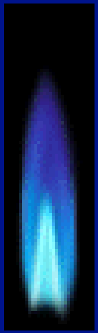
Hydrogen Supply–Overview, System Considerations and Planning

Northeast GAS ASSOCIATION

Hydrogen
1
H
1.008



Christopher A. Cavanagh, PE
Consulting Engineer
Gas Asset Management Engineering

June 5, 2026

nationalgrid

Agenda

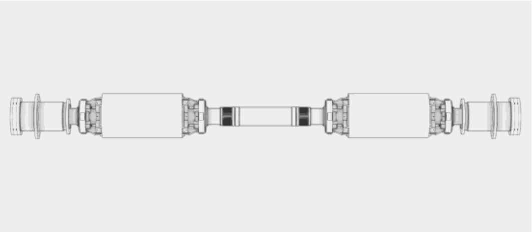
01

The Role of Hydrogen

nationalgrid

Five Hydrogen Use cases that will bring value to the region

Affordable Options for Hard - to - Electrify Stationary Sectors

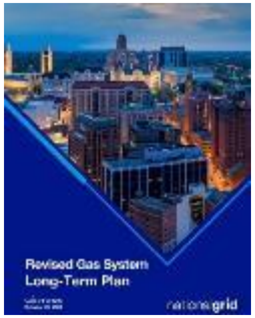


Mainspring Linear Generator

Residential Heat

Two approaches decarbonizing different sections of the network that enable our zero-fossil goals

1. **Hydrogen blending into the gas network** to supplement renewable natural gas as a clean residential fuel for older (e.g. steam) buildings



Revised Gas System Long-Term Plan

national grid

2. **Islanded, 100% hydrogen buildings or neighborhoods** to transition residential and community buildings in specific sections of the network to clean fuel

Commercial & Industrial

3. **C&I hydrogen clusters** anchored by one or more large customers to provide clean hydrogen to high temperature applications that hard-to-decarbonize

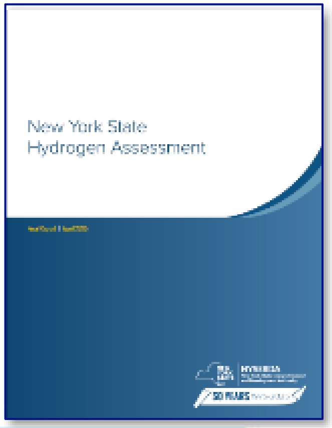
Power Generation

A range of options for dispatchable power, depending on the needs of the region

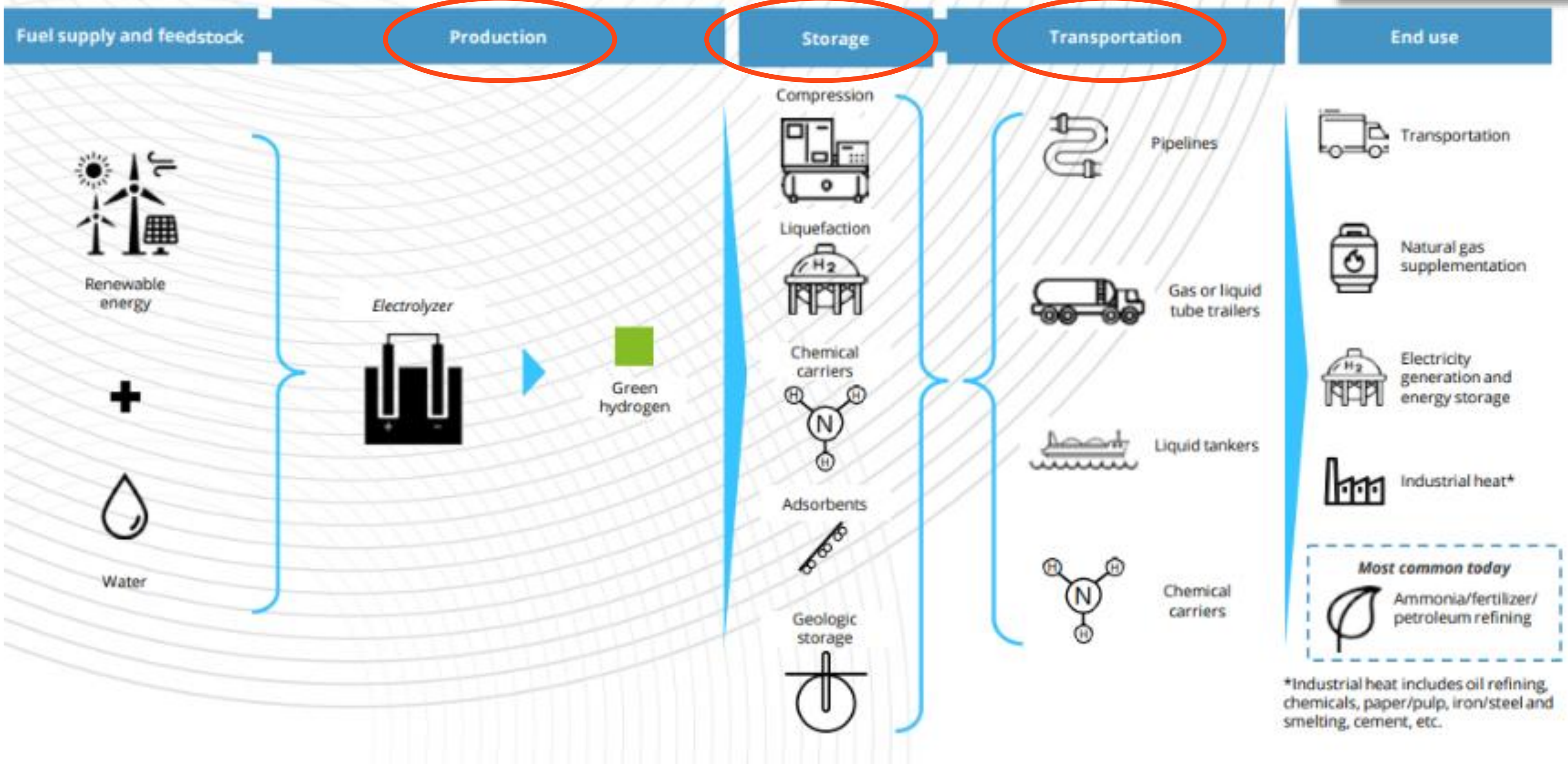
4. **Hydrogen-fueled peaking capacity** to provide grid reliability and cost-effective balancing to complement intermittent renewables

5. **Hydrogen-fueled combined cycle generation** to provide firm power and grid stability despite large amounts of inverter-based renewable power on the future grid

The use of hydrogen in high-temperature applications can be increased by focusing on three stages of the green hydrogen value chain: <u>production, storage, and transportation delivery models.</u>


New York State
Hydrogen Assessment

The Zero Carbon Hydrogen Value Chain



*Industrial heat includes oil refining, chemicals, paper/pulp, iron/steel and smelting, cement, etc.

Hydrogen in high-temperature applications: Transportation

Delivered Fuels: High-pressure cylinders carrying compressed hydrogen gas.

Flexible and can reach remote/rural locations, but higher transportation costs (compared to pipeline), especially at larger volumes.

Pipeline Transport: Hydrogen can be transported through pipelines from external production sites to end-users.

Efficient and cost-effective for transporting large volumes of hydrogen over long distances, but requires significant infrastructure investment.

Liquid Tankers:

Hydrogen can be transported in its liquid form using specialize tankers designed for cryogenic liquids.

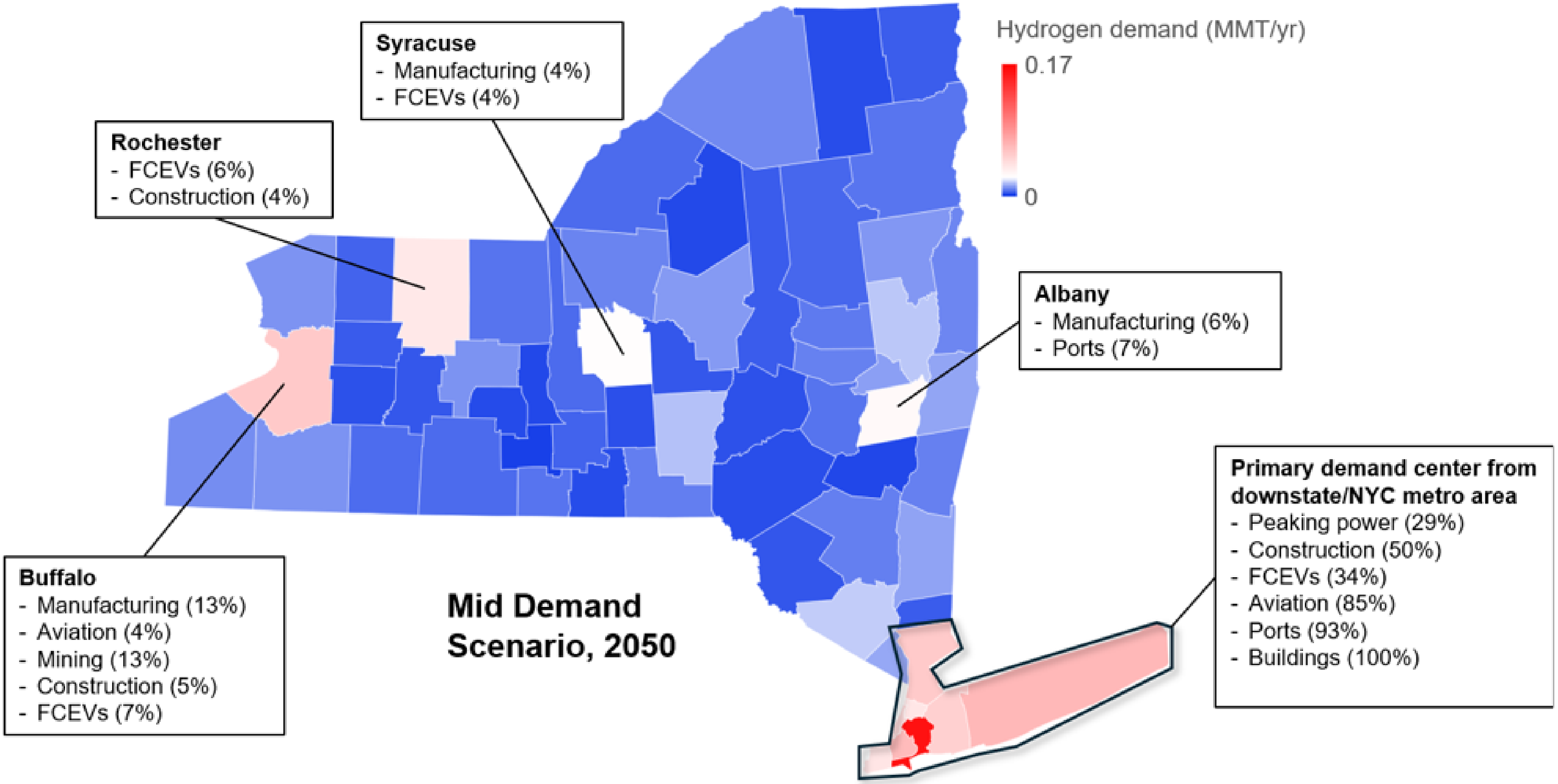
Higher energy density compared to gaseous hydrogen, which results in higher volume carried, but advanced technology and safety measures required.

Chemical Carriers:

Hydrogen can be transported in chemical form, such as ammonia (NH3) or liquid organic hydrogen carriers (LOHCs), which can release hydrogen upon demand.

Safer and stable method of hydrogen transport, yet additional processing required to extract hydrogen from carriers.

Temporal and Geographic Disaggregation of Demand



Syracuse
- Manufacturing (4%)
- FCEVs (4%)

Rochester
- FCEVs (6%)
- Construction (4%)

Albany
- Manufacturing (6%)
- Ports (7%)

Buffalo
- Manufacturing (13%)
- Aviation (4%)
- Mining (13%)
- Construction (5%)
- FCEVs (7%)

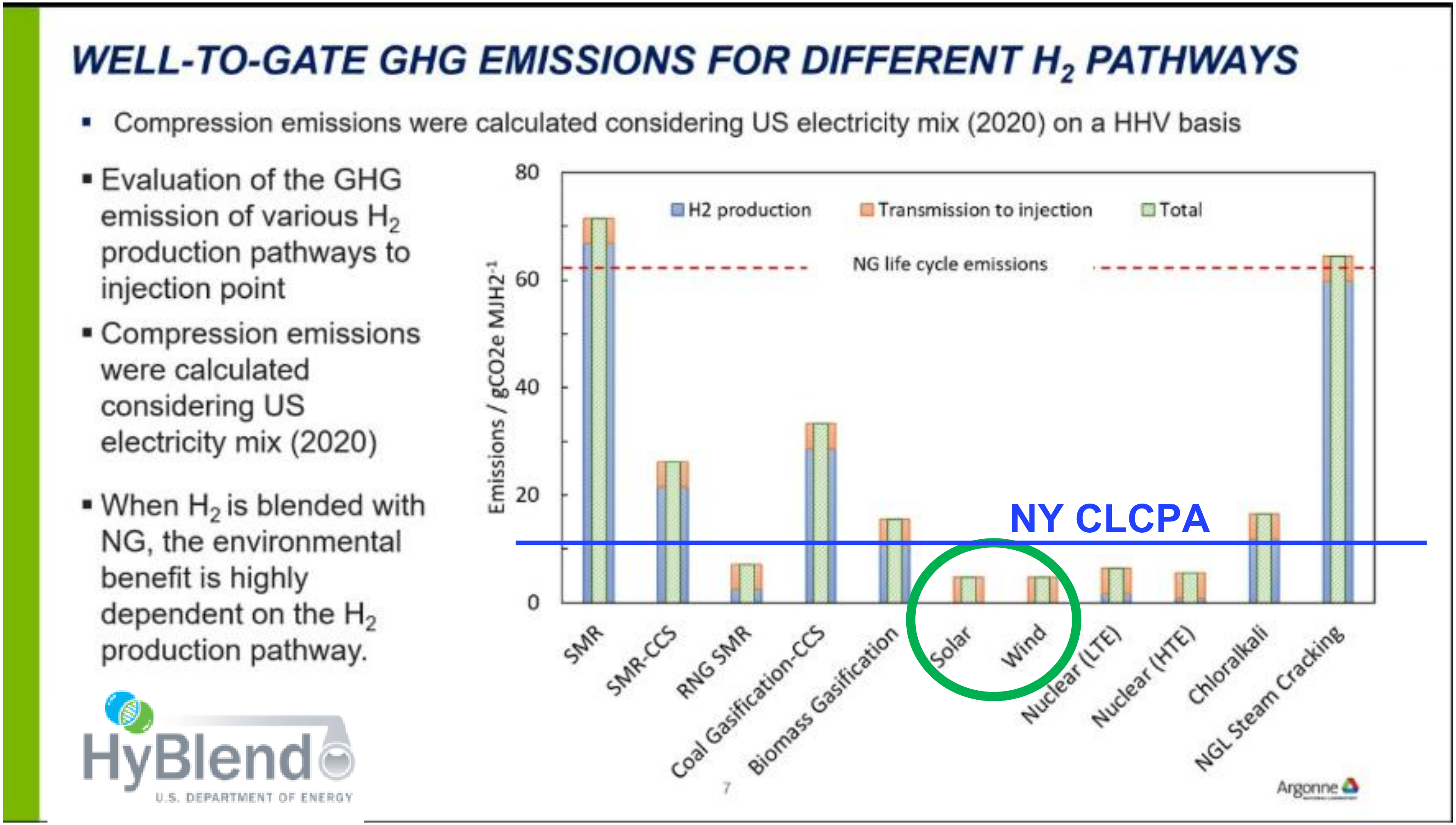
Mid Demand Scenario, 2050

Primary demand center from downstate/NYC metro area
- Peaking power (29%)
- Construction (50%)
- FCEVs (34%)
- Aviation (85%)
- Ports (93%)
- Buildings (100%)

◆ Total H_2 Market share ranges from 0.06% of NY total energy demand (low) to 18.91% (high) in 2050

◆ A winter-peaking electrical grid drives hydrogen demand for power generation, causing surges during colder months, with January as the peak. Smaller, less dramatic demand spikes also occur in the summer due to increased electricity use. Seasonal shifts highlight the need to design hydrogen systems with built-in flexibility to balance supply and demand.

When H_2 is blended with natural gas, the environmental benefit is highly dependent on the H_2 production pathway and pathways that meet climate goals exist



WELL-TO-GATE GHG EMISSIONS FOR DIFFERENT H_2 PATHWAYS

- Compression emissions were calculated considering US electricity mix (2020) on a HHV basis

- Evaluation of the GHG emission of various H_2 production pathways to injection point
- Compression emissions were calculated considering US electricity mix (2020)
- When H_2 is blended with NG, the environmental benefit is highly dependent on the H_2 production pathway.

Note: CA LCFS Carbon Intensity for Green H_2 is zero

02

Why Hydrogen?

nationalgrid

Hydrogen's Flexibility and Progress Enables Multiple Synergistic Uses

- **Hydrogen is very versatile**
- **Hydrogen has a strong safety record**
  - Wider flammability limits than natural gas and higher pressures but
  - Disperses quickly
  - High flame speed
- **Hydrogen use has no GHG emissions**
- **Gas & electric utilities have experience with hydrogen and projects in progress**

NJ Resources Blending

NFPA

2

Hydrogen Technologies Code

2020

Hempstead, NY Vehicle Fueling & Blending 2025

Hydrogen Use Today

- **US Pipelines to Support the Petrochemical Industry**
  - 891 miles of H_2 pipelines in the US
  - 3 miles in NY state regulated by the NY PSC (Linde)
- **Industrial Gas Delivery and Use**
- **US Space Program**
  - Propellants
    - Space Launch System
    - Future Hypersonic Aircraft
  - On board power generation
    - Fuel Cell power since the 60's
- **Coolant for Electric Generation and Transmission** e.g., Synchronous Condenser

Air Products 600 Miles H_2 Network
1.4 billion SCFD at 700 psig

Utility Experience with Hydrogen

- Produced Hydrogen as part of the synthetic gas production facility plant (70/80’s).
  - Hawaii Gas Today Typically has 12% Hydrogen distributed in 1,100 miles pipelines on Oahu
  - Singapore and Honk Kong have as much as 55% hydrogen in their SNG
- United Technologies (Doosan), GE and other Fuel Cell Systems have onboard hydrogen production many were maintained by utility subsidiaries
- National Grid owned Town of Hempstead Hydrogen Fuel Station (2008-2011). Applied Process Safety Program.
- Utilities supported planned Fleet demos of Hybrid Fuel Cell vehicles
- Electric Transmission Operations. Coolant e.g. “Synchronous Condenser” cooled with hydrogen

Green Hydrogen Benefits at National Grid

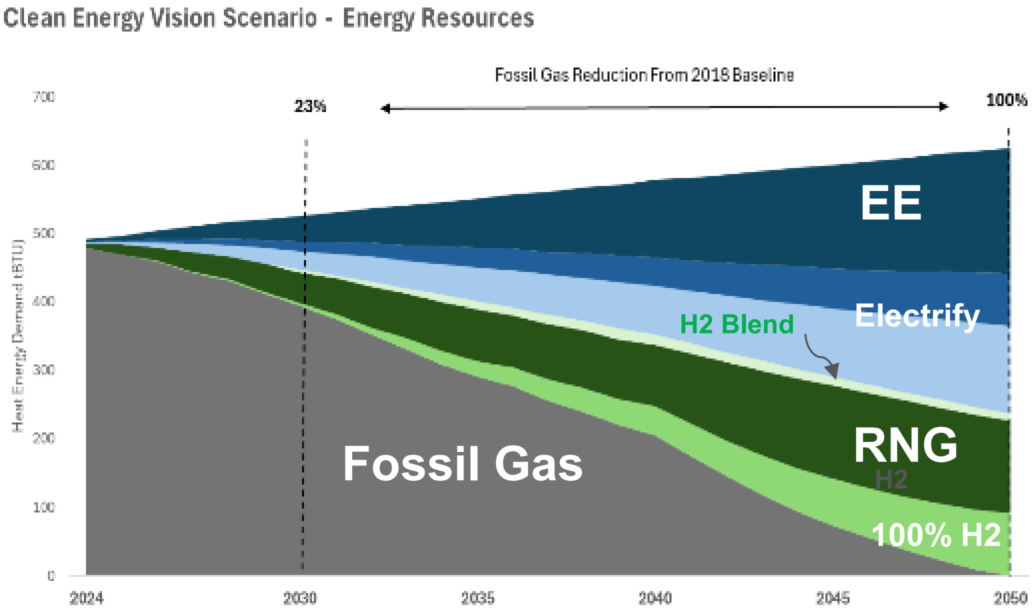
- **Customers**

Complete electrification of heat in NY is incrementally both highly disruptive and exorbitantly expense *(ref NYC Pathways)*

- **Company**

- Long Term Capacity Plan (NYPSC)

- Fills potential gaps in RNG supply using existing infrastructure:
  - 20% Blending in new pipelines or pipelines replaced through the Leak Prone Pipe (LPP) program
  - 100% hydrogen can be provided in upgraded existing pipelines



Clean Energy Vision Scenario - Energy Resources

- Modern pipelines can safely transport large volumes of green hydrogen produced in NY with new wind power.
  - Limits in hydrogen will be due to customer appliance transition which has a shorter cycle-time.

