Hydrogen Production, Storage, Distribution and Use

Northeast Hydrogen Hub Group F

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Future of Heat

9/1/2022

nationalgrid

Contents page

Today's Goals

- **New York State Climate Leadership and Community Protection Act – Signed by Governor July 18, 2019**
  - **Statewide greenhouse gas (CO_2e) emission limits**
    - 60% of 1990 emissions by 2030; 15% of 1990 emissions by 2050
    - Statewide electrical demand system will be zero emissions by 2040
      - Ground source heat pump qualifies as a renewable energy system
    - Rules and regulations to ensure compliance
    - Regulatory measures for "beneficial electrification" of vehicles and buildings
    - Cost-benefit calculations, including social cost of carbon
- **Massachusetts Global Warning Solutions Act**

  "A level of statewide **greenhouse gas emissions that is equal in quantity to the amount of carbon dioxide or its equivalent that is removed** from the atmosphere and stored annually by, or attributable to, the Commonwealth**"**

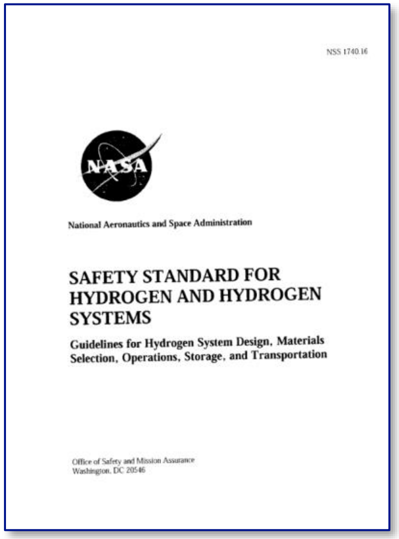
Hydrogen's Flexibility and Progress Enables Multiple Synergistic Uses

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

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

Space Launch System Launching This week

NJ Resources Blending



NSS 1740.16

NASA

National Aeronautics and Space Administration

SAFETY STANDARD FOR HYDROGEN AND HYDROGEN SYSTEMS

Guidelines for Hydrogen System Design, Materials Selection, Operations, Storage, and Transportation

Office of Safety and Mission Assurance
Washington, DC 20546

Hempstead, NY Vehicle Fueling

Hydrogen – A Natural Extension of Utility Service

(New York for example)

Electric – Delivers Renewable Energy but needs Energy Storage

PSL § 74(1): A qualified energy storage system is a *"commercially available technology that is capable of absorbing energy, storing it for a period of time, and thereafter dispatching the energy using mechanical, chemical, or thermal processes to store energy that was generated at one time for use at a later time."*

Gas – Still Growing but Must Decarbonize

PBS § 2 defines a gas corporation as to include *"all real estate, fixtures and personal property operated, owned, used or to be used for or in connection with or to facilitate the manufacture, conveying, transportation, distribution, sale or furnishing of gas (natural or manufactured or mixture of both) for light, heat or power, but does not include property used solely for or in connection with the business of selling, distributing or furnishing of gas in enclosed containers.".*

Both – New Retail Sector Growth (e.g. Zero Emission Transportation)

(See state Zero-emission Vehicle Program 10/24/2013

National Grid Vision Statement

Clean hydrogen will play an important role in the decarbonization of the Northeast. It is a critical, **cleaner residential heating fuel, an energy resource for industrial customers that are hard to decarbonize, and a carbon-free fuel for power generation.** These uses will allow for a balanced and resilient decarbonization approach, requiring fewer new assets and ultimately minimizing the impact on customer energy bills, all while achieving regional net zero goals. Incorporation of hydrogen into the energy mix will begin to ramp up throughout the decade and eventually scale to meet the needs of the communities we serve.

Example: Multi-Use Hydrogen Facility Approved on 1/8/2022

- **Niagara Mohawk Ratecase**
  - National Grid's first project proposal from the REV CONNECT Portal (PSC follow-on to REV program
  - Developed by Standard Hydrogen Inc. (Ithaca, NY)
  - Included in Future of Heat portion of ratecase
  - Joint Proposal Filed 9/27/2021, approved 1/8/2022.
- **The Energy Transfer Station**
  - One nominally (1) MW customer-sited electrolyzer facility using purchased green power to produce hydrogen and sell (9) energy products dispatched economically
    - Backup Power
    - On Peak Electricity
    - Electric Demand Response
    - Electric Customer Demand Charge Mgmt.
    - Gas Demand Response
    - Renewable Natural Gas (i.e. blending)
    - Fuel Cell Vehicle Fueling
    - Electric Vehicle Service (Level 3)
    - Oxygen Off-taker (e.g. Hospital)

NEW YORK STATE OF OPPORTUNITY. | NYSERDA

NEW YORK STATE OF OPPORTUNITY. | Reforming the Energy Vision

NAVIGANT

NY BES+ New York Battery and Energy Storage Technology Consortium, Inc.

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 (200ºC-1700ºC, typically 900ºC)
  - Non-GHG emissions lower than incineration but not zero
  - Produces tar and solid pollutants, potentially toxic.

