ET Summit 2024

Presented by

H2 Blends for Residential and Commercial End-use Equipment

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GTI Energy

Content

- **GTI Energy Introduction**
- Hydrogen Blending Overview
- GTI Energy Projects Introduction
  - Lab Appliances Studies
  - Field Appliances Studies
- Summary

We develop and deploy solutions in the transition to low-carbon, low-cost energy systems

SOURCE MAKE MOVE STORE USE

490+ Employees

TOP WORK PLACES 2019 Chicago Tribune

TOP WORK PLACES 2020 Chicago Tribune

TOP WORK PLACES 2021 Chicago Tribune

TOP WORK PLACES 2022 Chicago Tribune

TOP WORK PLACES 2023 Chicago Tribune

We work collaboratively to address critical energy challenges impacting gases, liquids, efficiency and infrastructure

OTD Operations Technology Development

UTD Utilization Technology Development

GTI ENERGY EMERGING TECHNOLOGY PROGRAM (ETP)

LCRI LOW-CARBON RESOURCES INITIATIVE

GTI Energy Expanding H_2 Utilization Laboratory Capabilities

Single Cylinder Testing
Everywhere marked with “ “ has current or planned tests with single cylinders (H2 or H2 blends), limited to ~250 CF and low firing rates (less than 200 kBtu/h)

Disclaimer: Details may change over time

Hydrogen Economy – Three R&D Pathways

Centralized Hydrogen Production

Blending into Current Grid

How do H_2/NG blends impact existing **customer gas assets and gas-fired equipment?**

Studying the blended hydrogen safety/efficiency/emissions impacts

Convert to Hydrogen Dist.

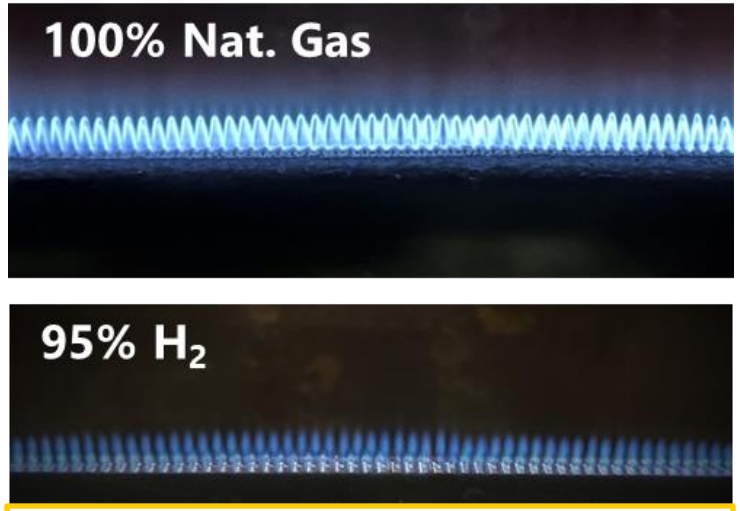
How can we assure that new gas equipment and retrofits are **hydrogen-ready?**

RD&D/Tech Transfer with equipment and sensors for hydrogen end use

Dist. H_2 Generation

Hydrogen Microgrids

How do we design and prepare for **hydrogen fuel-flexible systems?**



Developing and demonstrating fuel-flexible combustion/CHP systems

Blending in Grid – Resources

Senoko Gas Works – Singapore (Today)

Learning from historical transition (Recent Project/Paper*)

- Hawaii Gas cited, syngas with ~15% H_2 to ~30k customers
- There still exist **large networks of H_2-rich gases** including
  - Large networks can serve up to ~1,000k customers with ~50% H_2 fuels
  - Utilities market products direct to customers, installation and O&M

Fuel	HHV Range Btu/ft³	Major Constituents (% vol., dry)			
		CH_4	H_2	CO	Other
Coal Producer Gas	135-180	0%	10%	30%	~40% inert
Coal Retort / Coke Oven Gas	500-650	50%	33%	6%	CHs+inert
Carbureted Water Gas	500-550	0%	40%	35%	CHs+inert
Oil Gas	550-1000	27%	50%	13%	CHs+inert
Town Gas (Singapore)	500	26.7%	49.5%	3%	~17.5% inert
Raw Biogas	430-750	45%-75%	0%	0%	~25% CO_2
Natural Gas	950-1050	90%-95%	0%	0%	0%-6% C2
20% H_2 / 80% CH_4 Blend	870	80%	20%	0%	
100% Hydrogen	320	0%	100%	0%	

Source: Pacific Coast Gas Association – A Century of Progress - 1993 // * Glanville, P., Fridlyand, A., Zhao, Y., (2023) From Town Gas to Hydrogen: Historical and Modern Perspectives on Transitions Between Delivered Fuels in the Built Environment, Proceedings of the 2023 ASHRAE Winter Conference.

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DOE Hydrogen Hubs: Overview

Government Investments

- DOE H_2 Hubs ($7B, 7 awards)
- GTI Energy major participants in

Appalachian Regional Clean Hydrogen Hub (EQT, Battelle, NETL) focus on H_2 + CCUS - https://www.arch2hub.com/

Midwest Focused Hydrogen Hub (Nuclear Operator, Utilities, Ind. End Users) - https://machh2.com

Gulf Coast H_2 Hub (Ports, Chem. Industry/Refiners) - https://www.hyvelocityhub.us/

Source: DOE – OCED

DOE Hydrogen Hubs: Details

Name/Federal Cost Share	Location	Production	Midstream	End Uses
Appalachian Hydrogen Hub (ARCH2) Up to $925 million	Ohio, Pennsylvania, West Virginia	Hydrogen produced from natural gas, with carbon capture and storage	Hydrogen pipelines, hydrogen fueling stations, permanent CO2 storage	Fuel cell electric mining vehicles, heavy-duty vehicles, heavy industry
California Hydrogen Hub (ARCHES) Up to $1.2 billion	California	Electrolysis	Freight network between California and Pacific Northwest Hub, hydrogen fueling stations	Backup power generation, heavy-duty vehicles, port equipment, public transit
Gulf Coast Hydrogen Hub (HyVelocity H2Hub) Up to $1.2 billion	Texas	Electrolysis, hydrogen produced from natural gas, with carbon capture and storage	Hydrogen pipeline, salt cavern storage, hydrogen refueling stations	Heavy-duty vehicles, power generation, ammonia, refineries/petrochemicals, marine fuel
Heartland Hydrogen Hub (HH2H) Up to $925 million	Minnesota, North Dakota, South Dakota	Electrolysis, Biomass Gasification	Open access to storage and pipeline infrastructure	Fertilizer, power generation
Mid-Atlantic Clean Hydrogen Hub (MACH2) Up to $750 million	Delaware, New Jersey, Pennsylvania	Electrolysis	Expanded pipeline infrastructure, upgraded bus mechanic depots, hydrogen refueling stations	Heavy duty vehicles, refuse and sweeper trucks, power generation, combined heat and power
Midwest Hydrogen Hub (MachH2) Up to $1 billion	Illinois, Indiana, Michigan	Electrolysis, hydrogen produced from natural gas, with carbon capture and storage	Hydrogen refueling stations	Steel and glass production, power generation, refining, heavy-duty vehicles, sustainable aviation fuel
Pacific Northwest Hydrogen Hub (PNWH2) Up to $1 billion	Montana, Oregon, Washington	Electrolysis	Freight network between California and Pacific Northwest Hubs	Heavy-duty vehicles, ports, refining, peaking plants/generators, refineries, data centers