03

Hydrogen Properties

Hydrogen and Synthetic Gas Production Methods

- **Catalytic Steam Methane Reforming (SMR)**
  - Steam reformation $CH_4 + H_2O + heat \rightarrow CO + 3H_2$
  - Water-gas shift reaction $H_2O + CO + heat \rightarrow CO_2 + H_2$
  - Potential Methane and CO slip

- **Electrolysis using Fuel Cell Stacks**

  cathode reaction (reduction)

  $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

  anode reaction (oxidation)

  $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

- **Gasification of Dry Waste Materials (e.g. MSW, Wood etc.)**
  - High Temperature (200^{o}C-1700^{o}C, typically 900^{o}C)
  - Non-GHG emissions lower than incineration but not zero
  - Produces tar and solid pollutants, potentially toxic.

- **Pyrolysis of Methane**
  - Several Techniques (Plasma torch, Thermal-Catalytic, Microwave etc.)
  - Energy intensive, temperatures above 1100–1200^{o}C . Plasma at 2100^{o}C
- **Production on Synthetic Methane (i.e. Methanation of Hydrogen)**
  - Nickel Catalyst (Sabatier reaction) $4\ H_2 + CO_2 \rightleftarrows CH_4 + 2\ H_2O + heat$
  - Biological; eight main species of the Methanothermobacter genus identified as functional methanogens

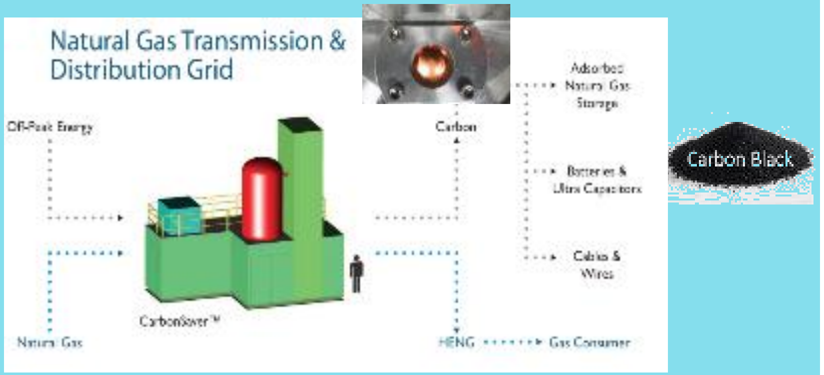
The “Colors” of Hydrogen”

Low or Zero Carbon Intensity Hydrogen Production Pathways

RENEWABLE ELECTTRICITY

NUCLEAR ELECTRICITY

SMR ➔ CARBON CAPTURE



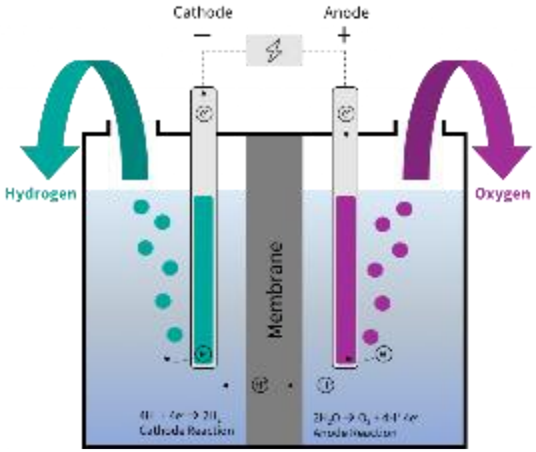
PROLYSIS of RENEWABLE METHANE OR WASTE

Naturally occurring geologic hydrogen found and called called White Hydrogen

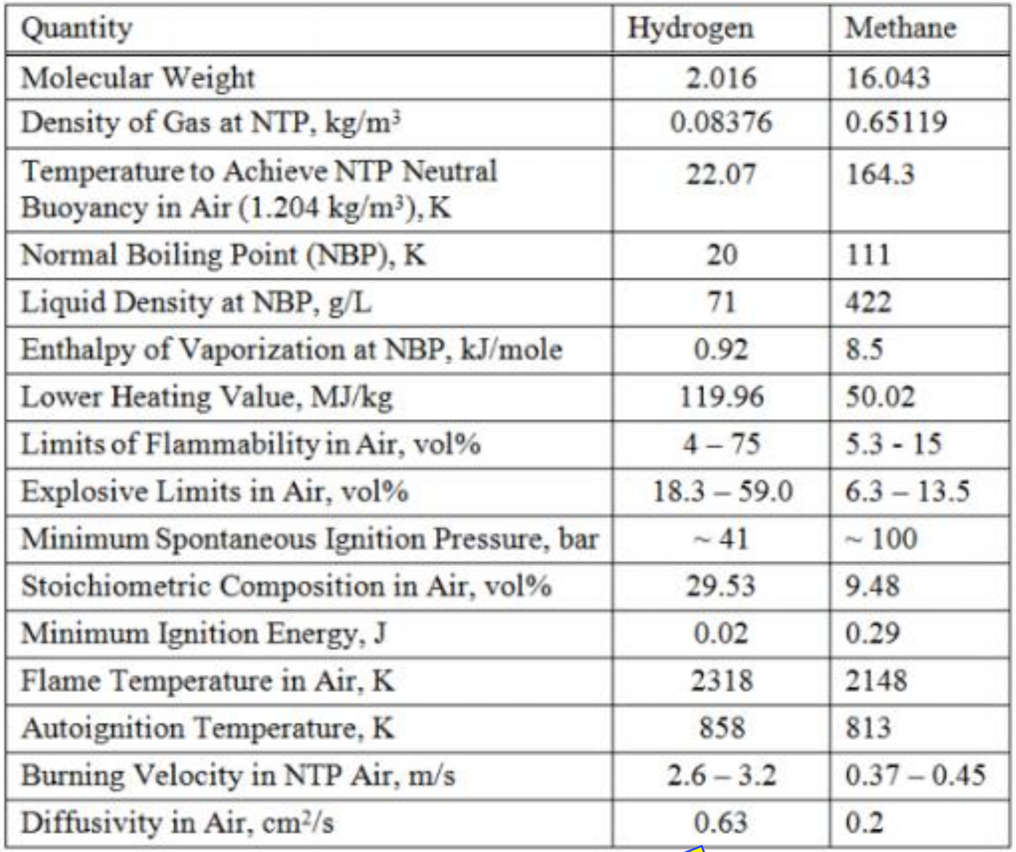
Green Hydrogen is Primarily Produced by Electrolysis

Electrolysis Process: Electrolysis is a method that uses electricity to split water (H2O) into hydrogen (H2) and oxygen (O2). This process occurs in an electrolyzer, which consists of an anode and a cathode separated by an electrolyte.

Water is oxidized to produce oxygen gas, while hydrogen ions are reduced to form hydrogen gas.



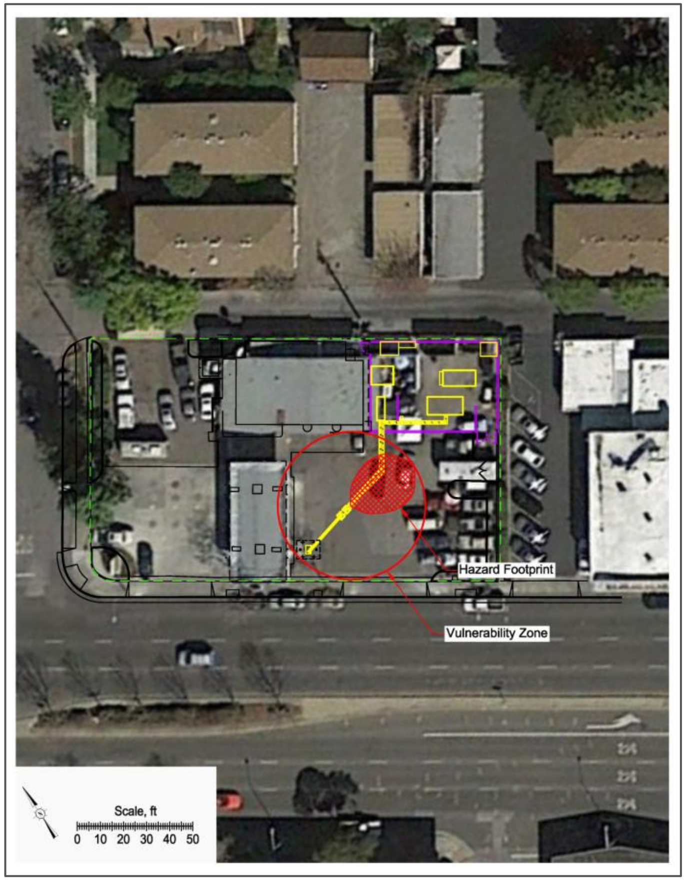
Hydrogen Safety Comparisons



Quantity	Hydrogen	Methane
Molecular Weight	2.016	16.043
Density of Gas at NTP, kg/m³	0.08376	0.65119
Temperature to Achieve NTP Neutral Buoyancy in Air (1.204 kg/m³), K	22.07	164.3
Normal Boiling Point (NBP), K	20	111
Liquid Density at NBP, g/L	71	422
Enthalpy of Vaporization at NBP, kJ/mole	0.92	8.5
Lower Heating Value, MJ/kg	119.96	50.02
Limits of Flammability in Air, vol%	4 – 75	5.3 - 15
Explosive Limits in Air, vol%	18.3 – 59.0	6.3 – 13.5
Minimum Spontaneous Ignition Pressure, bar	~ 41	~ 100
Stoichiometric Composition in Air, vol%	29.53	9.48
Minimum Ignition Energy, J	0.02	0.29
Flame Temperature in Air, K	2318	2148
Autoignition Temperature, K	858	813
Burning Velocity in NTP Air, m/s	2.6 – 3.2	0.37 – 0.45
Diffusivity in Air, cm²/s	0.63	0.2

Sandia SAND2016-6456 J

- **Higher Pressures**
  - Storage
  - Transmissions and Distribution



H_2 Vehicle Fueling Qualitative Risk Assessment

Hazard Footprint and Vulnerability Zone for the High Pressure Hydrogen Transfer Pipe to the Dispenser

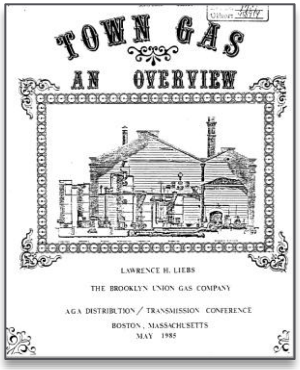
Hydrogen Blends
Changes in Combustion Properties

CH4 (Vol%)	H2 (Vol%)	Laminar burning velocity (cm/s)	Adiabatic flame temperature (K)	Flammability range (Vol.% in air)	Minimum ignition energy (mJ)
100	0	36.6	2228	4.99–14.73	0.24
98	2	37.1	2228	4.97–14.97	0.23
95	5	37.8	2230	4.93–15.35	0.22
90	10	39.1	2232	4.88–16.01	0.20
70	30	46.0	2244	4.67–19.39	0.13
0	100	252.0	2384	4.07–74.24	0.03

The First Conversion: Interstate Pipelines 1952

The Second Conversion: RNG & Hydrogen

A purge burner igniting manufactured gas being replaced in a main by natural gas during the 'great conversion' in 1952



TOWN GAS

AN OVERVIEW

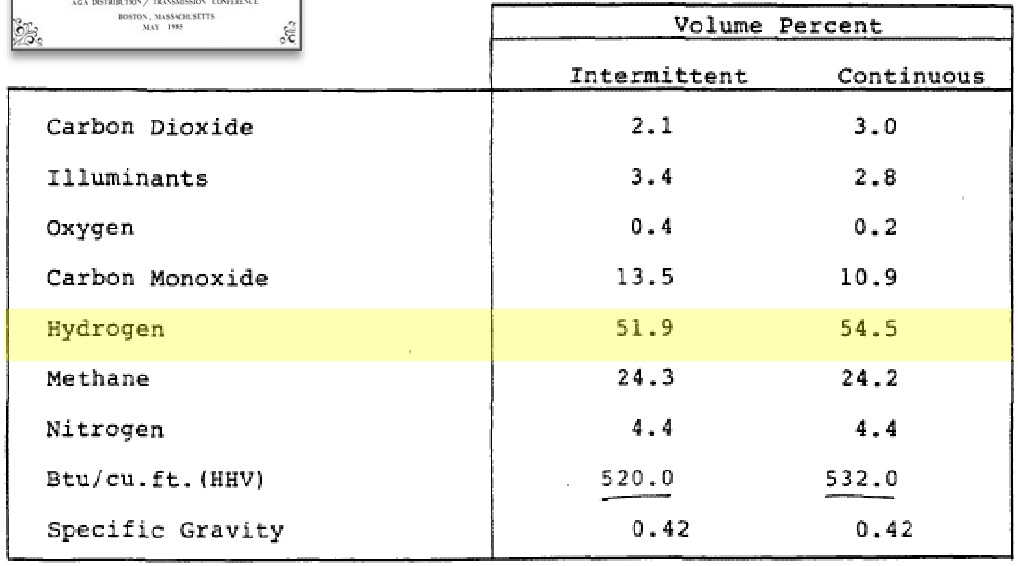
LAWRENCE H. LIEBS

THE BROOKLYN UNION GAS COMPANY

AGA DISTRIBUTION / TRANSMISSION CONFERENCE

BOSTON, MASSACHUSETTS
MAY 1985

SNG from Naphtha 1970's



	Volume Percent	
	Intermittent	Continuous
Carbon Dioxide	2.1	3.0
Illuminants	3.4	2.8
Oxygen	0.4	0.2
Carbon Monoxide	13.5	10.9
Hydrogen	51.9	54.5
Methane	24.3	24.2
Nitrogen	4.4	4.4
Btu/cu.ft.(HHV)	520.0	532.0
Specific Gravity	0.42	0.42

04

Hydrogen Pipelines & Storage

Hydrogen in high-temperature applications: Delivery

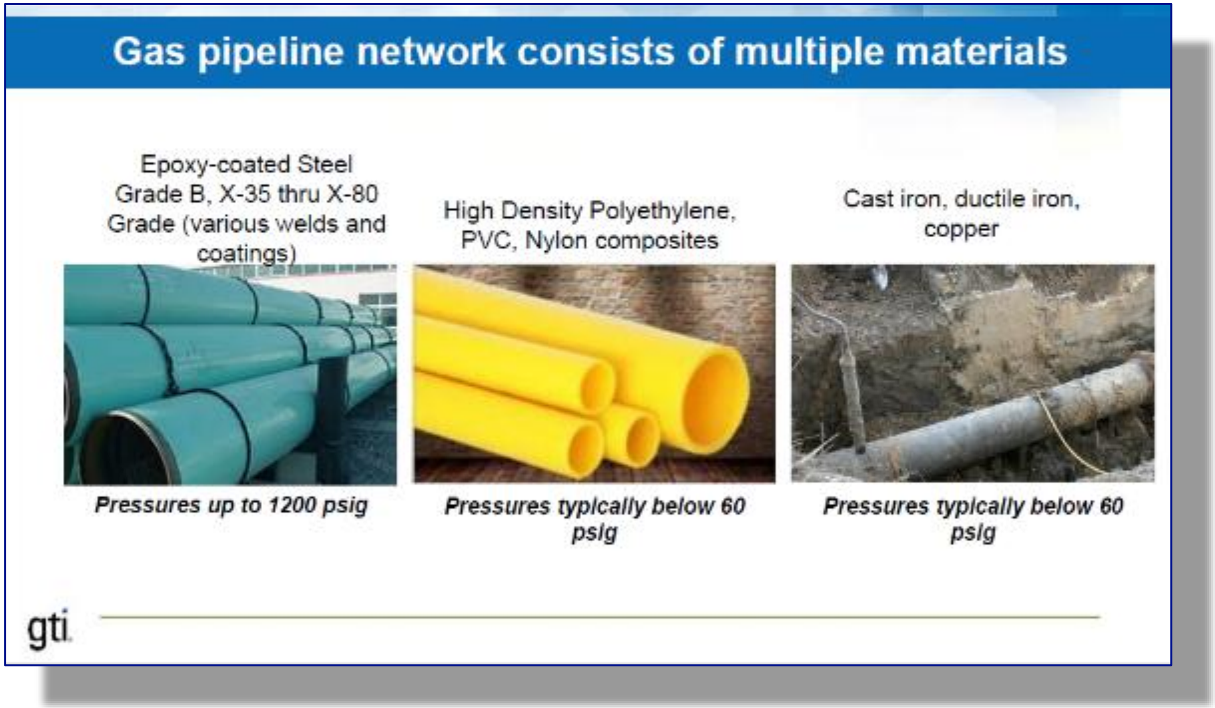
Option	CapEx	OpEx	Emissions (if green H_2)	Maturity	Key Barriers
On-site Electrolysis	High	Medium	Near-zero	Medium	Electricity price + water use
Delivered H_2 (truck)	Low–Med	High	Varies	High	Transport + storage cost
Pipeline H_2	Low	Low	Near-zero	Low	Access + infra cost
Blending H_2 in gas	Low	Low	Moderate (7–20% cut)	Medium	Technical blend limit

Codes, standards & regulatory context

- 49 CFR Part 192 defines “gas” broadly; hydrogen is a flammable gas, so pipelines transporting hydrogen-blended gas are required to meet Part 192;
- PHMSA considers a change from natural gas to hydrogen-blended natural gas a product change and released 2014 guidance for pipeline product changes. The guidance highlights code requirements to address before initiating a product change.
- In New York State, Part 255 of Title 16 NYCRR outlines safety requirements applicable to gas distribution pipelines.
- Customer piping and end-use equipment are subject to local building codes, utility instructions, and NFPA-54.

