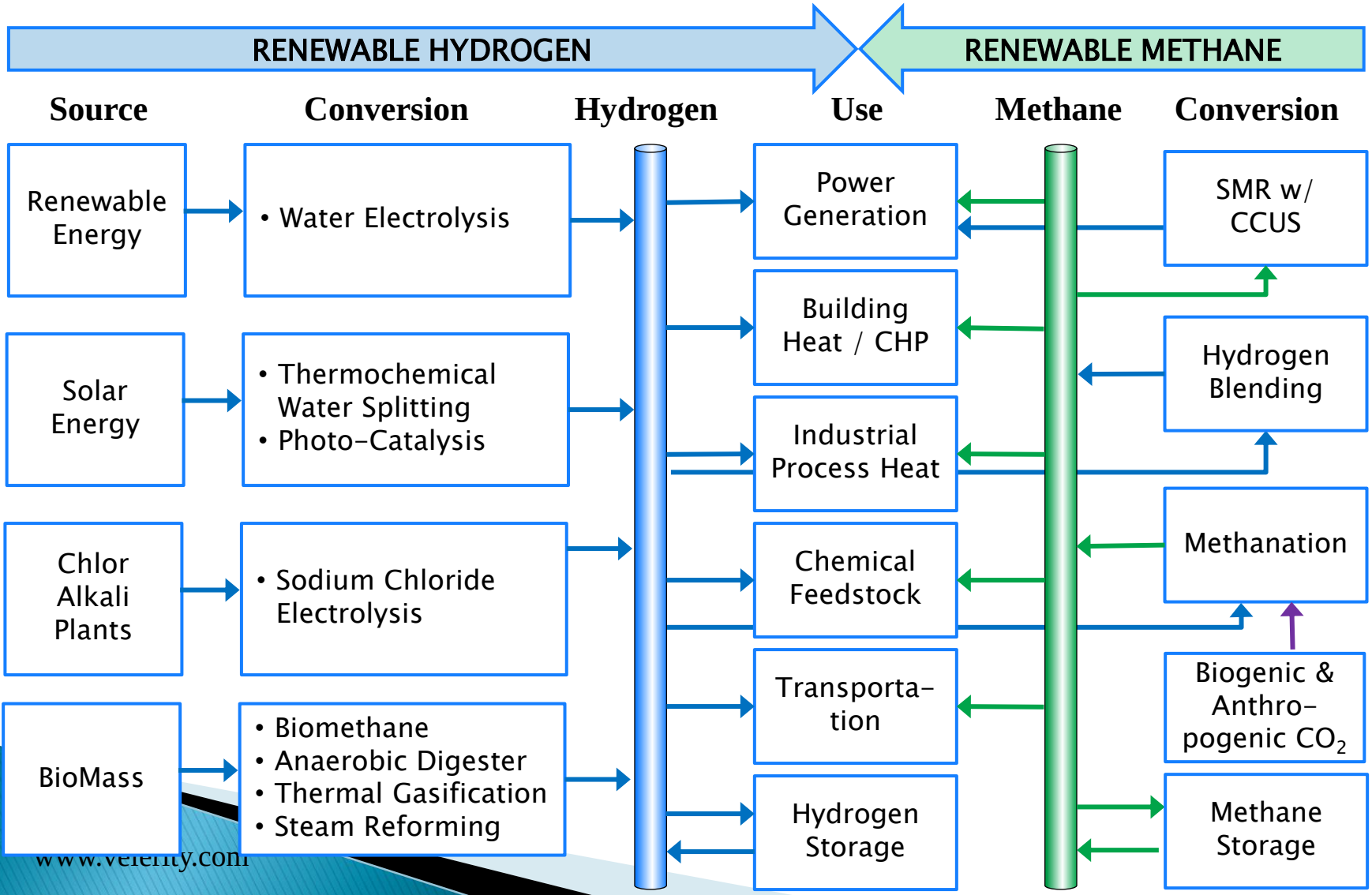
Source: Energy Technology Perspectives 2020, IEA