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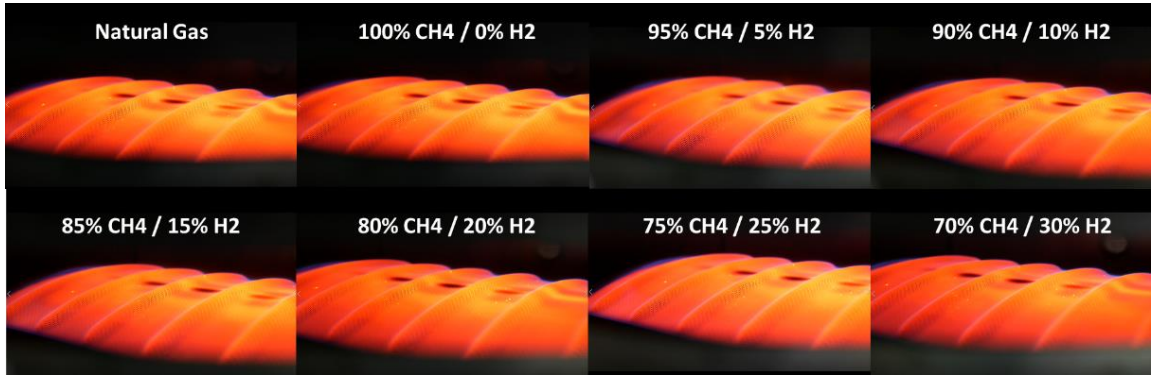
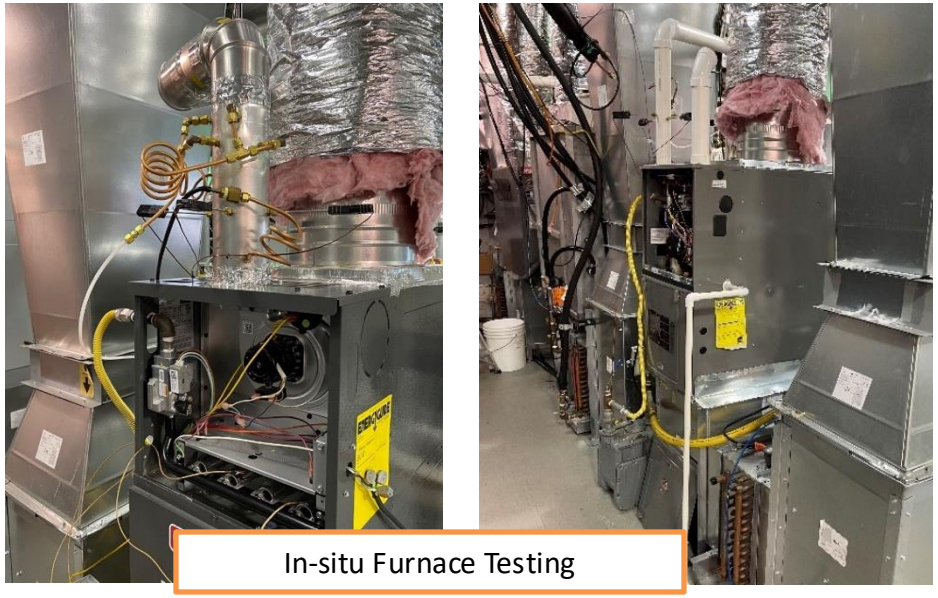
GTI Energy Lab Work: Hydrogen Blending

Scope of Testing - “Simulator” testing and In-situ

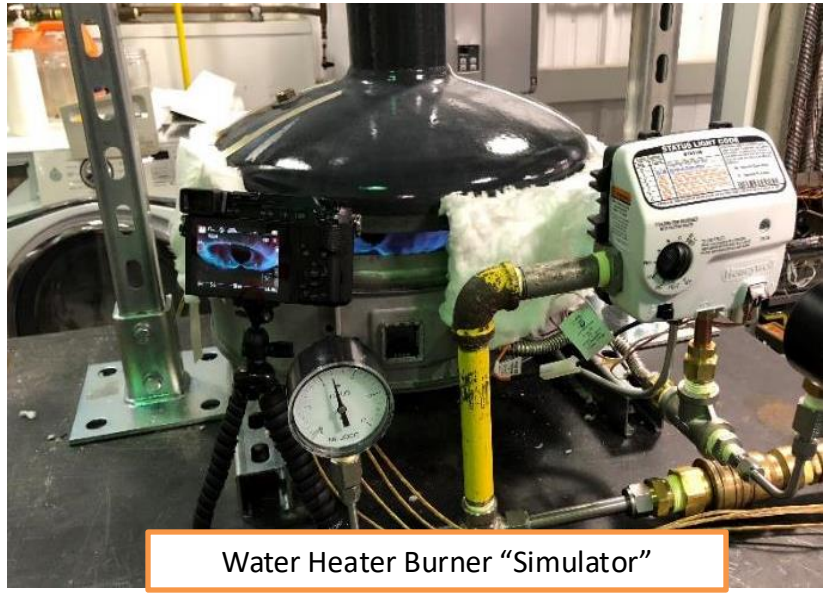
- Natural gas, 0%-30% H_2 in CH_4 in 5% increments
- Simulator tests operated manually: Furnace (in-shot), Water heater burners: Standard NOx (2), Ultra Low NOx (2)
- For in-situ, appliances with automation of loads: Two furnaces, Three water heaters