Hydrogen Blending Safety Considerations

- **Hydrogen Embrittlement & Corrosion**
  - Metallic
- **PE & Sealing Materials**
- **Odorants**
  - Hydrogen Interactions
  - H_2S Formation?
- **Detection**
  - Technician Safety
  - Building Detectors
- **Appliances**
- **Potential Impact on LNG Operations**



Gas pipeline network consists of multiple materials

Epoxy-coated Steel Grade B, X-35 thru X-80 Grade (various welds and coatings)	High Density Polyethylene, PVC, Nylon composites	Cast iron, ductile iron, copper
Pressures up to 1200 psig	*Pressures typically below 60 psig*	*Pressures typically below 60 psig*

gti

H_2 Pipeline in NY

The integrity of repurposed natural gas pipeline systems has been studied

- **Pipeline Research Council International**
  - Emerging fuels – Hydrogen SOTA, Gap Analysis, Future Project Roadmap Issued; November 2020
  - § Summary of State-of-the-Art and Gap Analysis
    - Standard carbon steel material properties (yield strength, tensile strength) used for stress-based design are normally not affected by hydrogen.
    - **Hydrogen does not cause degradation of polyethylene pipe. Rather, the primary concern is with permeation of hydrogen through the pipe and seals/connections leading to losses. Additional data is needed to quantify this risk**
    - ***"the impact of hydrogen admixing is heavily driven by the partial pressure of hydrogen in the mixture"***
  - **Impact on Fatigue Crack Growth and Fracture Toughness** *(ref DNV Repurposing Assessment)*
    - ASME B31.8, B31.8S and B31.12
    - e.g.: despite susceptibility, alloys generally suitable for hydrogen service at low stress (<30% SMYS), esp. new/defect-free assets.

HYDROGEN SAFETY

Integrity and Safety of Repurposed Hydrogen Pipelines in the European Union

RESEARCH

AURELIEN PITOIS
ERIK SMEDBERG
REMI KLEINE
PIETRO MORETTO
BEATRIZ ACOSTA IBORRA

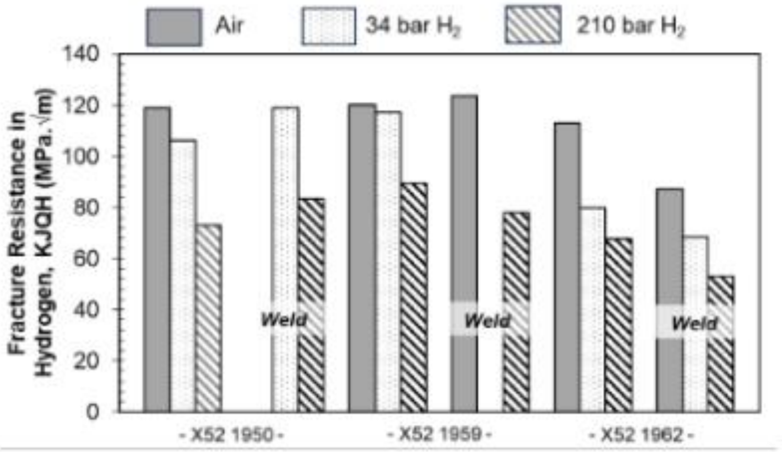
KIT Scientific Publishing

hySafe

ABSTRACT

Hydrogen Impacts on Metallic Materials

Fracture Toughness (K_{IC})

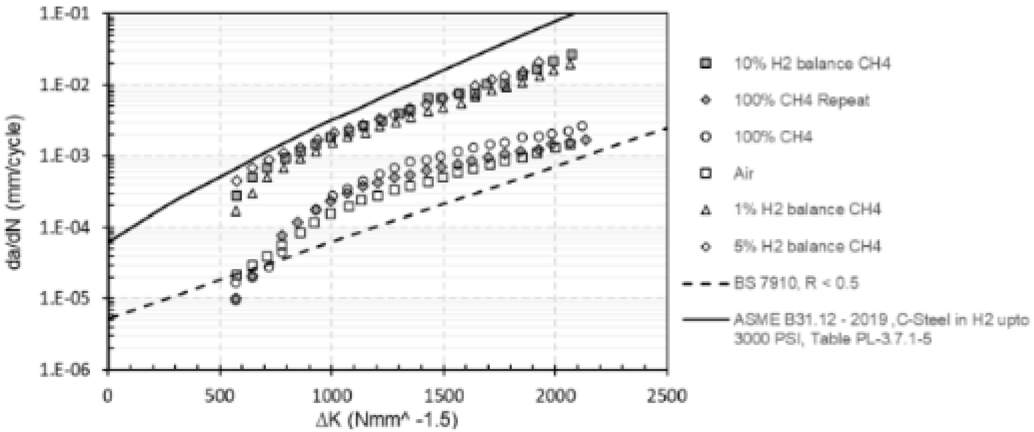


Magnitude of HE proportional to partial pressure of Hydrogen, however even relatively small amounts of hydrogen significantly impact toughness properties

Exact impact is material specific, requiring specialized material testing (Charpy V-notch is not valid); however, conservative assumptions of up to a 50% reduction in lower bound toughness can be made.

For distribution operating conditions, this is a pragmatic solution to validate fitness for service

Fatigue Crack Growth Rate (FCGR)



Hydrogen significantly impacts FCGR. In many instances, up to an order of magnitude increase is realistic.

Exact impact is material specific, requiring specialized material testing; however, conservative assumption of a 10-fold increase can be reasonably made

For distribution operating conditions, this is a pragmatic solution to validate fitness for service

Material Compatibility – Hydrogen Embrittlement (Steel)

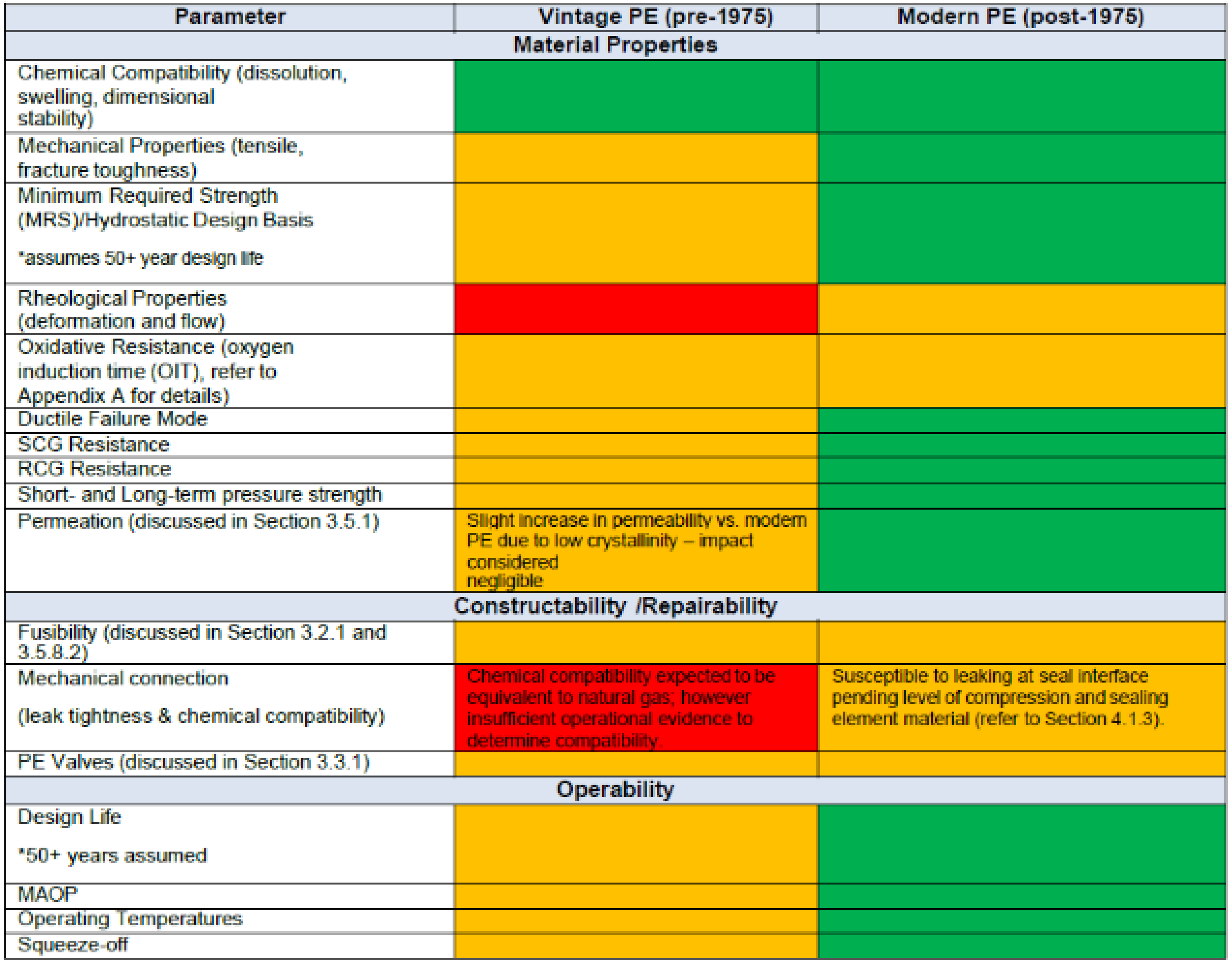
Sandia National Laboratories (SNL) has preliminarily stated,

“Hydrogen seems very unlikely to induce unstable fracture in distribution piping from quality pipe steels”

An independent consultant, ARUP, was commissioned by National Grid to review pipeline materials specified in the LPP program.

- **Protected steels outlined in the NGUSA’s updated material specs are H_2 compatible.**
- **ASTM A106 Grade B, API 5L Grade B, PSL1 or PSL2, X42 PSL 2, X52 PSL2 are all compatible.**
- **X60 steel is not compatible and must be replaced.**

Hydrogen Impacts on Polymeric Materials



Parameter	Vintage PE (pre-1975)	Modern PE (post-1975)
Material Properties		
Chemical Compatibility (dissolution, swelling, dimensional stability)	🟩	🟩
Mechanical Properties (tensile, fracture toughness)	🟨	🟩
Minimum Required Strength (MRS)/Hydrostatic Design Basis *assumes 50+ year design life	🟨	🟩
Rheological Properties (deformation and flow)	🟥	🟨
Oxidative Resistance (oxygen induction time (OIT), refer to Appendix A for details)	🟨	🟨
Ductile Failure Mode	🟨	🟩
SCG Resistance	🟨	🟩
RCG Resistance	🟨	🟩
Short- and Long-term pressure strength	🟨	🟩
Permeation (discussed in Section 3.5.1)	🟨 Slight increase in permeability vs. modern PE due to low crystallinity – impact considered negligible	🟩
Constructability /Repairability		
Fusibility (discussed in Section 3.2.1 and 3.5.8.2)	🟨	🟨
Mechanical connection (leak tightness & chemical compatibility)	🟥 Chemical compatibility expected to be equivalent to natural gas; however insufficient operational evidence to determine compatibility	🟨 Susceptible to leaking at seal interface pending level of compression and sealing element material (refer to Section 4.1.3).
PE Valves (discussed in Section 3.3.1)	🟨	🟨
Operability		
Design Life *50+ years assumed	🟨	🟩
MAOP	🟨	🟩
Operating Temperatures	🟨	🟩
Squeeze-off	🟨	🟩

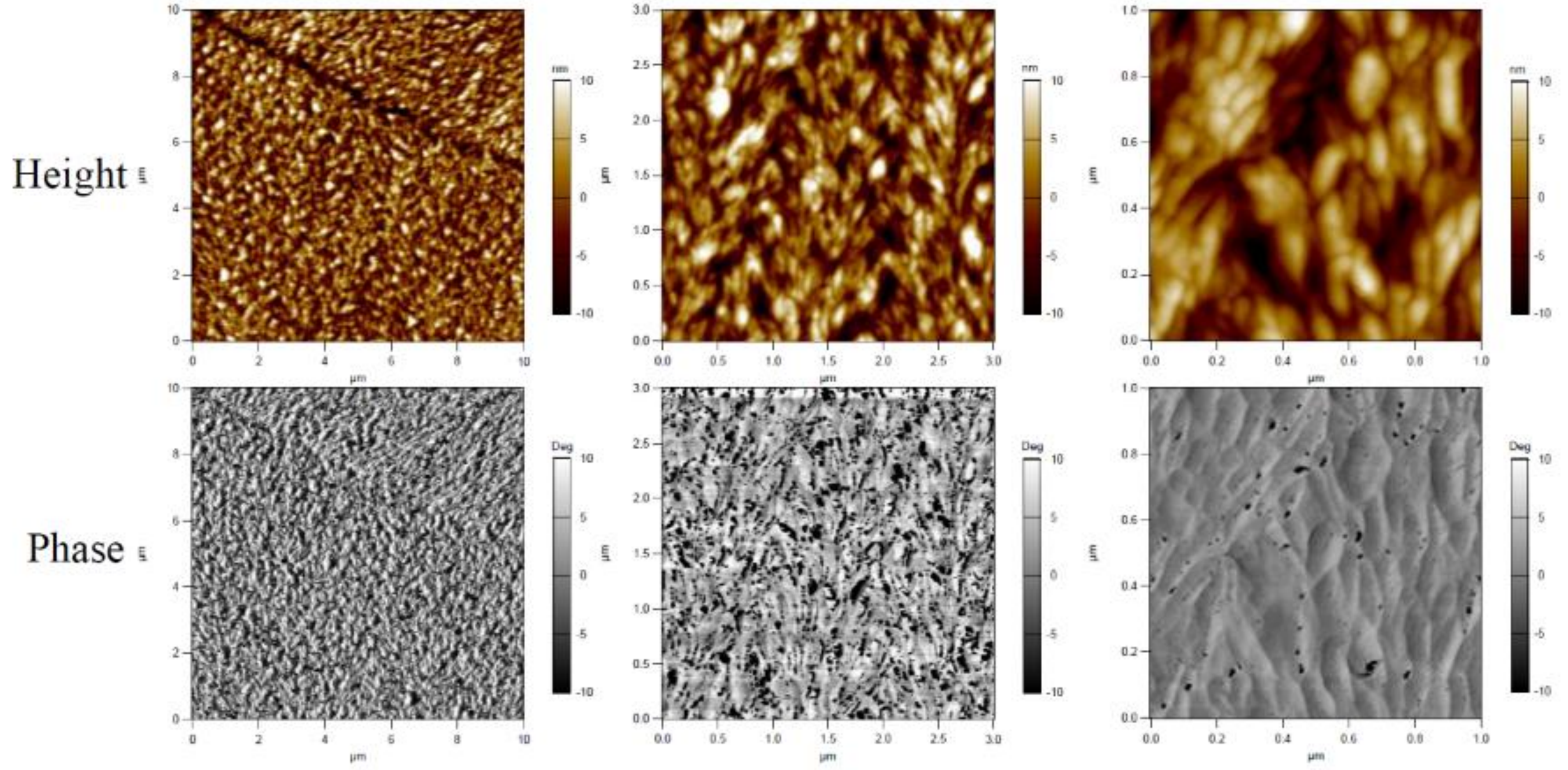
Green = Equivalent behaviour to natural gas expected

Yellow = Equivalent behaviour to natural gas likely

Red = Insufficient evidence to determine equivalence with natural gas

Material Compatibility – PE (Before)

