GTI ENERGY

solutions that transform

U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration

GTI Energy – Hydrogen Project Updates and Industry Needs

Dennis Jarnecke – Sr. Director of R&D

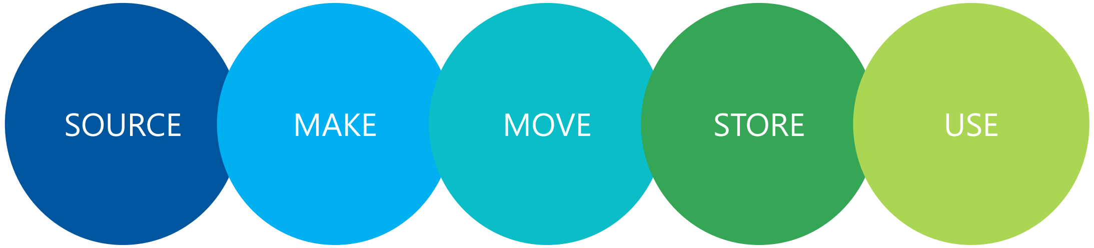
DOT PHMSA R&D Forum | October 31, 2023

GTI Energy Overview

Serving the Energy Industry Since 1941

- GTI Energy is a leading research and training organization focused on developing, scaling, and deploying innovations that support low-carbon, low-cost energy systems.
- Our energy solutions transform lives, economies, and the environment.
- Technology development focus on safety, improving efficiency, and reducing emissions
- Research Facilities
  - 18-acre campus near Chicago
  - Laboratories in Agoura Hills, CA & Davis, CA
  - Pilot and demo facilities worldwide

Across the entire energy value chain



GTI's Energy Delivery R&D Program

GTI ENERGY

- GTI has an expanding R&D portfolio focused on industry priorities:
  - **Safety, Integrity, Reliability, Operational Efficiency, and the Environment**
- Collaborative R&D efforts:
  - Highly cost effective
  - Leverages collective intelligence and experience of funders to develop the best possible solutions

- SAFETY & RISK MANAGEMENT
- DIGITALIZATION & DATA UTILIZATION
- MINIMIZING METHANE EMISSIONS
- EXPANDING ROLE FOR RENEWABLE GAS & H2

U.S. DEPARTMENT OF ENERGY

PHMSA

OTD Operations Technology Development

CALIFORNIA ENERGY COMMISSION

Hydrogen in a Pipeline Network: Is it Feasible?

GTI ENERGY

Can I Transport H2 in My Pipelines?

What are the Economics?

What is the End Use Impact of Hydrogen Injection?

What are "Lifecycle" and Social Benefits of Hydrogen Injection

Are There Adverse Impacts on Material

Is Gas Leakage Manageable?

Source Documents: NREL, "Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues", Melaina, Antonia, and Penev, March, 2013

LCRI
LOW-CARBON RESOURCES INITIATIVE

EPRI

GTI ENERGY

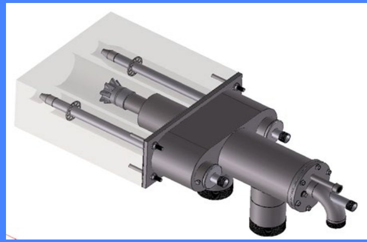
Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis

www.lowcarbonLCRI.com/netzero

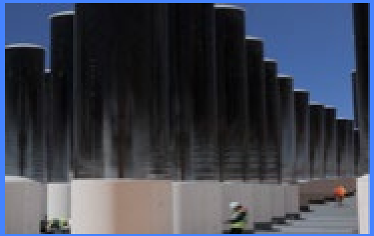
Current LCRI Technology Demonstration Portfolio

LCRI LOW-CARBON RESOURCES INITIATIVE

H_2 Production from Nuclear



Advanced Oxy-Combustion



Direct Air Capture of CO_2

Flexible Gasification for Generation

Moving-Bed Gasifier Performance

H2@Scale Electrolyzer

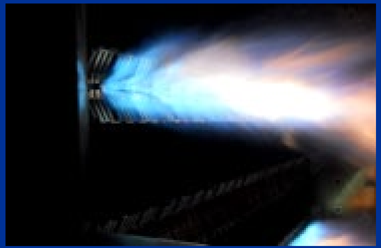
H_2 Storage for Flex Fossil Power Gen

Integrated H_2 Energy Storage

H_2 Grid Integration and Scaling

HyBlend Pipeline Demos

H_2 Negative Emissions Demonstration



H_2 Storage for Load Following

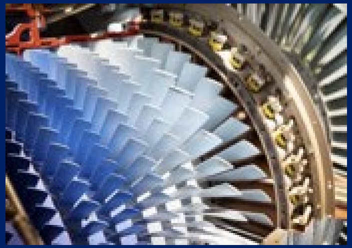
H2@Scale H_2 Fueling Station

H_2 Leak Monitoring

H2@Scale Fuel Cell Demo

H2@Scale SMR from Landfill Gas

H_2 Locomotive



H_2 in Combustion Turbines and RICE

www.lowcarbonLCRI.com

EPRI GTI ENERGY

HYDROGEN TECHNOLOGY CENTER

Investing in Resources and Capabilities

Talent

- Added Technical Staff
- Energy Transition Manager/Market Analyst
- Large Scale Project Development

Facilities

- Exterior H2 Test “pad”
- H2 Res/Com Lab
- Hydrogen Generator Pilot
- H2 Infrastructure – Simulated piping system
- Hydrogen Production