Hydrogen applications

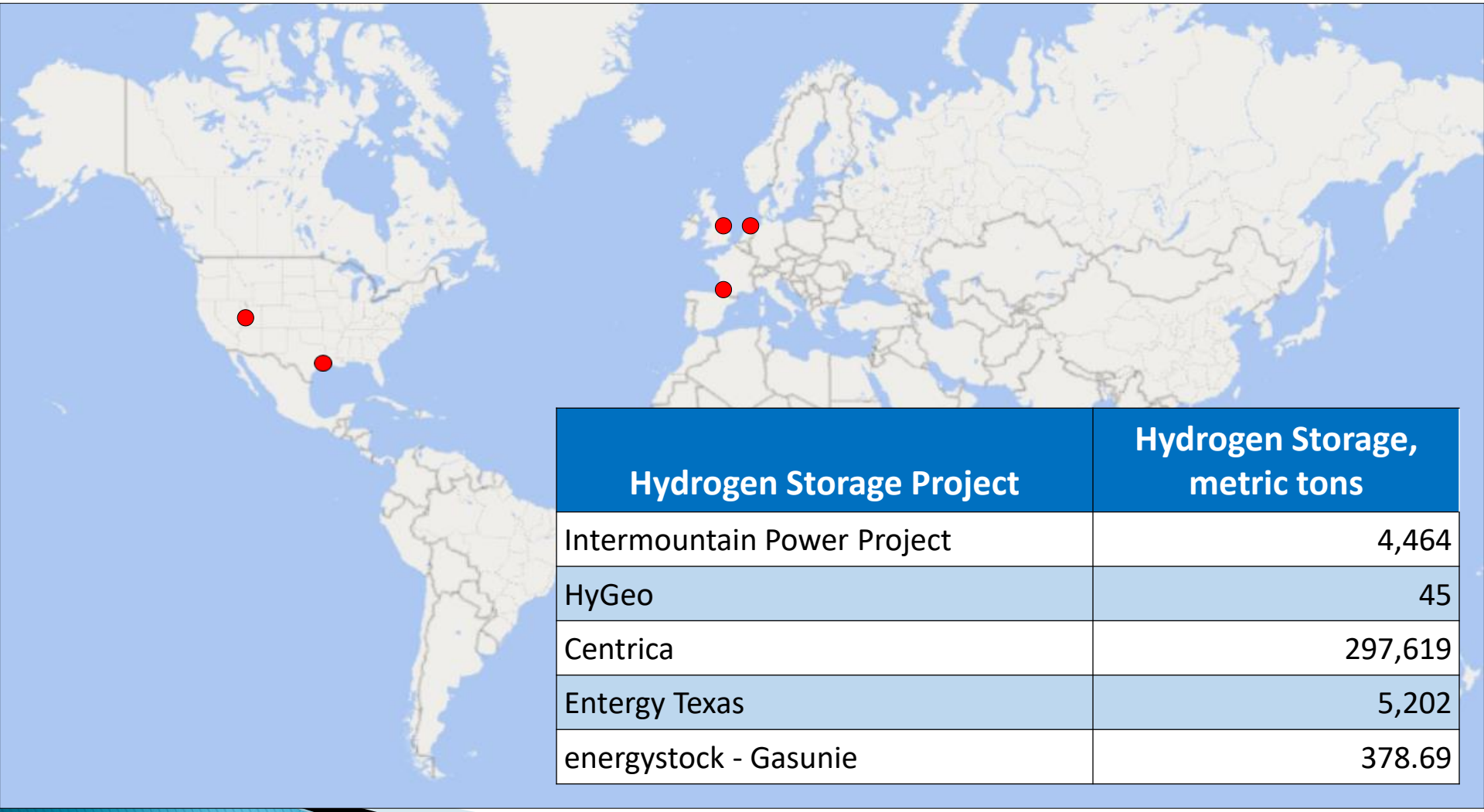
- Case Studies
  - Decarbonizing the Gas Grid
  - Long Duration Energy Storage
  - Heavy Vehicle Transportation
  - Hydrogen for Power Generation
  - Hydrogen Hubs

- Other Hydrogen Applications
  - Hydrogen to the Home
  - Backup Power
  - Industrial Process Heat