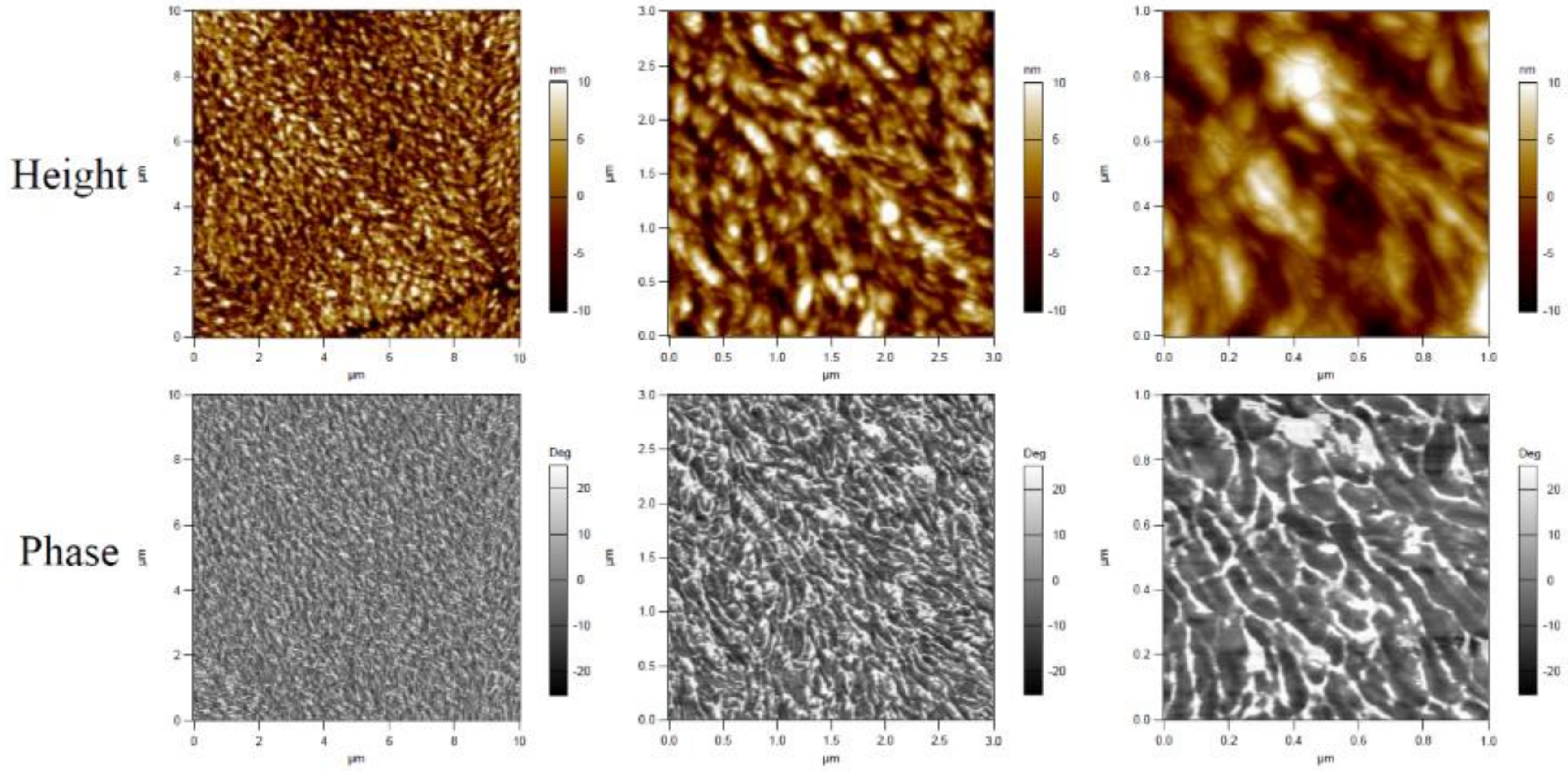
HDPE-1 : 74.5nm   Before H_2 exposure



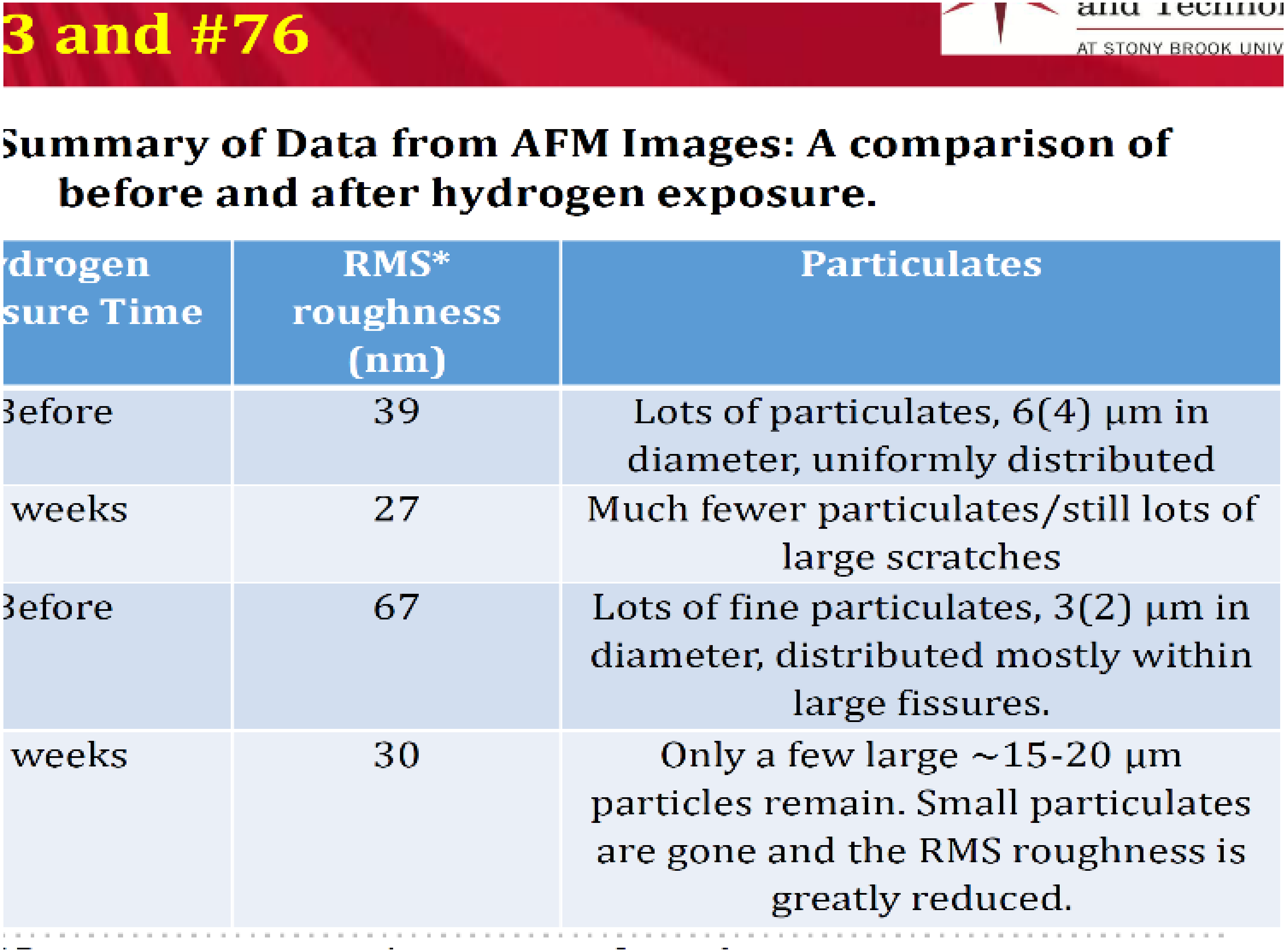
Material Compatibility – PE (After)

Institute of Gas Innovation and Technology
AT STONY BROOK UNIVERSITY

HDPE-1 After H_2 exposure



Additional Conclusion: Hydrogen acted as a cleaning agent



3 and #76

AT STONY BROOK UNIV

Summary of Data from AFM Images: A comparison of before and after hydrogen exposure.

ydrogen sure Time	RMS* roughness (nm)	Particulates
Before	39	Lots of particulates, 6(4) µm in diameter, uniformly distributed
weeks	27	Much fewer particulates/still lots of large scratches
Before	67	Lots of fine particulates, 3(2) µm in diameter, distributed mostly within large fissures.
weeks	30	Only a few large ~15-20 µm particles remain. Small particulates are gone and the RMS roughness is greatly reduced.

Summary of Material Compatibility – Distribution Service

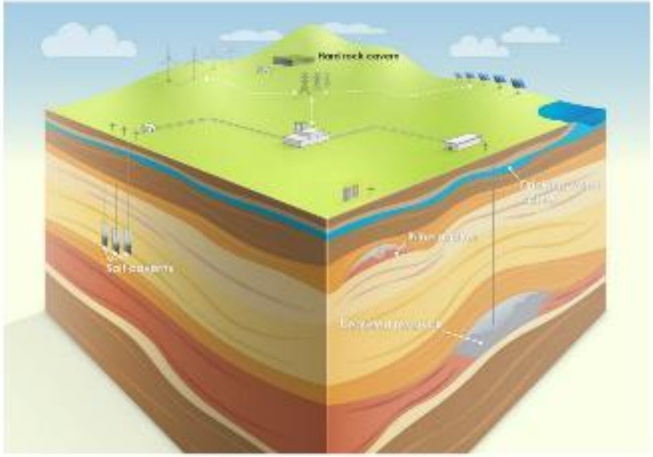
Category	Material Type	20% H2
Polymer	Polyethylene (MDPE & HDPE)	Compatible with hydrogen. Some considerations for modern vs. vintage materials.
Polymer	PVC	No anticipated issues from the perspective of material compatibility, but NOT recommended for use in hydrogen-blended gas or pure hydrogen service due to poor resistance to failure and overall operability challenges.
Elastomer	Elastomers commonly utilized within Gas Distribution industry	Generally suitable for hydrogen blended gas and pure hydrogen
Metallic	Low Alloy Carbon Steel (API 5L, A106, A333, etc.)	Broadly suitable; validation of pipeline integrity prior to introducing hydrogen blended gas or pure hydrogen is required (design review and targeted inspection(s)).
	Malleable/Ductile Iron	Suitable for use in fittings, valves, etc. at distribution pressures.
	Cast Iron	Suitable for use in fittings, valves, etc. at distribution pressures. Not recommended as mainline material.
	Stainless Steel — Austenitic	Compatible with hydrogen
	Stainless Steel — Ferritic & Martensitic	Likely suitable pending specific use case (pressure containing, cyclical stress, etc.)
	Aluminium	Suitable provided no exposure to severe cyclical service.
	Copper	Compatible with hydrogen at distribution pressures.

Transmission & Storage

- **Trucking**
- **Marine**
- **Rail**
- **Pipeline**
  - Pure Hydrogen
  - Blended and De-blended
- **Liquids (MeOH or Ammonia)**
- **Storage**
  - Compressed
    - Tanks
    - Caverns
  - Liquefied H_2
  - Absorbed
  - Liquids (MeOH)

Compressed Gas Injection Station

Liquefaction



Large Scale Caverns

Local Hydrogen Storage

		Density [kg/cu.ft]	Hazard Profile	Capital Cost [$/kg]	Efficiency	Complexity
Compressed Hydrogen						
	3,000 psi	0.33	Medium	$ 1,000	1.4 kWh/kg	Low
	6,000 psi (PDC)	0.65	Medium	$ 1,000	2.7 kWh/kg	Low
Liquified Hydrogen		1.98	High	$ 800	11 kWh/kg	Cryogenic - 253^{o}F
Absorbed Hydrogen at 580 psi.		1.12	Low	$ 4,800	4.5 kWh$_{th}$/k	Thermal Mgmt
Liquids (ammonia, organic etc.)		1.56	Very Low	varies	8 kWh$_{th}$/kg	Thermal Mgmt
		(varies)			(varies)	

Compressed Risk Contour

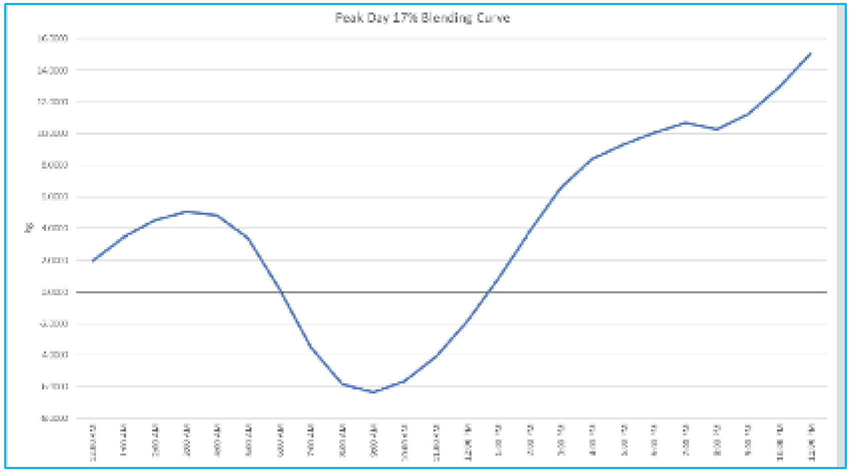
Compressed

Absorbed

Ammonia

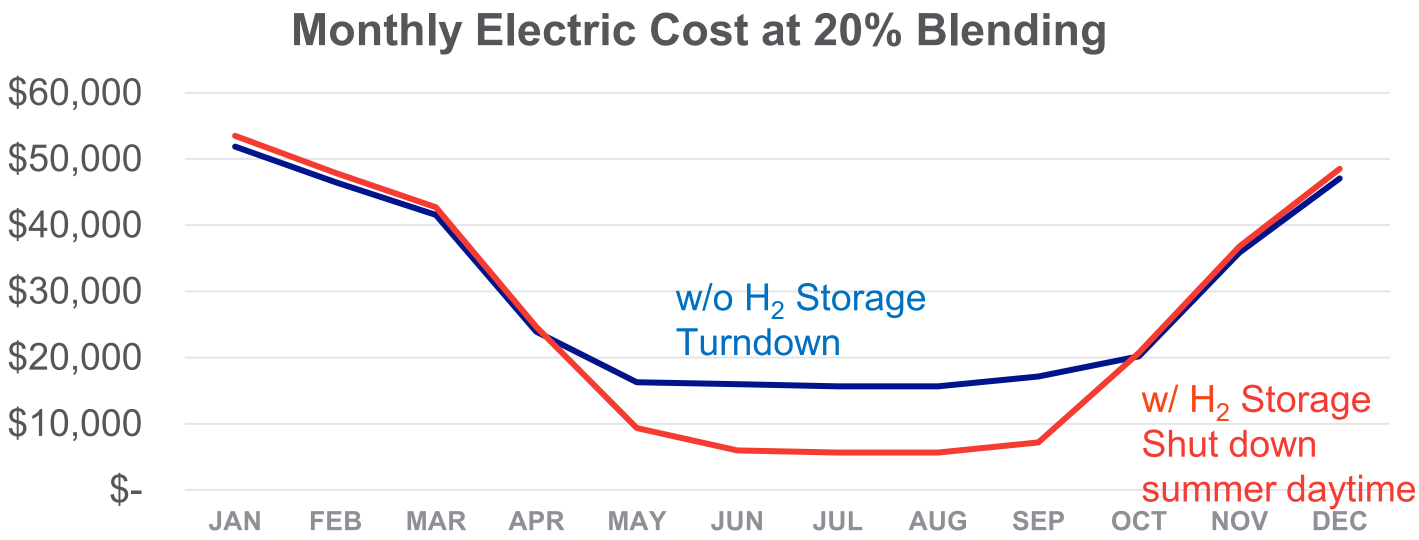
Liquified

Hydrogen Storage Design

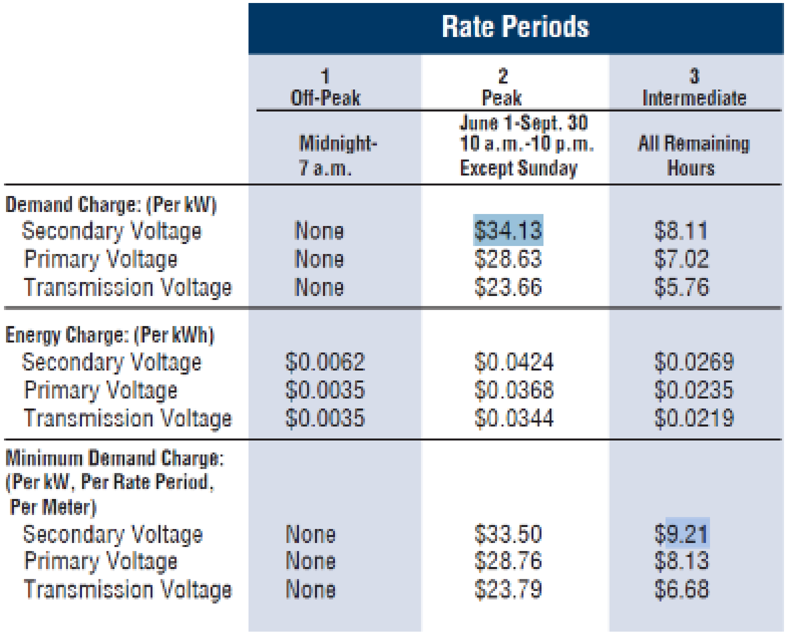

Hourly Hydrogen Demand for Blending

- **Storage Design Parameters**
  - Storage Purpose
  - Winter – Peak Hour Heating Load (i.e., Capital Efficiency)
  - Summer – Nighttime Electrolysis to reduce electric delivery costs
  - Pressure Selection
    - High pressure (6,000psi) Lower footprint, supports vehicles
    - Lower pressure (3,000 psi) lower hazard, less compression
- **Evaluating Absorbed Storage**
  - Positive – Lower Pressure = Lower Hazard
  - Negative – High cost, complexity (thermal management) ***3X storage at 40 bar***

Storage Reduces Electric Cost for Electrolysis (example)



Monthly Electric Cost at 20% Blending



	Rate Periods		
	1 Off-Peak	2 Peak	3 Intermediate
	Midnight- 7 a.m.	June 1-Sept. 30 10 a.m.-10 p.m. Except Sunday	All Remaining Hours
Demand Charge: (Per kW)			
Secondary Voltage	None	$34.13	$8.11
Primary Voltage	None	$28.63	$7.02
Transmission Voltage	None	$23.66	$5.76
Energy Charge: (Per kWh)			
Secondary Voltage	$0.0062	$0.0424	$0.0269
Primary Voltage	$0.0035	$0.0368	$0.0235
Transmission Voltage	$0.0035	$0.0344	$0.0219
Minimum Demand Charge: (Per kW, Per Rate Period, Per Meter)			
Secondary Voltage	None	$33.50	$9.21
Primary Voltage	None	$28.76	$8.13
Transmission Voltage	None	$23.79	$6.68

US LNG Operations

- Largest H_2 liquefaction facility was developed by Linde at 170 tons per day or the equivalent of 21 MDTH per day vs 62 MMDth LNG vaporization capacity in Greenpoint, NY
- For US peak-shaving, blended H_2, is a non-condensable in the liquefaction / tank management process
- Will need to be rejected or "de-blended" prior to introducing liquid to the tank system
- In general, de-blending (or gas separation) could play a significant role in providing the flexibility needed to control gas concentrations exiting the transmission system: PSA, membrane or cryogenic. *UK-GSO*

05

Hydrogen Blending

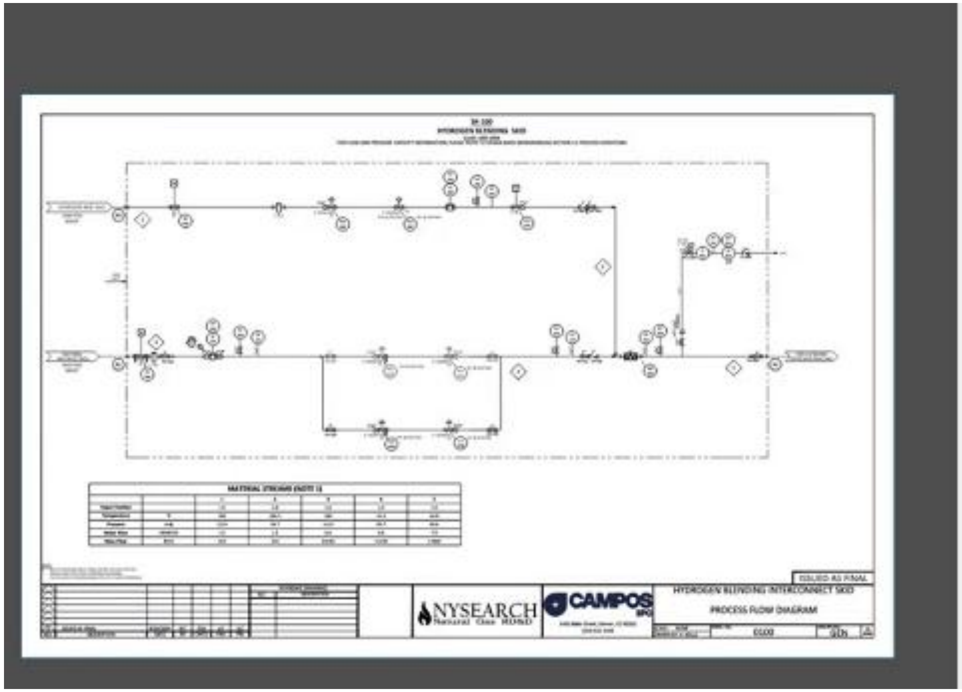
nationalgrid

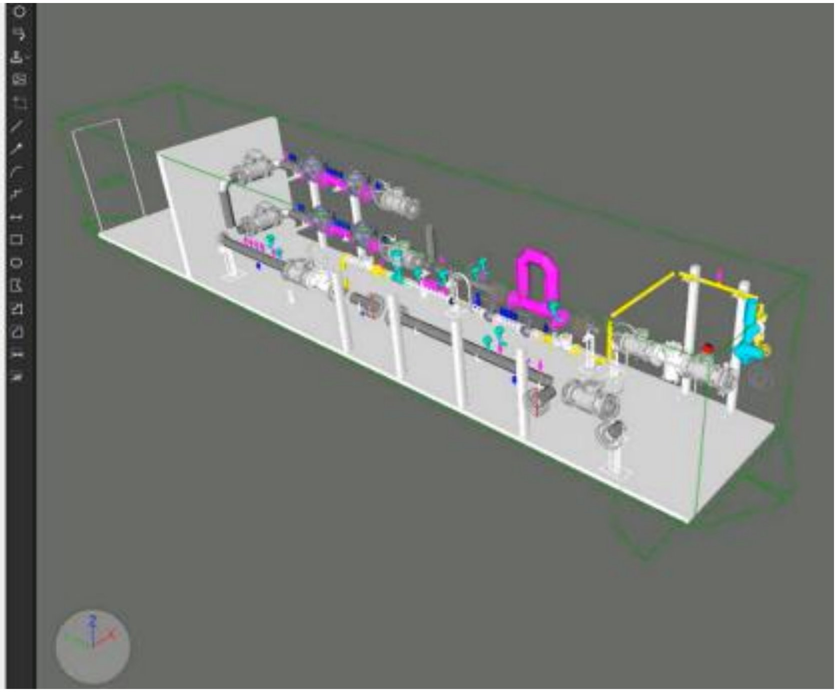
Hydrogen Blending in the UK HyDeploy and HyDeploy2,