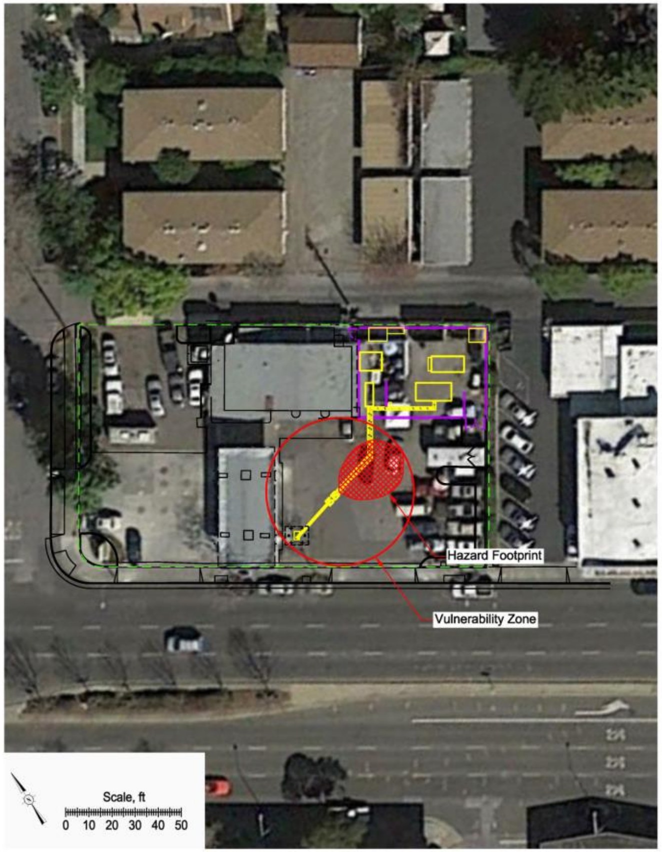
- **Pyrolysis of Methane**
  - Several Techniques (Plasma torch, Thermal-Catalytic, Microwave etc.)
  - Energy intensive, temperatures above 1100–1200ºC . Plasma at 2100ºC
- **Production on Synthetic Methane (i.e. Methanation of Hydrogen)**
  - Nickel Catalyst (Sabatier reaction) $4\,H_2 + CO_2 \rightleftarrows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

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

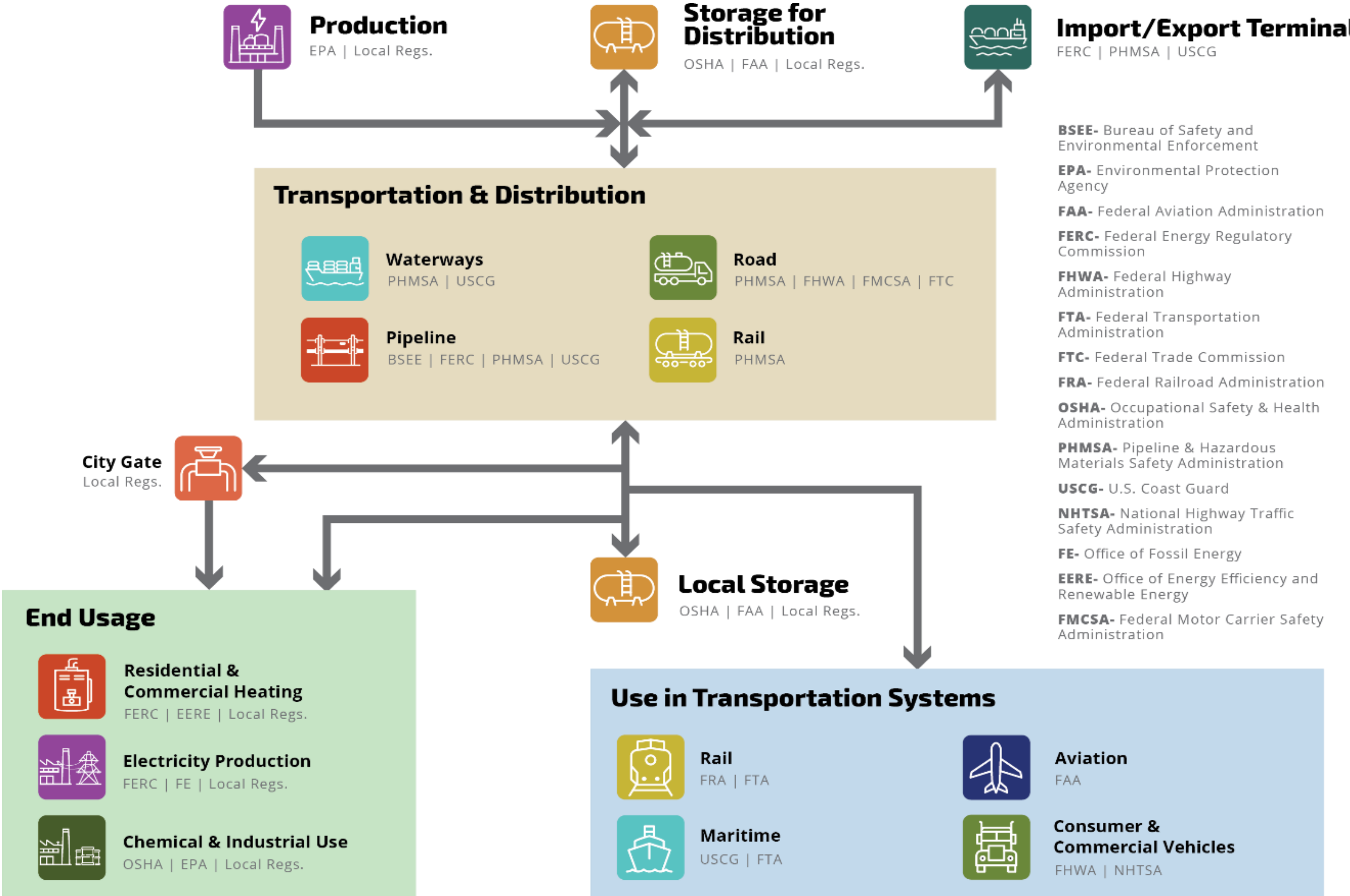
- **Higher Pressures**
  - Storage
  - Transmissions and Distribution



