STRATEGEN

# Hydrogen Power Study Task Force: Infrastructure Working Group Meeting #3

Hosted by Strategen Consulting
November 17, 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.

# Agenda

- Welcome and Introductions – 10 minutes
- Connecticut Hydrogen Infrastructure Discussion:
  - Ancillary Infrastructure Needs – 20 minutes
  - Safety and Supply Chain – 10 minutes
- Discussion and Next Steps – 20 minutes

# 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 in advance of 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<br>4-5pm</td><td>10/26<br>10:30am-12 pm</td><td>11/18<br>10:30am-12 pm</td><td>12/15<br>10:30am-12:00 pm</td></tr>
<tr><td>Infrastructure</td><td>9/28<br>2-3pm</td><td>10/24<br>2-3pm</td><td>11/17<br>3-4pm</td><td>12/19<br>3-4pm</td></tr>
<tr><td>Policy<br>& Workforce<br>Development</td><td>9/26<br>3-4pm</td><td>10/20<br>12-1pm</td><td>11/29<br>12-1pm</td><td>12/15<br>12-1pm</td></tr>
<tr><td>Sources</td><td>9/27<br>1-2pm</td><td rowspan="2">10/25<br>2-3:30pm</td><td>11/17<br>11am-12pm</td><td rowspan="2">12/20<br>1-2:30pm</td></tr>
<tr><td>Uses</td><td>9/27<br>12-1pm</td><td>11/22<br>12-1pm</td></tr>
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# Auxiliary Infrastructure

# Compression

+ **Hydrogen is produced at low pressures (20–30 bar) and must be compressed to between 200 and 500 bar to be economically transported.**
  + Transporting compressed hydrogen on trucks is a cheaper option than liquid hydrogen or other alternatives for short distances (<100 miles).
  + Hydrogen's energy content by volume is roughly 1/3 that of natural gas – i.e., it requires 3 times as much space to hold the same amount of energy in hydrogen vs. natural gas.
  + Hydrogen's energy content by mass is 3x that of gasoline — 120 MJ/kg for hydrogen versus 44 MJ/kg for gasoline. On a volume basis, however, liquid hydrogen is less dense (8 MJ/L vs. 32 MJ/L)
+ **Hydrogen compression makes up roughly 55-65% of compression, storage, and distribution costs, equating to 1.10 - 1.54$ per kilogram of compressed hydrogen.**