In-situ Furnace Testing

In-situ Water Heater Testing

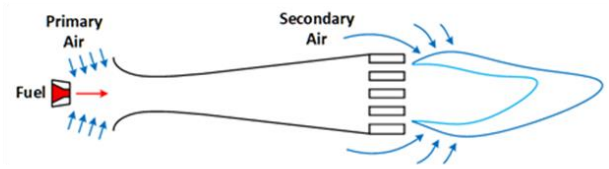


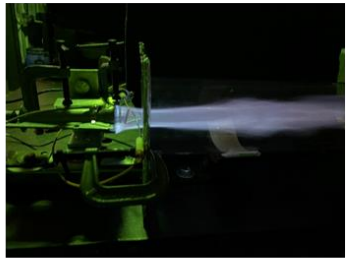
Water Heater Burner “Simulator”

https://www.mdpi.com/1996-1073/15/5/1706

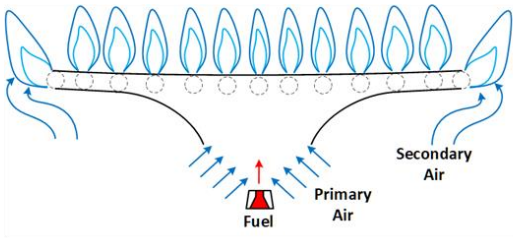
GTI Energy Lab Work: Hydrogen Blending

"In-Shot" Warm-air Furnace Burner (< 40 ng NOx/J)

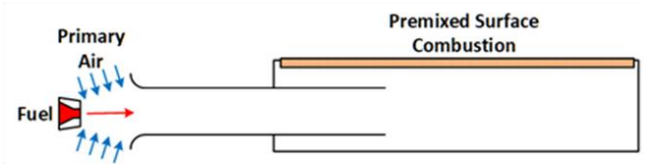


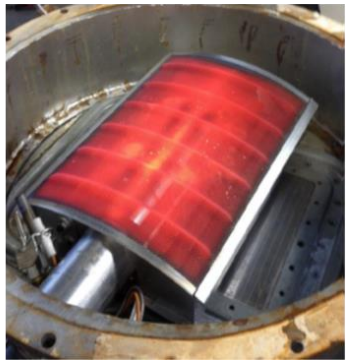


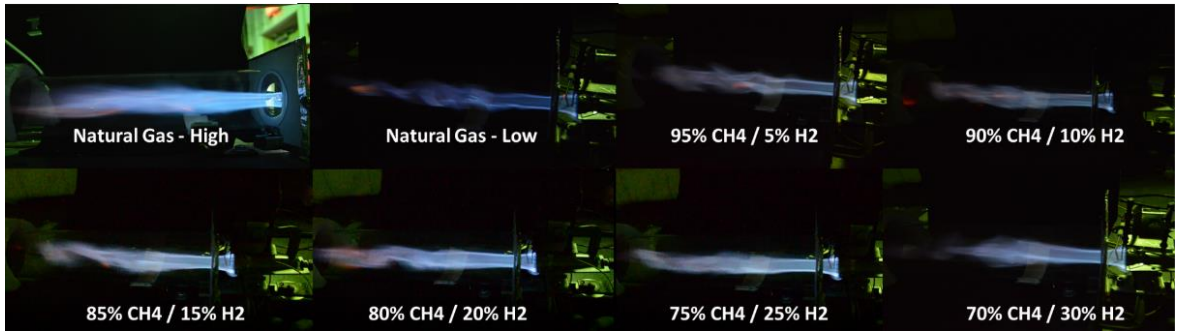
Standard NOx Water Heater Burner (< 40 ng NOx/J)

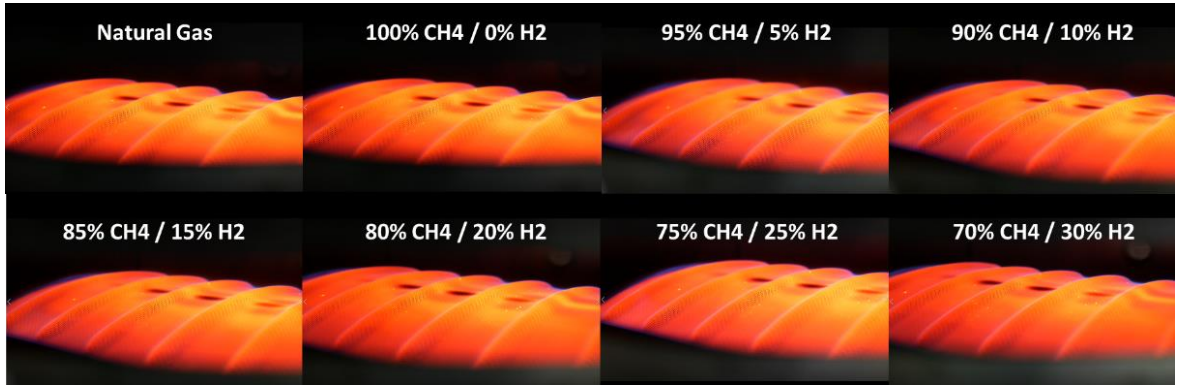


Ultra-Low NOx Water Heater Burner (< 10 ng NOx/J)