Green Hydrogen Pathways for Decarbonizing the Gas Grid

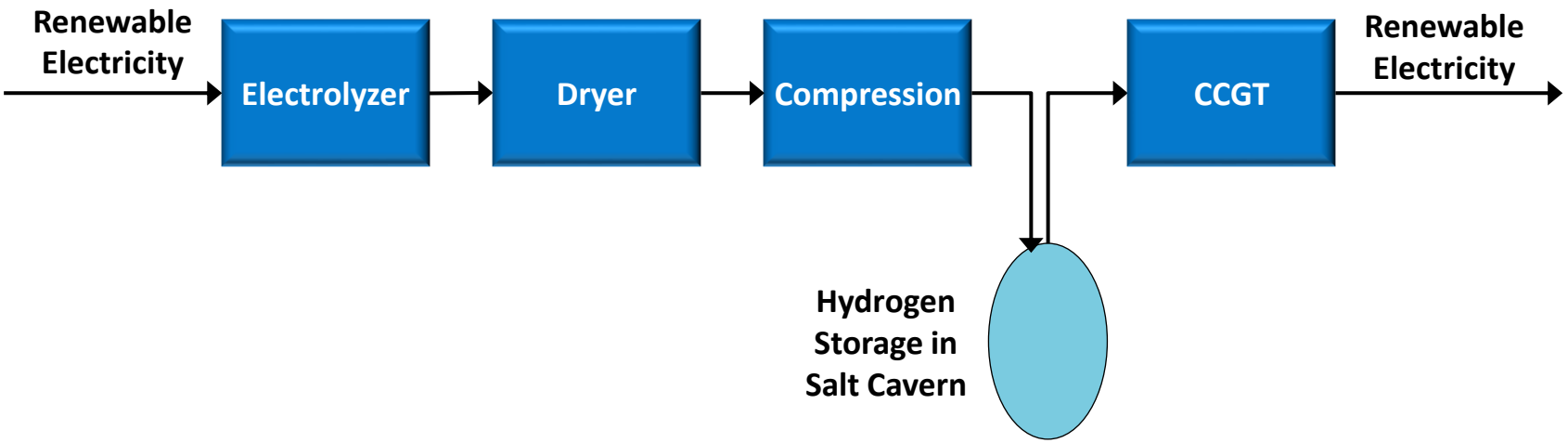


Major Hydrogen Storage Projects



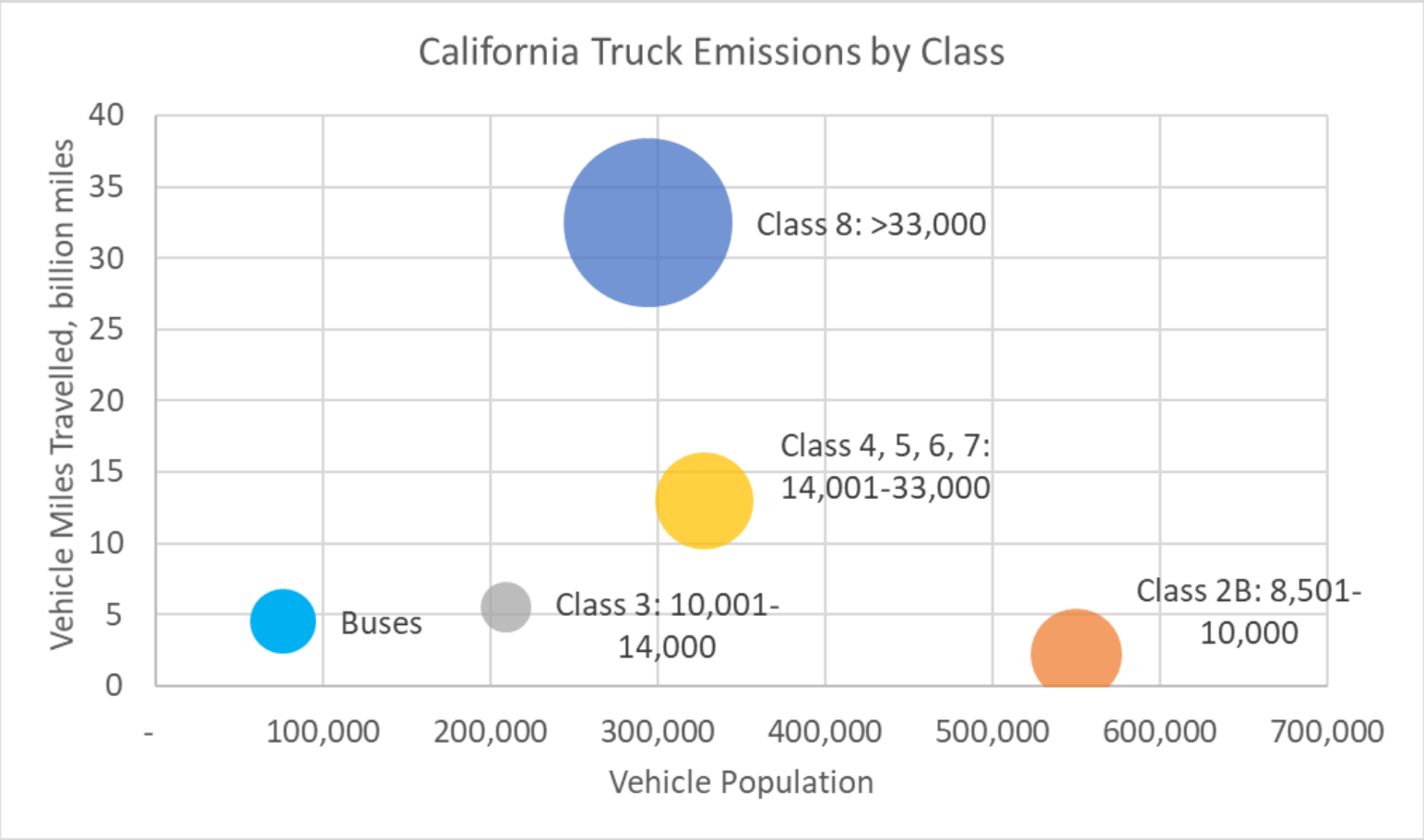
Hydrogen Storage Project	Hydrogen Storage, metric tons
Intermountain Power Project	4,464
HyGeo	45
Centrica	297,619
Entergy Texas	5,202
energystock - Gasunie	378.69

