Emerging Technology Forum

Hydrogen 101

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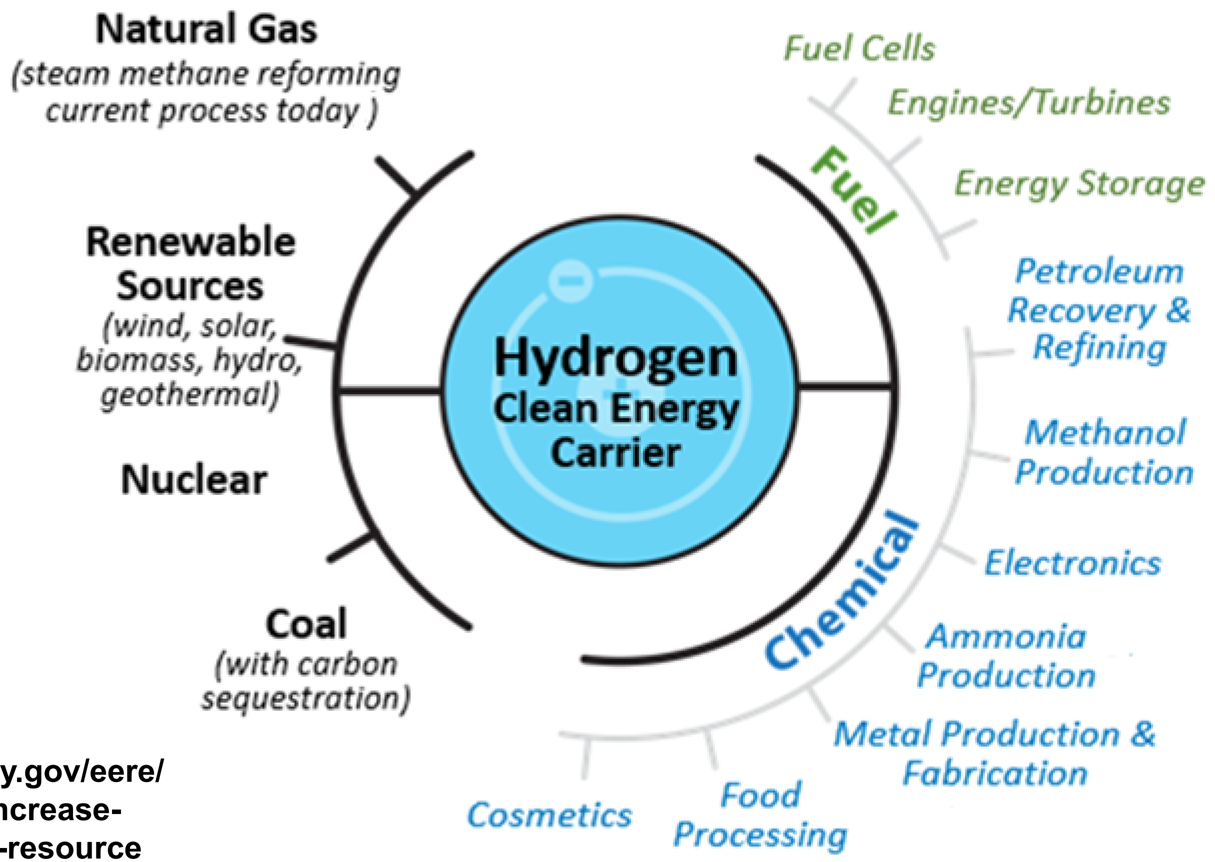
March 17, 2022

What is Hydrogen?