- **Effort led by Cadent (UK Distribution Company) for Demonstration of a 20 v% hydrogen blend**
- **Phase I: 10-month H_2 blending Demonstration at Keele University, in operation**
- Successfully tested 130+ properties and buildings, including 230+ appliances, prior to go-live
- No new appliance leakage detected
- **Phase II: ~700 homes on the distribution network in the North East UK, early 2020's**

100 v% methane versus 28 v/v% hydrogen/methane –"HyDeploy: The UK's First Hydrogen Blending Deployment Project"

Standardized Hydrogen Blending Skid



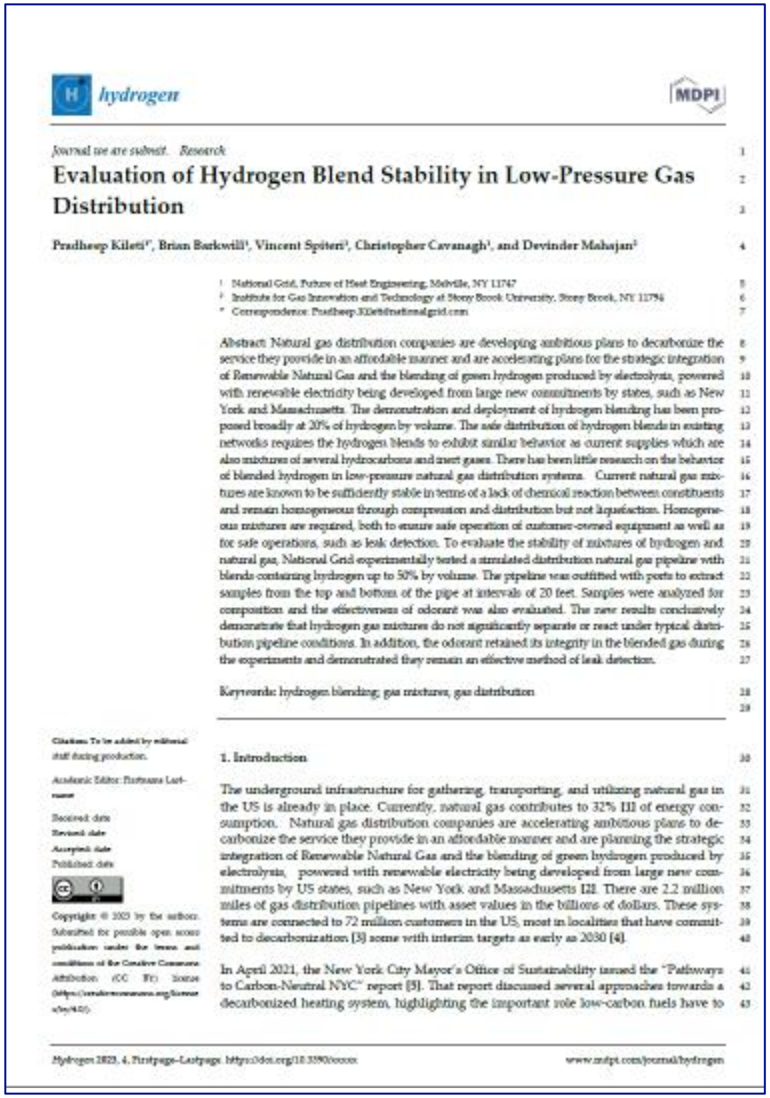


Do hydrogen gas mixtures separate?

Objective	• Testing different blend rates (1% → 50%). • At varying pressures (LP, 15 psi, 30 psi, 60 psi). • Along 100 ft of PE pipe.
Why	• Test if CH_4 and H_2 will separate due to density difference. • Test if H_2 will mask the odorant reducing its effectiveness. • Test if the odorant will separate from the blend.
Progress	• Testing has concluded as of 8/4/2022 • Data analysis completed • Separation of CH_4 and H_2 not apparent.

Hydrogen Mixture Stability and Sulfur Interactions

- Odorant Fade: I-GIT reports that reactions with mercaptans occurs at far higher temperatures (>266°F) or with UV light, conditions not possible in gas distribution
- The mercaptan molecule is already saturated with hydrogen atoms and can not form H_2S.
- 2023 paper by National Grid
  - Natural gas-hydrogen mixtures in gas distribution systems will show homogeneous behavior, i.e., the gases do not naturally separate under typical distribution pipeline conditions or temperatures, pressures, and gas flow rates or at times of no flow.
  - When odorant performance is measured using established performance indicators, such as RDL, the performance met the current 393 standards for human detection



hydrogen MDPI

Journal we are submit. Research

Evaluation of Hydrogen Blend Stability in Low-Pressure Gas Distribution

Pradheep Kileti[1,*], Brian Barkwill[1], Vincent Spiteri[1], Christopher Cavanagh[1], and Devinder Mahajan[2]

[1] National Grid, Future of Heat Engineering, Melville, NY 11747
[2] Institute for Gas Innovation and Technology at Stony Brook University, Stony Brook, NY 11794
[*] Correspondence: Pradheep.Kileti@nationalgrid.com

Abstract: Natural gas distribution companies are developing ambitious plans to decarbonize the service they provide in an affordable manner and are accelerating plans for the strategic integration of Renewable Natural Gas and the blending of green hydrogen produced by electrolysis, powered with renewable electricity being developed from large new commitments by states, such as New York and Massachusetts. The demonstration and deployment of hydrogen blending has been proposed broadly at 20% of hydrogen by volume. The safe distribution of hydrogen blends in existing networks requires the hydrogen blends to exhibit similar behavior as current supplies which are also mixtures of several hydrocarbons and inert gases. There has been little research on the behavior of blended hydrogen in low-pressure natural gas distribution systems. Current natural gas mixtures are known to be sufficiently stable in terms of a lack of chemical reaction between constituents and remain homogeneous through compression and distribution but not liquefaction. Homogeneous mixtures are required, both to ensure safe operation of customer-owned equipment as well as for safe operations, such as leak detection. To evaluate the stability of mixtures of hydrogen and natural gas, National Grid experimentally tested a simulated distribution natural gas pipeline with blends containing hydrogen up to 50% by volume. The pipeline was outfitted with ports to extract samples from the top and bottom of the pipe at intervals of 20 feet. Samples were analyzed for composition and the effectiveness of odorant was also evaluated. The new results conclusively demonstrate that hydrogen gas mixtures do not significantly separate or react under typical distribution pipeline conditions. In addition, the odorant retained its integrity in the blended gas during the experiments and demonstrated they remain an effective method of leak detection.

Keywords: hydrogen blending; gas mixtures; gas distribution

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Received: date
Revised: date
Accepted: date
Published: date

1. Introduction

The underground infrastructure for gathering, transporting, and utilizing natural gas in the US is already in place. Currently, natural gas contributes to 32% [1] of energy consumption. Natural gas distribution companies are accelerating ambitious plans to decarbonize the service they provide in an affordable manner and are planning the strategic integration of Renewable Natural Gas and the blending of green hydrogen produced by electrolysis, powered with renewable electricity being developed from large new commitments by US states, such as New York and Massachusetts [2]. There are 2.2 million miles of gas distribution pipelines with asset values in the billions of dollars. These systems are connected to 72 million customers in the US, most in localities that have committed to decarbonization [3] some with interim targets as early as 2030 [4].

In April 2021, the New York City Mayor's Office of Sustainability issued the "Pathways to Carbon-Neutral NYC" report [5]. That report discussed several approaches towards a decarbonized heating system, highlighting the important role low-carbon fuels have to

Hydrogen 2023, 4, Firstpage–Lastpage. https://doi.org/10.3390/xxxxx www.mdpi.com/journal/hydrogen

I-GIT PE Permeability Results

Institute of
Gas Innovation
and Technology
AT STONY BROOK UNIVERSITY

- Polymer materials are used in the gas industry for their excellent barrier properties.
- High Density Polyethylene (HDPE) pipes, a semicrystalline polymer was exposed to different gases.
- Permeability measurements were performed with HDPE at different temperatures with pure and mixed gases: H_2, CH_4, 5% H_2 in Ar, O_2, Ar, CO_2.
- The intrinsic permeability coefficient of each component of a gas mixture was determined along with its temperature dependence.
- Leakage (m3 from the pipe of 1,000 m long during 1 year period) = 2.4 m3 .

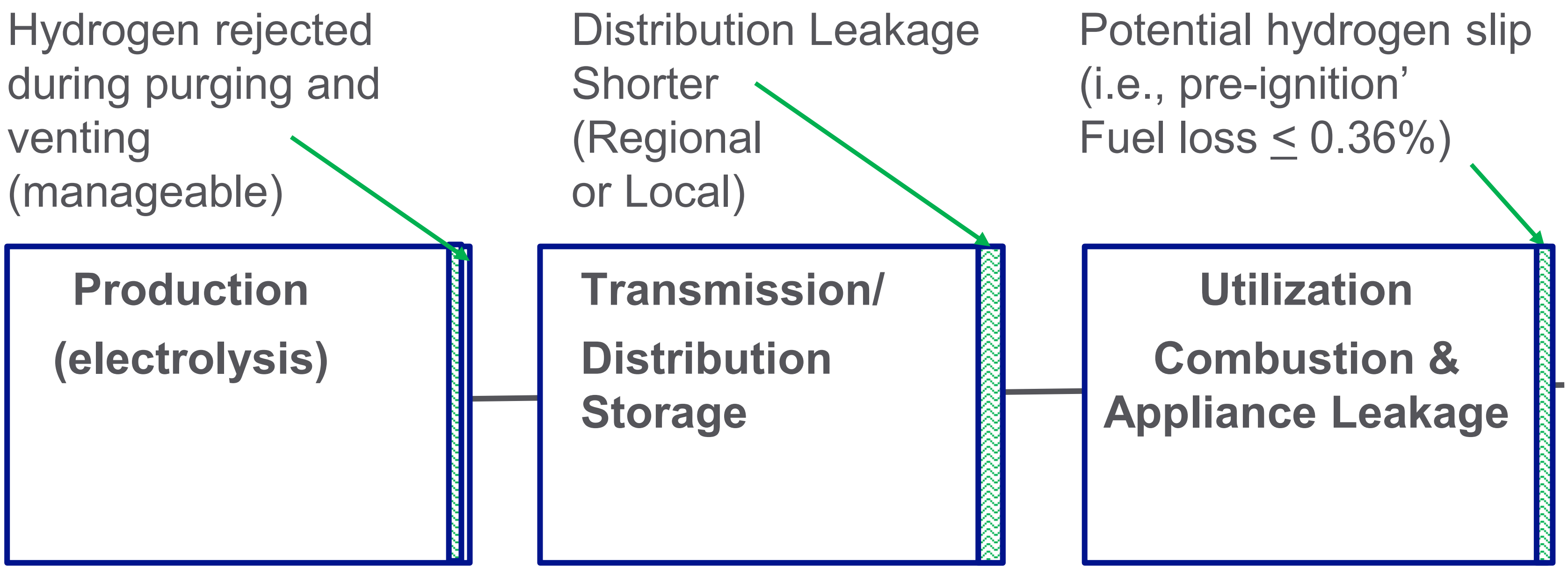
Physical leaks of hydrogen blends from metal pipelines are comparable to natural gas and will decline

- Within the different flow regimes pure H_2 will leak at a different rate comparatively to pure methane.(UC Irvine for CPUC)
  - Typical Flow in gas distribution – H_2 leaks a volumetric rate of 1.29x higher than methane for same pipe. ✓
- Hydrogen leaks at the same rate as natural gas in typical low-pressure gas infrastructure (UC Riverside)
- GTI studies
  - Hydrogen blended in natural gas does not leak preferentially through orifices.
- Gas blend leaked at a higher rate with the increase in hydrogen concentration.
  - UK H21 Project: A main that doesn't leak when it carries natural gas will not leak when it carries hydrogen
- Studies by Swain et al. and Mejia et al. (NREL)
  - Low pressure and small aperture
  - Leak rate of methane, propane, and hydrogen were similar

Odorization and Leak Detection

- Key method: mercaptan-based odorants; likely required for hydrogen-blended gas and pure hydrogen.
- Common blend ~80% TBM + ~20% methyl-ethyl sulfide; National Grid uses Scentinel® E (TBM, IPM, NPM).
- Studies show suitability to 30–50% H_2 and slightly higher odor intensity; current National Grid odorant expected to **be suitable for blended gas**.
- CHS Best Safety Practice confirms that most sensors detect H2-NG blends effectively, but IR-only methane detectors cannot detect H_2. *(see also OTD Project 7.2.m)*

Full Cycle Hydrogen Leak Rates Much Lower than Natural Gas



Hydrogen rejected during purging and venting (manageable)

Distribution Leakage Shorter (Regional or Local)

Potential hydrogen slip (i.e., pre-ignition' Fuel loss ≤ 0.36%)

Production

(electrolysis)

Transmission/ Distribution Storage

Utilization

Combustion & Appliance Leakage

HyBlend CRADA

- **Hydrogen Emissions Factor Dependent on Source of Electricity**
    - Electrolysis
    - Compression

UTD Project 1.18.F

Global Warming Impact of Leaked Hydrogen

- **Hydrogen**
  - Indirect greenhouse gas (Reacts with hydroxyls)
  - GWP_{20} = 5-10 vs 82.5 for methane
    - NYS DEC Establishing a Value of Carbon, GUIDELINES FOR USE BY STATE AGENCIES Table 2
    - 88-94% lower
- **Hydrogen Not Listed by IPCC** *ref. PACE University*
  - The GWP of hydrogen is less well understood
  - Estimated that the **leak** of 1 kg of this gas is equivalent to the release of about 5 kg of carbon dioxide from **combustion** in terms of climate impact over 100 years
  - Hydrogen's short atmospheric lifetime of less than three suggests that the GWP of this fuel over 20 years is higher than 5 kg of carbon dioxide
- **CA LCFS Carbon Intensity for Green Hydrogen is zero**

07

End-Use Equipment

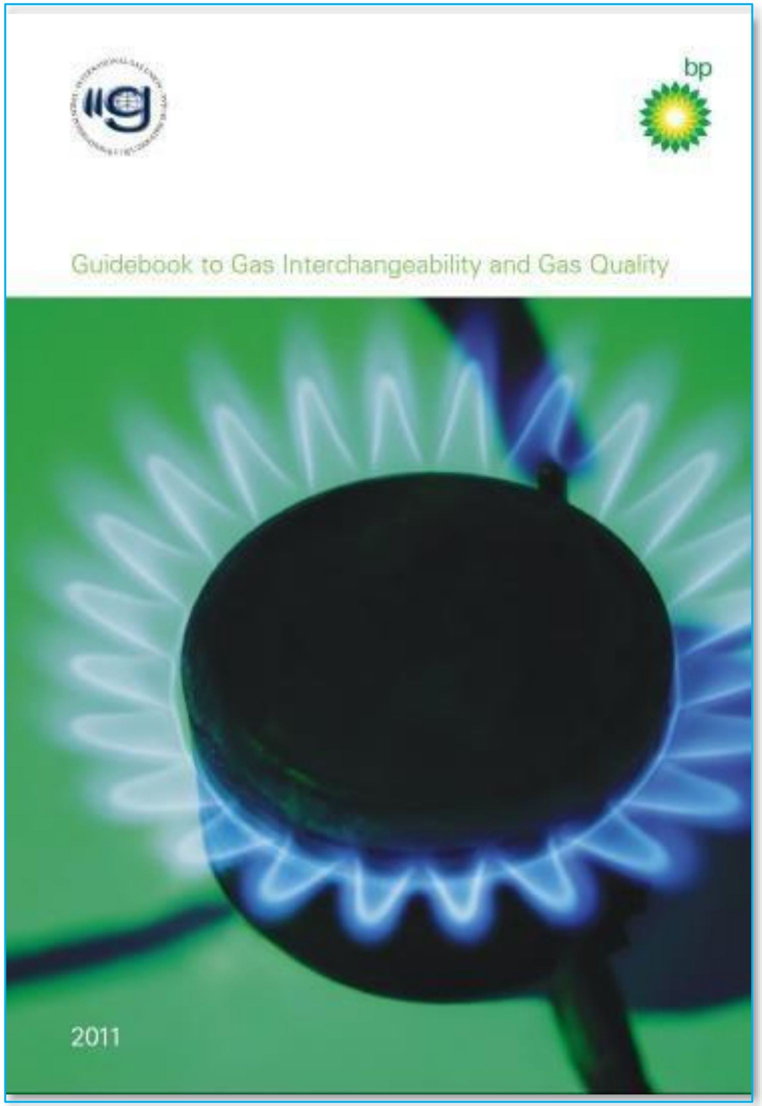
rent information and timely
tification, near-misses or

nationalgrid

Gas Interchangeability

- **From transition to natural gas from manufactured gas, there was significant effort to predict interchangeability:**
  - AGA indices were common, still in limited use today to predict combustion such as flashback
  - Weaver indices developed in 50’s, less practical use
  - UK defaults to Dutton indices
- **All approaches are semi-empirical, based on burners/equipment testing, and have a “shelf life”**

  These AGA parameters were accurate for the burner tested and appliance types at the time but are not appropriate for the high efficiency, low emissions burner technology prevalent today
- **NYSEARCH RANGE ™ Plus Model Recently Updated for Hydrogen**

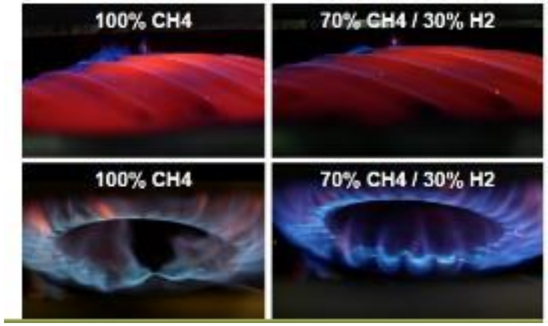


bp

Guidebook to Gas Interchangeability and Gas Quality

2011

Appliances

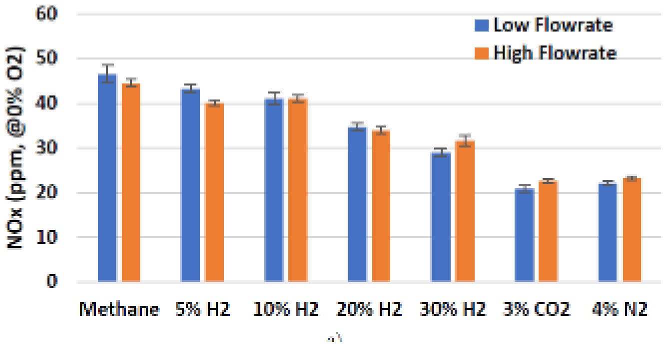


- **H_2 Blending Impacts on Burner Performance (GTI)**
  - While impacts vary, general blending levels are:
    - **Low Blending:< 10% H_2 by vol**.
      - No or minor equipment adjustments
    - **Med. Blending: 10%-30% H_2 by vol**.
      - Adjustments may be necessary for components/controls
    - **High Blending: > 30% H_2 by vol**.
      - Specially-designed equipment required (e.g.H_2 Boiler)
- **Appliance Integrity(GTI)**
  - **Appliance leakage likely not worsened by hydrogen blending, though limited data (non-GTI)**
    - CSA* tested equipment components & manifolds (below), not sig. difference
    - Also tested pipe segments per NFPA 54* @ 5/20 psi, Steel, Copper, CSST piping/connections passed for up to 15% H_2
  - **NO_X Emissions generally do not increase.**
    - NO_X a function of flame temperature, not fuel, and can decline or rise.
    - Standard NO_X control techniques for combustion equipment applicable
  - **Should investigate High Temperature Hydrogen Attack (HTHA) in Ultra low NO_x burners**