These projects need a significant gap between the electricity purchase price and electricity sales price for the financials to pencil out



Renewable electricity purchase	1,000,000	MWh/yr
Renewable electricity cost	0.02	$/kWh
Electricity production	423,360	MWh/yr
Electricity price	0.16	$/kWh
Electrolyzer size	254	MW
Cavern hydrogen capacity	5,300	tons
Turbine size	107	MW
Capital investment	$ 295,988,636	
NPV @8%	$ 21,650,514	

Heavy Transport – Key Driver
Truck emissions in California by class of truck



CalHEAT Roadmap
CaFCP MD & HD FCET Action Plan

Leading fuel cell truck manufacturers

Hyzon Motors

- Truck and Fuel Cell System Sales by end of 2020
  - Heavy Truck 70
  - Light Truck 350
  - City Bus 5
- Building out Rochester, NY plant designed for assembling 10,000 vehicles per year
- Building out Illinois Plant for Fuel Cell Manufacturing

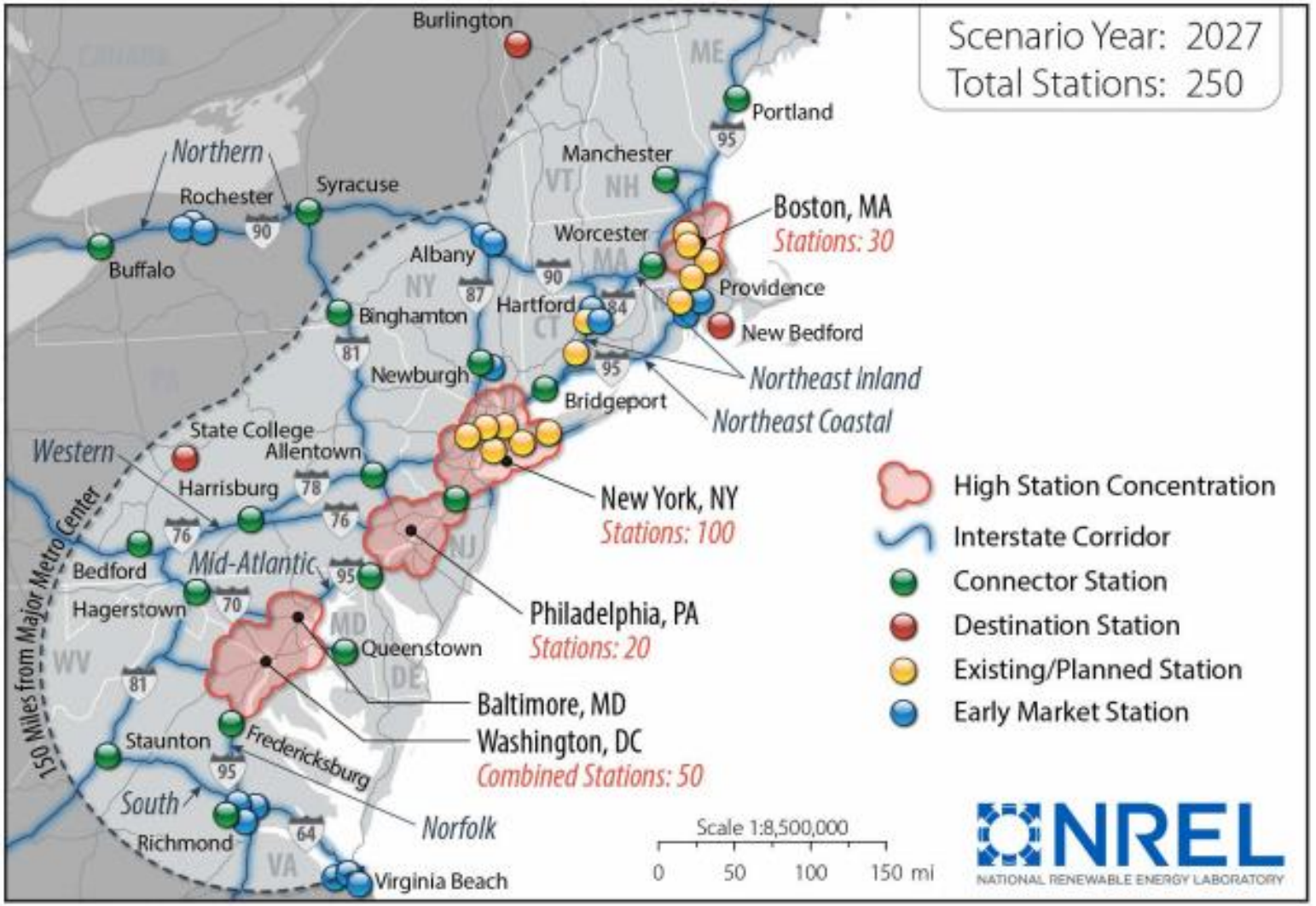
Hyundai Xcient

- Switzerland
  - 50 trucks, 1,600 by 2026
  - Range 400 km
  - H2 Storage 34.51 kg
  - Fuel Cell 190 kW
- California
  - 30 trucks planned
  - Range 800 km

Heavy vehicle fueling strategies

- **Hyzon Motors**
  - 2021: 95% On-site customer supply, 5% existing stations
  - 2021-2024: Hyzon created capacity for 25%, 75% on-site and existing stations
  - After 2024: Hyzon Network 50%, 3rd party capacity 50%
- **Plug Power**
  - Liquid hydrogen production from renewable sources
  - Distributed and stored on fueling site in liquid form
  - Partnerships with Apex, Brookfield and Linde
  - Acquired Giner for electrolysis
- **Nikola**
  - Sourcing inexpensive electricity where available
    - Arizona Public Service quoted at 2.7 cents/kWh
  - Transporting hydrogen in liquid or gaseous form where needed
  - Plans to build stations, current estimate at $16 million per station and targeting $10 million per station buildout
  - Nikola, IVECO and OGE to build 124 mile pipeline for distributing hydrogen to fueling stations
  - Nikola plans a network of 700 hydrogen stations across the U.S. and Canada by 2028

