STRATEGEN

Hydrogen Power Study Task Force: Infrastructure Working Group Meeting #2

Hosted by Strategen Consulting
October 24, 2022

Meeting Logistics

- Mute Microphone – in order to prevent background noise that disturbs the meeting, if you aren't talking, please mute your microphone or phone.

- Chat Box – if you aren't being heard, please use the chat box or raise your hand to ask a question. Please try to limit comments in the chat as these may not be officially captured in the record.

- Recording Meeting – we will record and post the meetings at www.ctgreenbank.com/hydrogentaskforce and you can also access meeting dates and dial-in information through Secretary of State.

- State Your Name – for those talking, please state your name for the record.

STRATEGEN

STRATEGEN

Agenda

+ Welcome and Introductions (10 min)
+ Review of Working Group Schedules (5 min)
+ Overview of Hydrogen Infrastructure (25 min)
  + Hydrogen Pipelines – location, costs, regulation
  + Hydrogen Storage – location, costs, technology
+ Discussion and Next Steps (20 min)

Reminder: Strategen's Role

- The Strategen team will handle meeting logistics including scheduling and recording meeting minutes.
- The Strategen team will coordinate with Working Group Co-Chairs to develop meeting agendas which will be provided to participants a week before Working Group meetings.
- The Strategen team will provide technical assistance (including research), where appropriate, for the Working Group.
- It is expected that this working group will meet on a monthly cadence. Meeting recordings and meeting minutes will be publicly available.

Introductions

Please share your name, title, and organization

Working Group Meeting Schedule

<table>
<tr><th></th><th>September</th><th>October</th><th>November</th><th>December</th></tr>
<tr><td>Funding</td><td>9/27
4-5pm</td><td>10/26
10:30am-12 pm</td><td>11/18
10:30am-12 pm</td><td>12/15
10:30am-12:00 pm</td></tr>
<tr><td>Infrastructure</td><td>9/28
2-3pm</td><td>10/24
2-3pm</td><td>11/17
3-4pm</td><td>12/19
3-4pm</td></tr>
<tr><td>Policy
& Workforce
Development</td><td>9/26
3-4pm</td><td>10/20
12-1pm</td><td>11/29
12-1pm</td><td>12/15
12-1pm</td></tr>
<tr><td>Sources</td><td>9/27
1-2pm</td><td rowspan="2">10/25
2-3:30pm</td><td>11/17
11am-12pm</td><td rowspan="2">12/20
1-2:30pm</td></tr>
<tr><td>Uses</td><td>9/27
12-1pm</td><td>11/22
12-1pm</td></tr>
</table>

Hydrogen Pipelines

General Background

- Hydrogen gas transmission pipelines are typically composed of steel, including stainless steel and carbon steel alloys.
- Hydrogen has a stricter set of material standards for pipelines than natural gas, and requires thicker pipelines walls at larger diameters
- There are approximately 1,600 miles of hydrogen pipelines currently operating in the United States. These pipelines are in areas with high concentrations of large hydrogen users (e.g., petroleum refineries and chemical plants), such as the Gulf Coast.

Map of Air Products H2 pipelines and plants in the Gulf Coast

Cost Profile for Hydrogen Pipelines

- **Under stable demand conditions, pipelines containing gaseous hydrogen can be the most economic form of hydrogen delivery**
  - Other forms of delivery, such as liquid hydrogen, are currently only competitive in applications beyond the reach of hydrogen pipeline supplies
  - Analysis indicates that pipeline delivery is the lowest cost option for large market demands (>150 metric tons per day)
- **Although hydrogen pipelines can be a cost-effective means of transporting hydrogen at scale, initial capital costs for development are high**
  - Capital investments in excess of $1M per mile with the inclusion of rights-of-way costs
  - Current research is aimed at lowering capital costs through novel materials (e.g., fiber-reinforced polymer) and improved characterization of conventional materials

Regulation of Hydrogen Pipelines

- **Like other forms of pipelines, hydrogen pipelines can face challenges around permitting and rights-of-way due to perceived environmental risks or potential risks to public safety**
  - Safety permits and environmental impact assessment are required to ensure that surrounding communities and ecosystems are not adversely affected
  - Building along existing rights-of-way for natural gas pipelines can help reduce permitting lead times and overall costs
- **DOT's Pipeline and Hazardous Materials Safety Administration is currently responsible for the safety of hydrogen pipelines**

Regulation of Hydrogen Pipelines (cont.)