Assessing H2 Compatibility with Natural Gas Delivery Infrastructure

GTI ENERGY

Scope of current GTI research

- Evaluated effects of hydrogen-natural gas blend on steel and non-metallic **material properties** and **operational safety**
- Determine **safety factors** for hydrogen gas systems need to be established based on materials tests
- Develop **engineering tools** to allow an integrity assessment and a safety margin determination of hydrogen blended gas use
- Determine **operational impacts** of a hydrogen blend in pipelines, such as leak detection, surveys, emergency response
- Complement ongoing work at National Labs

HyBlend U.S. DEPARTMENT OF ENERGY

OTD Operations Technology Development

UTD Utilization Technology Development

The Flame of Innovation SMP

U.S. DEPARTMENT OF ENERGY

U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration

Material Properties most affected
Toughness
Reduction in Area
Crack Growth Resistance

Hydrogen - Codes and Standards -

GTI ENERGY

Hydrogen concentration in natural gas networks	Applicable standard to comply with 49 CFR parts 191 and 192	
No mention of H2	ASME B31.8-2020	Rules for Gas Transmission and Distribution Piping Systems (Natural Gas)
10% to 100%	ASME B31.12-2019	Primarily covers metallic components. Revisions necessary for natural gas network assets not covered in the standard.

Current GTI work focusing on H2 codes and standards

- Addressing gaps in US Codes, Standards and Regulations for hydrogen blending and pipeline repurposing
- Using work in UK, Europe, Japan and Australia as benchmark approaches

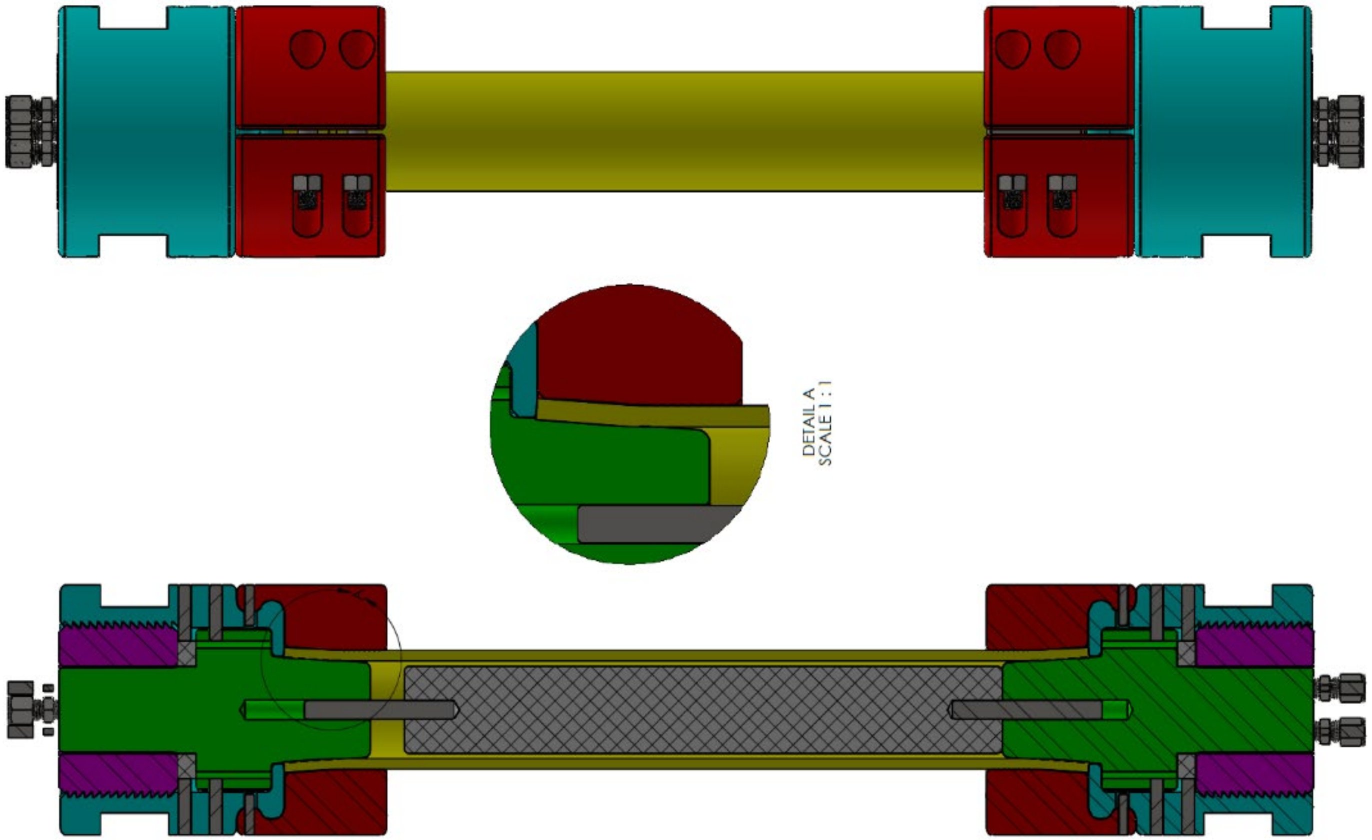
Research on Hydrogen Blending Impact – GTI Projects

"Hydrogen Blending Impact on Aldyl-A and M8000 Pipes"

- Objective – To develop a lifetime prediction and risk model for Aldyl-A and vintage HDPE pipes
  - Remaining life of Aldyl-A and other vintage HDPE pipes exposed to 20% hydrogen blend.
- The new test rig for testing pipes with hydrogen blends will also accommodate future investigation of joints/fittings, leak rates, and permeation rates.
  - Temp. of 23°C to 90°C – Pressure 0-500 psig.

