CHESAPEAKE
UTILITIES
CORPORATION

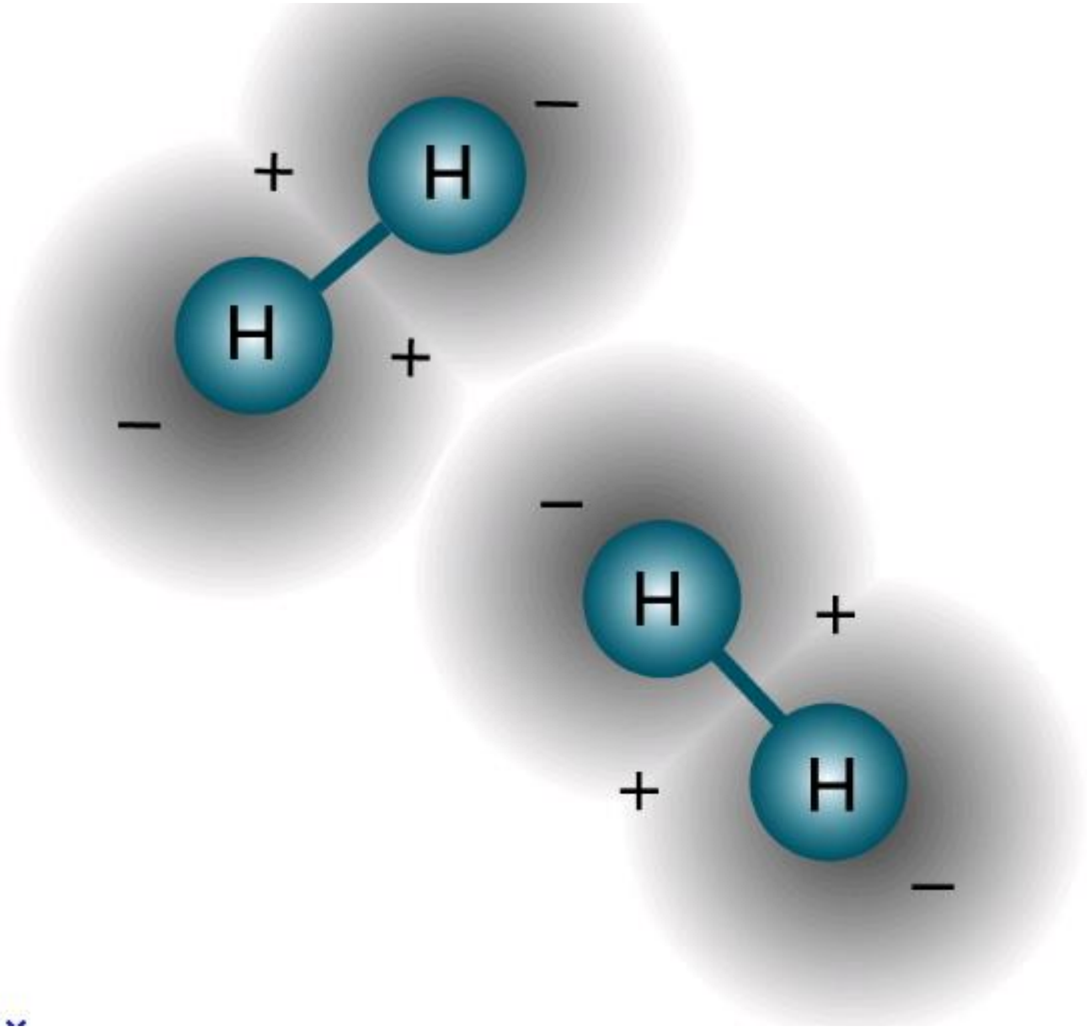
Introduction to Hydrogen

H2 uses, safety, and challenges

Introduction to Hydrogen

What is hydrogen?