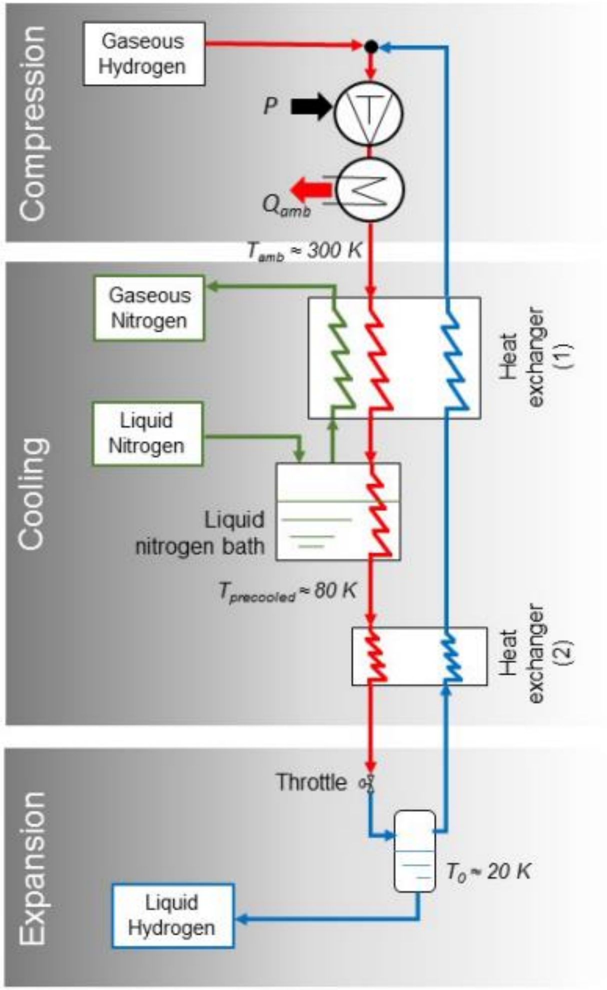


# Local Storage

- **Hydrogen's high energy per mass and low energy per volume requires the development of local, high density storage methods.**
- **On-site hydrogen storage is used at central hydrogen production facilities, transport terminals, and end-use locations.**
  - Storage options include insulated liquid tanks and gaseous storage tanks.
  - Potential tank materials for gaseous include all-metal cylinders, and resin-impregnated continuous filament,
  - Cryogenic liquid storage containers, or dewars, are a common way of storing large quantities of hydrogen.
- **Localized hydrogen storage is key to enabling the advancement of hydrogen and fuel cell technologies, especially in applications like stationary power and transportation.**

# Liquefaction

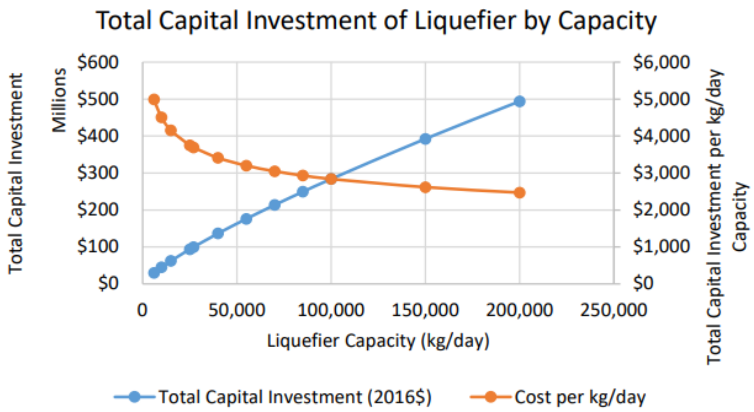
+ **Liquid hydrogen is often desirable compared to gaseous hydrogen due to its higher energy density and lower cost at high volumes.**
  + Liquefying hydrogen is especially valuable for truck deliveries
  + Truck delivery of liquid hydrogen is more cost-effective than that of gaseous hydrogen when transported over long distances (e.g. >400 miles)
+ **The liquefaction process typically consists of three separate sub-processes: compression, cooling, and expansion.**




Source: Connelly, Elizabeth et al. (2019). *Current Status of Hydrogen Liquefaction Costs* DOE Hydrogen and Fuel Cells Program Record #19001.