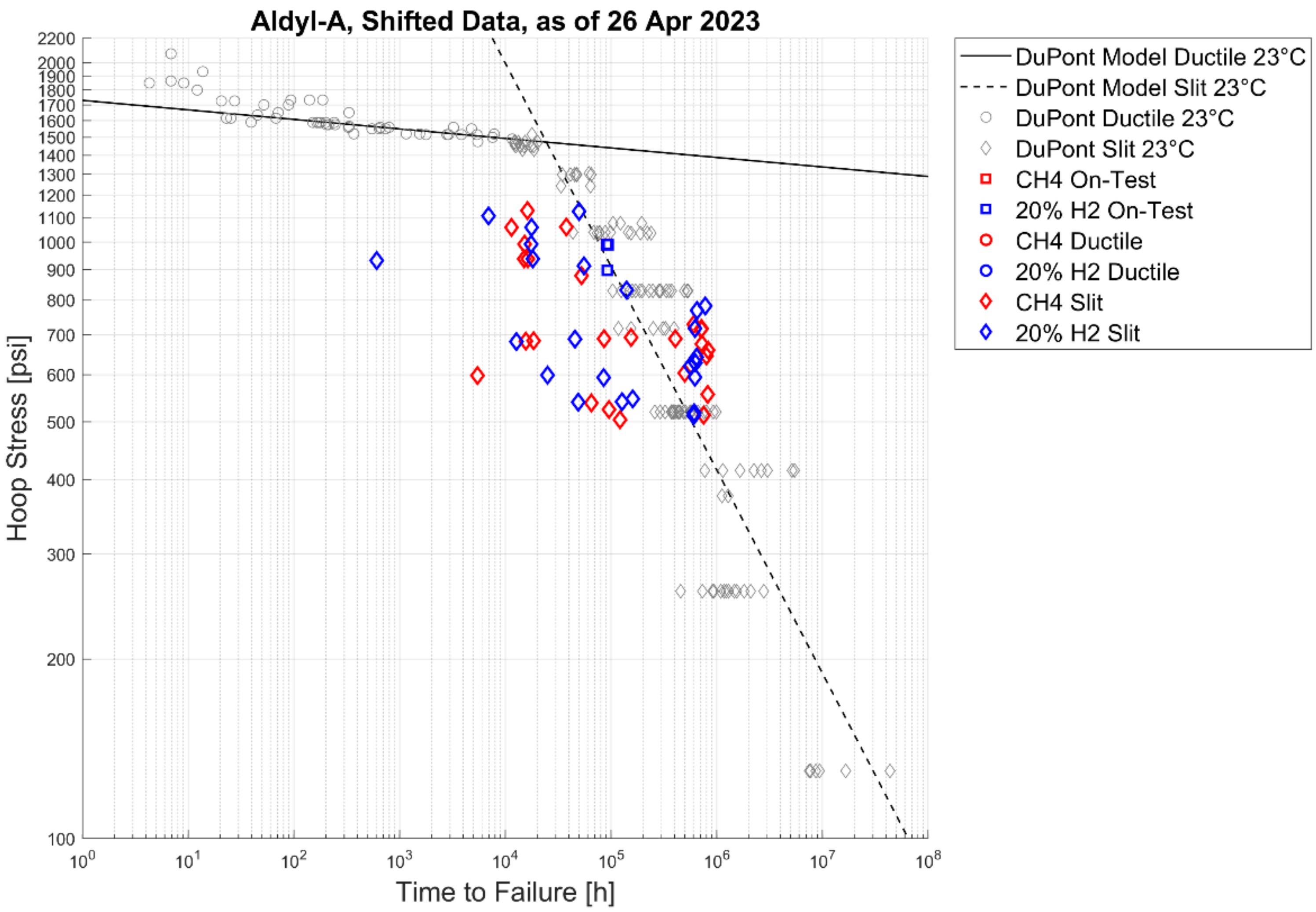
Test Apparatus for Gas Pressure Testing of Pipes - Continued

- Custom pipe cap design that:
  - Avoids use of elastomeric seals – we only want to test the PE pipe.
  - Enables use of a volume filler to minimize both gas consumption and gas release upon failure.



Results Thus Far

- Obtained 49 (of 54) Aldyl-A failures to date:
  - 25 with CH_4
  - 24 with 20% H_2 blend
- All failures are slow-crack-growth (SCG) slit-mode failures, as targeted.



GTI Energy Research on Hydrogen Blending's Impact on PE – Findings to Date

GTI ENERGY

- Testing of modern TR-418 MDPE (PE2708) in the ductile regime found a 6.2% stress drop off in the mean ductile performance line when testing with a 20% H2 blend.
- Testing of pre-1981 Aldyl-A MDPE (PE2306) in the slow-crack-growth (SCG) regime found a mean percent increase in equivalent stress intensification factor (SIF) of 7.3% when testing with a 20% H2 blend.
- Both findings above are commensurate with PNNL findings of reduced stiffness in PE nano-indentation tests after exposure to hydrogen.
  - The reduced stiffness (softening) could be due to greater mobility of the amorphous region of the polymer, which would also explain the accelerated SCG.
- Testing of electrofusion saddles fused to pipes saturated and pressurized with 20% H2 blend did not find an adverse effect on fusion quality.