Lightest of all gases and a versatile, clean and flexible energy carrier

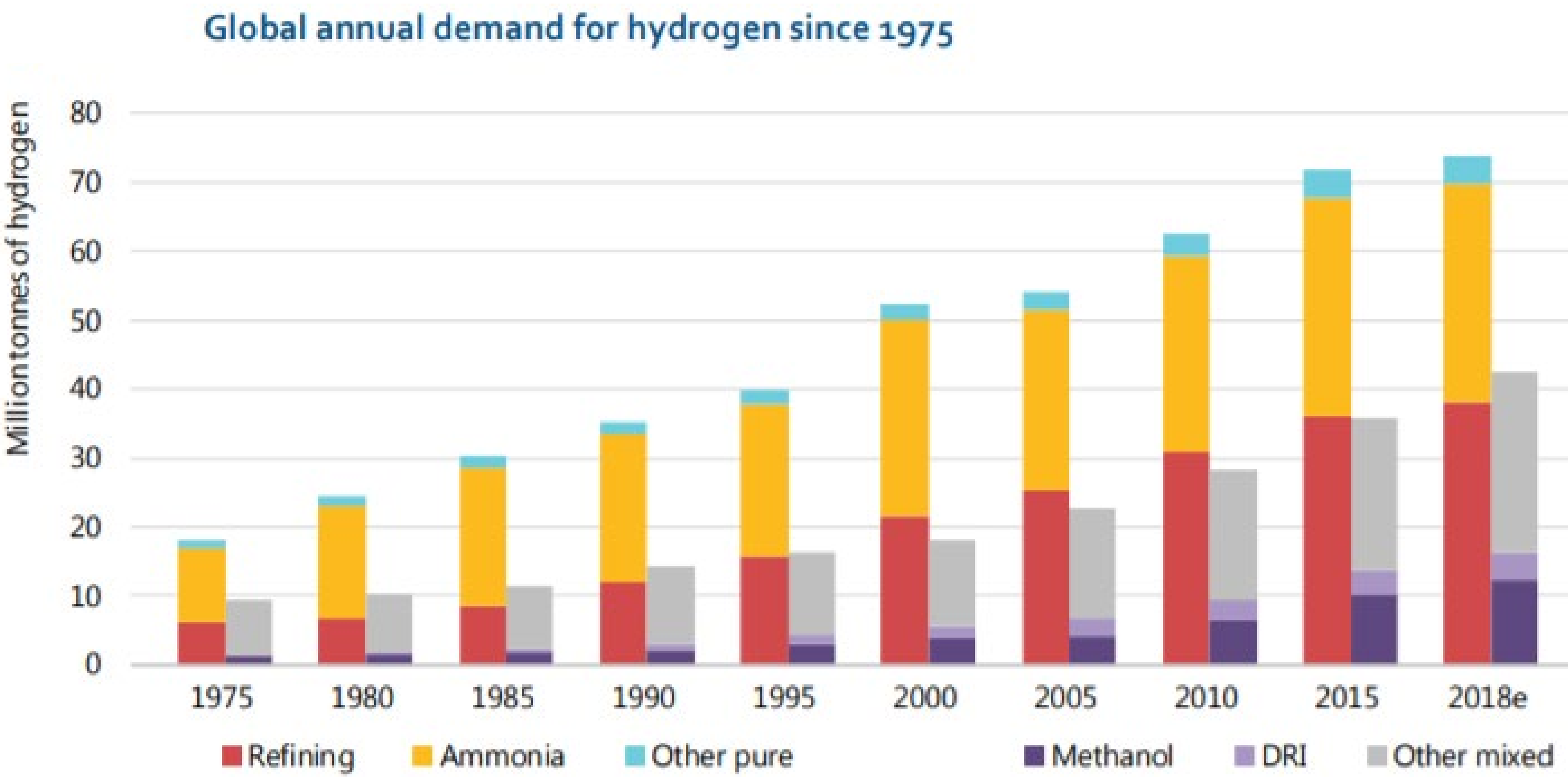


Source: DOE
https://www.energy.gov/eere/fuelcells/articles/increase-your-h2iq-training-resource

Produced from diverse domestic resources and used in many applications

Global Hydrogen Demand Growth

Global demand for hydrogen has experienced an annual growth rate of ~10-15% from 1975 to 2018