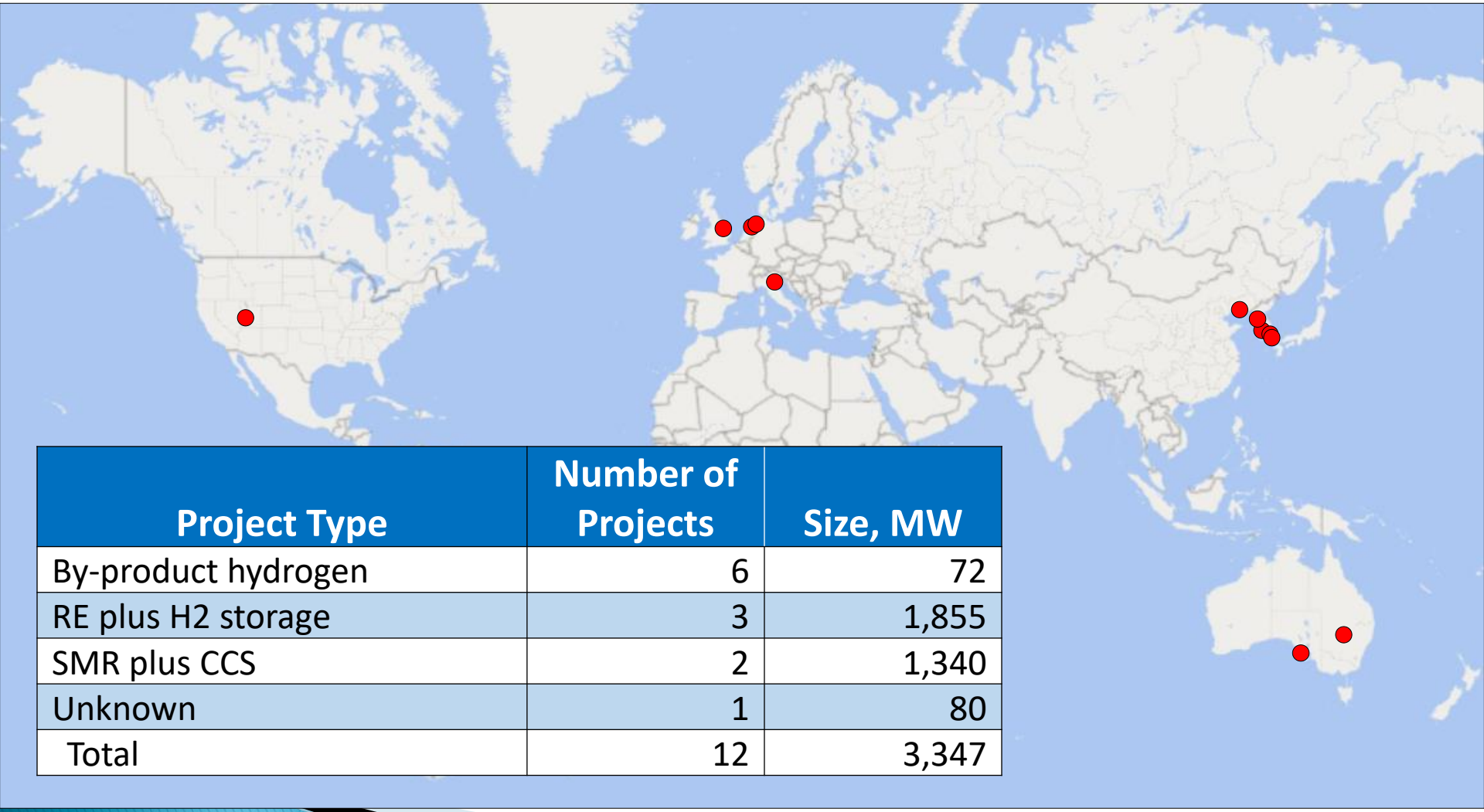
2027 Northeast Hydrogen Station Deployment Plan – H2USA