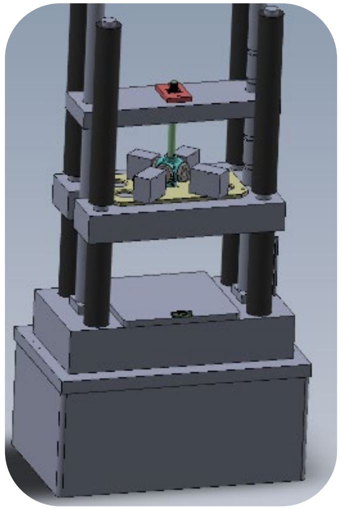
GTI Energy Research on Hydrogen Blending's Impact on PE – Next Steps

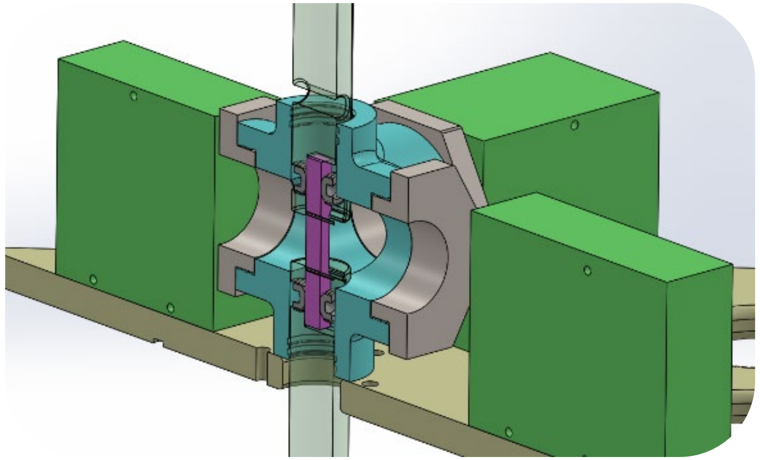
GTI ENERGY

- Testing of M8000 pipes is next on schedule.
- There is interest in testing:
  - Modern HDPE (PE4710) and modern MDPE (PE2708) with 100% hydrogen and 20-30% blends.
  - Ductile and SCG performance regimes in modern PE's.
  - Testing of PE pipe and various components
  - Testing of fusion quality with pipes carrying 100% hydrogen.

Metallic Material Research on Hydrogen Blending Impact – GTI Projects

- Effects of Hydrogen Blending – metallic materials and operational safety
  - Literature review and summary findings
  - Test campaign for materials and operating conditions based on operator priorities
  - Conduct in-situ physical testing to assess the impacts of hydrogen blended fuel on metallic materials





  - Develop engineering tools to allow an integrity assessment and a safety margin determination of hydrogen blended gas use.

Additional Research on Hydrogen Blending Impact – GTI Projects

GTI ENERGY

- Impact of H2 Blends on Meters and Metering Assembly Components
  - Testing meter-sets, service regulators, and threaded connections on MSAs.
  - Created two test rigs for flow recirculation of various H2 blends.
- Evaluation of new “smart meters” and performance with various H2 blends
  - Ultrasonic meters
  - Thermal mass flow meters
- Testing various components for blended and 100% hydrogen service