- Hydrogen is the chemical element with the symbol of H, and an atomic number of 1
- It is the lightest element
- Under standard conditions hydrogen is a gas, and it is found as two joined particles H2
- Hydrogen is odorless, and tasteless
- Under extreme conditions hydrogen can be liquified



Introduction to Hydrogen

Hydrogen Conversions:

Natural Gas is normally sold by volume and converted to energy based on the btu value – Mcf and Dth

In the Hydrogen industry the unit of measurement is in kilograms – kg

Most common conversions

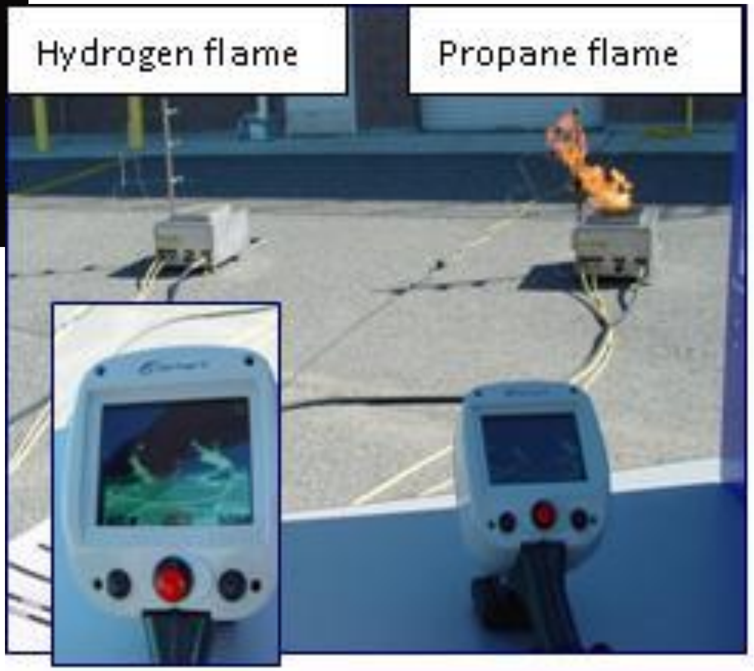
1 kg	=	423 scf
2.36 kg	=	1,000 scf or 1 Mcf
1 kg	=	134,000 btu (hhv)
1 mcf	=	316,000 btu
3.16 mcf	=	1,000,000 btu or 1 Dth

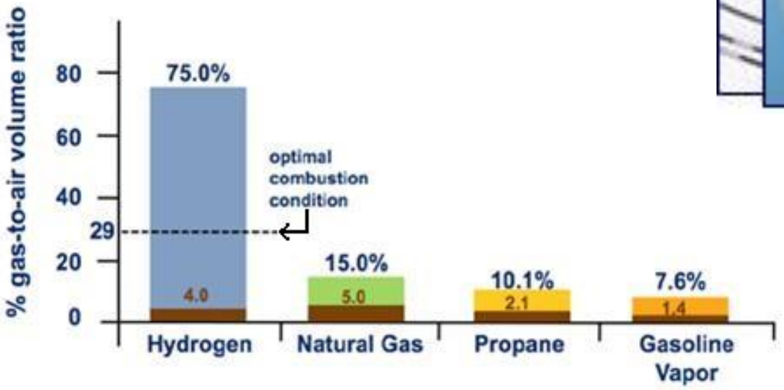
Hydrogen Safety & Training

- Hydrogen safety covers the full range of activities from safe production, handling, storage, and the use of gaseous or liquid hydrogen.
- Hydrogen is highly flammable and carries the highest flammability rating of 4 within the NFPA 704 because it is still flammable when small amounts are mixed in air. Flammability range from 4 to 75%
- There is no rating for toxicity or reactivity
- Liquid hydrogen carries additional hazards due to its increased density and cryogenic temperature required to maintain the liquid state

Hydrogen Safety & Training

- Burns with a pale blue flame
- Nearly invisible in daylight
- Pure hydrogen flame will not produce smoke
- Low radiant heat so you may not feel it until you are very close
- Widest flammable range
- Flame temperature
  - Hydrogen 4820° F in O2
    3713° F in air
  - Methane 5090° F in O2
    3554° F in air





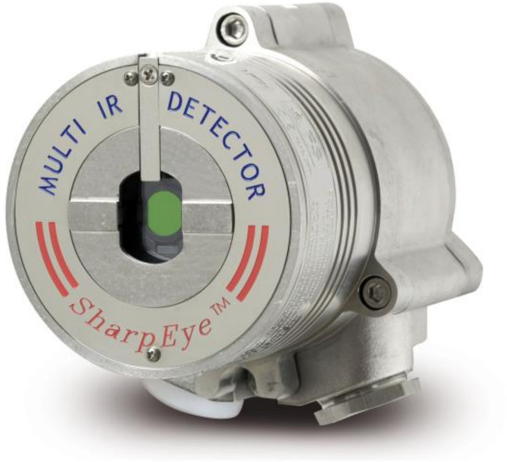
movie

Hydrogen Safety & Training

Potential ignition sources Include but are not limited to.