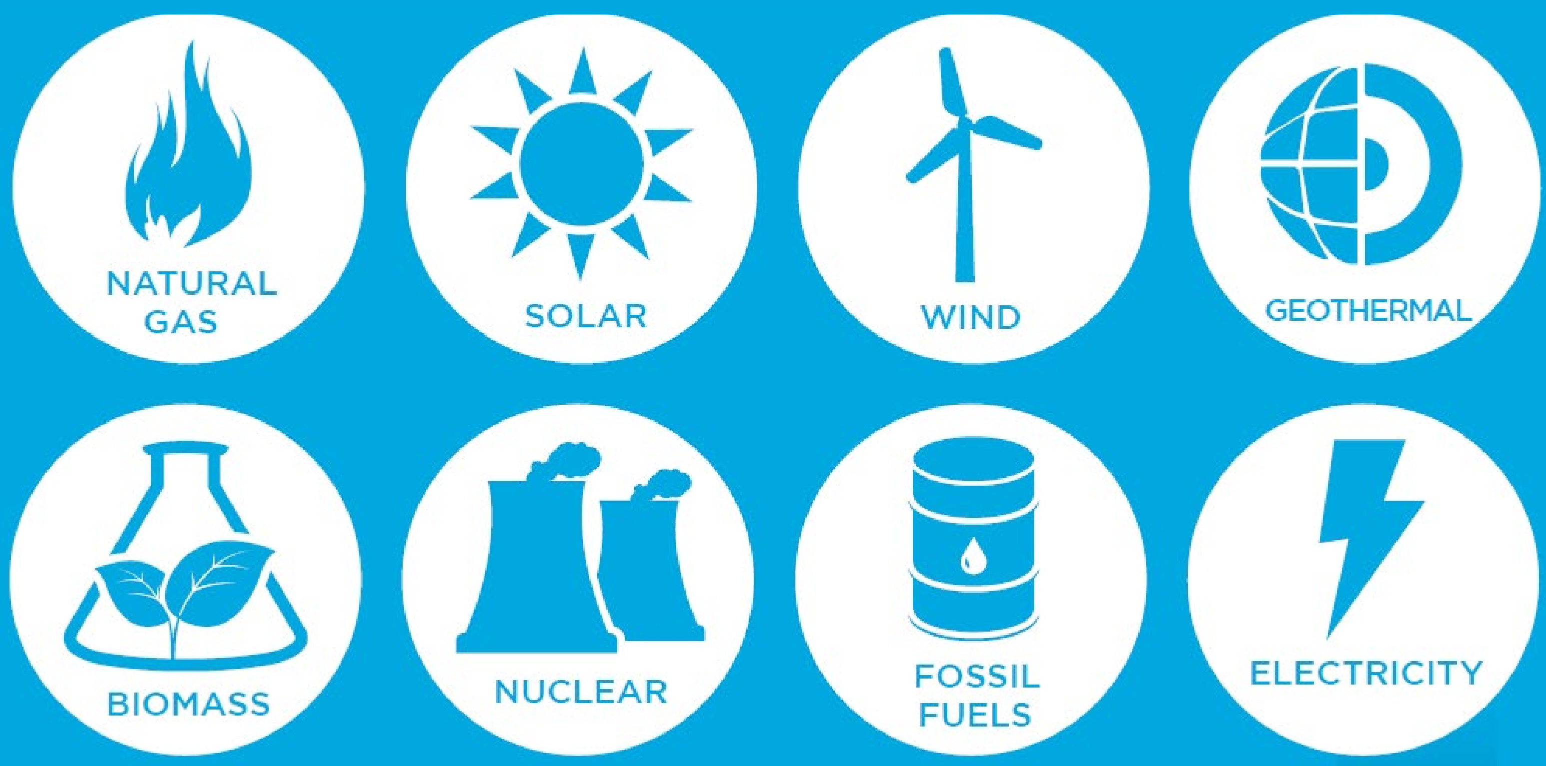


Source: IEA report "The Future of Hydrogen, Seizing today's opportunities"

Many Domestic Energy Sources for Hydrogen Production

Domestic energy sources can be used to produce hydrogen

Most of today's hydrogen comes from natural gas



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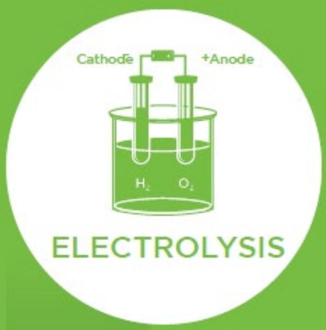
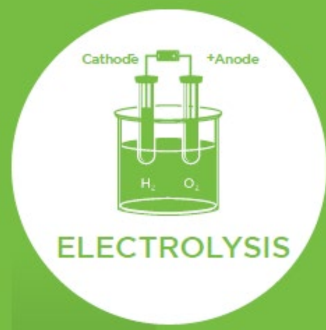
Many Pathways for Hydrogen Production

Today >90% of hydrogen is produced through natural gas steam methane reforming



Alkaline Electrolysis

Electricity separates water into oxygen and hydrogen



Low & High Temperature Electrolysis

Electricity separates water into oxygen and hydrogen

Energy from direct sunlight and sun heat splits molecules

Steam and hydrocarbons come together under high temperature

	Alkaline Electrolysis	Low & High Temperature Electrolysis	Direct Solar Water Splitting	Steam Methane Reforming
Advantages	- Ultra pure H_2 produced - Zero carbon emissions - Scalable - >30 yrs. in use	- Ultra pure H_2 produced - Zero carbon emissions from nuclear and renewable electricity	- Ultra pure H_2 produced - Zero carbon emissions from H_2 production	- Scale & Large capacity production - Incumbent technology for >90% of H_2 production
Disadvantages	- Lower efficiency electrolysis	- Scale & large scale production	- Scale & large scale production	- Hi CO_2 emissions without capture and sequestration

Multiple Uses for Hydrogen

Hydrogen can be used in many sectors throughout the economy

FUEL CELL VEHICLES

Including other mobile applications like buses, trucks, and forklifts

ENERGY STORAGE

Good for limiting renewable power curtailing and stabilizing grid

STATIONARY FUEL CELLS

Interest from cell phone towers, data centers, hospitals, and supermarkets

PETROLEUM REFINING

Largest use of hydrogen produced today

CHEMICALS

Second largest use of hydrogen produced today

Source: DOE https://www.energy.gov/eere/fuelcells/articles/increase-your-h2iq-training-resource

Hydrogen Demand: Growth Progression for Decarbonization

Current Demand
Refining
Chemicals (Ammonia & Methanol)
Steel & metals refining
Forklifts