Operational Impacts of Hydrogen Blending

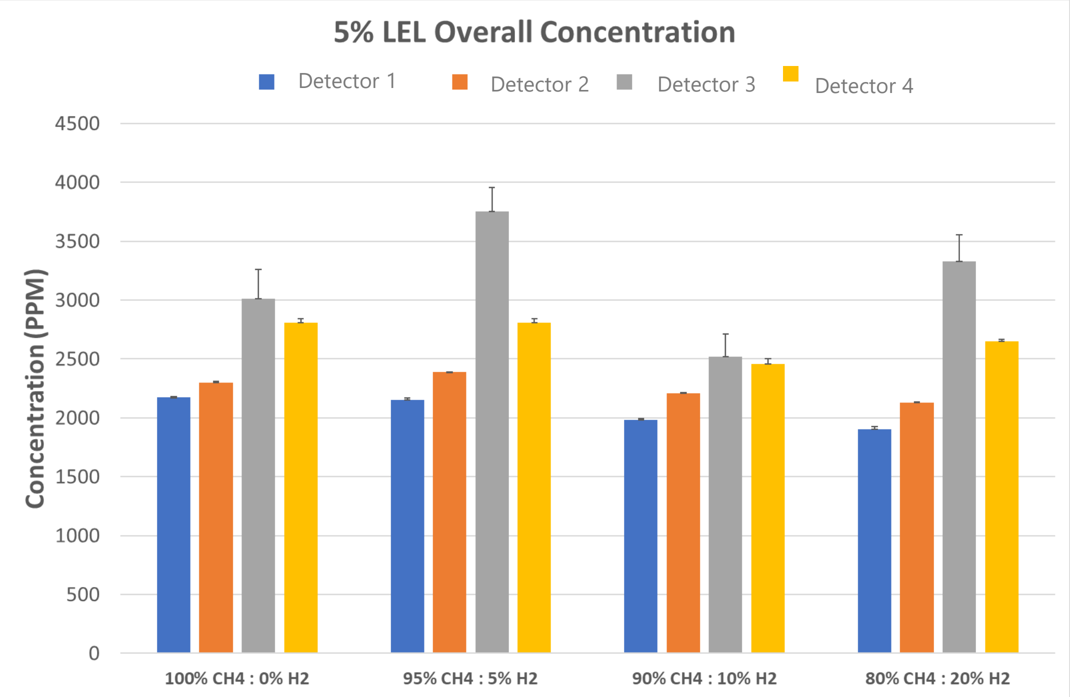
GTI ENERGY

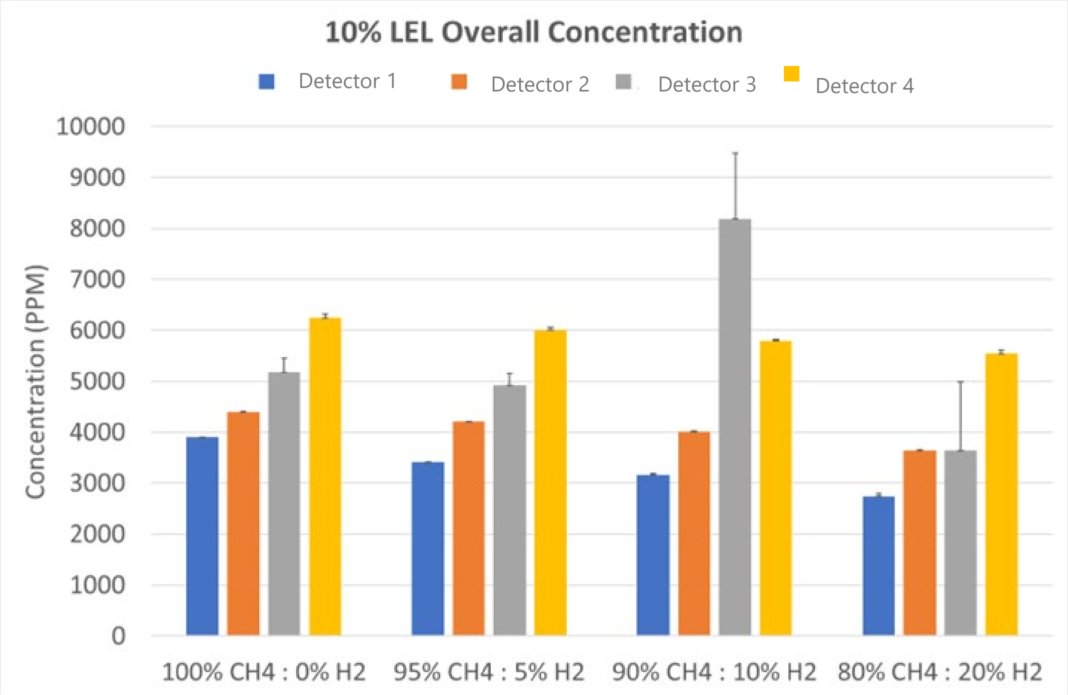
- Leak detection
- Operating pressure
- Compression, flow, and capacity
- Metering
- Gas quality
- Welding, joining, hot tapping, stopping, squeeze-off, and purging
- Education and training of workforce, contractors, and first responders

Effects of Blended H2/NG on Natural Gas Leak Detection Equipment

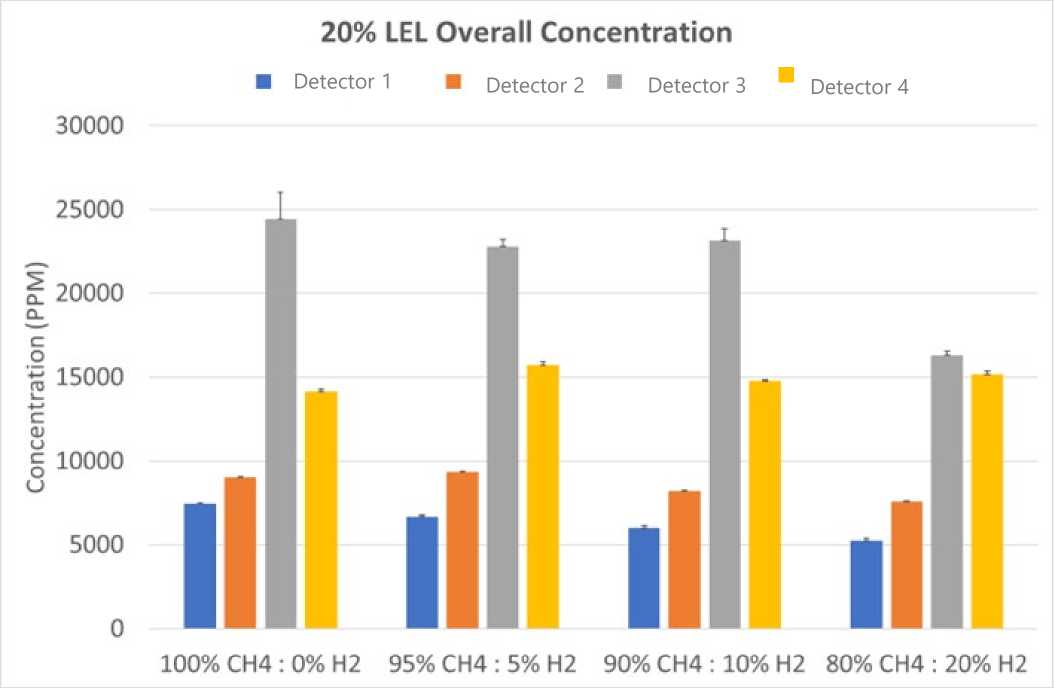
Objective: To determine the change in reported concentrations of a leak detection device when hydrogen was introduced.