- Electrical
- Static electricity
- Electric charge from equipment operation
- Mechanical
- Impact
- Friction
- Metal fracture
- Thermal
- High velocity jet heating
- Hot surfaces. E.g an exhaust manifold
- Vehicle exhaust
- Chemical
- Catalysts
- Reactants

- Safety equipment.
  - Flame detectors. Fixed and portable
  - Gas detectors adjusted for hydrogen.



Liquid Hydrogen

- Hydrogen exists as a liquid at -253°C or -423°F, contact with the material at these temperatures can cause frostbit and cryogenic burns
- LH2 is approximately 14x less dense than water
- LH2 is non-corrosive and has a light blue tint
- Hydrogen undergoes a rapid phase change from liquid to gas when exposed to higher temperature
- The volume ratio of liquid to gas is 1:848
- All gases except Helium are solid at LH2 temperatures and if present in the LH2 may cause malfunction due to particles of solid ice
- Condensed air will form on the outside of an uninsulated container filled with LH2
- Uninsulated LH2 piping could result in oxygen enrichment and explosive conditions
- LH2 will cause cryo pumping when exposed to air which will result in solid oxygen and nitrogen along with frozen water
- Continued evaporation of LH2 increases the pressure within a closed container and may result in pressure failure of the component

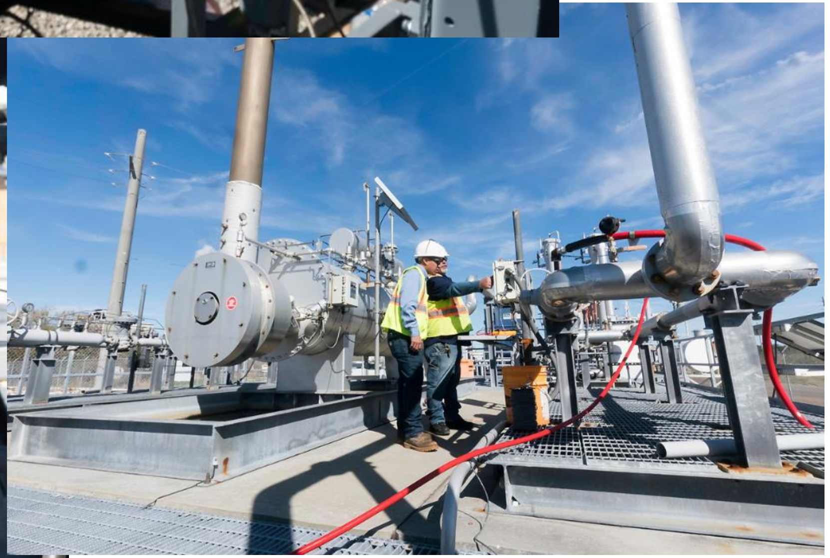
8-Flags Hydrogen Testing

2021 8-Flags H2 Testing

- **In early 2022 FPU conducted a pilot test at the 8-Flags CHP Facility on Amelia Island, FL**
- **A 4% blend of H2 was blended on site into the natural gas flow into the CHP**
- **The test was done to determine feasibility of on site blending, impacts to the CHP turbine, and impacts to the stack emissions from the plant**