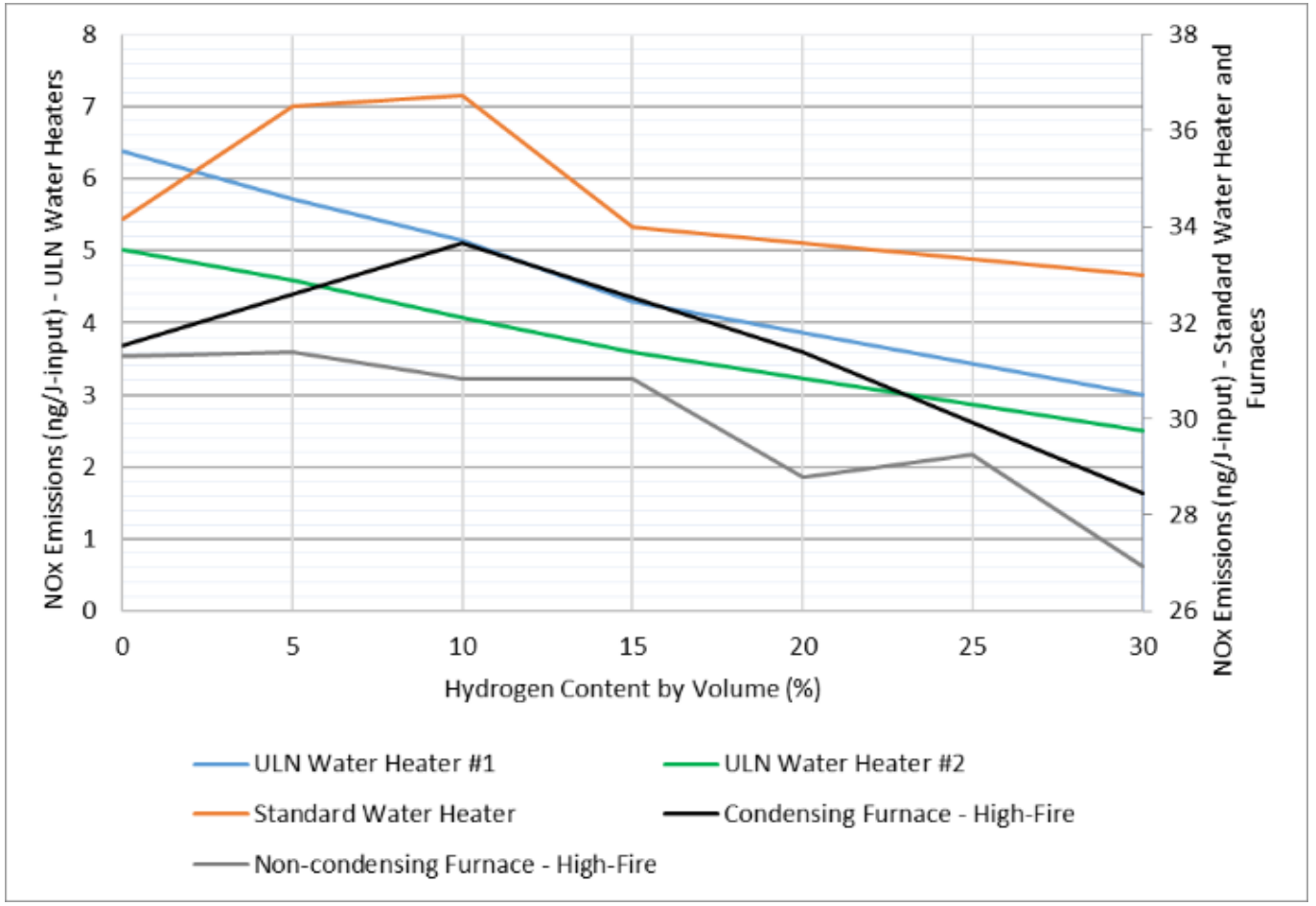




GTI Energy Lab Work: Hydrogen Blending

Based on data collected to date in typical, unadjusted customer equipment, will blended H_2/NG…

- Cause equipment to immediately malfunction? **Not likely**
- Lead to unsafe operating temperatures? **Not likely**
- Adversely impact efficiency? **Not likely**
- Increase NOx or CO emissions? **Generally no**
- Increase leakage within building? **Not worsened by blending**



https://www.mdpi.com/1996-1073/15/5/1706

Cross-cutting – Hydrogen Microgrids

Equipment designed for fuel-flexibility (0%-100% H2) or hydrogen-firing are essential for **H_2-energy microgrids** in demonstration phase and "proto-hubs" **today**

Demo projects of H_2-microgrids underway at Army & Navy facilities, from backup power to central heating to containerized solutions

HYDROGEN ENERGY RESEARCH OPERATION
HERO
POWERED BY GTI ENERGY

Source: Upstart / Bloom Energy / GTI Energy

Integrated energy systems development & extended life testing of mCHP and fuel cells in GTI Energy labs

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Industrial Decarbonization – Hydrogen

Three Sets of Research Questions

Centralized H_2 Production

1) Blending into Gas Grid

How do H_2/NG blends impact existing customer gas assets & process quality?

2) H_2 Infrastructure

How can we assure that new gas equipment and retrofits are H_2-ready?

Distributed H2 Generation

3) H_2 Microgrids

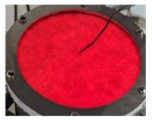
How do we design and prepare for H_2 fuel-flexible systems?

Recent DOE Starts for H_2 Flexible Industry (2023 / 2024)

Hydrogen Fuel-Flexible Boiler for the Food & Beverage Industry

- In-situ retrofit system for in use hot water/steam boilers
- Advanced zero GHG burner
- AI-assisted controller/mixer
- Digital twin model of system
- Partner with dairy/beverage processors

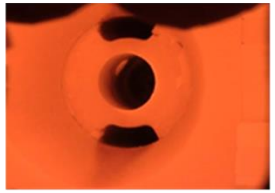
Source: Mountaintop Beverage



Source: ORNL

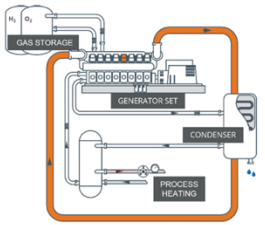
Regenerative High-Efficiency Low-Carbon Fuel-Flexible System

- Advanced regenerative burner for iron/steel industry, for 30%-100% H_2 and biofuel injection
- Low NO_x & 5:1 turndown
- Partner with large steel producer



Noble Thermodynamics Zero Emission CHP System

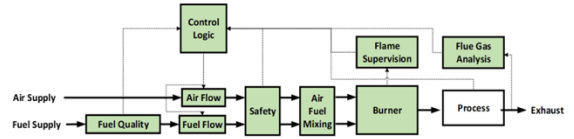
- Scale-up of novel power cycle for industrial CHP with H_2
- Elimination of GHGs (H_2) and NO_x (Recirc. Ar) through "mechanical fuel cell" process
- Proposed 300 kWe / 200 kW_{th} System



Source: Noble Thermodynamics

Fuel-flexible, Ultra-low NOx, Omnivore Combustion System

- Cross-cutting process heating solution for full fuel flexibility (0%-100% H_2, biogas, syngas, etc.)
- Ultra-low Emissions Tuning
- Demonstrated at pilot scale, with feed forward/backward controls



Blending-to-H_2 Ready – CEC C&I Project

California-Focused Project

Large effort to quantify the potential of hydrogen to decarbonize **large buildings and industry in California**:

- Develop techno-economic roadmap to decarbonize **~50%** of CA's nat. gas use
- Large effort across diverse team to:
  - Develop CA-specific techno-economic analysis for H_2 use, quantify potential/costs of conversions to H_2
  - Test/model H_2 tolerance of wide range of large equipment categories (e.g. boilers)
  - Material testing for long-term impacts
  - Air Quality simulation on regional impacts
  - Stakeholder outreach and engagement