# Liquefaction

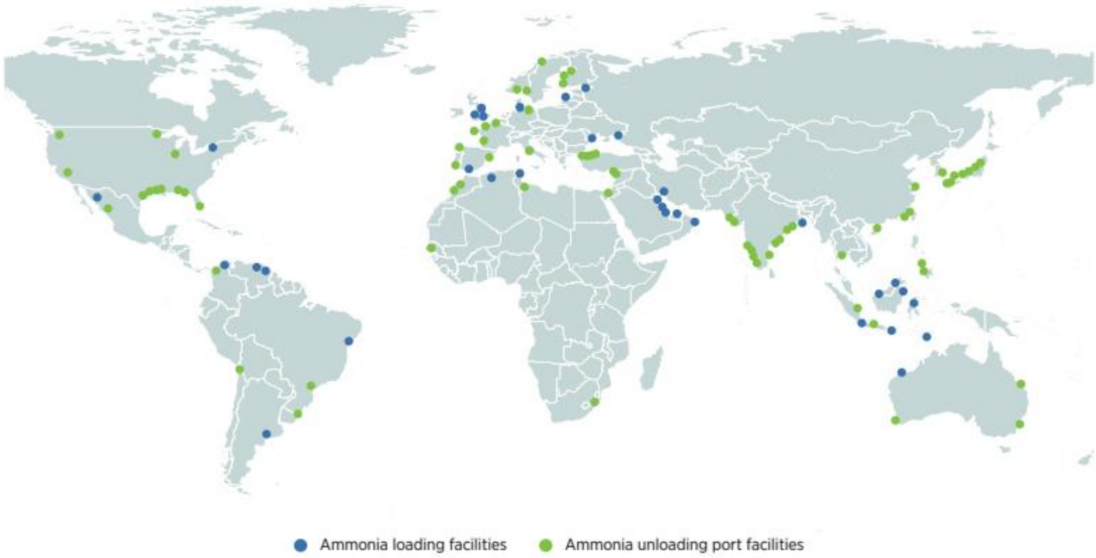
- **Current research on the economics of industrial liquefaction is focused on a range of capacities from 6,000 to 200,000 kg/day.**
  - Estimated capital costs range from $30 million to $490 million.
  - The capital investment for liquefication per kg/day of capacity decreases with scaling, but these reductions diminish with increasing capacity.
- **At a capacity of 27,000 kg/day (which is fairly typical for current commercial liquefiers), the capital cost contribution for the liquefier is around 1.4 $/kg**
  - Additional operational costs (e.g. electricity and distribution) can increase levelized cost contribution to 2.75 $/kg




Source: Connelly, Elizabeth et al. (2019). *Current Status of Hydrogen Liquefaction Costs* DOE Hydrogen and Fuel Cells Program Record #19001.

# Derivative Fuels

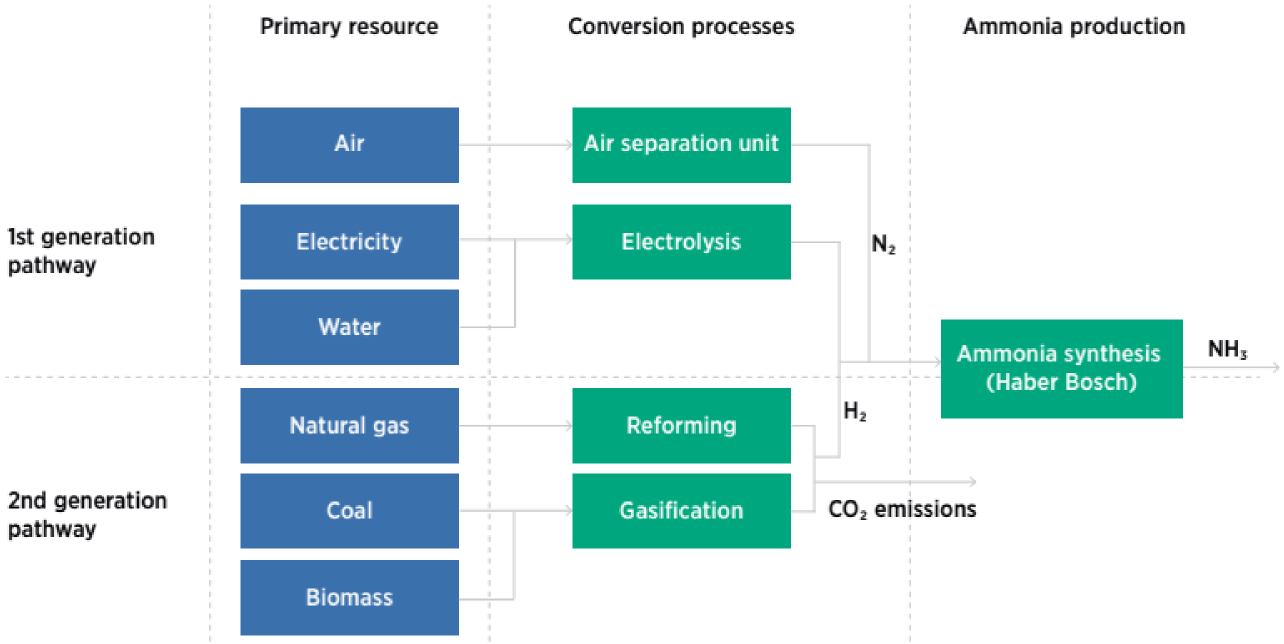
- Ammonia and synthetic fuels can be derived from hydrogen.
- They can either be converted back to hydrogen via thermal decomposition and separation processes or used as fuels or chemical feedstocks.
- Ammonia is particularly promising as an energy carrier because it is easier to store and transport than hydrogen, has a relatively high density, and already has widespread infrastructure.