- **Marlin Gas Services provided the Hydrogen and blending equipment.**

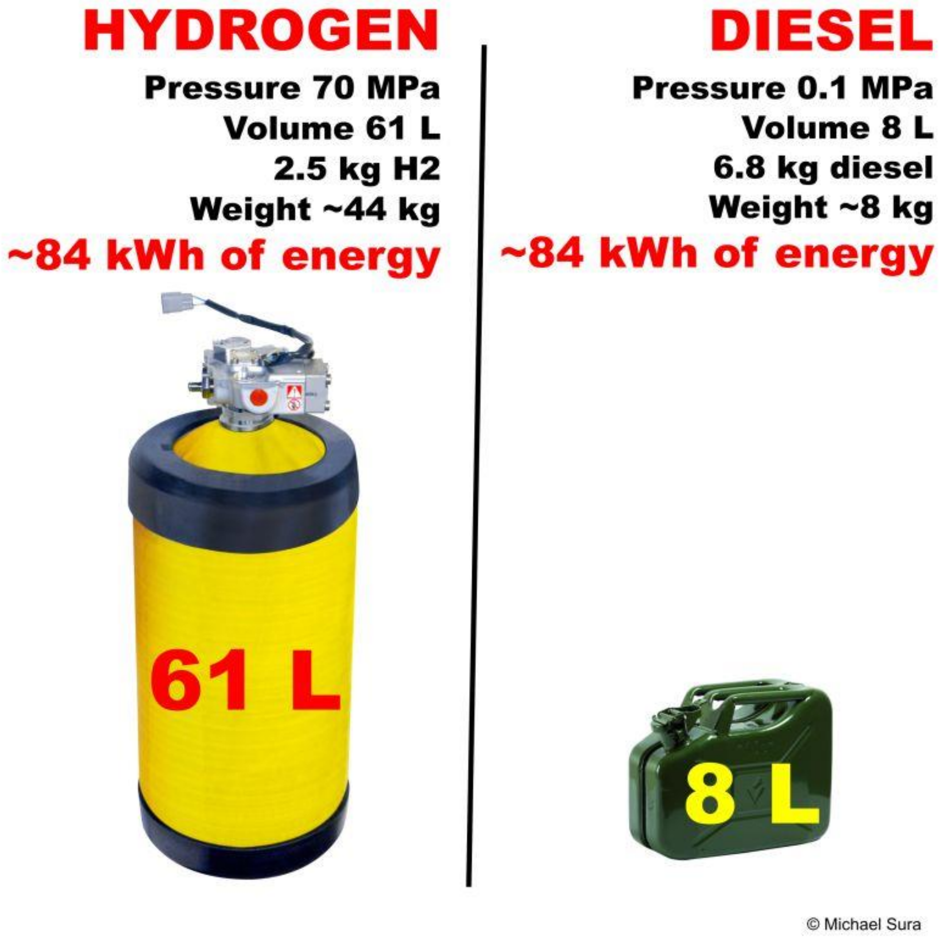
8-Flags Hydrogen Testing



CHESAPEAKE UTILITIES CORPORATION

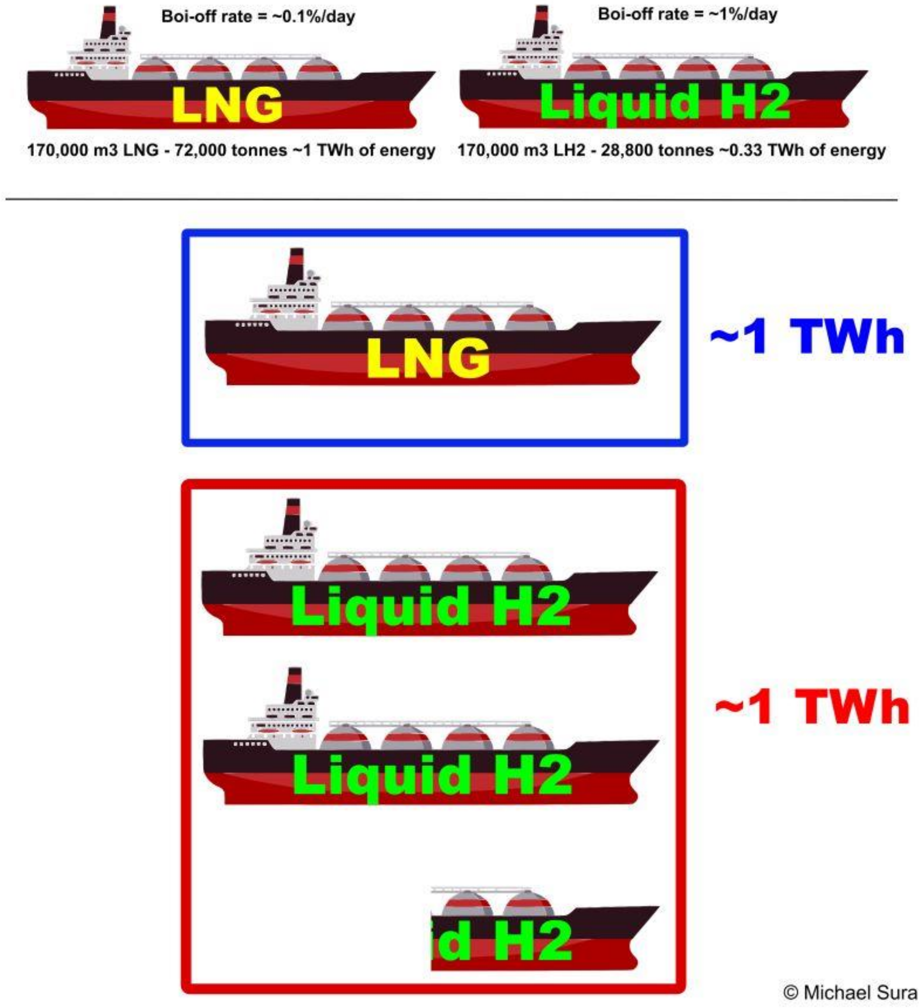
Hydrogen Costs & Challenges

On Road Use



Hydrogen Costs & Challenges

As a maritime fuel



It would take 2.5x transport vessels of liquid hydrogen to equal the energy contained in 1 LNG transport vessel

Hydrogen Costs & Challenges

How is H2 delivered to end users?

- On site production
- Delivery by high pressure trailer (7,500 psig)
- Delivery from production site into adjacent pipeline (blending)
- Ammonia or methanol

7.45kg H2 = 1 dth of Natural Gas

Hydrogen Costs & Challenges

H2 Transportation

Current pricing for trailer transportation:

- ~$6/kg FOB production plant
- ~$2-$5 per kg transportation cost of gaseous H2 via high capacity composite trailer
  - Trailer and cab combined weight 80,000lbs full
  - Delivery per trailer ~550-750kg (1,100 – 1,600 lbs.)
- Delivered cost per kg ~$8-$11
- Delivered price per dth ~$60-$82

Delivery price via pipeline at production site ~$45 per dth gas

Hydrogen Costs & Challenges

H2 Transportation

Delivery price via pipeline at production site ~$45 per dthBtu gas

Pipeline Challenges:

- 3,000,000 miles of natural gas pipeline in the US
- 1,200 miles of H2 pipeline
- Conversion of natural gas pipeline to H2 pipeline is highly disputed

Experts agree:

- 5% H2 and 95% of 1,030 btu natural gas = 994 btu gas
- Pipeline would have to deliver a 3.5% increase in volume for the same amount of energy