H_2 Vehicle Fueling Qualitative Risk Assessment

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

Hydrogen Safety Codes and Standards



Overview of Regulatory Landscape in U.S. for Hydrogen Projects from Sandia National Laboratories (Baird, Ehrhard, Glover, & LaFleur, 2021) Provided by NYSEARCH

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

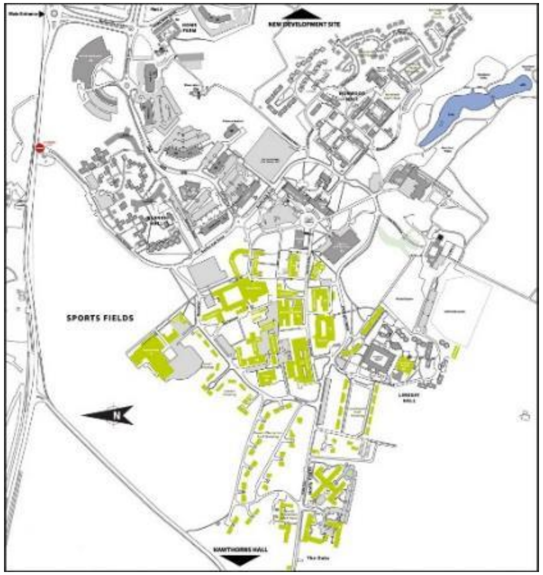
University 'as today'

University 'in trial'

Secured the UK's first hydrogen exemption in November 2018

Hydrogen Blending in the UK HyDeploy and HyDeploy2,

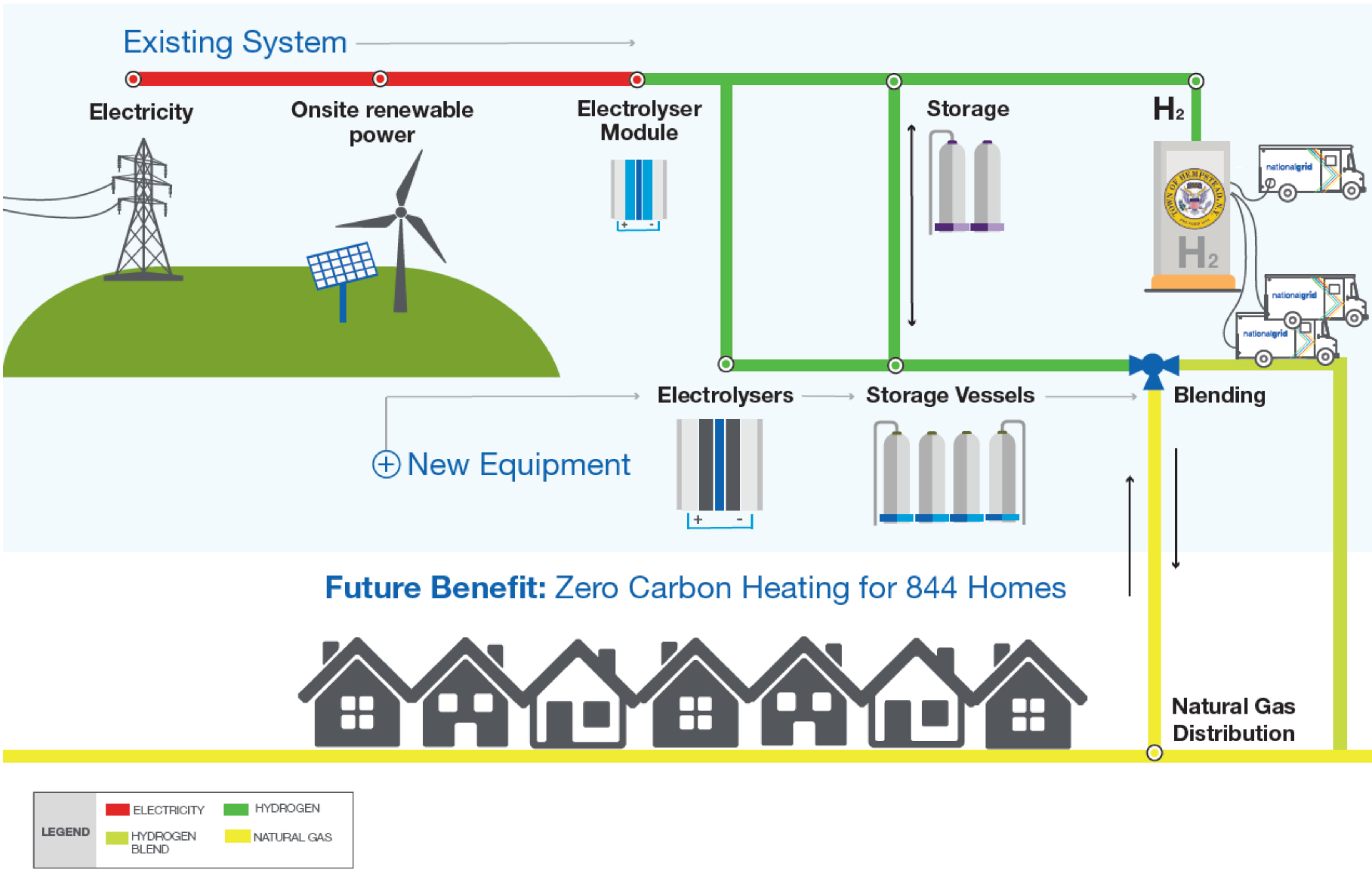
- **Effort led by Cadent (UK Distribution Company) for Demonstration of a 20 v% hydrogen blend**
- **Phase I: 10-month H_2 blending Demonstration at Keele University, in operation**
- Successfully tested 130+ properties and buildings, including 230+ appliances, prior to go-live
- No new appliance leakage 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"