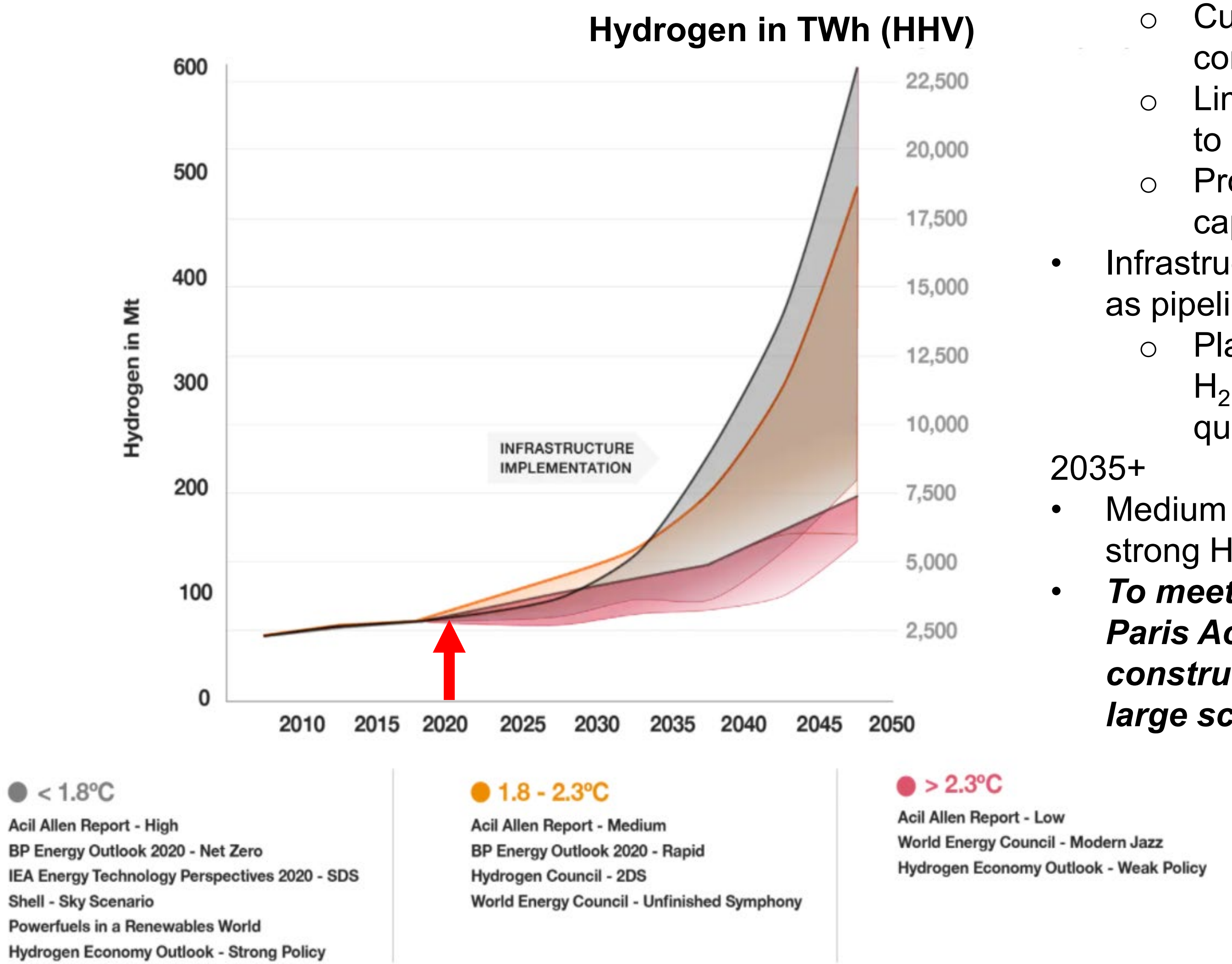
Future Demand
Light Duty Vehicles
Injection into the natural gas system
Steel
Synthetic & bio- fuels
Medium & Heavy duty trucks
Refining
Aviation & Marine
Methanol
Ammonia

Captive Production	**5.26**
Petroleum Refineries	*3.60*
Ammonia	*1.27*
Methanol	*0.11*
Other(e.g., cyclohexane, aniline, etc.)	*0.28*
Merchant Production	**3.77**
Refineries	*2.64*
Ammonia	*0.87*
Other (e.g., cyclohexane, aniline, methanol, etc.)	*0.26*
Total Domestic Production	**9.03**

Million metric tons/yr.

Source: https://www.hydrogen.energy.gov/pdfs/16015_current_us_h2_production.pdf

Hydrogen Forecast



Current to 2030

- **Steady growth of H_2 demand**
  - Current H_2 projects under construction and in operation
  - Limited by electrolyzer capacities to ≤50 MW
  - Proposed electrolyzer plants with capacities of 100 MW
- Infrastructure for large scale use such as pipelines require >7 years to build
  - Plan to build in parallel to growing H_2 demand to transport large quantities of H_2

2035+

- Medium and high scenarios exhibit strong H_2 growth and demand
- ***To meet the climate targets of the Paris Accord, planning and construction for H_2 infrastructure for large scale H_2 deployment is needed***

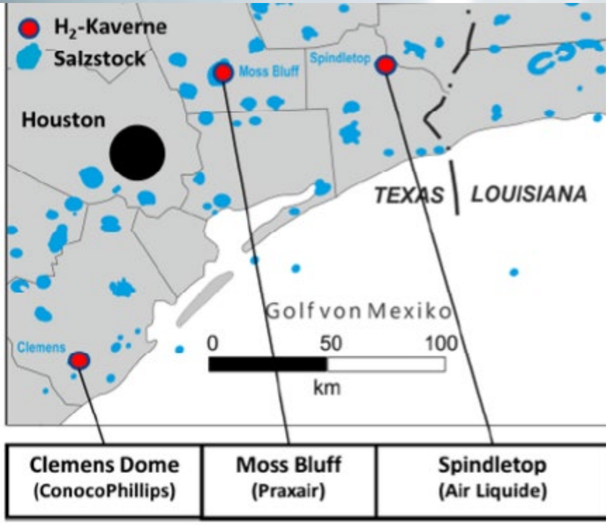
Source: PwC "The green hydrogen economy **Predicting the decarbonisation agenda of tomorrow"**