Hydrogen Pipelines

ISSUES

- Lack of technical specifications
- High investment costs
- Potential for hydrogen embrittlement of pipe and welds
- Need to control permeation and leaks
- Need for lower cost and more durable hydrogen compression
- Impact on plastic piping, compressors, valves, and other non-pipeline equipment

Hydrogen Pipelines

Challenges of converting an existing system

- ASME and CGA have issued two new documents to address the construction of new hydrogen pipelines ASME B31.12 “hydrogen piping and pipelines”. CGA G5.6 “ hydrogen pipeline systems”
- Neither document is a mandatory standard
- Legacy pipelines
- Require to understanding of the previous operation of the pipeline and assess against even low levels of hydrogen
- Existing material’s properties and the impact hydrogen will have on those properties are understood and quantified using critical flaw size and remaining life calculations
- Hydrogen is known to impact material toughness and fatigue crack growth in certain steels
- Existing gas network may be more beneficial for conversion to hydrogen from a capital investment aspect
- Design
- Follow PHMSA regulations 49 CFR 192(6), 49 CFR 195(7) and ASME 31.8
- ASME 31.12 uses the same formula for hydrogen pipelines with additional design factors relating to fracture control and material performance in hydrogen environments
- Both factors tend to derate the MOP/MAOP for a particular pipeline to recognized the degrading effects of hydrogen absorption