HyGrid

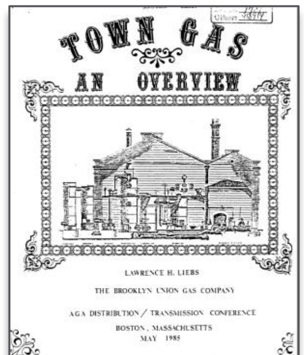
Green Hydrogen Facility Expansion



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

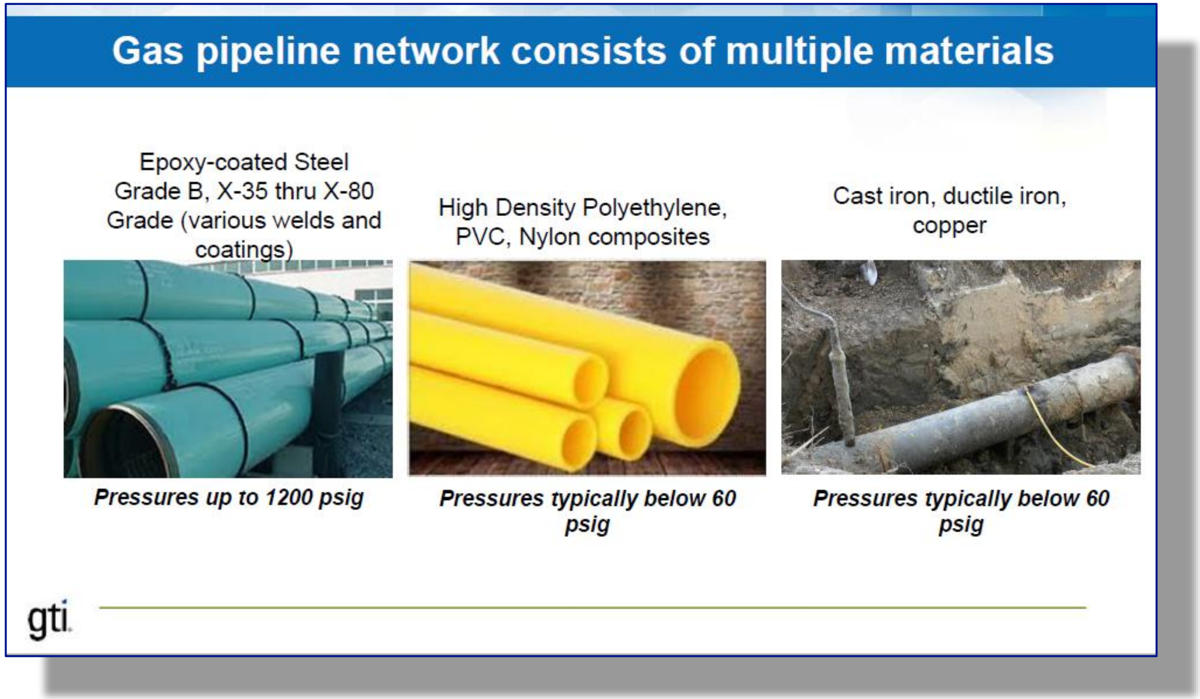


SNG from Naphtha 1970's

	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

The First Question – Pipeline Integrity

- **Hydrogen Embrittlement & Corrosion**
  - Metallic
- **PE & Sealing Materials**
- **Appliance Integrity**



OTD Operations Technology Development

NYSEARCH

Pipeline Safety and Gas Composition Standards for Utility Distribution by State

- **New York State TITLE 16. DEPARTMENT OF PUBLIC SERVICE**
  - Chapter III Gas Utilities
    - Subchapter A – Service- Part 229 Gas Standards
      - 229.42 Standards of interchangeability
    - Subchapter C - Safety - Part 255 Transmission and Distribution of Gas
- **Massachusetts**
  - **M.G.L Title XXII Chapter 164, Section 106: Regulation of quality of gas**
  - **220 CMR: Department of Public Utilities**
    - **220 CMR 100.00: MASSACHUSETTS GAS DISTRIBUTION CODE**
  - **220 CMR 101.00: Massachusetts natural gas pipeline safety code**
    - **References 49CFR Part 192,**
      - Gas is defined as natural gas, flammable gas, or gas which is toxic or corrosive
- **Fuel Gas Codes in NY State, NY City and Massachusetts don't mention Hydrogen (ref: International Fuel Gas Code Chapter 7 for Hydrogen)**