** Note: All H_2 standard now in NFPA-2*

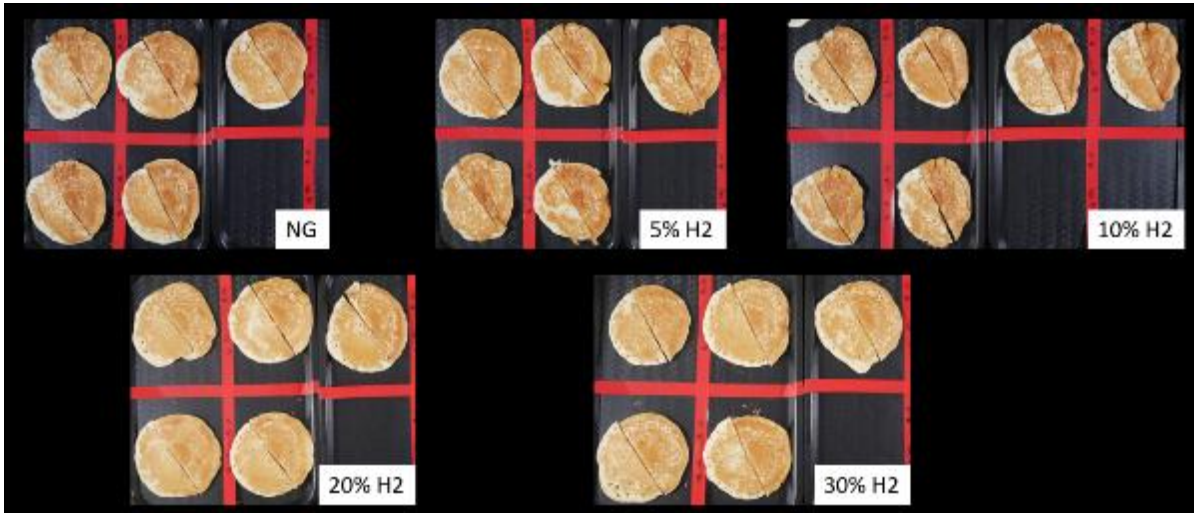
UTD
Utilization Technology Development

Appliance Testing



Manufacturer Tested at 30% Hydrogen and installed n Tiny Houses

Rinnai



Hydrogen Pancakes Anyone?

Gas Fireplace 20% Hydrogen

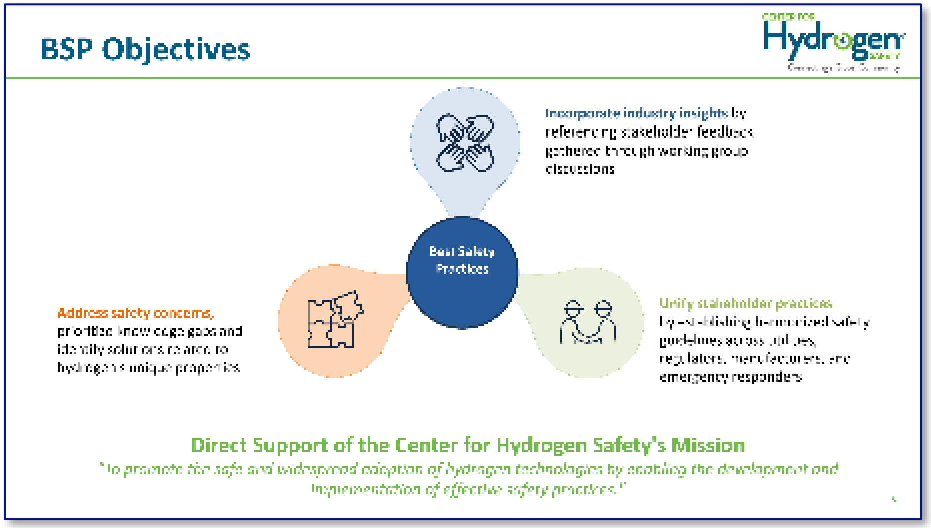
08

New Tools for Economics and Safety

nationalgrid

Codes, Standards, Processes & Tools

- **Center for Hydrogen Safety** (AiChe and DOE Sponsored)
  - Blending Best Safety Practice (Completed April 2026)
  - Safety Training (e.g. First Responders)
  - h2tools.org portal
    - H_2 Incident summaries
    - HyScan Codes Tool
- **New Sponsored Tools**
  - OHI–GHG Emissions Value
  - HyBlend (NREL)
    - HYPSTAT Hydrogen Cost Estimator
    - HELPR – Pipeline Integrity Assessment
    - BlendPath – Pipeline Blending Economics
    - HyRam+ Risk Assessment & HyCReD Failure Analysis Models



BSP Objectives

Best Safety Practices

Incorporate industry insights by referencing stakeholder feedback gathered through working group discussions

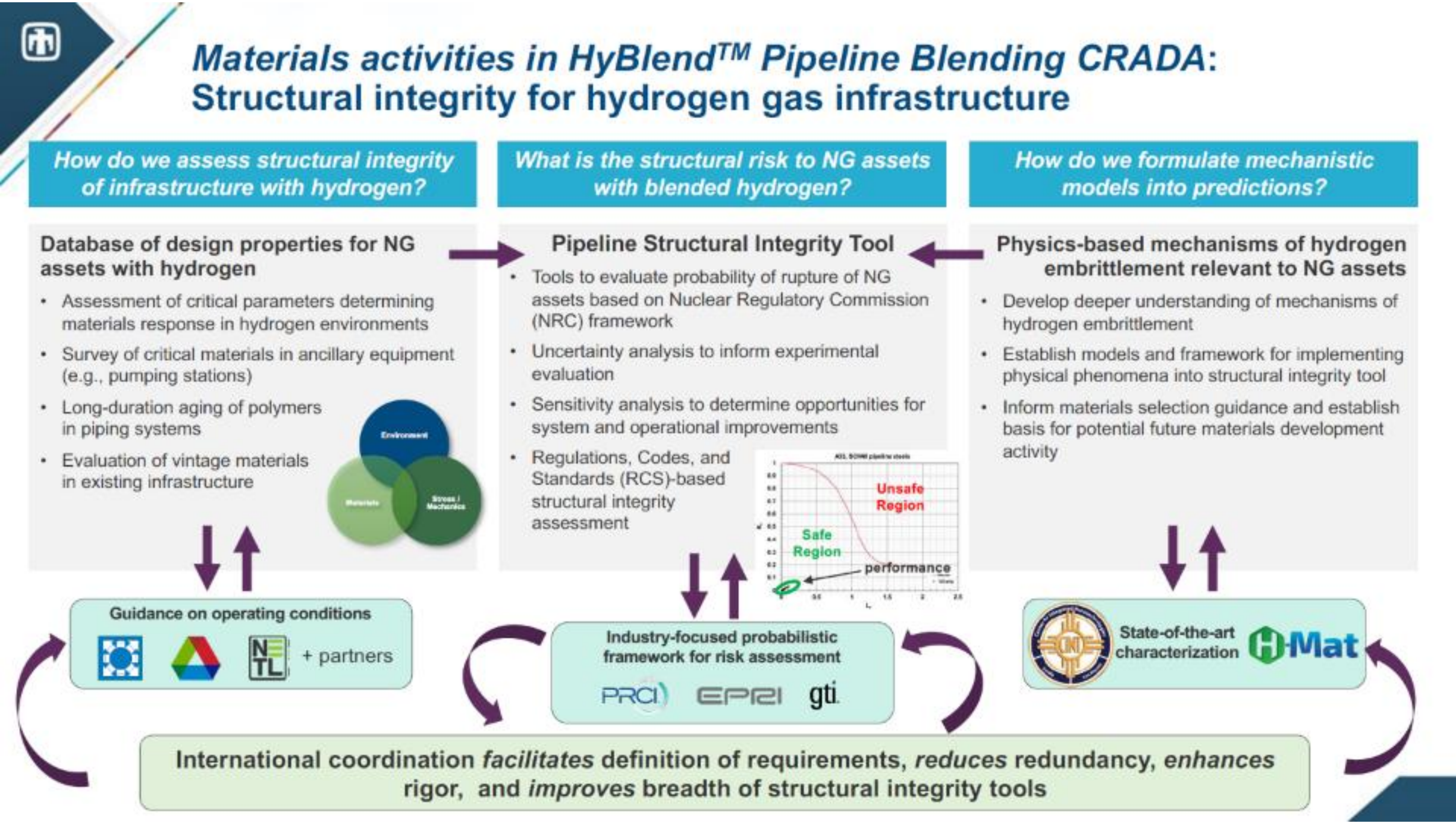
Address safety concerns, prioritize knowledge gaps and identify solutions related to hydrogen's unique properties

Unify stakeholder practices by establishing harmonized safety guidelines across utilities, regulators, manufacturers, and emergency responders

Direct Support of the Center for Hydrogen Safety's Mission

"To promote the safe and widespread adoption of hydrogen technologies by enabling the development and implementation of effective safety practices."

DOE HELPR Tool for Assessing Pipeline Integrity



Materials activities in HyBlend™ Pipeline Blending CRADA: Structural integrity for hydrogen gas infrastructure

How do we assess structural integrity of infrastructure with hydrogen?

Database of design properties for NG assets with hydrogen

- Assessment of critical parameters determining materials response in hydrogen environments
- Survey of critical materials in ancillary equipment (e.g., pumping stations)
- Long-duration aging of polymers in piping systems
- Evaluation of vintage materials in existing infrastructure

Guidance on operating conditions

+ partners

What is the structural risk to NG assets with blended hydrogen?

Pipeline Structural Integrity Tool

- Tools to evaluate probability of rupture of NG assets based on Nuclear Regulatory Commission (NRC) framework
- Uncertainty analysis to inform experimental evaluation
- Sensitivity analysis to determine opportunities for system and operational improvements
- Regulations, Codes, and Standards (RCS)-based structural integrity assessment

Industry-focused probabilistic framework for risk assessment

PRCI EPRI gti

How do we formulate mechanistic models into predictions?

Physics-based mechanisms of hydrogen embrittlement relevant to NG assets

- Develop deeper understanding of mechanisms of hydrogen embrittlement
- Establish models and framework for implementing physical phenomena into structural integrity tool
- Inform materials selection guidance and establish basis for potential future materials development activity

State-of-the-art characterization H-Mat

International coordination *facilitates* definition of requirements, *reduces* redundancy, *enhances* rigor, and *improves* breadth of structural integrity tools

L098-1593

Critical Usability Improvements to the Hydrogen Plus Other Alternative Fuels Risk Assessment Models (HyRAM+) Software

Prime Recipient: *Sandia National Laboratories;* **PI:** *Brian Ehrhart*

Key Participants: *Hydrogen Fuel Cell Partnership, Electric Power Research Institute*

Topic/AOI(s)	**Period of Performance**
Topic 4c/AOI 3 [HFTO]	10/23-9/24

Requested Funding Amount: $400,000

Estimated Cost-Share Amount: $50,000

Project Summary

This project will enable and expand the commercial adoption of Hydrogen Plus Other Alternative Fuels Risk Assessment Models (HyRAM+, available at hyram.sandia.gov), a software toolkit that integrates data and methods relevant to assessing the safety of the delivery, storage, and use infrastructure of hydrogen and other alternative fuels (i.e., natural gas and propane). The HyRAM+ toolkit can be used to support multiple types of analysis, including code and standards development, safety basis development, and facility safety planning.

This project will address current usability and utility shortcomings of HyRAM+ through three tasks:

1. Developing a new graphical user interface (GUI) for the software enabling cross-platform installation and use on both macOS and Windows machines,
2. Improving the GUI by reorganizing, adding context, and real-time guidance for user inputs and outputs, and
3. Making algorithmic improvements to increase the speed of the calculations.

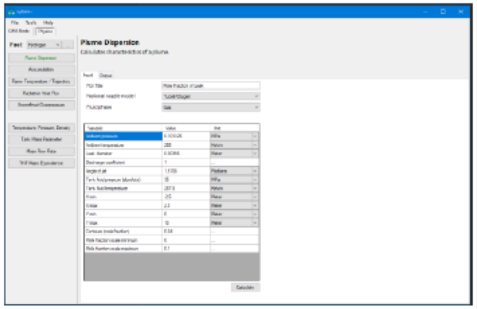
These improvements will enable increased adoption of HyRAM+ along with improved user experience, performance, and confidence. In turn, this will enable continued and expanded use for hydrogen safety analyses at a critical time when hydrogen hubs begin siting large-scale hydrogen infrastructure throughout the country.

Impact and Key Takeaways

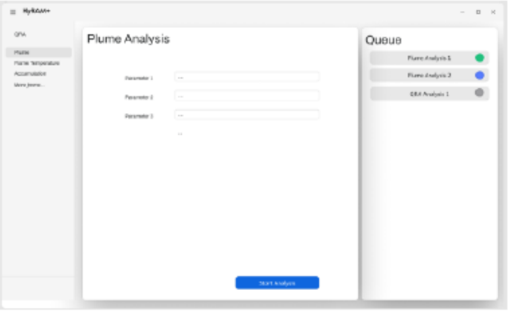
- Cross-platform installation and use of HyRAM+
- Easier to use and understand user interface for safety models
- Faster-running models to consider multiple scenarios
- Easier to understand modeling code for researchers and modelers
- Easier to maintain source code for more widespread collaborative development

Proposed Goals

Make HyRAM+ more accessible, easier to use, and easier to maintain by various hydrogen and other alternative fuel safety stakeholders



Current



Future Concept

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Blending Pipeline Analysis Tool

HyBlend
U.S. DEPARTMENT OF ENERGY

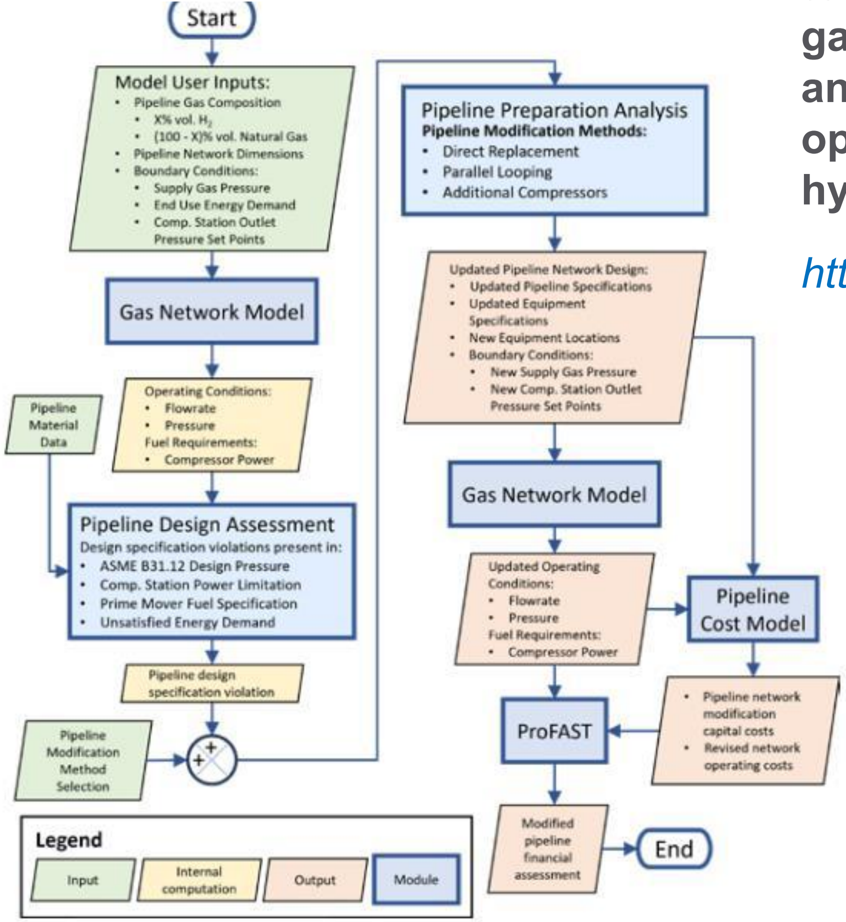
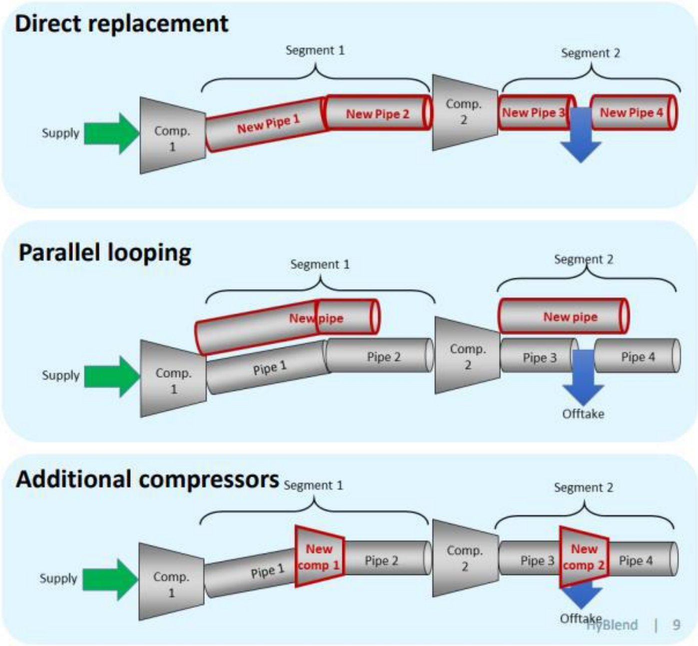


Figure 1: Blending Pipeline Analysis Tool for Hydrogen framework.