Source: IRENA (2022). *Global Hydrogen Trade to Meet the 1.5C Climate Goal: Technology Review of Hydrogen Carriers.*

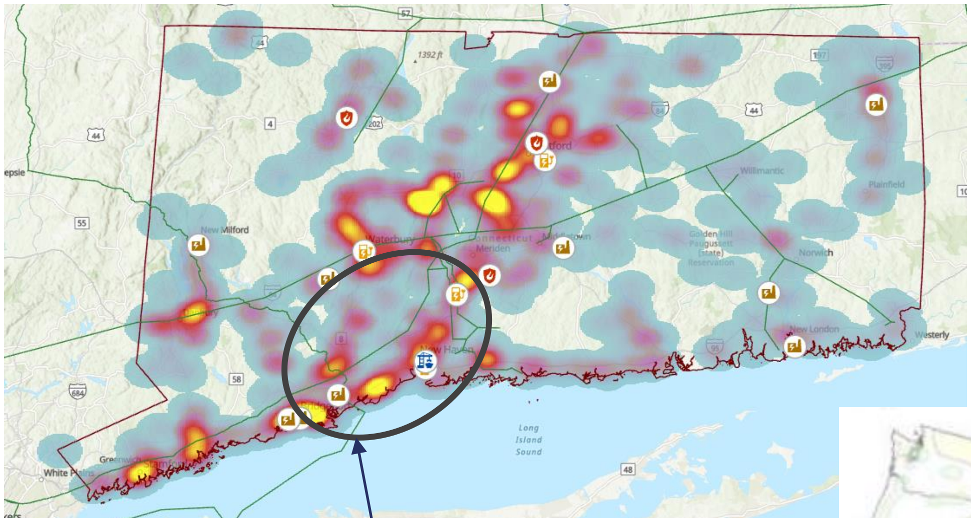
# Derivative Fuels

- The current commercial-scale method for converting hydrogen to ammonia is the Haber-Bosch process, but new electrochemical conversion methods are being investigated to reduce process emissions.
- Other derivative fuels include methanol and synthetic kerosene, which can be used in applications like aviation