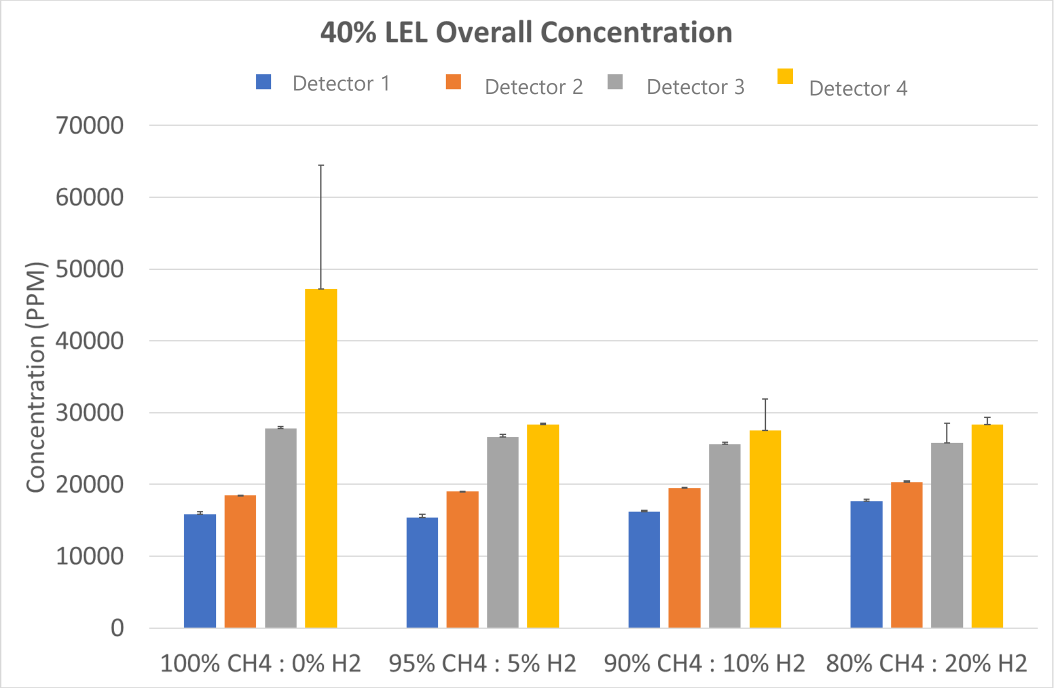
- Specific blends of H2/NG including 0%, 5%, 10%, and 20% hydrogen
- At four concentrations: 5% LEL, 10% LEL, 20% LEL, and 40% LEL.





Effects of Blended H2/NG on Natural Gas Leak Detection Equipment (continued)





<u>Summary:</u> All devices were able to still detect the various gas concentrations up to 20% blended H2 with Natural Gas.

- The variation across blends and concentrations was greater than any differences introduced by the hydrogen blend.
- The difference between the reported concentrations and the GC concentrations across the sensors was higher than any difference driven by changes due to a hydrogen blend.

DOT PHMSA Project on Detection

GTI ENERGY

- Title: "Advancing Hydrogen Leak Detection and Quantification Technologies Compatible with Hydrogen Blends"
- Objective: Advance leak detection as hydrogen is introduced into natural gas infrastructure which will be realized through five different areas of effort

1. Evaluate leak detection equipment currently used by natural gas pipeline operators
2. Provide guidance on new/altered usage protocols
3. Map out any threshold of hydrogen blending above which these devices become ineffective
4. Map out the impact of varying amounts of hydrogen on the calibration and analytics of currently used leak detection equipment
5. Develop a proof-of-concept hydrogen detection scheme to fill any gaps identified by the project team

DOT PHMSA Agreement 693JK32210004POTA

Existing Leak Detection Methodologies and Equipment

Sensor Type	Range	H_2 Effect on Calibration	H_2 Damage to Sensor	Gas	Primary Mode of Use
Thermal Conductivity	%Gas	1	No effect	H_2 CH_4	Walking
Catalytic	LEL ppm	1, 3	Damage possible at high levels	H_2 CH_4	Walking, Fixed
MOS	ppm	1, 3	Damage possible at high levels	H_2 CH_4	Walking
Flame Ionization (FID)	ppm	1	No effect	H_2 CH_4	Walking, Mobile
Electrochemical	ppm	2, 3	Damage possible at high levels	CO O_2 H_2S	Confined space
Mass Flow	LPM	1	Not evaluated	CH_4	Odor Concentration
Laser Infrared	ppm.m	0	No effect	CH_4	Walking, fixed, mobile
NDIR	LEL %Gas	0	No effect	CH_4	Walking, fixed
Etalon	ppm %Gas	0	No effect	CH_4	Walking, mobile