BlendPATH is a Python tool developed at the National Lab of the Rockies that allows users to figure out what modifications to a natural gas transmission pipeline network are needed and the incremental capital investment and operating expense required for blending hydrogen to a specified % in pipeline gas.

https://github.com/NatLabRockies/BlendPATH



Opportunities for Cost Mitigation in Hydrogen Production and Delivery (NYSERDA)

- **Strategic Planning for Resource Allocation and Hydrogen Generation**
  - The cost of renewable energy to power electrolysis accounts for more than half of the hydrogen cost
  - Deploying low-cost renewable resources must be a priority.
- **Developing Pipeline Transport Infrastructure**
  - Transitioning from truck-based delivery to pipelines can reduce transportation costs by up to 64% and support efficient hydrogen distribution as demand grows.
- **Managing Temporal Mismatches in Hydrogen Supply and Demand**
  - Tank Storage – Short-term
  - Salt caverns, where available , provide a cost-effective option for balancing multiday supply-demand fluctuations during winter

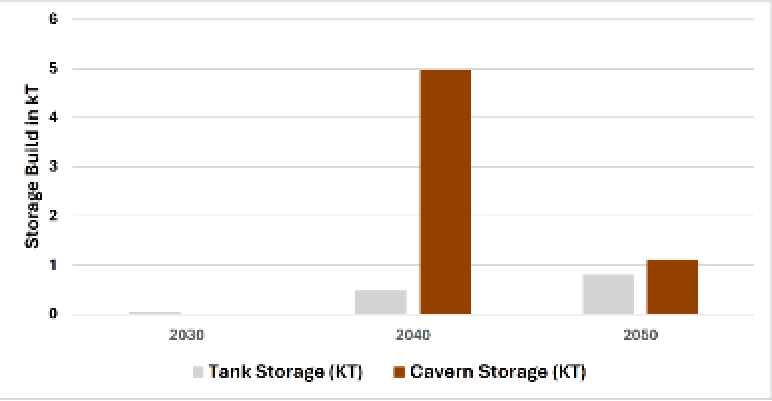
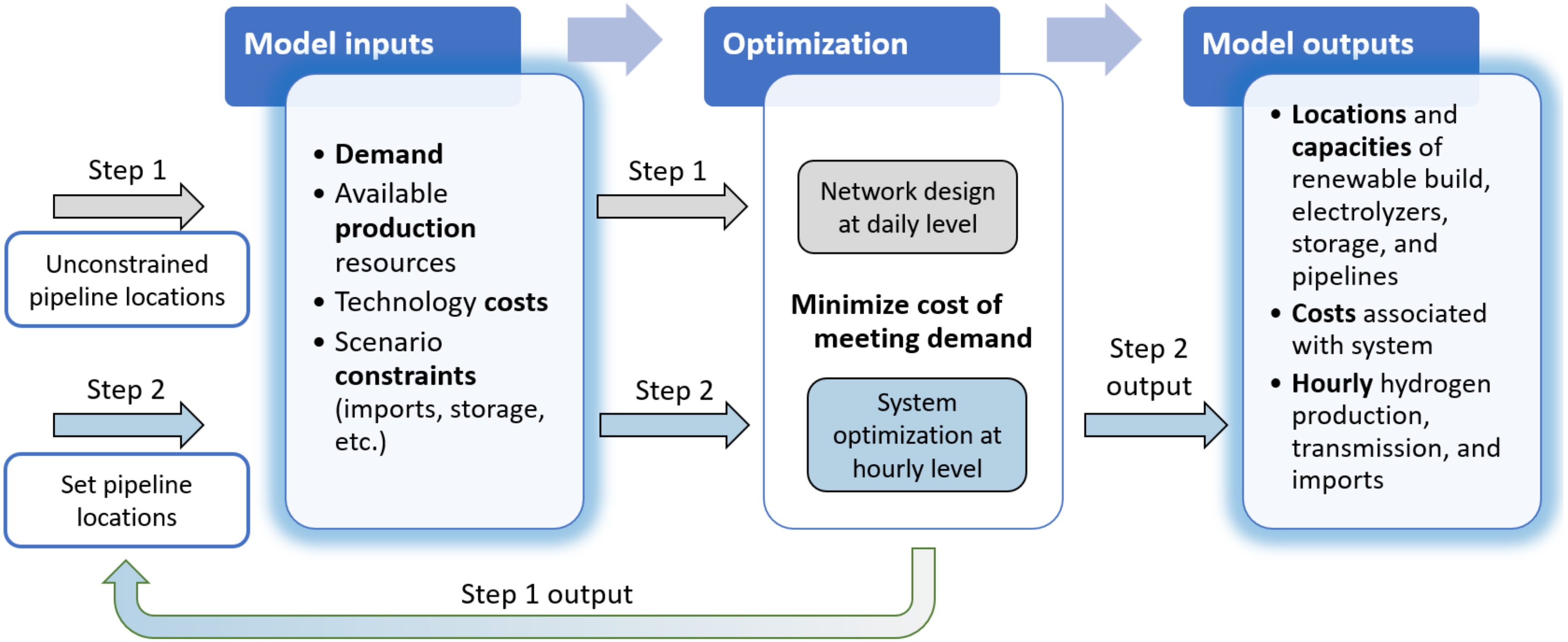


Figure 14. Case 2: Storage Build Capacity Results

- **Accelerating Electrolyzer Cost Reductions**

Infrastructure Costs and Opportunities

- **The Hydrogen Production, Storage, and Transmission Analysis Tool Model (HYPSTAT by NREL).**



Step 1

Unconstrained pipeline locations

Step 2

Set pipeline locations

Model inputs

- **Demand**
- Available **production** resources
- Technology **costs**
- Scenario **constraints** (imports, storage, etc.)

Step 1

Step 2

Optimization

Network design at daily level

Minimize cost of meeting demand

System optimization at hourly level

Step 1 output

Step 2 output

Model outputs

- **Locations** and **capacities** of renewable build, electrolyzers, storage, and pipelines
- **Costs** associated with system
- **Hourly** hydrogen production, transmission, and imports

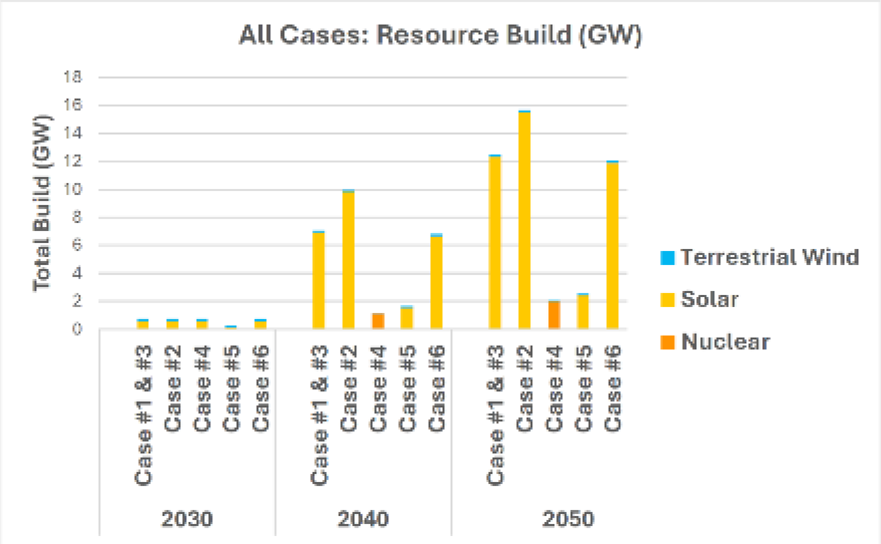
HYPSTAT Model Results

- **Projected Levelized Cost of Hydrogen**
- **New Renewable Power is Required**

Table 11. Summary of Modeled Levelized Cost of Hydrogen Across Cases (2030, 2040, and 2050)

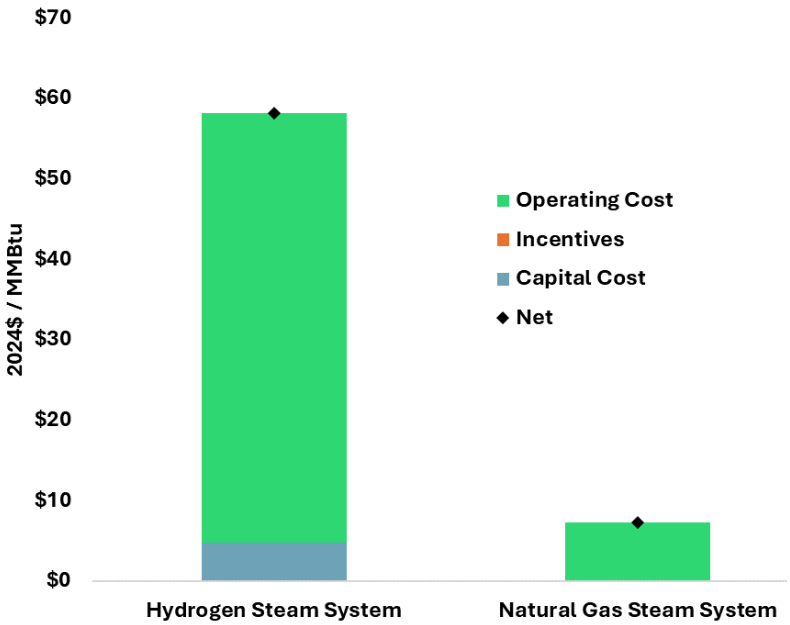
No.	Cases	2030 ($/kg)	2040 ($/kg)	2050 ($/kg)
1	Limited renewable, no power (base case)	5.5	5.0	4.5
2	Limited renewable with power demand	5.5	5.1	4.5
3	Accelerated renewables, OSW	5.5	5.0	4.5
4	Accelerated clean energy, nuclear	5.5	2.9	2.4
5	No pipeline, industrial only	4.7	5.7	5.2
6	Low-cost electrolyzer	4.7	3.8	3.5

Figure 7. Summary of Resource Build Across Cases (2030–2050)

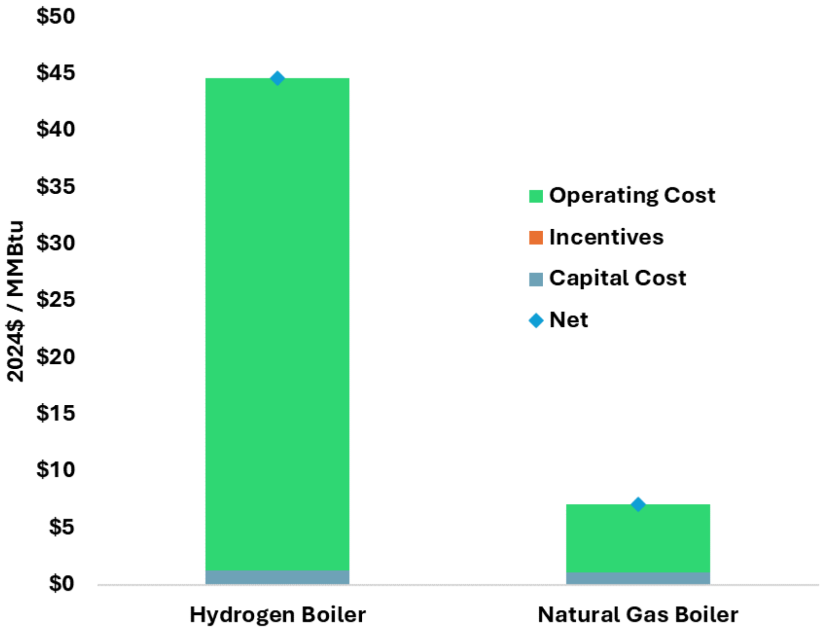


Deployment Pathways

- **Scaling low-cost production technologies, improving delivery efficiency, and optimizing integration methods are essential for deploying hydrogen in hard-to-electrify sectors.**
- **Total Cost of Ownership Model Results**



District Energy



High temperature Industry

09

Global Demonstration Projects

nationalgrid

New Utility Hydrogen Initiatives Around the World

HyDeploy

UK Pilot project led to the Health and Safety Executive to Authorize 20% hydrogen blending

- Phase 1 Successfully tested 130+ properties and buildi 0- prior to go-live, No new appliance leakage detected
- Phase 2 ~700 homes on the distribution network in the North East, UK (Winalton)

North American Blending Demonstrations

New Projects Operating (1% - 20%)

- Enbridge – Toronto
- Dominion Delta Project, Utah
- New Jersey Natural Gas
- ATCO - Ft. Saskatchewan, Alberta
- Minneapolis

Utility Hydrogen Demonstration Homes

Northern Gas Networks

SoCalGas

Hydrogen Projects in NY

- **NYSERDA Projects in Progress-$22 Million awarded including:**
  - Linear Generator Demonstration (NGV)
  - PON 6021 to develop maritime vessel to ship hydrogen at larger scale.
  - PON 5944 to design hydrogen fuel cell-based solution for peaking power or industrial application
  - Hydrogen production, storage and use (Stony Brook U. and Northwell)
- **National Grid Projects**
  - Hydrogen Blending Evaluation (NYSERDA, Stony Brook)
  - DNV Blending Safety Protocol
  - Center for Hydrogen Safety Blending Best Safety Practices (h2tools.org)
  - NLR HyBlend 2 (DOE pipeline CRADA)
  - Collaborative Gas R&D
    - Operations Technology Development
    - Utilization Technology Development (incl. methane pyrolysis tool)
    - NYSEARCH (Northeast Gas Association)
  - Standard Carbon – Design - Synthetic Methane from H_2 and CCS
  - Low Carbon Resources Initiative (EPRI and GTI Energy)

StandardCarbon

THE CITY UNIVERSITY OF NEW YORK

Process Safety

- **Facility Siting Assessment**
- **Process Hazard Analyses**
  - Design
  - Construction
- **Layer of Protection Analysis**
- **Management of Change (MOC)**
- **Safety Instrumented System (SIS)**
- **Alarm Rationalization**
- **Pre Start-up Safety Review (PSSR)**
- **Human factors,**
  - Safety in design
  - Safety critical activity
  - Procedure categorization / risk assessment.

National Grid

Process Safety Framework and
The 12 Risk Control Standards

1. Leadership & Organisational Change
2. Asset Design, Modifications & Operational Readiness
3. Operating Procedures & Instructions
4. Workforce Competence
5. Human Factors
6. Emergency Arrangements
7. Protective Devices Instrumentation & Alarms
8. Inspection & Maintenance
9. Permit To Work
10. Record Management
11. Third Party Protection
12. Audit, Investigation, Close Out & Review

Process Safety

Quantitative Risk Analysis (2013) at H2 Production Facility

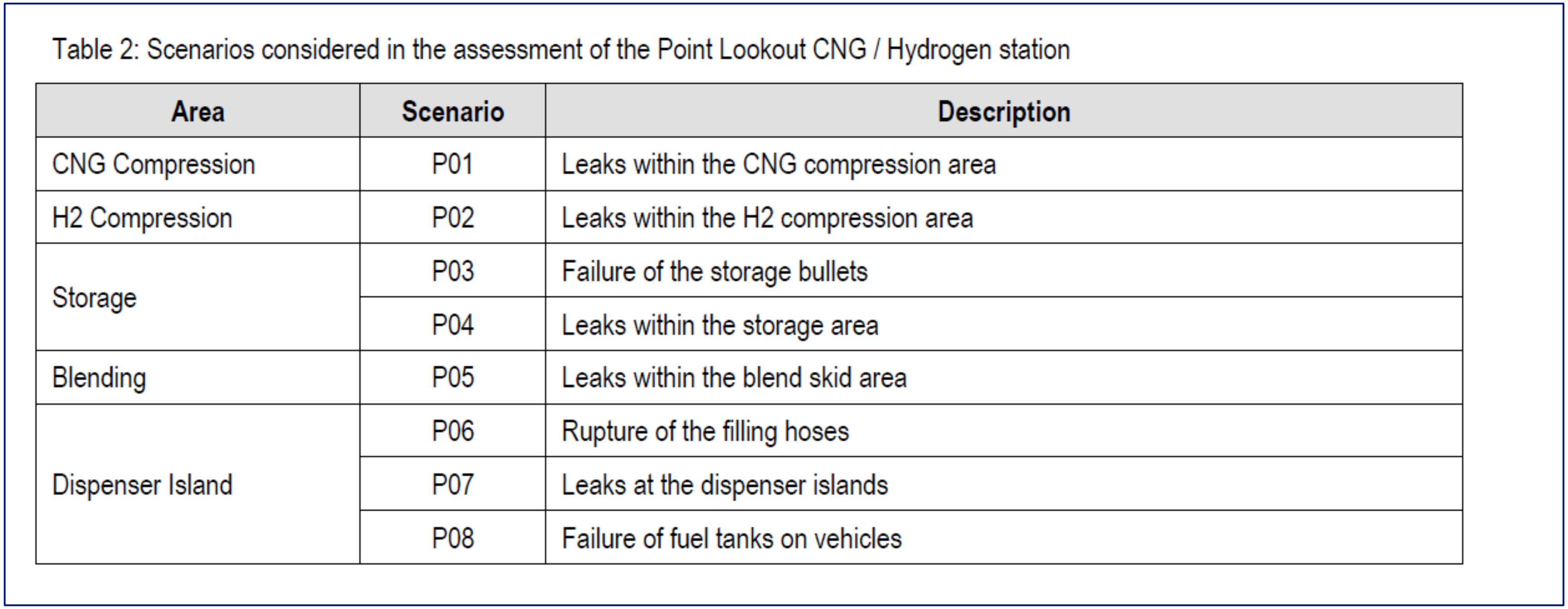


Table 2: Scenarios considered in the assessment of the Point Lookout CNG / Hydrogen station

Area	Scenario	Description
CNG Compression	P01	Leaks within the CNG compression area
H2 Compression	P02	Leaks within the H2 compression area
Storage	P03	Failure of the storage bullets
	P04	Leaks within the storage area
Blending	P05	Leaks within the blend skid area
Dispenser Island	P06	Rupture of the filling hoses
	P07	Leaks at the dispenser islands
	P08	Failure of fuel tanks on vehicles

.. Societal risk was considered to be "broadly acceptable" per National Grid's company risk tolerance. (Individual risk was ALARP.).

10

Transition

nationalgrid

Planning for Hydrogen

Evaluate → Demonstrate → Transition

At present, all services along the value chain are open to gas utilities. These services include:

- Local Production
- Long Distance Transportation
- Local Injection, Distribution, & Storage
- Utilization

Evaluate

- Gap Analyses
- Safety Research - $7.0 M in progress

Demonstrate

- Blending Demonstrations
- Hydrogen Microgrids

Transition

- Support Customer Transitions
- Codes, Standards, & Developer Tools

Transitioning to Hydrogen - Putting it All Together

Fuel Cell w.H_2 Blend at BNL

- **New GHG and NO_x Factors – HyBlend & NYSERDA Oil & Emissions Project at BNL**
- **Develop Best Practices Guides**

CENTER FOR Hydrogen SAFETY
Connecting a Global Community

- **Update Codes and Standards (e.g., NFPA-2, ASME B31.12 etc.)**
- **New Odorants and Illuminants?**
- **Developer Tools** (e.g., NYSEARCH RANGE Model)

NYSEARCH

HyDeploy UK

- **Update Utility Processes (e.g., billing)**
- **Academic Partnerships**

Institute of Gas Innovation and Technology
AT STONY BROOK UNIVERSITY

COLUMBIA UNIVERSITY

UMASS LOWELL

- **Reducing Leakage**
  - Integrate H_2 into Leak Prone Pipe Programs

Bio-methanation SoCalGas

- **De-blending or Methanation for Sensitive Equipment**

UK Regulatory Process “Exemption” Approved

Safety Case → **Install** → **Trial**

It is not permitted to transport hydrogen in the grid above $0.1\%_{vol}$ in the UK

The Health and Safety at Work etc. Act 1974
The Gas Safety (Management) Regulations 1996
Certificate of Exemption N0.1 of 2018

Exemption to GS(M)R is required to transport blended gas.