Decarbonizing Large Commercial and Industrial Equipment with Hydrogen (PIR-22-001)

Reviewed in Fall '23

CALIFORNIA ENERGY COMMISSION · GTI ENERGY · UCIrvine · EPRI ELECTRIC POWER RESEARCH INSTITUTE · AHRI AIR-CONDITIONING, HEATING, & REFRIGERATION INSTITUTE · SoCalGas · Pacific Gas and Electric Company · SOUTHWEST GAS · UTD Utilization Technology Development · LCRI LOW-CARBON RESOURCES INITIATIVE

Test Equipment Selection
- 2+ units per equip. category
- Finalized after Preliminary TEA

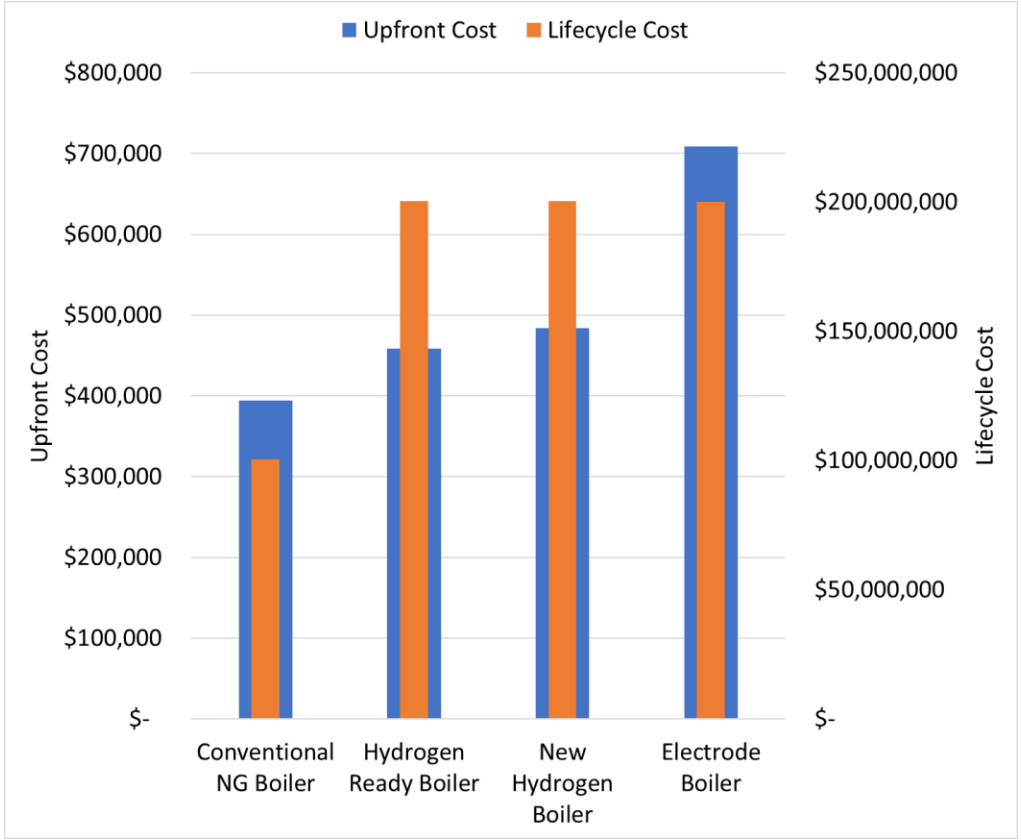
Commercial Examples:
- Furnaces/Weatherized HVAC
- Water Heater/Hot Water Boilers
- Cooking / Catering Equipment

Industrial Examples:
- Steam Boilers / Process Heaters
- Ovens / Dryers / Kilns
- Heat Treating / Furnaces

Blending-to-H_2 Ready – CEC C&I Project

TEA: On Costs & Benefits - For H_2 ready/100% H_2 equipment, *equipment* costs are limited but so is data

- Similar & maximum statewide GHG reductions from *Partial Electrification + H_2*
- Increasing evidence that for **H_2 < 30%, no cost/retrofit needed**, manufacture self-certifications in US/Canada already active
- UK/EU OEMs have noted H_2-ready and 100% H_2 equip. will have comparable costs at scale to natural gas equipment.
  - Key components: controls, burner, ignition/flame supervision; "cross over" points differ by type/vendor



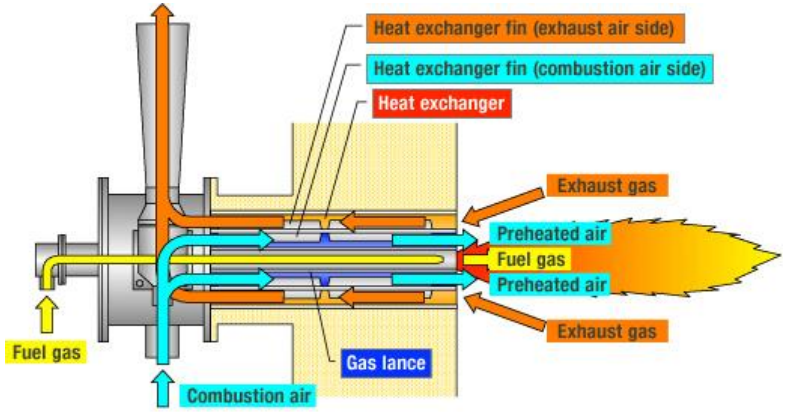
1) Boiler capacity of 15 MW and annual operating hours of 8000 are assumed
2) Lifecycle costs of Electrode boiler includes cost reductions due to monetized non- energy benefits

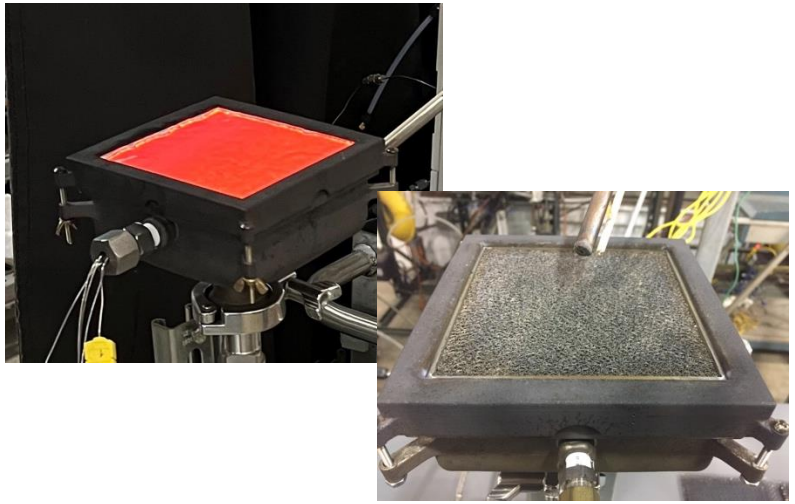
Prelim. TEA Summarized in 2023 ACEEE Conference Proceedings: link