Infrastructure

Major challenge for Hydrogen is infrastructure

Hydrogen infrastructure components

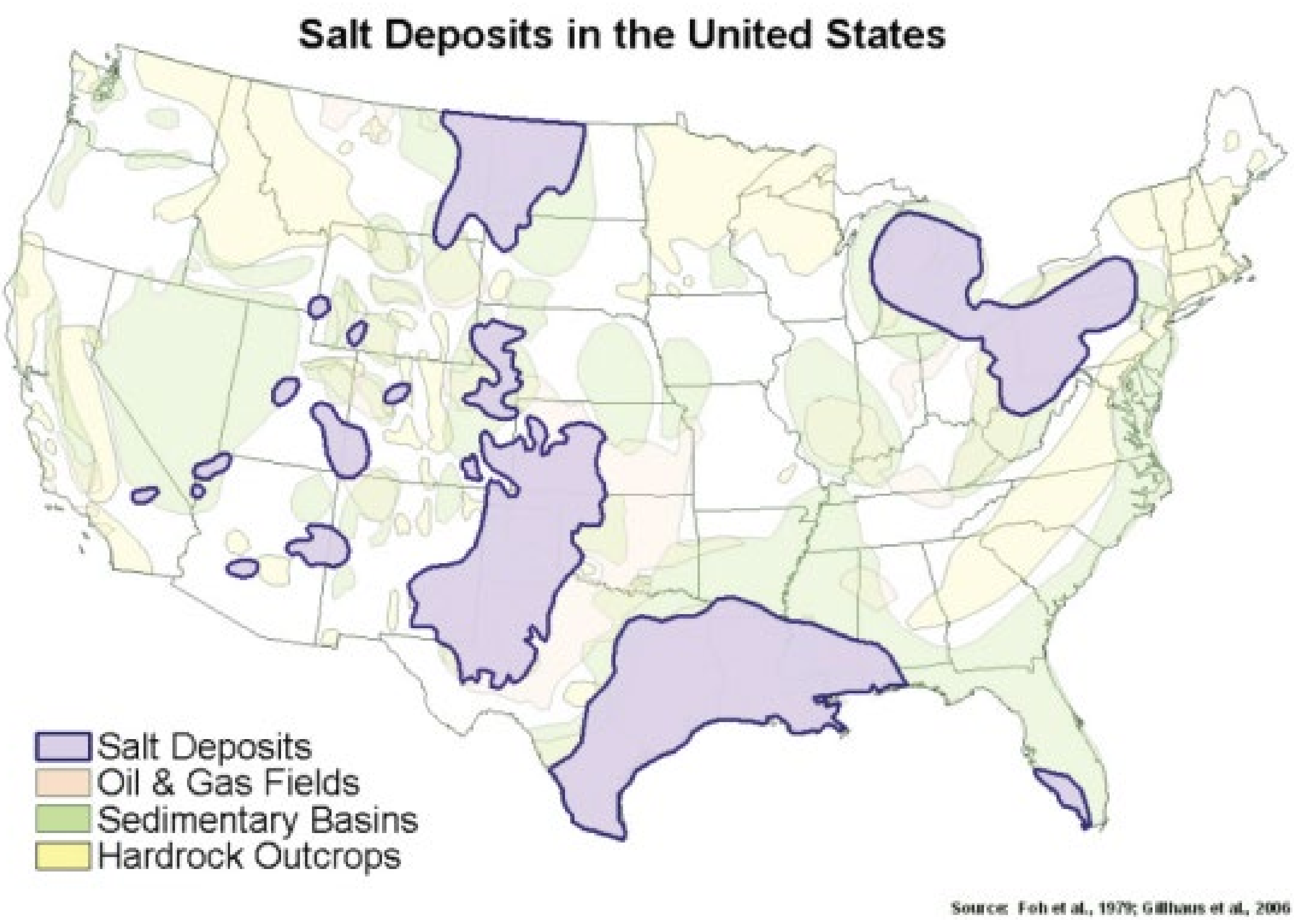
- **Storage**
  - Gaseous
    - Above ground tanks – compressed gas
    - Geologic
      - 3 geologic storage caverns and 1 under construction
      - ~50 tonne capacity per cavern
      - Located in Gulf Coast region
  - Liquid
    - Cryogenic
      - Classic example: NASA



- **Delivery**
  - Gas tank truck
  - Liquid tank truck
  - Pipeline
    - ~1,600 miles of hydrogen pipelines in US
      - Located in Gulf Coast, LA and Indiana lake region

Geologic Storage for Hydrogen

Potential Cavern Storage



Geologic Storage:

- *Salt deposit attributes*
  - Excellent for storage of high purity hydrogen
  - Large volume storage
  - Minimal leakage potential
- *Sedimentary basins*
  - Excellent for storage of high purity hydrogen
  - Large volume storage
- *Depleted Oil & Gas fields*
  - Large volume storage
  - **NOT Suitable** for storage of high purity hydrogen

Source: Sandia National Laboratory

Comparison of 2 Energy Systems: Natural Gas and Hydrogen Infrastructure

Infrastructure	Natural Gas	Hydrogen
Pipeline	Many miles throughout the US	~1,600 miles exist *Requires alloy piping for high pressure*
Storage	Cavern storage, intermediate storage in depleted oil & gas formations	3 caverns at 50 tons per cavern, 1 under construction *Requires salt dome geologic storage for high purity H_2*
Liquid systems	LNG systems and terminals	H_2 liquefiers around the US and Canada, more under construction *Systems cost ~$160 M per 30 ton/day unit, high electricity demand*
Purity requirements	Meet the FERC requirements for heating value	High purity for fuel cells, moderate purity for refining applications *Require hydrogen purity of 99.9999% for fuel cell applications*

Electrical Markets

How can the ISOs benefit the buildout of clean hydrogen?