Hydrogen Power Generation
Four use cases dominate hydrogen power generation

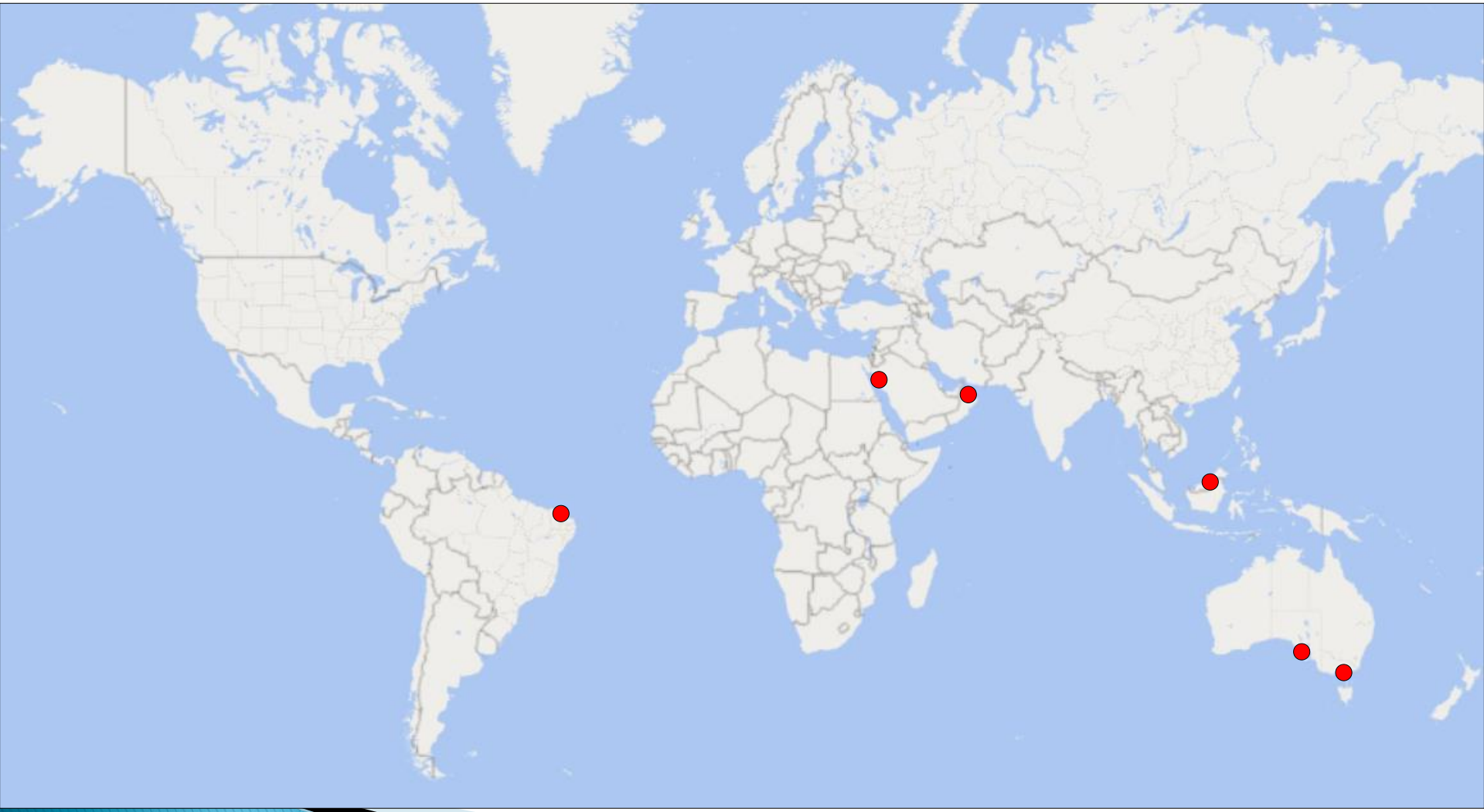
1	**Capturing excess hydrogen from industrial processes for in-the-fence power generation**
2	**Baseload power generation using hydrogen from steam methane reforming coupled with carbon capture and sequestration**
3	**Long duration energy storage using stored hydrogen generated from wind, solar and hydropower**
4	**Baseload power with methane pyrolysis feeding hydrogen to gas turbines and sequestering elemental carbon or putting the carbon black to use**

Twelve grid scale hydrogen power plants around the world, either operating or in advanced planning stages, have been identified