Gas Composition Standards for Utility Distribution

- **GAS INTERCHANGEABILITY (FERC)**
  - AGA Report No. 4A
    Natural Gas Contract Measurement and Quality Clauses
    - Only natural gas quality specifications contained in a FERC-approved tariff can be enforced.
    - Specifications must be flexible and allow pipelines to balance safety and maximize supply.
    - Specifications must be based on science, and negotiations must involve all interested parties.
    - The NGC+ Interim Guidelines should serve as a common technical reference point for resolving issues
  - White Paper on Natural Gas Interchangeability and Non-Combustion End Use, NGC+ Interchangeability Work Group February 28, 2005
    - *The ability to substitute one gaseous fuel for another in a combustion application without materially changing operational safety, efficiency, performance or materially increasing air pollutant emissions*.
  - Sample Interstate FERC Pipeline Tariff
    - Gas delivered shall be of **merchantable quality** and shall have a system-wide weighted average heat content of not less than 950* Btus per cubic foot on a dry basis
    - Gas from crude oil refineries shall contain no more than trace amounts of free hydrogen. ** some provide a range e.g., 975 Btu/scf to 1110 Btu/scf*

Standard Interconnection Guideline for the State of New York

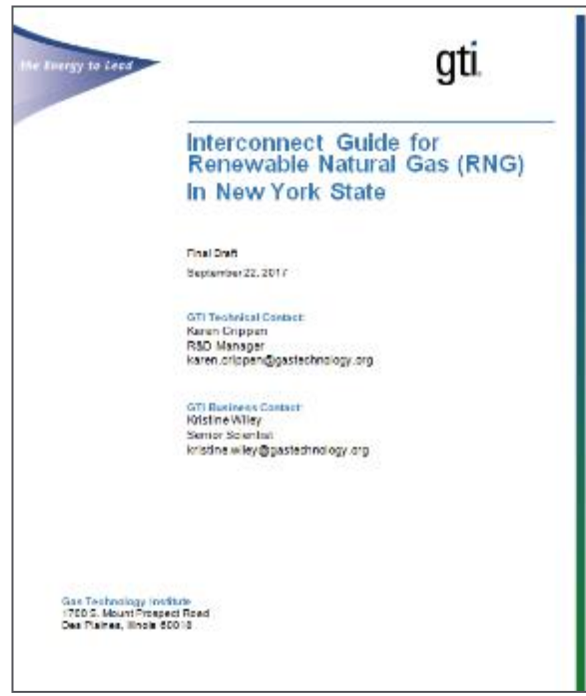
- One of RNG’s biggest barriers was injection into distribution system
  - Most utilities did not understand interconnection or gas quality issues
  - Guideline released in 2018 and undergoing revision

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

First Major Revision in Progress and will include Hydrogen injection.