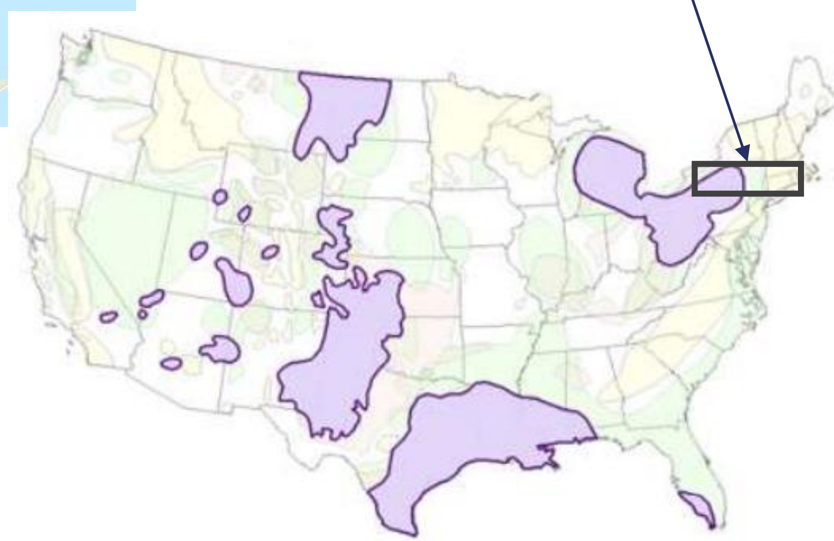



Source: IRENA (2022). *Global Hydrogen Trade to Meet the 1.5C Climate Goal: Technology Review of Hydrogen Carriers.*