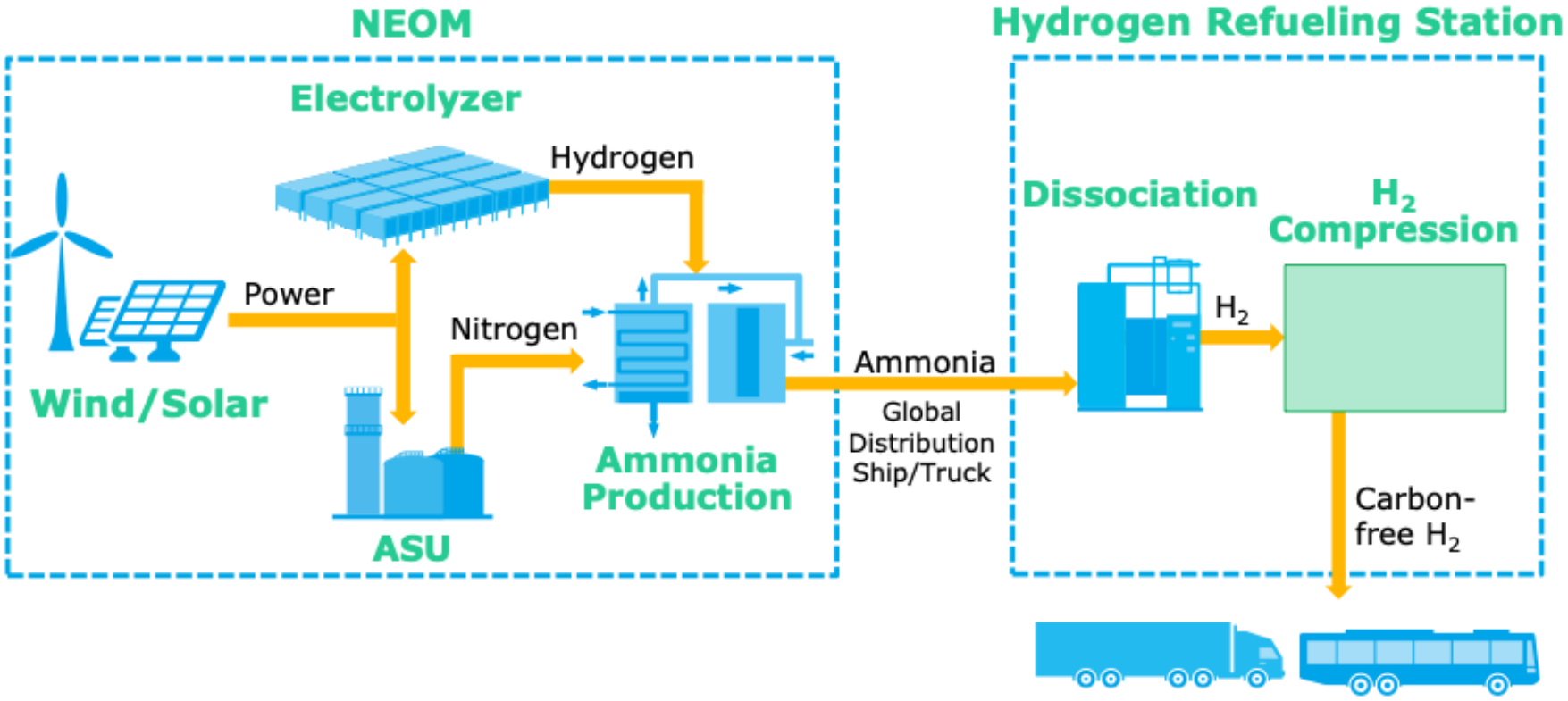


Project Type	Number of Projects	Size, MW
By-product hydrogen	6	72
RE plus H2 storage	3	1,855
SMR plus CCS	2	1,340
Unknown	1	80
Total	12	3,347

Multiple hydrogen hubs are being developed around the world, representing billions of dollars of investment



Neom is a $7 billion project to produce renewable hydrogen, convert the hydrogen to ammonia, and ship the ammonia around the world



The Noem project will produce and distribute green ammonia globally for refueling trucks and buses with hydrogen

NEOM نيوم

thyssenkrupp

HALDOR TOPSOE

- Wind & solar — 4 GW
- Investment in Noem — $5 bil.
- Hydrogen production — 650 tons/day
- Ammonia production — 1.2 mil. tons/yr
- Distribution infrastructure — $2 bil.
- Noem Facility Partners
  - Noem — 33%
  - Air Products — 33%
  - Acwa Power — 33%
- Electrolyzers — Thyseenkrupp
- Ammonia Tech. — Haldor Topsoe
- Ammonia Distribution — Air Products

Question and Answer