CHESAPEAKE UTILITIES CORPORATION

Hydrogen Storage

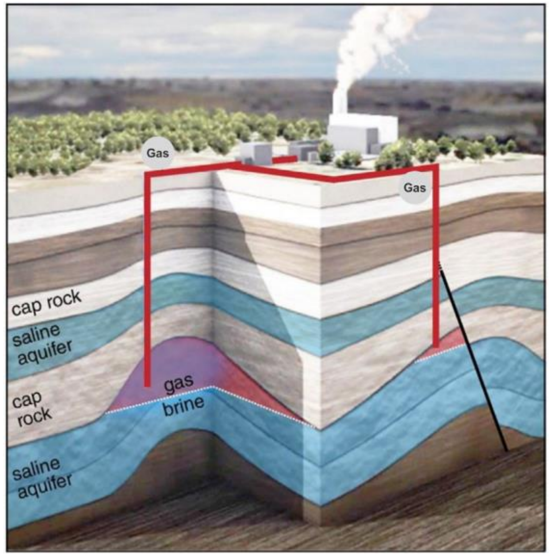
SPECIALIST TANKS OR STORAGE VESSELS

Liquified Hydrogen storage or high-pressure compressed gas

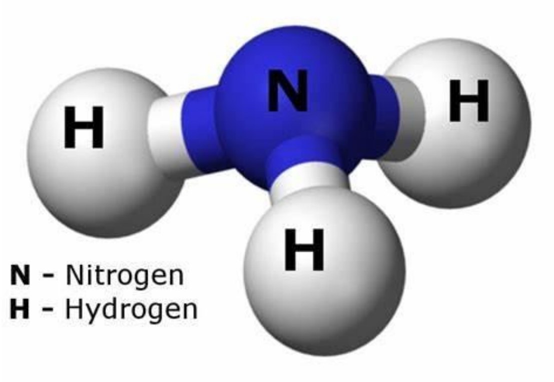
SALT CAVERNS

large volumes of gas stored in specifically designed caverns

DEPLETED GAS OR OIL FIELDS



MATERIALS BASED STORAGE

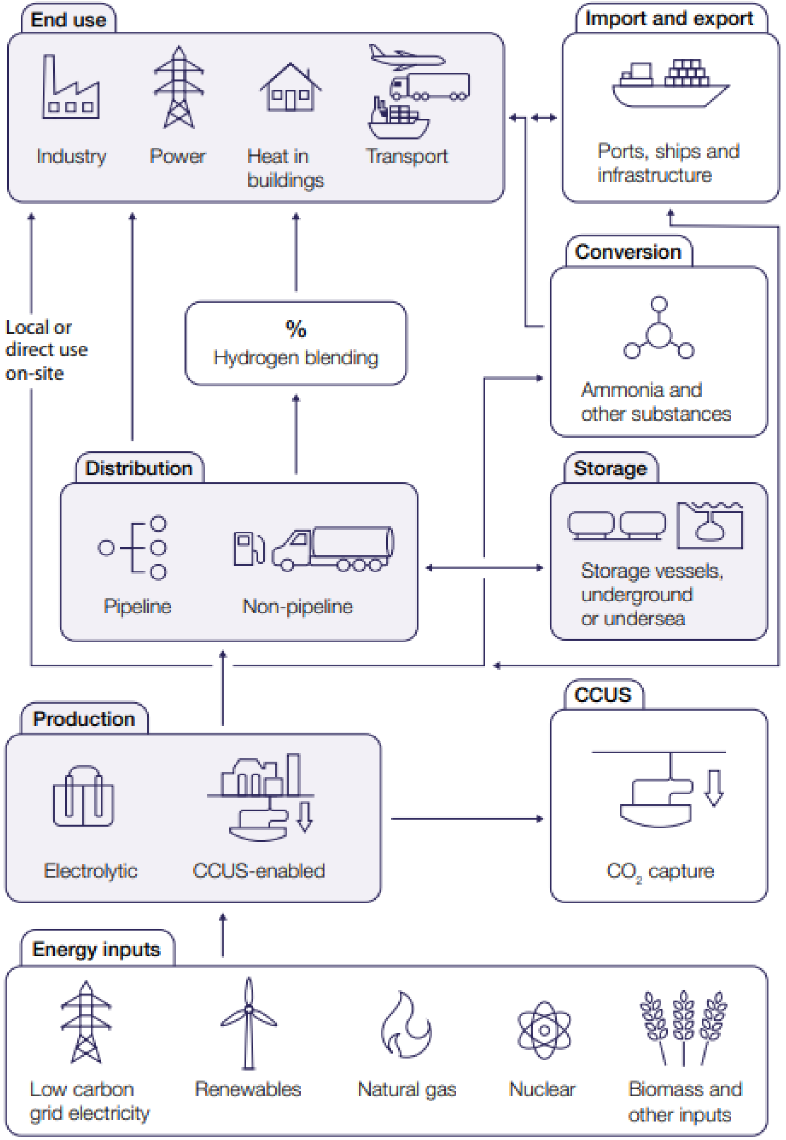


Ammonia is a carrier for hydrogen

Methanol is a carrier for hydrogen

Hydrogen Use Case: United Kingdom

- Hydrogen is to be used to reduce the pressure of renewables, CCUS and Nuclear.
- Proposed key roles for hydrogen in 2020/2030
  - Flexible power generation ('Gas to Power')
  - System flexibility through electrolysis and storage
- Key barriers
  - Technology and user readiness
  - Designing supporting policy and market frameworks:
  - Availability of networks and storage