- **When transported alone, hydrogen is covered by the Hepburn Act, which has two iterations:**
  - Pipelines carrying petrochemicals with current or potential future energy uses are regulated by FERC and the Interstate Commerce Act (ICA)
  - Pipelines carrying material for energy purposes that either do not compete with energy petrochemicals or whose transport costs do not impact energy markets are regulated by the STB and the Interstate Commerce Commission Termination Act
- **Up until now, hydrogen has generally been considered subject to STB regulation**
- **As hydrogen is being explored as an energy carrier, lawmakers and regulators have begun to re-evaluate the regulatory approach to interstate hydrogen pipelines, likely under either FERC or ICA**
- **Natural gas pipelines with hydrogen blended in are subject to the Natural Gas Act, and therefore within FERC's jurisdiction**

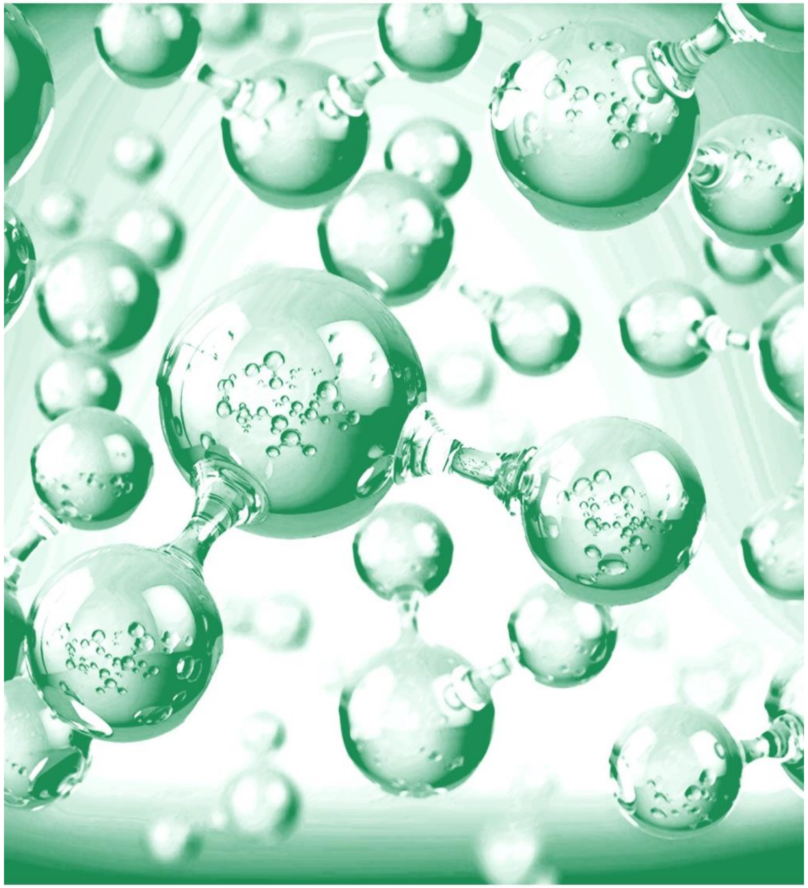
Fugitive Emission Concerns

Background:

+ Recent research has indicated that leaked hydrogen may contribute more to global warming than previously estimated
+ Some research suggests that hydrogen leaked into the atmosphere at any point in the supply chain can act as an indirect greenhouse gas, reacting with pollutants like methane to extend their lifetime in the atmosphere