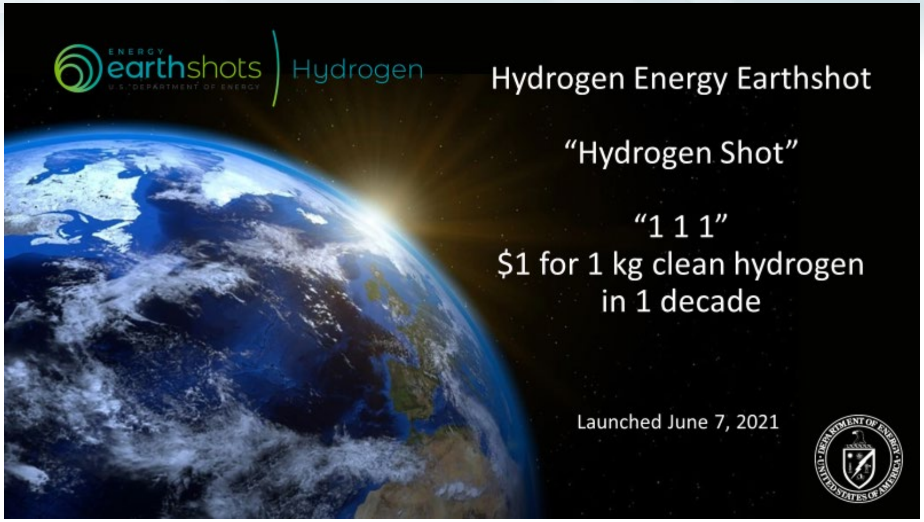
Electrical Grid Offers an Infrastructure Solution for Hydrogen through Distributed Electrolysis

US Electric Power Markets (FERC 2020)

Why hydrogen?

Hydrogen is a DOE Priority

- **Hydrogen is central to the Department of Energy's clean energy strategy**
- DOE Hydrogen Fuel Cell Technologies Office
  Hydrogen Earthshot
  - Announced by DOE Secretary Granholm in 2021
  - Goal to reduce the cost of hydrogen to $1/kg in one decade (1-1-1)
- **Infrastructure Investment and Jobs Act**
  - Signed into law on November 15, 2021 by President Biden
  - Section 813. Regional Clean Hydrogen Hubs
    - Support the development of at least 4 regional hydrogen hubs
    - Demonstrate the production, processing, delivery, storage and end-use of clean hydrogen
    - Each hub eligible for up to $2 billion in federal support



DOE Request for Information (RFI) in advance of the planned FOA

- Issued Feb. 16, 2022
- Response due March 8, 2022
- Requests responses for up to 40 questions (not all need to be answered)
- Describes Phases of Hub Funding
  - Phase 1 - Hub Planning (8-12 $1-$4 M DOE awards over 3-18 months)
  - Phase 2 - Hub Construction and Deployment (4-6 $500 M-$1 B awards over 5 or more years)

Infrastructure Investment and Jobs Act




Regional Clean Hydrogen Hubs

Criteria

- Demonstrate the production of clean hydrogen with a focus on one of the following:
  - Nuclear Energy
  - Renewable Energy
  - Fossil Fuels
- H_2Hubs ***must***
  - Demonstrably aid the achievement of the clean hydrogen production standard developed under Section 822(a) [defined as 2 kg CO_2e/kg H_2 at the point of production];
  - Demonstrate the production, processing, delivery, storage, and end-use of clean hydrogen; and
  - Aid the transition to a national clean hydrogen network to facilitate a clean hydrogen economy.




Regional Clean Hydrogen Hubs

End-Use Diversity

- At least one regional clean hydrogen hub shall demonstrate the end-use of clean hydrogen in:
- Electric Power Generation
- Industrial
- Residential and Commercial Heating
- Transportation

Geographic Diversity

Each regional clean hydrogen hub:

- Shall be located in a different region of the U.S.
- Use energy resources that are abundant in that region

Regional Clean Hydrogen Hubs

Feedstock Diversity

- At least one hub demonstrating clean hydrogen production from each of the following sources (i.) fossil fuels, (ii.) **renewable energy**, (iii.) **nuclear energy**

Employment

Priority given to regional clean hydrogen hubs that are likely to create opportunities for skilled training and long-term employment to the greatest number of residents in the region