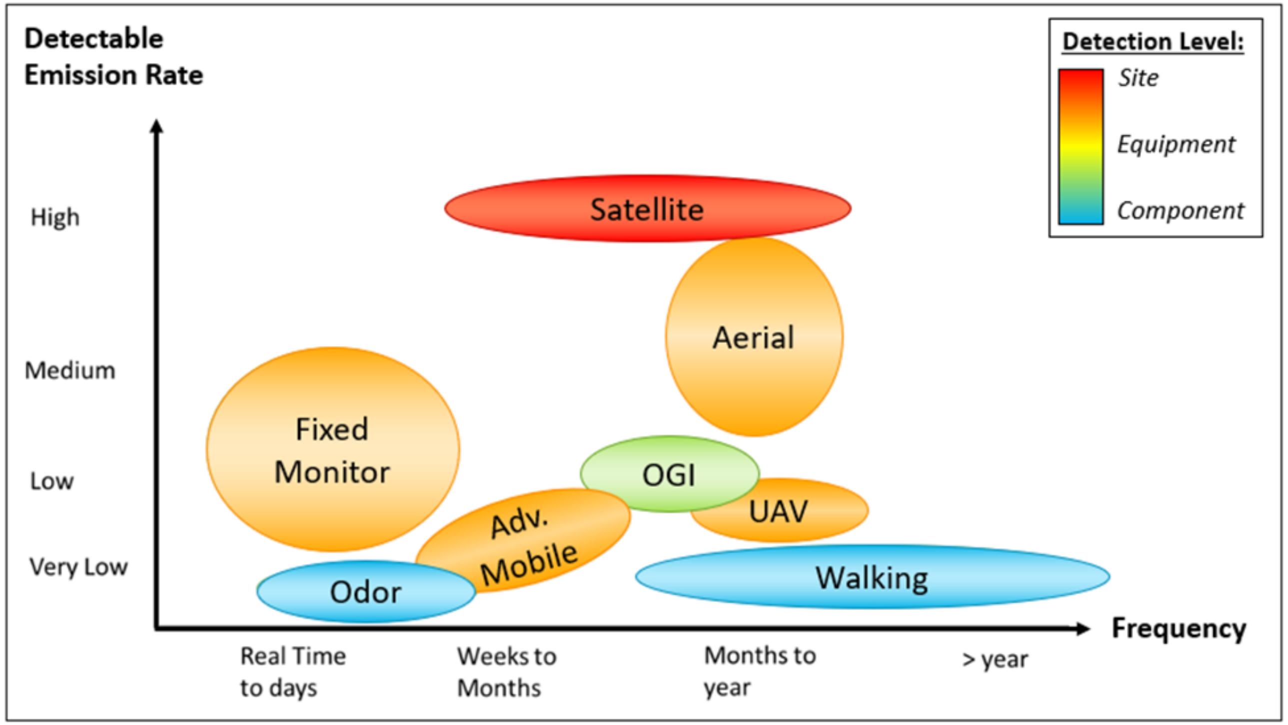


Table Notes:
0: Calibration specific to methane, not affected by other gas types. Will underreport flammable gas levels with hydrogen blends.
1: Calibration accuracy specific to gas ratio of calibration gas. If calibration gas is methane, then blended gas will read higher/lower, error increasing with percent of blend
2: Large cross sensitivity possible. Will produce false positive or false negative reading
3: Significant effects if exposed to high concentrations, may cause permanent damage

Leak Detection Impacts – Existing Methods & Equipment

GTI ENERGY

- **Odorization**
  - Studies suggest some odorants can continue to be effective when H_2 is present
  - Need to validate if a person can continue to readily smell a gas blend at one-fifth LEL
- **Electrochemical sensors (CO, O_2, H_2S)**
  - Cross-sensitivity can lead to false positives or negatives
- **Thermal conductivity, catalytic, MOS, flame ionization, and mass flow sensors**
  - If calibration gas is methane, then blended gas will read higher, increasing blend%
- **Infrared and etalon sensors**
  - Calibration specific to methane and not affected by other gas types; will underreport flammable gas levels with H_2 blends

Equipment Technical Specifications and Requirements for Hydrogen Blends

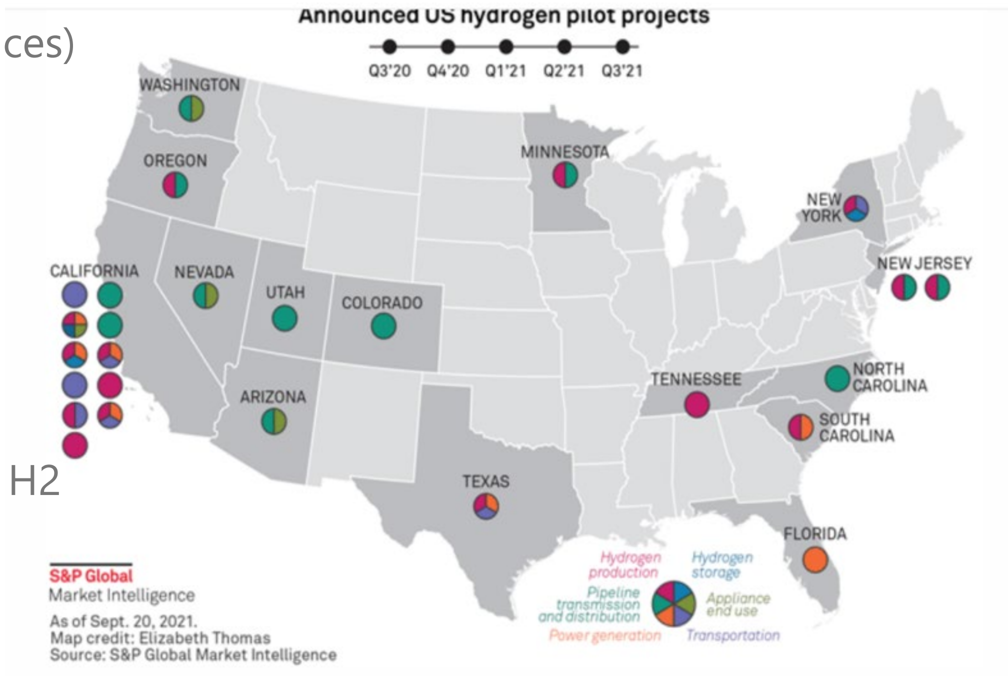
GTI ENERGY

Parameter	Notes
Accurate/Repeatable	Is the technology accurate in general or for methane, hydrogen, or blends? What change in accuracy will hydrogen induce?
Cross Sensitivity/Selectivity	Can distinguish between chemical species? What change in sensitivity will hydrogen induce?
Detection Range	What change in detection range will hydrogen induce
Minimum Detection Limit (MDL)	Does the introduction of hydrogen impact the minimum level of gas that the technology measures
Response/Recovery Time (T90/T10)	Will hydrogen reduce the response rate of the sensor?
Robustness/Reliability	Is the sensor robust to be used for leak detection in the field?
Hazardous Location Certification	Can the technology be potentially made "intrinsically safe"
Power Consumption	How much power does the technology need? Could this be prohibitive for leak detection?