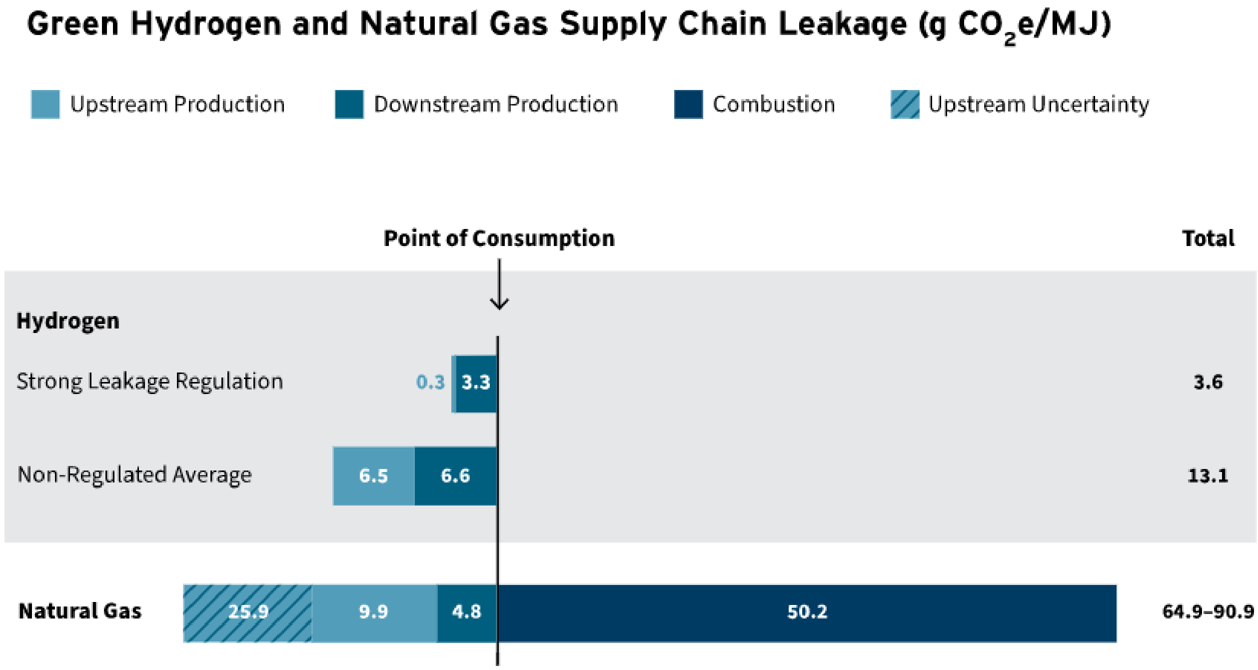
Status of Current Research:

+ Hydrogen leakage is still an area of active study
+ There is very little data on hydrogen leakage along the existing value chain, and that which does exist comes from theoretical assessments, simulation, or extrapolation rather than measures from operations (Columbia University)



Comparative Emissions to Natural Gas

+ Hydrogen's emissions impacts along the supply chain are lower than those of natural gas, even when excluding combustion emissions
+ Stronger regulation of H2 leakage is key to reducing emissions impact



Source: RMI (2022), https://rmi.org/hydrogen-reality-check-1-hydrogen-is-not-a-significant-warming-risk/

Hydrogen Leakage Best Practices

1. Advance research of hydrogen's indirect radiative effects and temperature responses to hydrogen emissions by incorporating them into chemistry-climate models
2. Employ climate metrics and/or models that effectively reflect the role that hydrogen could play in meeting net-zero goals in the desired time frames
3. Improve quantification of hydrogen leakage rates by developing technologies that can be taken into the field to accurately measure hydrogen emissions at low detection thresholds (i.e. ppb level);
4. Include the likelihood of hydrogen leakage and its impacts in decision-making about where and how to effectively deploy hydrogen – such as co-located production and end-use applications
5. Identify leakage mitigation measures and best practices before building out infrastructure

Source: Environmental Defense Fund (2022), https://acp.copernicus.org/articles/22/9349/2022/