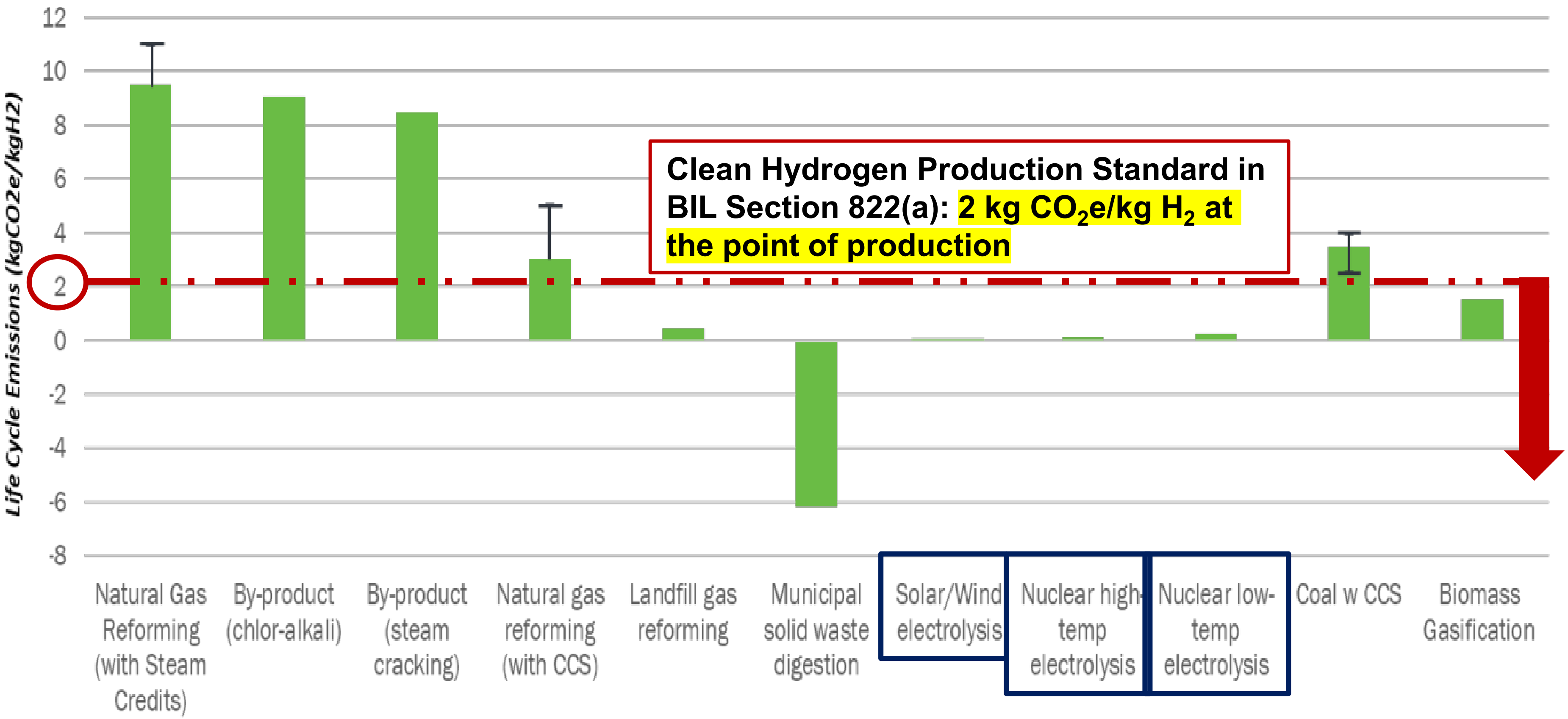
DEI

Expected that DOE will require a plan for diversity, equity and inclusion

CO2 Emissions

CO_2 Emissions from Hydrogen Production Pathways

Emerging technologies can meet and exceed "Clean H_2" standards



Ranges shown reflect potential variability in upstream leak rates, CCS efficiency, and capture rates. Baseline assumes 90% capture.

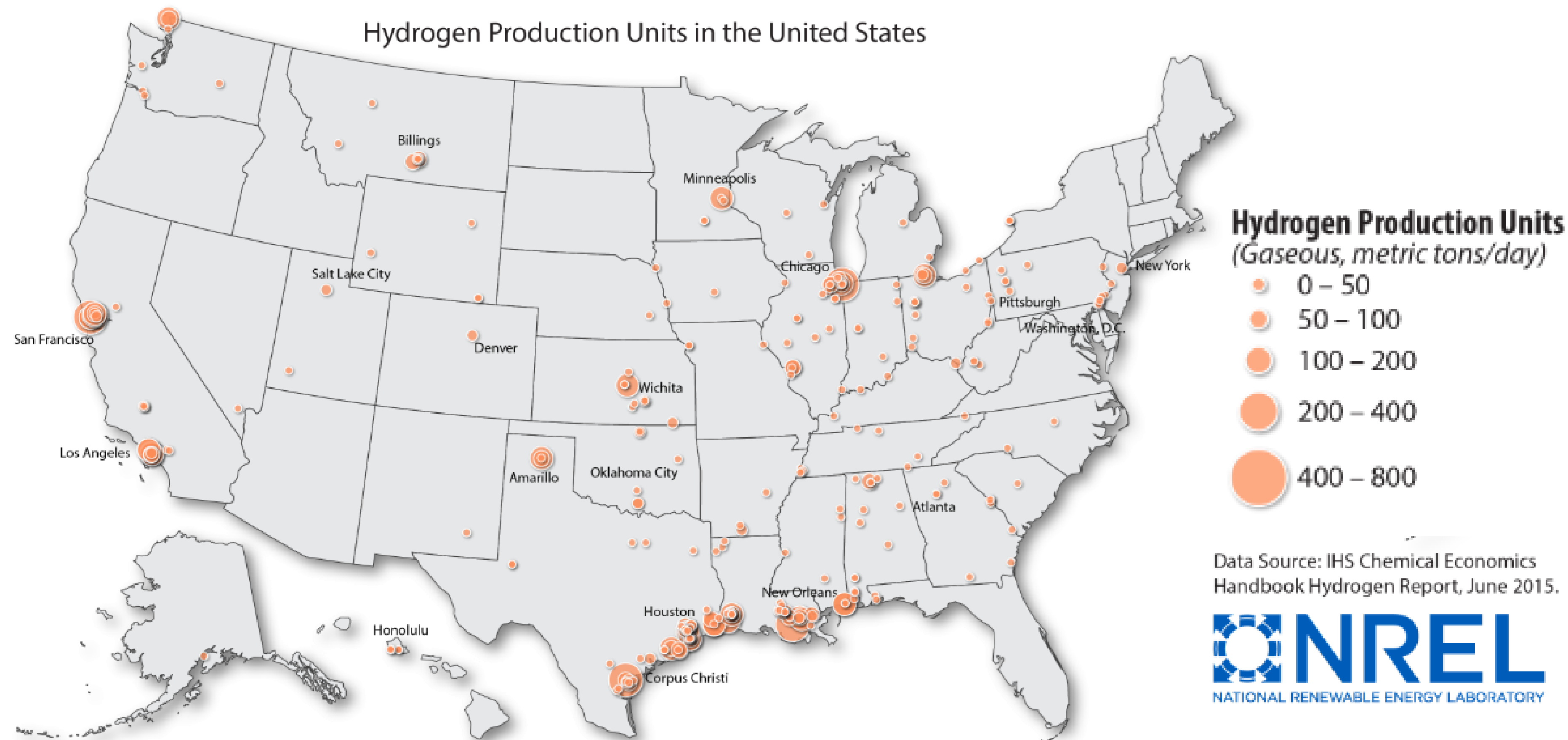
Source: Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model 2021, https://greet.es.anl.gov/