Blending-to-H_2 Ready – CEC C&I Project

Technical Review: Structure of Survey

- Objective / Scope of Review
- Literature Review – Impact in Existing Equipment
  - Combustion Fundamentals
  - Combustion Component Impacts (Burners, Controls)
  - Leakage Enhancement from Blending
  - Equipment-Specific Studies
    - Boilers (Steam, Hot Water)
    - Industrial Process Heating Equipment (Furnaces, Ovens, Dryers, etc.)
    - Commercial HVAC
    - Commercial Cooking Equipment
  - Impacts on End Users
- Literature Review – Adopting H_2-based Fuels
  - Adapting Existing Equipment
  - Designing for 100% H_2
- Synthesis and Recommendations





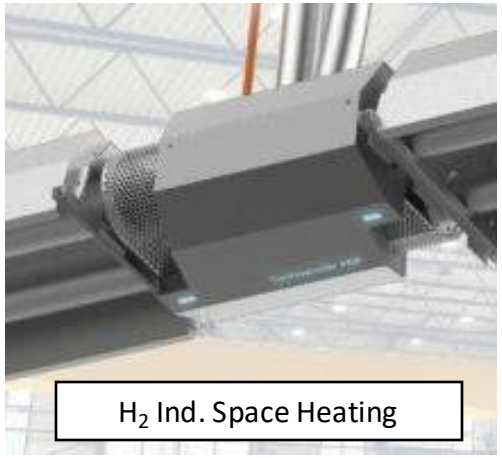
Full review by GTI / UCI available to UTD members and by request to GTI

Survey includes detailed descriptions of fundamentals and review of published results (examples above Osaka Gas, GTI Energy)

Blending-to-H_2 Ready – CEC C&I Project

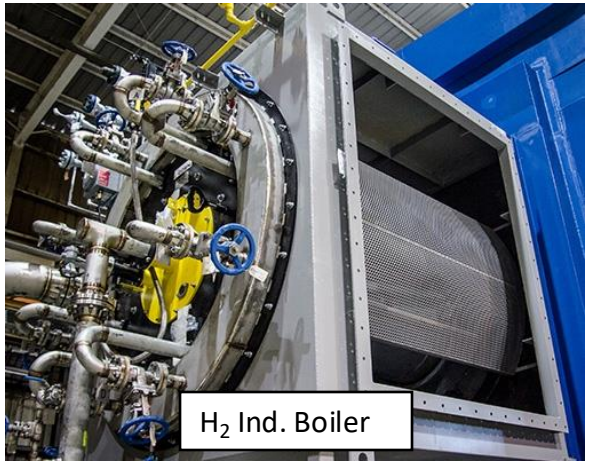
Technical Review: Designed for H_2

- Distribution, gas trains, combustion controls (air moving, valving, ignition), burners, and finished equipment are increasingly:
  - Designed for blends "H_2 ready", typ. 20%-30%
  - Hydrogen-fired applications
  - Certified in US markets



Source: Schwank

Source: Clearsign



Source: Babcock & Wilcox

CLIFFS
CLEVELAND-CLIFFS INC.

In 2023, Cleveland Cliffs announced a successful firing of 30% H_2 / 70% NG in a blast furnace at Middletown works, stating that modifications can allow up to 70% H_2

Source: https://www.clevelandcliffs.com/sustainability/environment/energy

Blending-to-H_2 Ready – CEC C&I Project

What's Ahead for This Study:

- Test rigs for **six categories** of heating equipment being built now
- Examples of natural gas equipment tested with increasing hydrogen **two ways (on / off rate)** over 2024
  - Data collected on performance, emissions (NO_x, CO, CH_4, H_2), noise, etc.
  - Evaluate retrofit options for higher H_2
- Calibrate **CFD combustion model** for extrapolation to equipment/designs
- Investigate **impact on materials** of construction (e.g. refractory) in parallel
- Perform statewide air quality modeling and revise **Final TEA**

Equipment Type	Sub-type(s)	Coverage Range	Test Unit Range
Boilers	Steam	Up to 50 MMBtu/h input	300 to 3,000 kBtu/h input
	Hydronic/Hot Water		
Direct-fired Process Heating	Ovens, kilns, and dryers	Up to 100 MMBtu/h input	500 to 2000 kBtu/h input
Industrial Furnaces	Recuperative / Non-recuperative Burners	Up to 100 MMBtu/h input	500 to 2000 kBtu/h input (200 to 500 kBtu/h Radiant tube)
Commercial HVAC	Warm-air Furnace, Duct Furnaces, & Unit Heaters	200 to 1,000 kBtu/h	
Commercial Cooking	A range equip.: fryers, broilers, griddles, ovens, charbroilers, and ranges	100 to 500 kBtu/h	