- Issued through the Northeast Gas Association


The Energy to Lead

gti

Interconnect Guide for Renewable Natural Gas (RNG) In New York State

Final Draft

September 22, 2017

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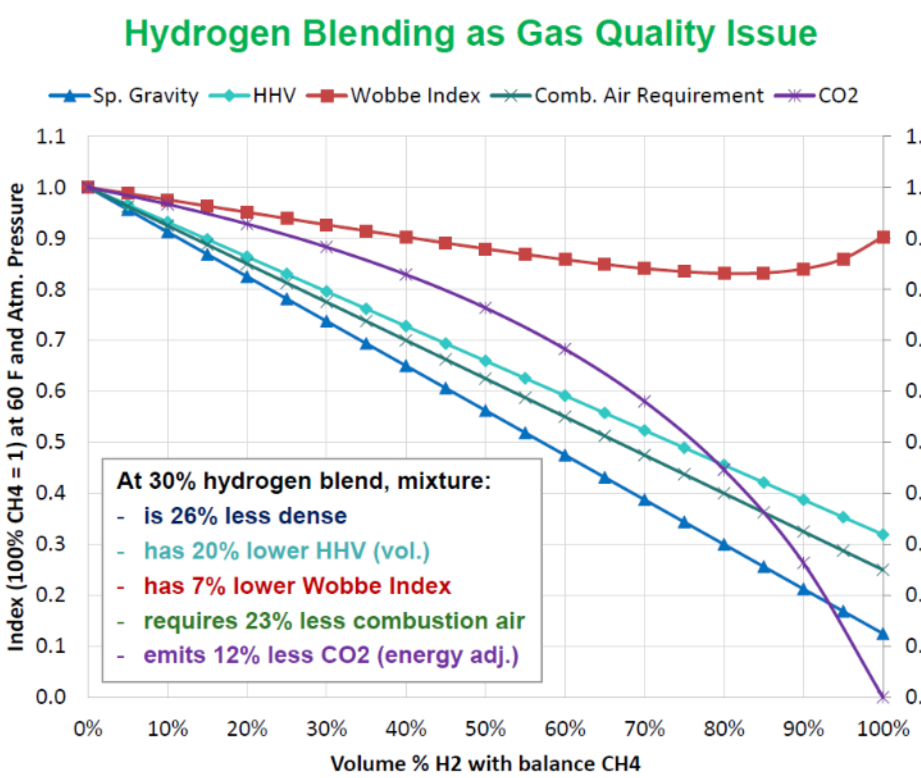
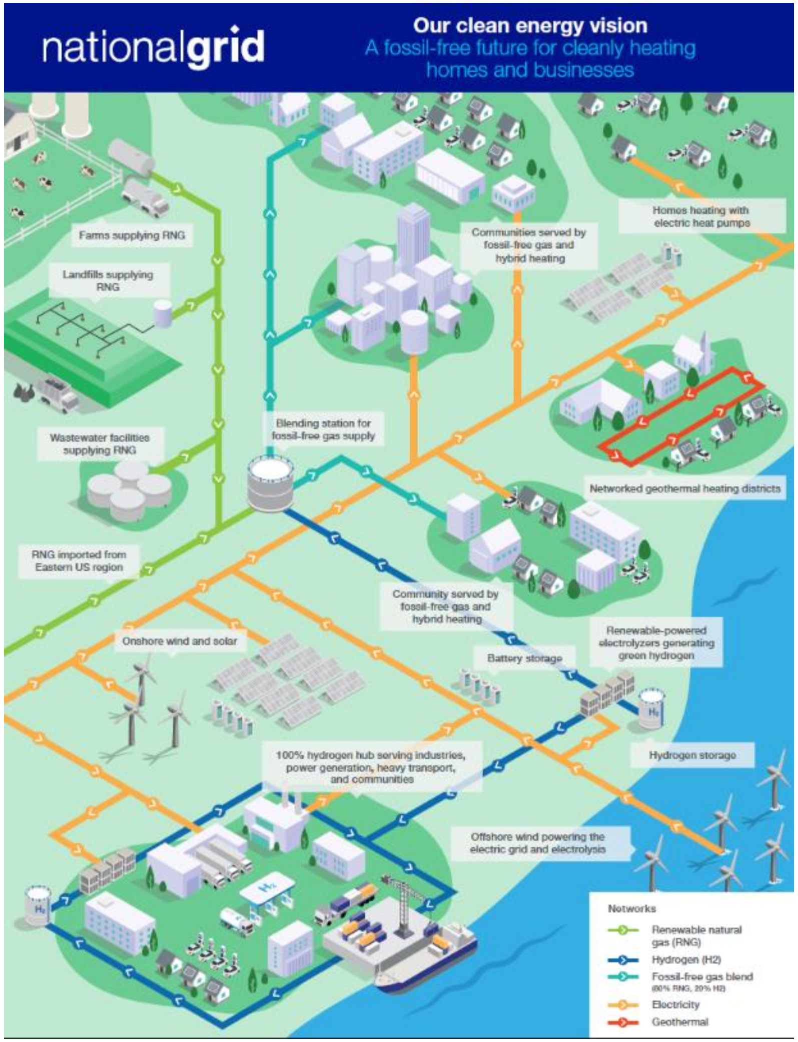
Gas Quality Minimum Considerations

Northeast GAS ASSOCIATION

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/m³)	
Other Volatile Metals	Comm Free(<213 μg/m³)	
Siloxanes as (D4)[13]	Comm Free(-<0.5 mg Si/m³)	
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)	