# Auxiliary Infrastructure in Connecticut

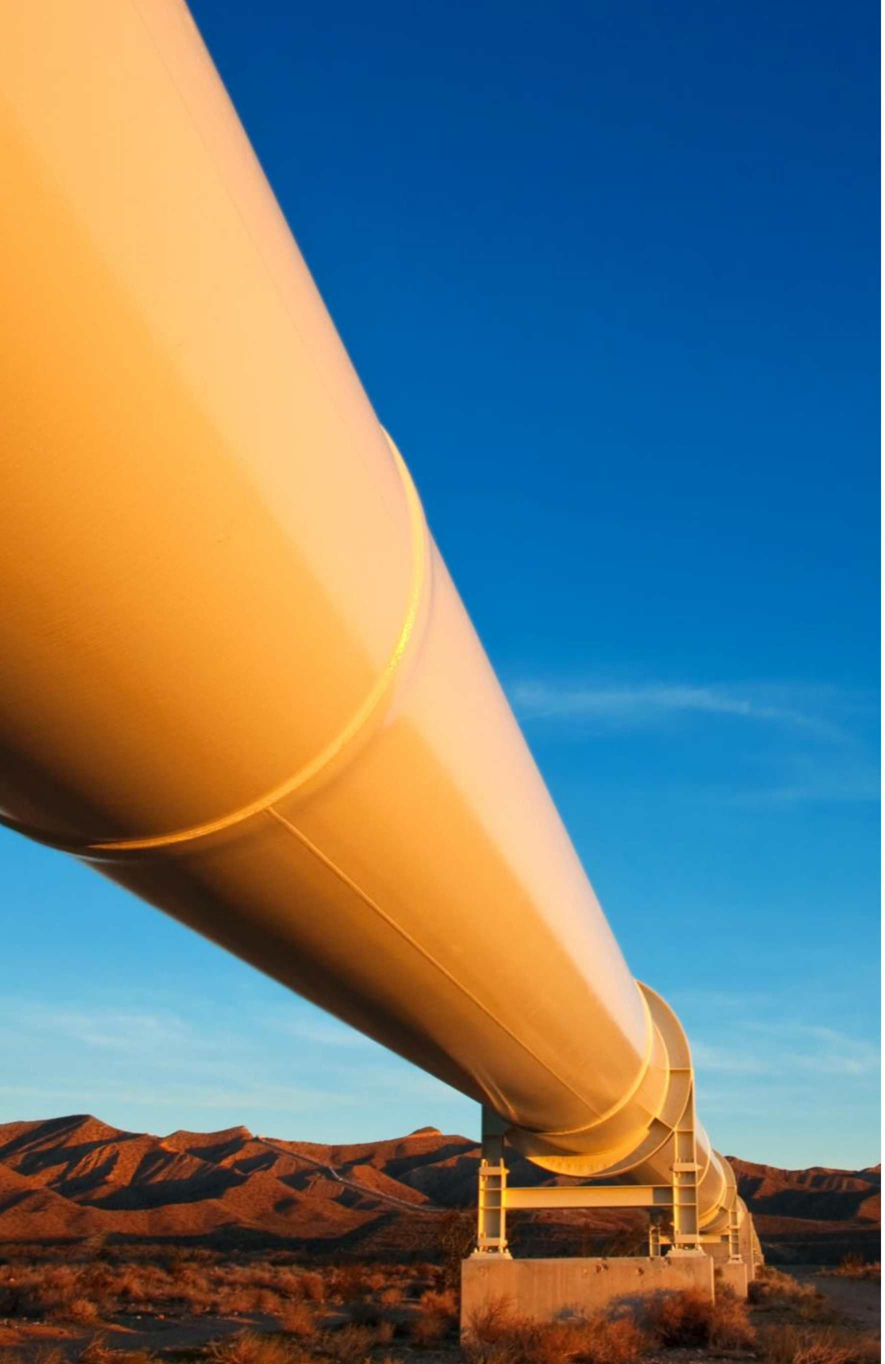



Liquefaction and derivative fuel production facilities can be advantageously located near major ports and transport routes



Compression would be required for pipeline transport and geologic storage

# Infrastructure Safety





# Pipeline Safety

- The potential for hydrogen embrittlement is a key safety parameter for hydrogen pipelines, particularly when hydrogen is introduced in pipelines designed to transport natural gas or other commodities.
  - Specialty steels can be used to mitigate concerns around pipeline embrittlement.
- Hydrogen is highly flammable, but hydrogen fire radiates significantly less heat than comparable fossil fuel fires, reducing risk of thermal damage.
- PHMSA has the primary authority to regulate the safety of energy commodity pipelines (both interstate and intrastate).
- Federal pipeline safety regulations cover pipeline design, construction, operation, and maintenance, as well as spill response planning.
- PHMSA provides grants for pipeline safety research and development to inform regulatory activities, including hydrogen-related research.

# Auxiliary Infrastructure Safety

- **As mentioned, the characteristics of hydrogen do create several risks that need to be managed, including:**
  - Vulnerability to leakage.
  - Low ignition energy.
  - Potential for combustion and embrittlement.
- **There are various codes and standards that outline safe practices for hydrogen handling, particularly in the case of liquid hydrogen.**
- **Liquid hydrogen storage tanks typically have several safety mechanisms, including overfilling protection, pressure-relief valves, rupture disks, and pressure-safety valves.**

# Infrastructure Supply Chain

# Hydrogen Electrolyzer and Fuel Cell Supply Chain

- **Equipment to produce and use hydrogen employs several materials with potential supply chain concerns, including:**
  - Graphite (100% imported, mostly from China).
  - Iridium (100% imported, mostly from South Africa).
  - Platinum (primarily imported from South Africa).
  - Strontium (currently 100% imported, although domestic sources do exist).
  - Yttrium (mostly imported, largely from China).
- **Several other materials used in electrolyzers and fuel cells face more moderate supply concerns, including cobalt, copper, nickel, and manganese.**
  - Ongoing efforts to develop domestic sources of supply for all resources may alleviate supply constraints in the future.
  - Supply chain strategies will be important to maintain flow of materials to local manufacturers.



# Pipeline Supply Chain

- **In general, supply chains for hydrogen infrastructure are less challenging than electrolyzers and fuel cells.**
- **Most hydrogen pipelines in the U.S. are developed and owned by merchant hydrogen producers. Major players include:**
  - Air Liquide.
  - Linde.
  - Air Products and Chemicals.
- **Some hydrogen infrastructure technologies (e.g., liquefaction) have not been commercially developed at required scale.**
  - Largest commercially available liquefaction stations can produce around 70,000 kg/day.
  - World's first liquified hydrogen carrier completed its maiden voyage from Australia to Japan in 2022.

# Questions and Discussion

+ Do you see any aspects of hydrogen safety procedures or supply chain constraints as a particular point of concern?
+ Are there any topics that you would like to have investigated more closely?
+ Are there any challenges to infrastructure development specific to Connecticut that should be foregrounded in the discussion?