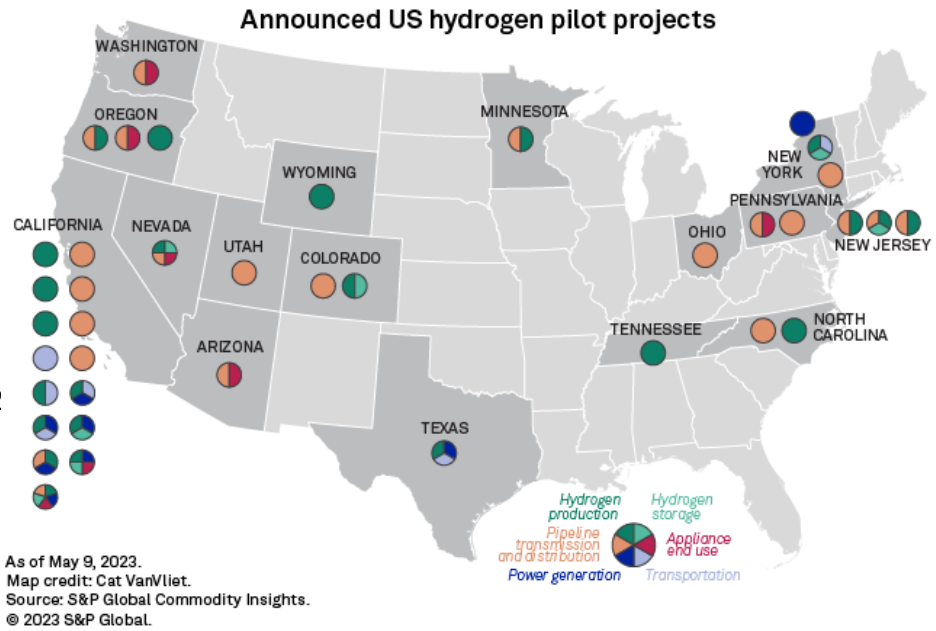


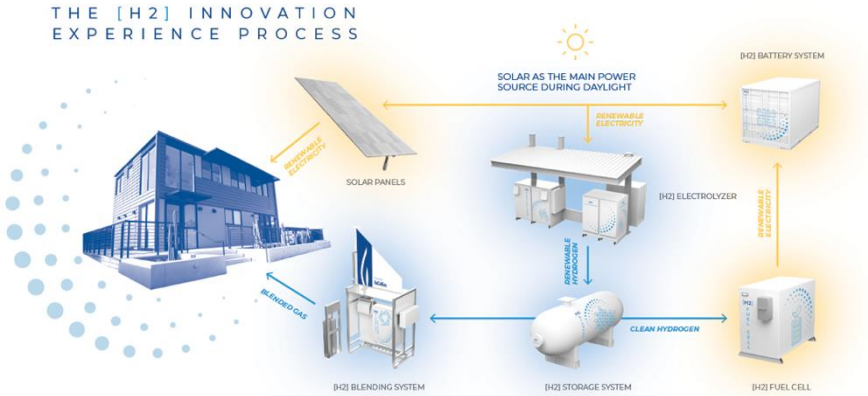


Regional Hydrogen Blending Efforts

Utility Investments

- Renewable natural gas/Biomethane, Bio-LPG, Biodiesel available in many markets to reduce GHG emissions
- Synthetic natural gas/E-methane projects underway, H_2 with captured CO_2
- Numerous States/Provinces have one or more H_2/NG blending demo projects in planning/underway
  - Several involving 100s – 2,000s of utility customers
- H_2 distribution projects are ramping up in US/Canada



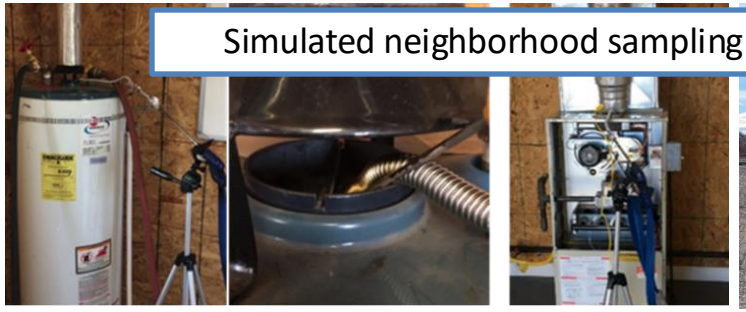


Blending-to-H_2 Ready – Field Research

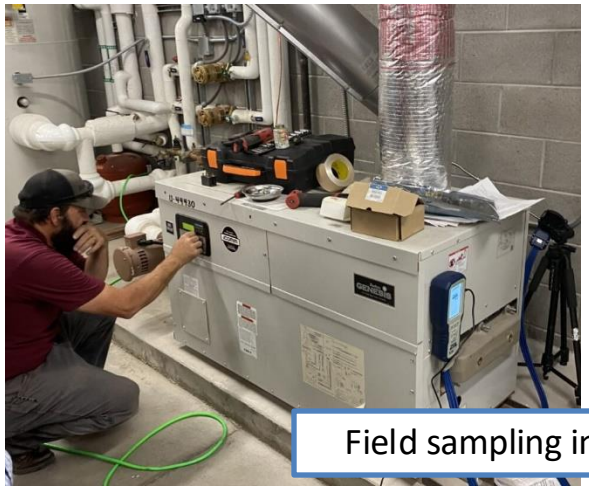
Guest presentation by NM in Fall '23

- **Field R&D growing** as complement to lab-based testing of H_2 blend impacts
  - Field sampling in NM, UT, NV, etc.; **collaborative equipment test programs**
  - Covers higher blends (20%+) and in-field samples in ~2,000 customer trial
    - Measuring leakage, equipment impacts, gas quality
  - Projects blending into central boiler plants in TX, MD, and elsewhere
- **GTI Leading** in 30-unit Las Vegas-area demo with **Southwest Gas**
  - Central/wall furnaces, space/water heaters, cooking, dryers, outdoor heating, and decorative appliances, design for 8 test stands, automated for long-duration impacts, emissions, customer safety, etc.