Must show that *“persons affected by the exemption, will not be prejudiced in consequence of it.”*

Evidence required to demonstrate $20\%_{vol}$ hydrogen is ‘as safe as’ natural gas

Quantitative Risk Assessment backed by rigorous evidence

Great Britain

University ‘as today’

University ‘in trial’

Secured the UK’s first hydrogen exemption in November 2018

Standard Interconnection Guideline for the State of New York

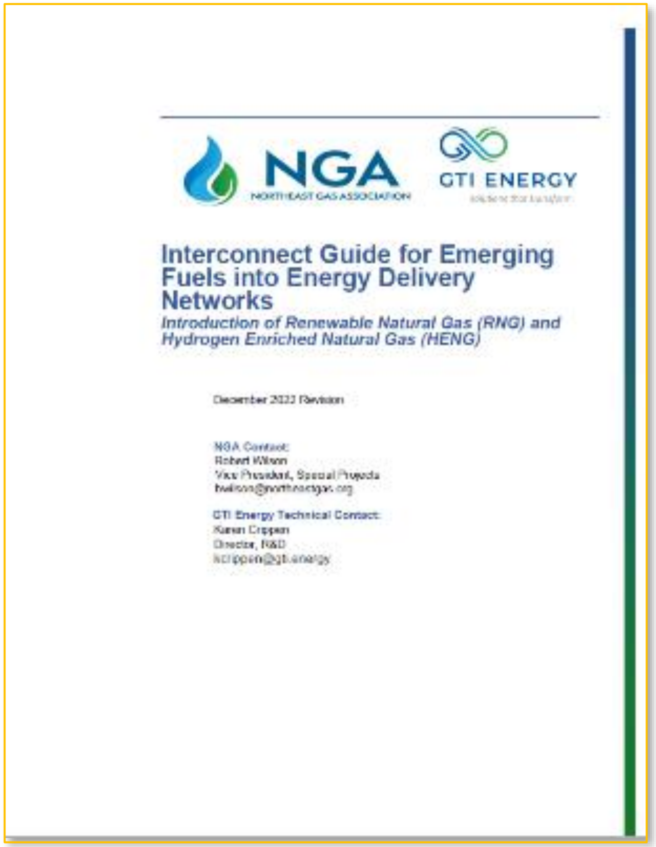
- One of RNG's biggest barriers is injection into distribution system
  - Most utilities do not understand interconnection or gas quality issues
  - Guideline released in 2018 and revised December 2022.

National Grid collaborating with NY utilities to develop a standard interconnection guideline.

- ◆ Reduce uncertainty for project developers
- ◆ Streamline the interconnection process
- ◆ First of its kind guideline in the U.S.
  - ◆ Specifies major attributes (e.g. Wobbe No.)
  - ◆ Process to limit trace constituents

NY PSC is supportive of guideline

- ◆ Issued through the Northeast Gas Association
- ◆ NY State Part 229 Gas Quality Regulation being revised in 2026



NGA NORTHEAST GAS ASSOCIATION

GTI ENERGY

Interconnect Guide for Emerging Fuels into Energy Delivery Networks

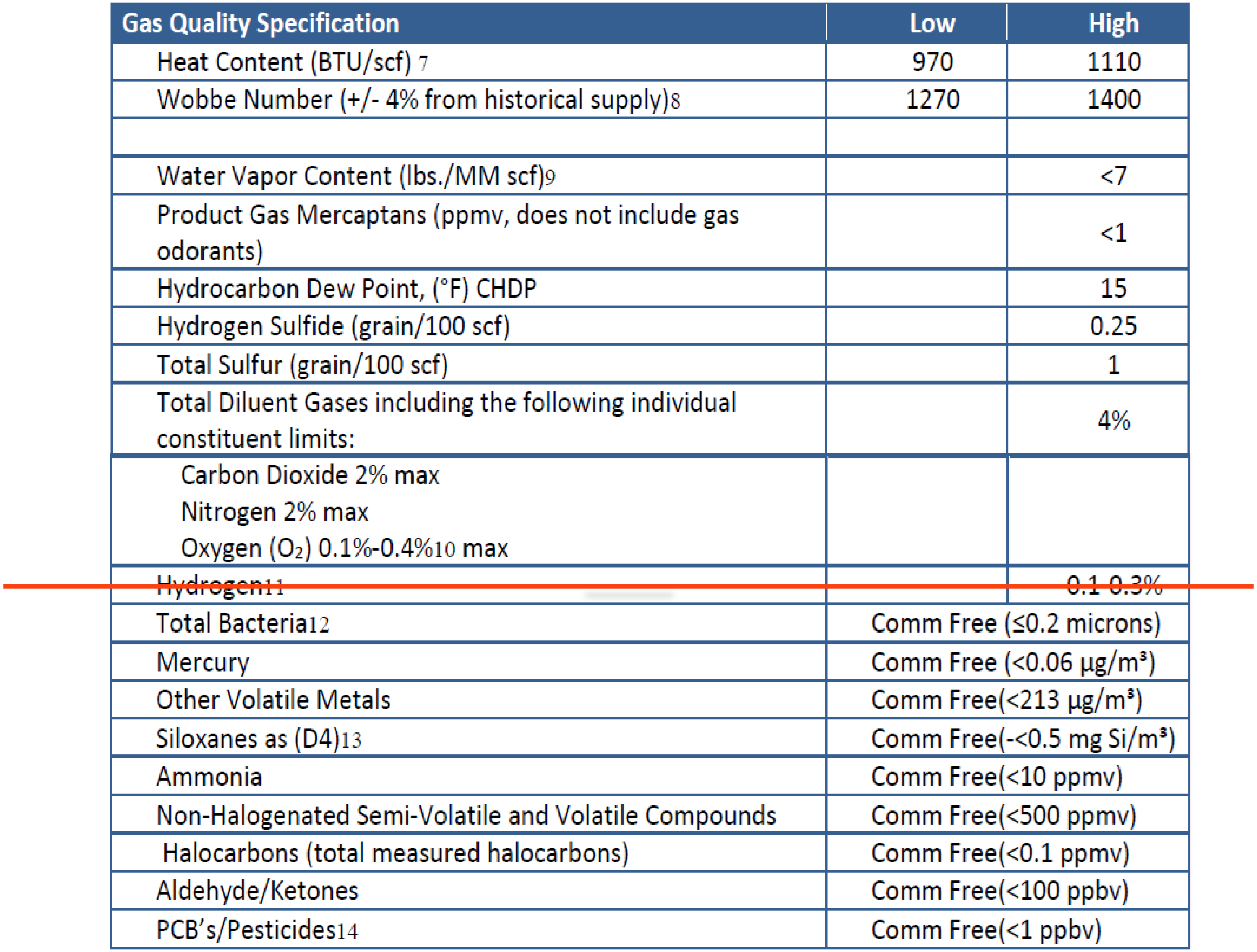
Introduction of Renewable Natural Gas (RNG) and Hydrogen Enriched Natural Gas (HENG)

December 2022 Revision

NGA Contact:
Robert Wilson
Vice President, Special Projects
bwilson@northeastgas.org

GTI Energy Technical Contact:
Karen Crippen
Director, R&D
kcrippen@gti.energy

Gas Quality Minimum Considerations

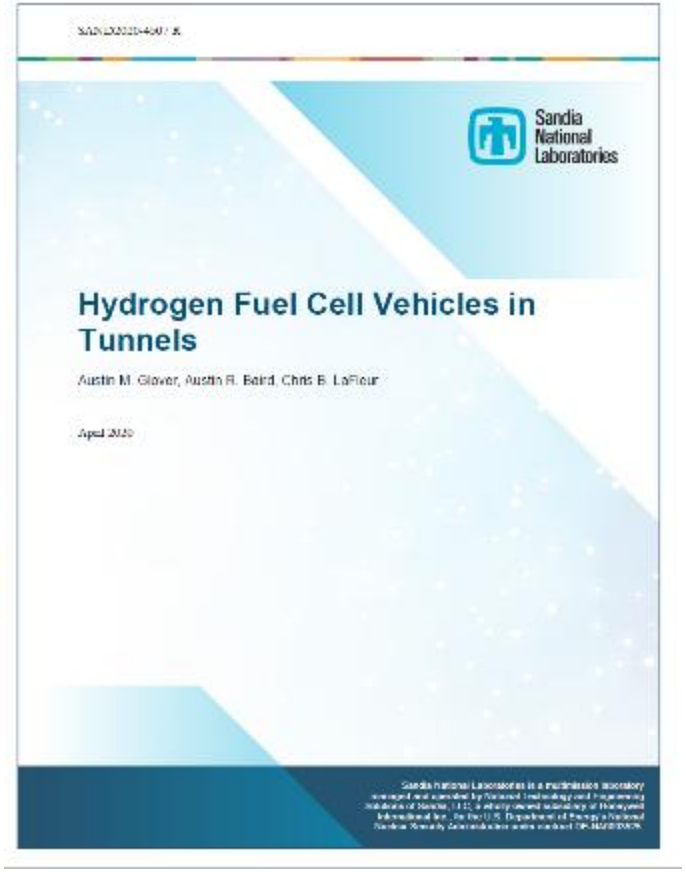


Gas Quality Specification	Low	High
Heat Content (BTU/scf) [7]	970	1110
Wobbe Number (+/- 4% from historical supply)[8]	1270	1400
Water Vapor Content (lbs./MM scf)[9]		<7
Product Gas Mercaptans (ppmv, does not include gas odorants)		<1
Hydrocarbon Dew Point, (°F) CHDP		15
Hydrogen Sulfide (grain/100 scf)		0.25
Total Sulfur (grain/100 scf)		1
Total Diluent Gases including the following individual constituent limits:		4%
Carbon Dioxide 2% max Nitrogen 2% max Oxygen (O_2) 0.1%-0.4%[10] max		
~~Hydrogen[11]~~		~~0.1-0.3%~~
Total Bacteria[12]	Comm Free (≤0.2 microns)	
Mercury	Comm Free (<0.06 µg/m^3)	
Other Volatile Metals	Comm Free(<213 µg/m^3)	
Siloxanes as (D4)[13]	Comm Free(-<0.5 mg Si/m^3)	
Ammonia	Comm Free(<10 ppmv)	
Non-Halogenated Semi-Volatile and Volatile Compounds	Comm Free(<500 ppmv)	
Halocarbons (total measured halocarbons)	Comm Free(<0.1 ppmv)	
Aldehyde/Ketones	Comm Free(<100 ppbv)	
PCB's/Pesticides[14]	Comm Free(<1 ppbv)	

Transportation – More Developed than Other Use Cases

- **Codes & Standards**
  - NFPA-2 Ch (10,11,17,18)
    - Vehicles
    - Fueling Stations
    - Repair and Parking Facilities
  - NYC Fire Prevention Code
  - SAE J2719, J2578, J2601 & SAE J2799

- **Guidelines**
  - Transit Buses
    - Federal Transit Administration *"Design Guidelines for Bus Transit Systems Using Hydrogen As An Alternative Fuel"* 1998



Sandia National Laboratories

Hydrogen Fuel Cell Vehicles in Tunnels

Austin M. Glover, Austin R. Baird, Chris B. LaFleur

April 2020

Summary of Sponsored Gap Analyses

MOTT MACDONALD

INGAA FOUNDATION

Study of hydrogen in natural gas infrastructure

December 15, 2022

Northeast GAS ASSOCIATION

GTI ENERGY

Interconnect Guide for Emerging Fuels into Energy Delivery Networks

Introduction of Renewable Natural Gas (RNG) and Hydrogen Enriched Natural Gas (HENG)

December 2022 Revision

NGA Contact

GTI Energy Technical Contact

Karen Crippen

NREL

Hydrogen Blending into Natural Gas Pipeline Infrastructure: Review of the State of Technology

Kevin Topolski,[1] Evan P. Reznicek,[1] Burcin Cakir Erdener,[2] Chris W. San Marchi,[3] Joseph A. Ronevich,[3] Lisa Fring,[4] Kevin Simmons,[4] Omar Jose Guerra Fernandez,[1] Bri-Mathias Hodge,[1,2] and Mark Chung[1]

1 National Renewable Energy Laboratory
2 University of Colorado Boulder
3 Sandia National Laboratories
4 Pacific Northwest National Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5400-81704
October 2022

Goal: Develop a strong operational, maintenance and safety culture to support: hydrogen technology deployment, system integrity, and protection of life/facilities by ensuring institutional commitment; stewardship; setting goals; proper planning; tracking and communicating progress; undertaking reskilling and training; providing resources and access to tools; and promoting internal and external collaboration *INGAA*

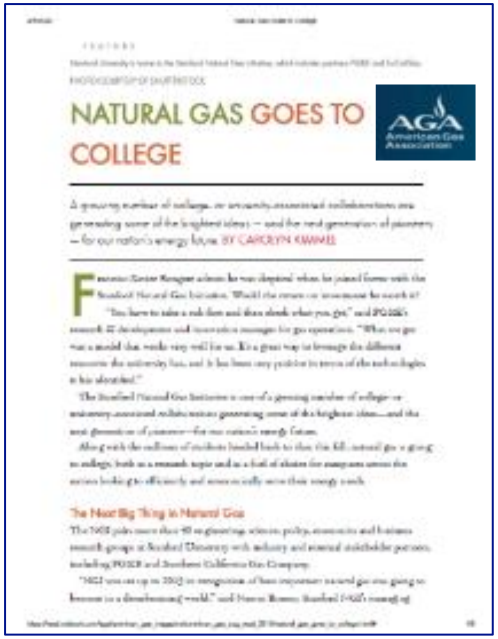
The Role of Academia

- **Basic and Longer-Term Research**
- **Academic Relationships**
- **Access to Incubator and Start-Up Eco-system**
- **Access to Funding Sources**
- **Objective and Independent**
- **Ability to Focus**
- **The Institute for Gas Innovation and Technology**
  - An institute of the Advanced Energy Reach and Technology Center at Stony Brook University; A university in the largest public university system in he US.
  - Founded in 2017 by AERTC and National Grid
  - Focused only on infrastructure efficiency, environmental performance and renewable energy technologies.
  - Success in developing programs in the US for Renewable Natural Gas and Hydrogen
  - A member driven- Industry-academic collaboration

acre

Greentown Labs

Clean Energy Business Incubator Program
AT STONY BROOK UNIVERSITY



NATURAL GAS GOES TO COLLEGE

BY CAROLYN KIMMEL

The Next Big Thing in Natural Gas

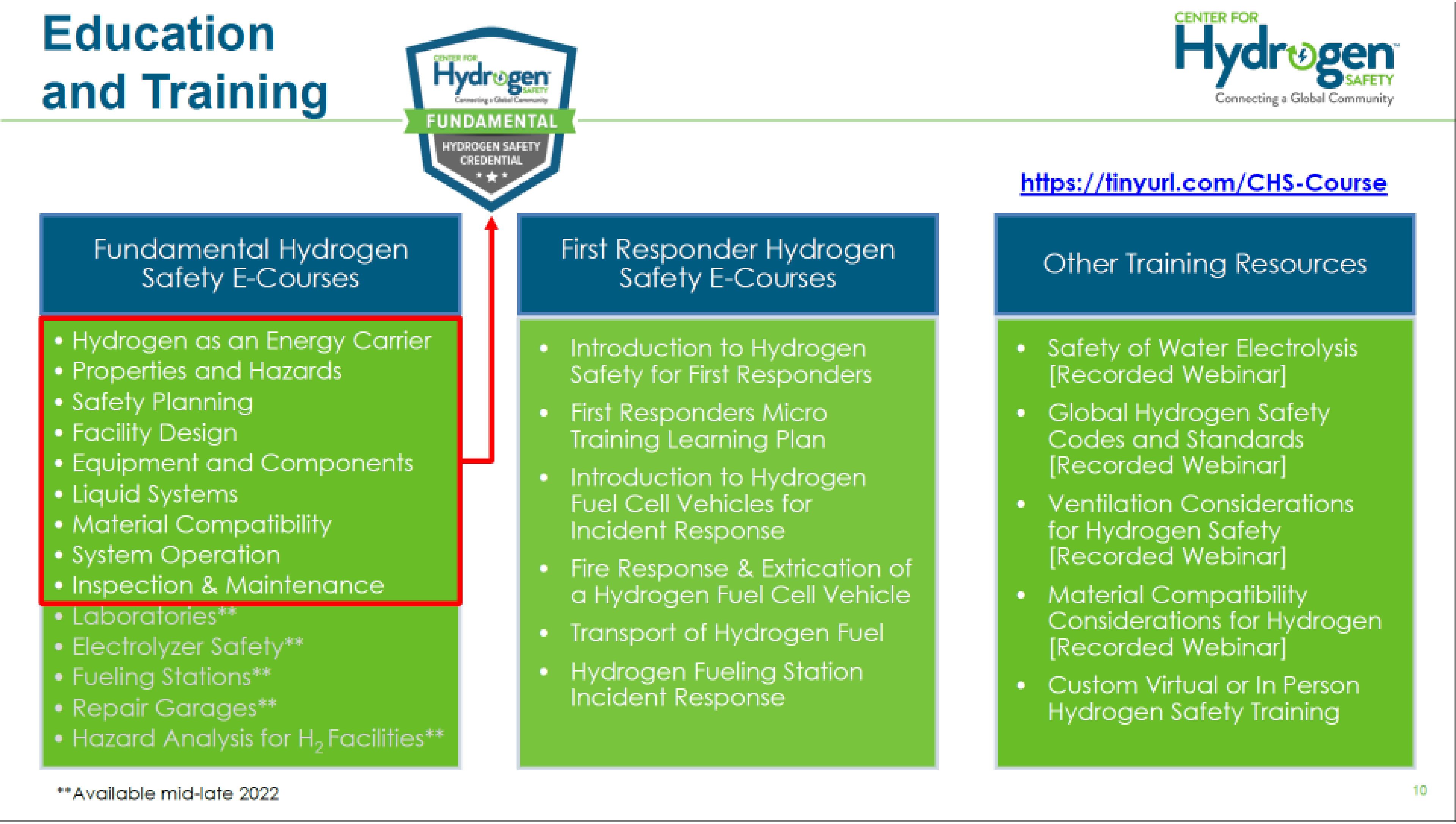
Institute of Gas Innovation and Technology
AT STONY BROOK UNIVERSITY

Center for Sustainable Energy

DANSKAMMER
ENERGY, LLC

EMEC ORKNEY
THE EUROPEAN MARINE ENERGY CENTRE LTD

Center for Hydrogen Safety



Education and Training

https://tinyurl.com/CHS-Course

Fundamental Hydrogen Safety E-Courses

- Hydrogen as an Energy Carrier
- Properties and Hazards
- Safety Planning
- Facility Design
- Equipment and Components
- Liquid Systems
- Material Compatibility
- System Operation
- Inspection & Maintenance
- Laboratories**
- Electrolyzer Safety**
- Fueling Stations**
- Repair Garages**
- Hazard Analysis for H_2 Facilities**

First Responder Hydrogen Safety E-Courses

- Introduction to Hydrogen Safety for First Responders
- First Responders Micro Training Learning Plan
- Introduction to Hydrogen Fuel Cell Vehicles for Incident Response
- Fire Response & Extrication of a Hydrogen Fuel Cell Vehicle
- Transport of Hydrogen Fuel
- Hydrogen Fueling Station Incident Response

Other Training Resources

- Safety of Water Electrolysis [Recorded Webinar]
- Global Hydrogen Safety Codes and Standards [Recorded Webinar]
- Ventilation Considerations for Hydrogen Safety [Recorded Webinar]
- Material Compatibility Considerations for Hydrogen [Recorded Webinar]
- Custom Virtual or In Person Hydrogen Safety Training

**Available mid-late 2022

With your help we can lead the way in creating the climate for change

See National Grid Hydrogen FAQ’s

https://www.nationalgrid.com/us/hydrogen-hub

H_2 Tiny Houses

Christopher.Cavanagh@nationalgrid.com

nationalgrid