High Blends and Local Storage are Needed

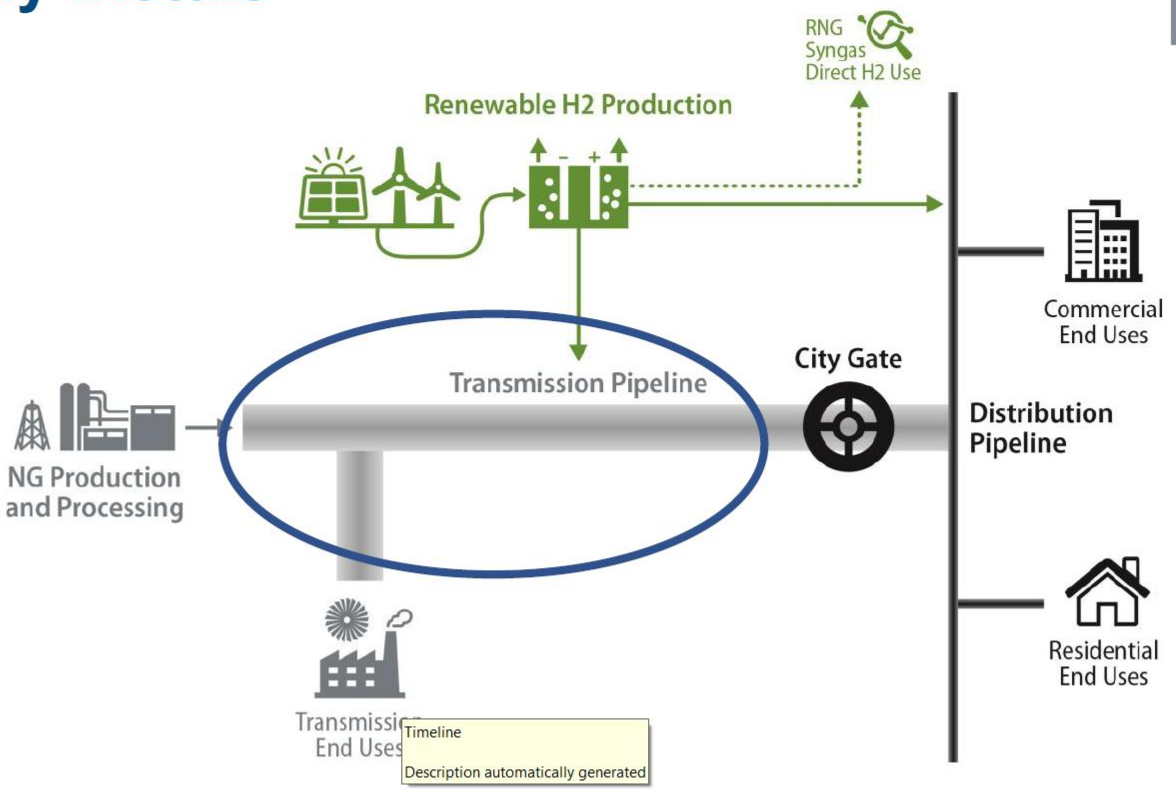




HyBlend CRADA

Transmission system

Primarily metals

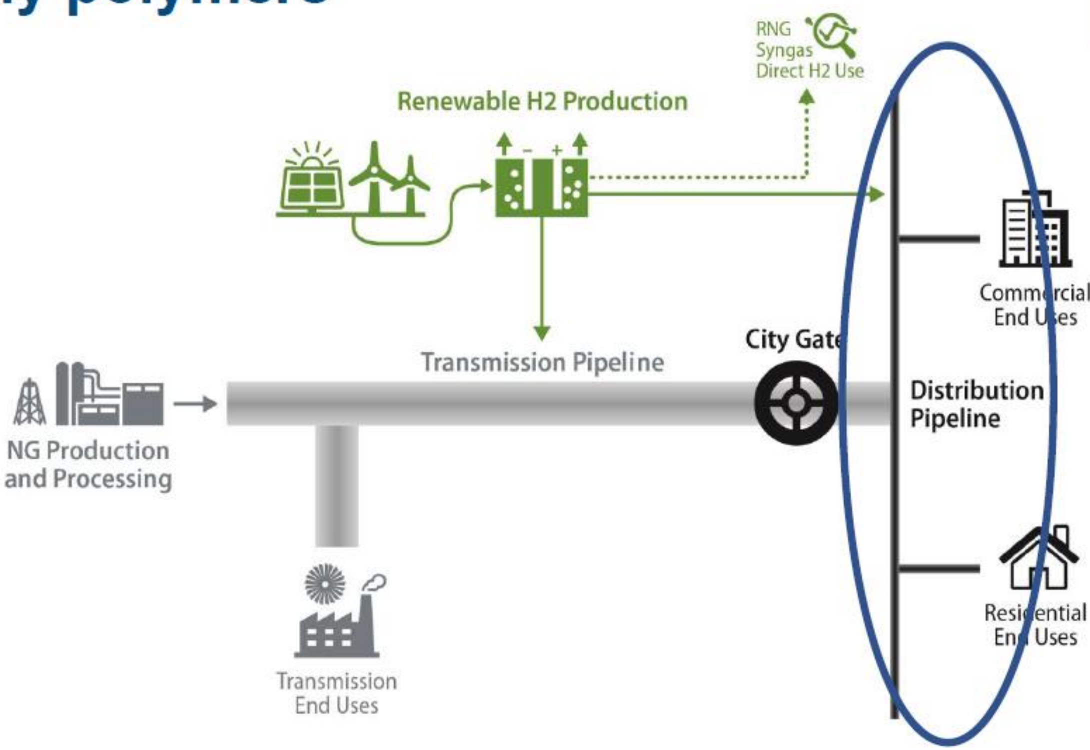


HyBlend CRADA

Distribution system

Primarily polymers

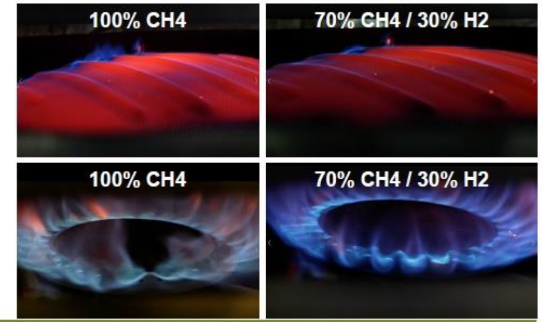
HyBlend
U.S. DEPARTMENT OF ENERGY



Pipeline Integrity

- **USDOT – Pipeline Hazardous Materials Safety Admin. 49 CFR Part 192 (Pipes Act of 2020 rulemakings)**
- **ASME B31.12 - Hydrogen Piping and Pipelines**
  - PL-3.21 STEEL PIPELINE SERVICE CONVERSIONS
    - Procedure for Evaluation
    - Hoop stress limited to 40% SMYS
- **Plastic Distribution Piping**
  - No specific hydrogen code sections?
    - Hydrogen does not cause degradation of polyethylene pipe
    - Operational stresses are much lower than the material capacity due to the application of industry accepted design factors (ref UC Riverside) developed by the Plastic Pipe Institute

Hydrogen Safety- Utilization



- **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) AHRI published similar results for 20% blends.**
    - 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
- **Large Package Boilers (e.g., Cleaver Brooks) designed for mixed gases**
- **Engines and turbines certified on multiple fuels during EPA emissions tests**

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

Odorants are required. Illuminants?