CHESAPEAKE UTILITIES CORPORATION

Hydrogen Use Case: United Kingdom

H 100 FIFE FIELD TRIAL

- Builds on H21 field trials conducted in Cumbria which tested the suitability of the existing gas network for taking 100% hydrogen

Fife suitability

- Offshore wind turbines provide 7 MW of power as the source of clean power
- Produces abundant source of green hydrogen from electrolysis which separates the hydrogen and oxygen from water
- Hydrogen is stored on-site in six purpose-built tanks
- Storage exceeds the requirement for supplying the allocated 300 homes even on the coldest days
- Hydrogen supplied through a purpose-built network
- State-of-the-art appliances were provided to all the participants to provide carbon-free heating and cooking for the duration of the trial
- Trail expected to commence in early 2024
- Provide information about the use and availability through the different seasons and loads

Hydrogen Use Case: United Kingdom

Future Trials

- Hydrogen village trials
- The hydrogen village trials will consist of 2000 to 3000 households.
- Safety of the public is essential.
- Hydrogen will be stored distributed and used in a safe way.
- Required it to satisfy the health and safety executive (HSE) that the trial will be run safely. Robust safety case required prior to trial
- Public support and engagement
- The outcome of the trial is expected to deliver real world evidence on the practicalities of converting the gas grid and individual properties to hydrogen and using hydrogen for heating and cooking.

<u>The areas selected for village trials in 2022</u>
Areas within Whitby Elsmere Port.

Areas within Redcar, Teesside. The option to go ahead is still being decided expected to convert boiler and cooking appliances in 2024 and trail to run for 2 years

Requirements for the trial to go ahead included strong public support within the area's concern. Reported in July that the support for the trial in Whitby was weak and residents were uneasy about the natural gas being turned off Hydrogen village trail Whitby Ellesmere port was officially canceled in July 2023 by the U. K. Government.

Hydrogen Use Case: United Kingdom

- **Trails for blended hydrogen mix of 20% within the existing network**
- **Phase 1 –Keele University Trial**
- 18-month trial, 100 homes, and 30 university buildings received the blended gas. This concluded in Spring 2021.
- The trial used a blended hydrogen content of up to 20% by volume, injected into fossil gas. Laboratory tests were carried out on a range of gas appliances and extensive research on the effects of hydrogen on the different materials found in the gas network and the appliances.
- This trial was permitted by the UK Health & Safety Executive (HSE) who were satisfied that the blend of hydrogen gas was as safe as the gas we all currently use.
- Keele University was chosen for this first trial because it has:
- its own private gas network
- a campus population similar in size to a small town
- an international reputation for research excellence
- a commitment to developing a carbon-free future through its Smart Energy Network Demonstrator Project (SEND)
- **Phase 2 –Winlaton Trial**
- larger trial in Winlaton, near Gateshead. Running from August 2021 for 10 months, until June 2022. The trial was operated by Northern Gas Networks and supplied 668 houses, a school, several small businesses, and a church with a 20% hydrogen blend. Gateshead Council was very supportive of the trial in their local area.
- Winlaton is located close to Northern Gas Network's site at Low Thornley, near Gateshead. Winlaton itself is a closed public gas network and is a good example of a typical UK gas network. This makes Winlaton an ideal community to receive blended gas and to act as a model for rollout in future locations

- On September 20, 2023 the prime minister has lifted all requirements for mandatory conversion to Hydrogen boilers and/or Heat Pumps. Thus, another rebuttal to Hydrogen.