Vintage equip. in NM



Simulated neighborhood sampling in UT, NM, NV



Field sampling in Delta, UT

Planned boiler blending in TX, MD

UTD Utilization Technology Development

SOUTHWEST GAS

UNLV

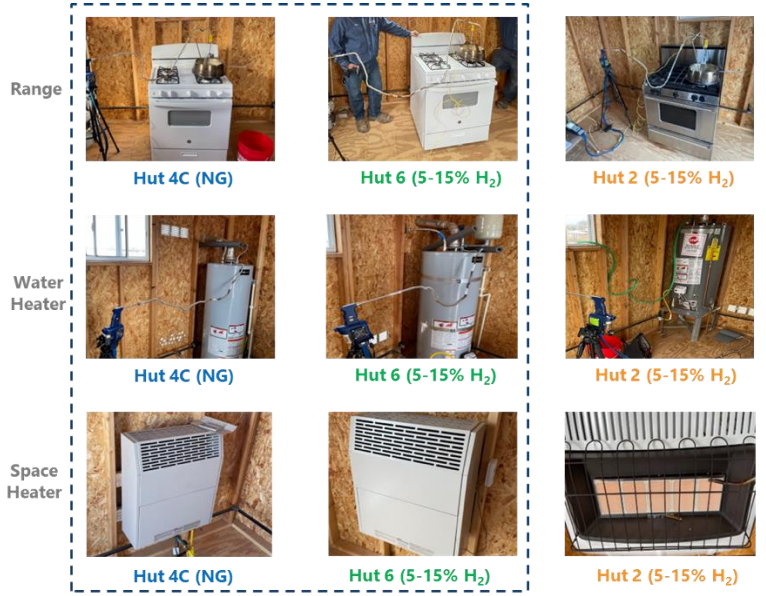
AHRI

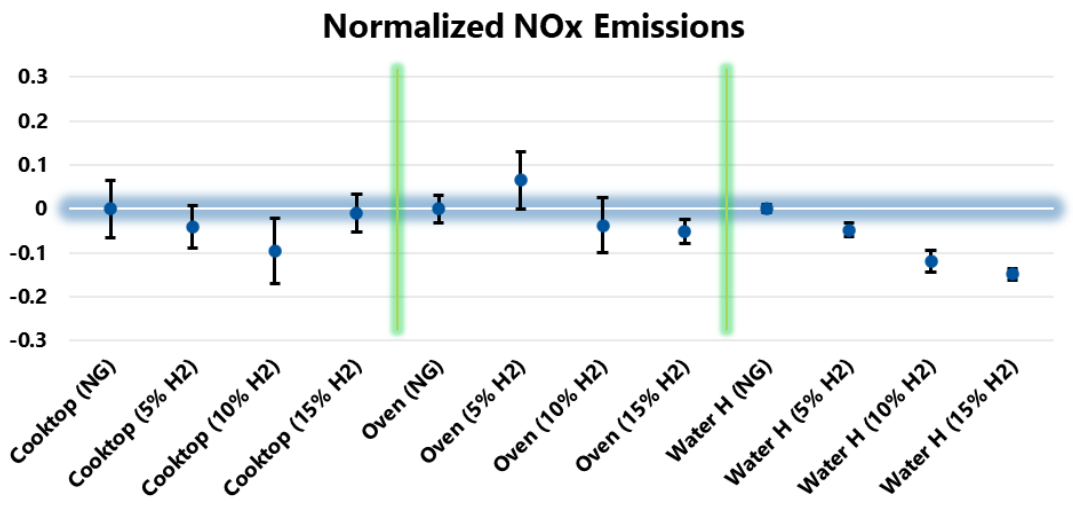
AHAM ASSOCIATION OF HOME APPLIANCE MANUFACTURERS

Based at a Southwest Gas mock neighborhood, GTI is working with a multidisciplinary team to expand on field research/best practices for utility blending & customer safety

New Mexico Hydrogen Blending

- In 2021-2022, New Mexico Gas Company and GTI Energy, tested a variety of appliances utilizing a 5% hydrogen blend. There was minimal deviation when comparing the baseline 100% natural gas to the 5% blended natural gas.
- In 2023, NMGC and GTI Energy increased the hydrogen blend tests to 10% and 15% hydrogen from 5%. The same tests were conducted, and similar results were achieved.
- In 2024, 20% H2 blend test were conducted
  - 3 Huts with 9 appliances were tested on NG and up to 20% hydrogen blends
  - Flame characteristics, CO/NOx emissions, water boiling efficiencies, etc. were compared and no significant difference was observed
  - 25% hydrogen blend test is being scheduled





Nevada Hydrogen Blending

Automated Test Stands:

- Central Warm Air Furnaces
  - Auto = Four
  - Manual = Two
- Wall Furnaces
  - Auto = Two
- Storage Water Heater
  - Auto = Four
  - Manual = Two
- Decorative Gas Lighting
  - Auto (Continuous)

Manual Test Stands:

- IR/Ventless Heater (Two products)
- Indoor Cooking/Ventless Hearth (2 + 1)
- Dryers & Direct Vent Hearth (2 + 1)
- Outdoor Appliances (Two grill / two heater)

Utah Hydrogen Blending

- In 2023, GTI Energy and Dominion Energy initiated the hydrogen blending pilot in the city of Delta (~2000 residents) and conducted baseline testing on 8 appliances and 7 gas sampling locations
- In Dec 2023, the electrolyzer (up to 43 kg/day of H2) was commissioned and started generating and blending hydrogen (< 5 vol%) into the city of Delta
- In March 2024, a long-term monitoring hydrogen sensor was installed at the pipeline system in the Delta High School District
- Future plans
  - Post hydrogen blending tests (appliances testing and gas quality checking) will be conducted in 2024
  - Electrolyzer performance and blending parameters will be monitored remotely in 2024 and 2025

Appliances Testing:

Gas Quality Testing:

Minnesota Hydrogen Blending

- In 2021, CenterPoint Energy successfully sought passage of the Natural Gas Innovation Act, a landmark new energy law in Minnesota that will allow the utility to invest further in innovative clean energy resources and technologies to reduce emissions.
- In June 2022, CenterPoint Energy announced that its green hydrogen project in Minneapolis was operational. The project uses renewable electricity to safely split hydrogen from water, and the zero-carbon hydrogen is then blended at low concentrations with natural gas in the utility's local distribution system.
- The project’s 1MW electrolyzer is powered by renewable electricity and can produce up to 432 kg H2/day, using approximately two gallons of water per minute. The water is sourced from the municipal water supply and highly purified before it enters the hydrogen production system.

Content

- GTI Energy Introduction
- Hydrogen Blending Overview
- GTI Energy Projects Introduction
  - Lab Appliances Studies
  - Field Appliances Studies
- **Summary**

Summary

- There is an increasing attention (funding) on hydrogen demonstrations from both government and private sectors
- Federal hydrogen hubs are at the end of negotiation stage, and local hydrogen hubs are at different stages (training facility, neighborhood demonstration, city gas grid blending, etc.)
- NOx emission regulations has been a driving factor for combustion technology advancement and stricter regulations will be seen/adopted
- More reliable (high efficiency, low emissions, fuel-flexible, etc.) end-use equipment are in demand

More information

Delta
Utah

https://www.dominionenergy.com/our-stories/hydrogen-blending-delta-ut

Henderson
Nevada

https://www.swgas.com/en/news/swgas-announces-groundbreaking-hydrogen-blending-pilot-program

Minneapolis
Minnesota

https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/centerpoint-outlines-rng-hydrogen-pilots-in-1st-minn-gas-innovation-plan-76363662

Ohio, Pennsylvania, etc.

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HYDROGEN TECHNOLOGY CENTER

https://www.gti.energy/hydrogen-technology-center/

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Acknowledgements:

OTD Operations Technology Development

UTD Utilization Technology Development

GTI ENERGY EMERGING TECHNOLOGY PROGRAM (ETP)

LCRI LOW-CARBON RESOURCES INITIATIVE

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