- *"As far as is known, the sulfur compounds now used to odorize natural gas are compatible with hydrogen and would be perfectly satisfactory"* IGT-72/0003
- *"Currently there is no available odorant for hydrogen, and this may require the development of a new odorant".* NREL/TP-5600-51995 , March 2013
- "When an odorant is being introduced into the gas, the simultaneous addition of an illuminant, which would make the hydrogen flame visible, would also be worth considering" IGT-72/0003
  - No illuminant yet developed
  - Potential materials: Aromatic-type organic material or volatile organo-metallic sodium

- In 2019 Scottish Gas Networks studied (15) potential odorants and concluded that their current odorant should be used for up to 100% hydrogen and is a blend of 78 % TBM (Tertiary butyl mercaptan) and 22 % DMS (Dimethyl sulphide)
- **Hydrogen and Sulfur Interactions**
  - Odorant Fade: I-GIT reports that reactions with mercaptans occurs at far higher temperatures (>266ºF) 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

Illuminants

- **For the 2021 Tokyo Olympics, engineers from Toyota and Eneos worked to create a hydrogen cauldron to mark the beginning of the event.**
  - In order to make the hydrogen flame visible sodium carbonate was sprayed into the cauldron.
  - With the sodium carbonate solution, they were able to achieve a visible, bright, yellow flame.

End-use Equipment & Detectors

- **Installation**
  - Fuel Gas Codes (NFPA-54)
- **Product Certification**
  - Most Building Codes Require Appliance Listing
    - e.g., NYC Fuel Gas Code – *“Appliances regulated by this code shall be listed and labeled.”*
  - Conforms to or Listed, in whole in in parts by
    - Nationally recognized laboratories
      - Underwriters Laboratories, CSA, or ETL.
        - Packaged products or individual components.
        - Example: CSA 13.1 includes hydrogen fuel cells
  - **Combustible gas detectors are tested and listed by UL**

Power Generation as an Industrial Use

- Hydrogen fueled power generation projects are becoming more common
- These pilots are being performed with the turbine OEMs driving integration
- Industry groups such as EPRI/GTI Low Carbon Resource Institute are also engaged in creating safety standards and filling research gaps
- Key areas of focus: Industrial fuel train, internal dynamics within turbine combustor

Brentwood, NY

- $8.5m invested in hydrogen blending retrofit by NY
- 6 – 8 week pilot should conclude fall 2022
- Airgas trucking “grey” hydrogen for small/varying blend in GE LM6000 turbine
- EPRI, GE, Sargent & Lundy providing engineering services
- Fresh Meadow providing BOP construction with GE

Cricket Valley, NY

- Cost / timeline TBD; to commence “late 2022”
- 1 of 3 GE 7F.05 turbines on site to be used in pilot phase
- Initially 5% - 15% blend, but hope to convert to 100%
- Initially trucks in hydrogen, but plan to manufacture “green” hydrogen on-site (H2Pro)

Long Ridge, OH

- 1st purpose-built hydrogen-burning power plant in the United States
- GE 7HA.02 turbine can burn 5-20% hydrogen initially / to transition to 100% over time
- Completed 5% initial blend test March 2022 / testing up to 20% today

Keadby, UK

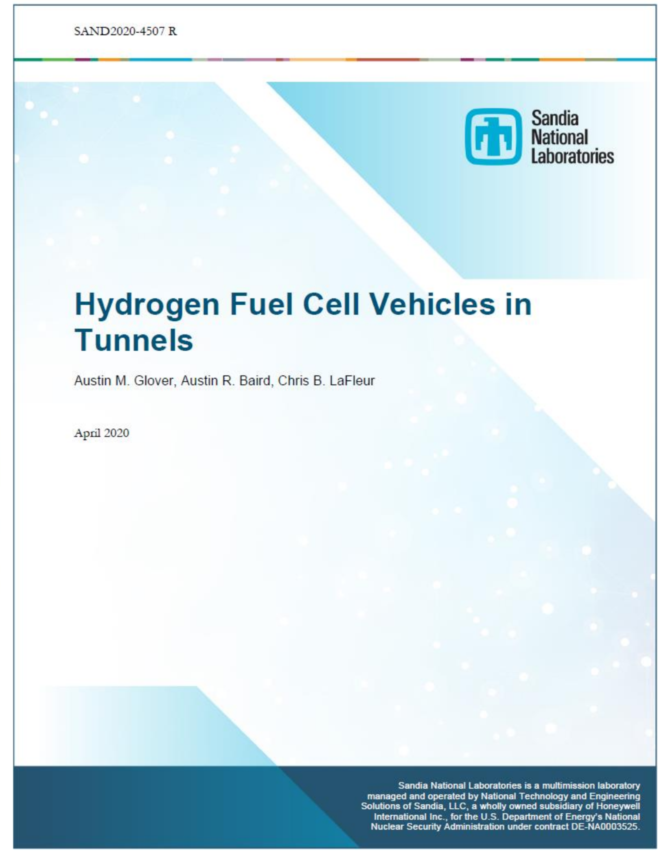
- Keadby Hydrogen power station peak demand of 1,800MW of hydrogen
- Planned to be world’s first major 100% hydrogen-fired power station
- Would use nearby hydrogen and CO2 pipeline developed by Zero Carbon Humber

Source: Company websites

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

MBTA Somerville



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Sandia National Laboratories

Hydrogen Fuel Cell Vehicles in Tunnels

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

April 2020

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Thank You

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