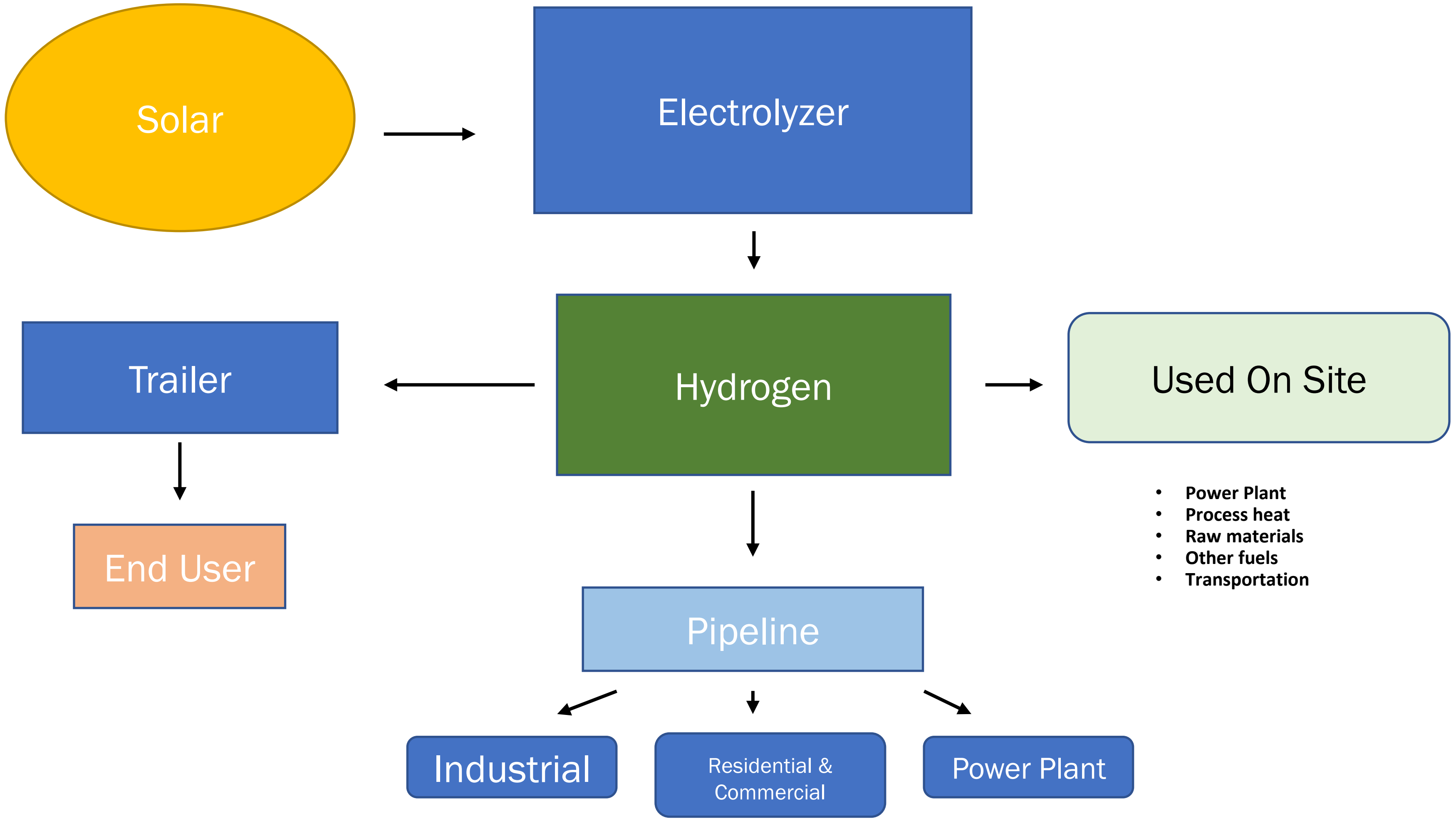
Hydrogen Use Case: Hawaii

HAWAII SNG

Hawaii is located 2,000 miles from the nearest continent

- Hawaii Gas was formed in 1904 by Royal decree
- Originally providing towns gas from oil sources
- Converted to Synthetic natural gas (SNG) derived from Naptha in the 1970's
- Naptha is regarded as a byproduct of oil refining
- SNG is a key component in meeting Hawaii's energy needs
- Conversion of Naptha using Lurgi process
- Removal of sulphur
- Reforming of Naptha into Methane, CO2, and hydrogen
- Removal of CO2 and recycling of Hydrogen to desulphurization
- Export of Methane and Hydrogen into pipeline system
- 10 to 15 % Hydrogen content in the SNG
- No adverse effects have been seen within the regulators for over 50 years

Conclusion – Hydrogen Reality



CHESAPEAKE
UTILITIES
CORPORATION

End Slide Title