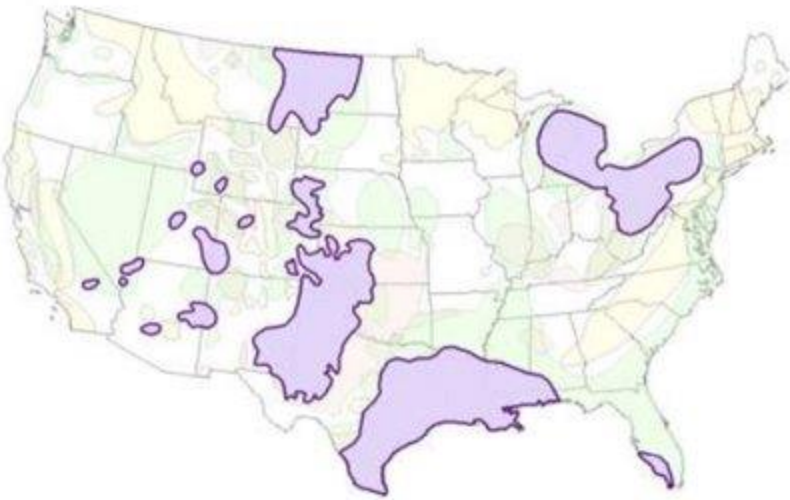
Hydrogen Storage

General Background

- Salt caverns are artificial chambers, either drilled within salt domes or created in bedded salt deposits through controlled freshwater injection processes
- Salt caverns are considered one of the best options for Underground Hydrogen Storage (UHS) because they have low permeability (hydrogen cannot escape through the rock) and can handle high pressures
- Hydrogen storage in salt caverns dates back to the 1980s in the United States
  - Clemens Dome [TX], operated by Conoco Phillips, since 1983 (92 GWh storage capacity)
  - Moss Bluff [TX], operated by Praxair, since 2007 (120 GWh storage capacity)
  - Spindletop [TX], operated by Air Liquide, since 2014 (> 120 GWh storage capacity)
- The Advanced Clean Energy Storage (ACES) Project is in development in Delta, Utah, and is planning to incorporate 300 GWh of seasonal hydrogen storage in salt caverns
- Relative ease of injection and withdrawal (compared to other geologic storage options) make salt caverns the ideal short- to medium-term storage option for hydrogen

Location of Hydrogen Storage Formations

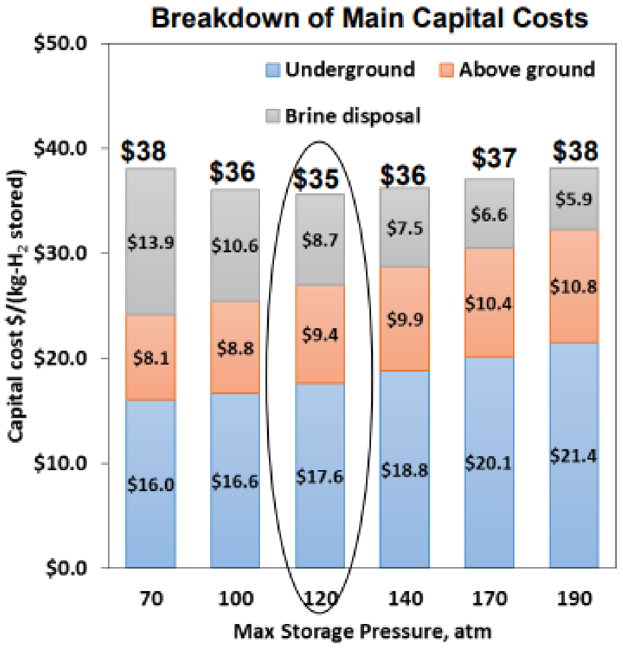
- **Formations with the potential for salt caverns that can be used to store hydrogen are concentrated along the Gulf Coast**
  - The three current salt caverns being used for hydrogen storage are located in Texas
- **Potential for hydrogen storage in salt caverns exists in other parts of the USA, including New York, Michigan, and Utah**
  - Utah is home to the largest salt deposit in the western US, where the ACES project is in development



Source: Lord et al. (2014). Geologic storage of hydrogen: Scaling up to meet city transportation demands. Int. J. Hydrogen Energy, 39, 15570-15582

Cost Profile for Hydrogen Storage

+ **Levelized cost of hydrogen storage in underground salt caverns is estimated at $0.21/kg-H2, based on H2 production of 50 tons per day and 10 days of H2 storage (i.e. 500 tons of storage)**
+ **75% of the levelized cost can be attributed to CAPEX**
  + Main capital costs can be broken down into underground costs, above ground costs, and brine disposal costs
  + The majority of capital costs are associated with cavern construction (underground costs)
+ **Capital costs vary depending on the max storage pressure in the cavern**



Source: Ahluwalia et al. (2019) *System Level Analysis of Hydrogen Storage Options.* U.S. DOE Hydrogen and Fuel Cells Program, 2019 Annual Merit Review and Peer Evaluation Meeting, Washington, D.C.

Other Storage Options

- **Other forms of geologic underground storage are currently being investigated for their potential to store H2**
- **Aquifers are subsurface layers of permeable rock filled with fresh or saline water, commonly found in sedimentary basins**
  - One major challenge for aquifers as UHS is that they require large volumes of cushion gas, greatly reducing the capacity available for hydrogen gas
  - No pure H2 storage has been successfully achieved in aquifers at this time
- **A third conventional option that is being considered for UHS is depleted oil and gas reservoirs, which are currently used for natural gas storage**
  - Some challenges with depleted reservoirs include the potential chemical reactions between the H2 and residual oil or gas, and a higher risk of leakage