Source: https://www.energy.gov/sites/default/files/2022-02/h2iqhour-02242022.pdf

CCS: Carbon Capture and Sequestration
GHG: Green House Gas
GREET: Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model

Backup

Hydrogen is an industrial commodity



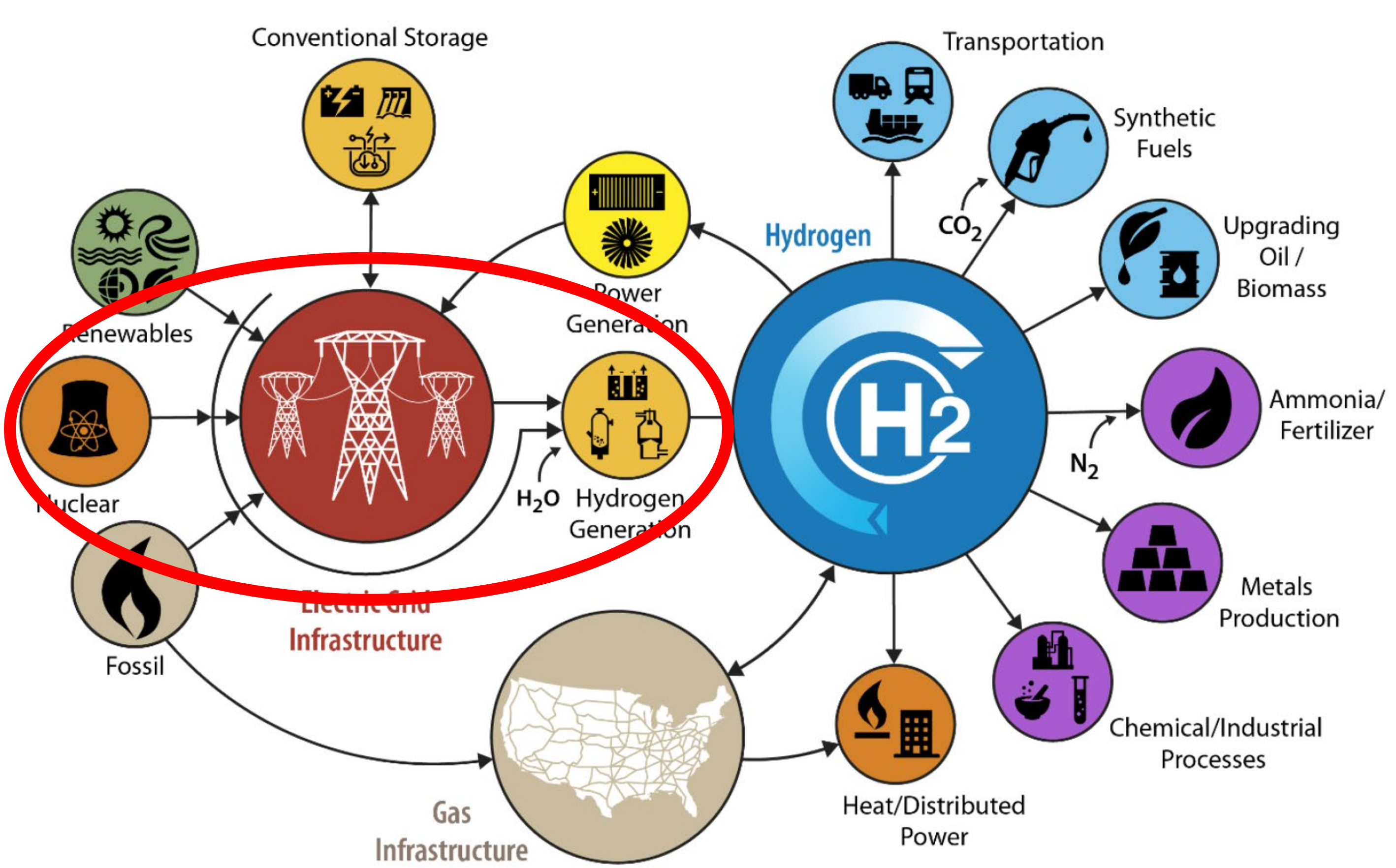
Source: DOE https://www.energy.gov/eere/fuelcells/articles/increase-your-h2iq-training-resource

U.S. annual hydrogen production
10 million metric tons

Largest users in the U.S.			
Petroleum Processing	68%	Fertilizer Production	21%

H_2@Scale

Nuclear Power is a key ingredient to the success of large scale hydrogen utilization of the DOE **H_2@Scale strategy**



H2@Scale lays a framework for the potential wide-scale production and utilization of hydrogen.

H2@Scale addresses high level energy-related issues such as enabling grid resiliency, energy security, cross-sector efficiency improvements, and emissions reductions.