Stages of Utility Hydrogen Blending Pilots

GTI ENERGY

– **Planning for blending into in-service utility systems** (from 1% to 20%)
  - System engineering design and material and component review (tolerances)
  - Sources of supply and blending options
  - Operational considerations (purging, leak detection, odorization, etc)
– **Operating and testing in simulated distribution system**
  - Testing of materials (exposed and not exposed to various blends of H_2)
  - Appliance testing and exhaust emissions analysis
  - Review of safety procedures and equipment related to various blends of H_2
– **On-line blending into customer serving distribution systems**
  - Dead-end or isolated portions of system
  - Well understood customer base and end-use equipment
  - Strive for operating experience gains, customer education, & variety of other reasons
– **Monitoring and assessing active blending operations**
  - End Use equipment performance
  - Material Impacts
  - Operational Procedure Lessons
  - Stakeholder, Regulators, Public, etc Reactions



Utility Hydrogen Blending Pilots

GTI ENERGY

Several Operators have initiated H2 / NG blending pilots:

- GTI supporting operators in simulating distribution system
  - Testing of materials (exposed and not exposed to various blends of H2)
  - Appliance testing and exhaust emissions analysis
  - Review of safety procedures and equipment related to various blends of H2
- Providing various operators with engineering design and analysis prior to conversion (pilot) to hydrogen blends up to 20% and beyond.
  - Material and component review (tolerances)
  - End use equipment selection
  - Sources of supply and blending options
  - Operational considerations

Supporting and consulting on various H2 demonstration projects

Hydrogen Utility Pilot Trial – New Mexico Gas

- Albuquerque Training Town H2/NG blending pilot:
  - Initiated H2 blending pilot in isolated training facility to simulate real world conditions
  - Gain knowledge to inform phase 2 – H2 blending with NG into distribution system
- Pilot Project Objectives to validate the following:
  - Pipeline operations
  - Material compatibility
  - Appliance compatibility
  - Leak detection
  - Gas quality impacts

Blended Fuel Impacts with NG-Equipment

GTI ENERGY

- **Field R&D growing** as complement_to lab-based testing of H_2 blend impacts
  - – Field sampling from wide range of building equipment in NM, UT, etc. in 2023
  - – Covers higher blends (15%+) and in-field samples in ~2,000 customer trial
    - Will measure leakage, equipment impacts, blend homogeneity
  - – Monitoring other trials (e.g. ATCO Fort Sask.)
- **GTI moving ahead** in 30-unit Las Vegas demo
  - – Central/wall furnaces, space/water heaters, cooking, dryers, outdoor heating, and decorative appliances
  - – Test planning/procurement underway, along with design for 8 test stands, ½ automated for long-duration impacts – including leakage

UTD Utilization Technology Development

SOUTHWEST GAS

UNLV

AHRI

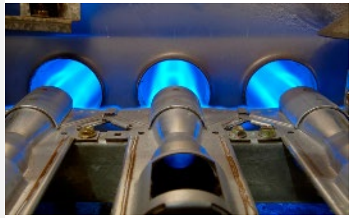
AHAM ASSOCIATION OF HOME APPLIANCE MANUFACTURERS

ThermH$_2$™ (Dominion Energy Utah Distribution H_2 Blending Pilot)

GTI ENERGY

Objective

- Inject up to 5% H_2 into a primarily plastic distribution system in Delta, Utah, feeding a community of approximately 2,000 customers
- Help validate any impacts to customer equipment and leakage
- Provide insights to operations and performance of H_2 production and blending equipment



Value

- Provide knowledge and lessons learned to support LCRI members who are planning to conduct their own H_2 blending pilots
- Develop recommended practices from the ThermH$_2$™ project development and execution
- Takes findings from Phase 1 demonstration to the field for validation and further learnings

ThermH$_2$ – Phase 1 Facility, DEU Training Academy.

Key Research Questions to be Addressed

- Would a hydrogen blend result in additional leaks?
- To what extent does a 5% H_2 blend vary throughout the gas network?
- Does end use equipment show a significant difference in flame stability, safe operation, emissions of NOx and CO, surface and process temperatures, and performance?

Key Tasks

- Compare leakage datasets from prior to and during blending
- Conduct fuel mixture homogeneity measurements
- Evaluate end use equipment performance and emissions prior to and during blending
- Collect and analyze performance data from H_2 production and blending facility

Lessons Learned from Blending Pilots

GTI ENERGY

- Existing leak detection equipment performs well, some recalibration may be needed depending on sensor technologies employed.
- Hydrogen was found to interfere with carbon monoxide (CO) sensors in some multi-function detectors, but % LEL not impacted.
- Appliance performance and emissions show no significant differences within the limits of field measurements (validation that ambient temperature, wind, humidity, and other weather conditions are difficult to compensate for in the field)
- Achieving a blend can be accomplished in many ways, so cost, logistics, availability, and run time duration, among other things need to be considered.
- Increased hydrogen in the natural gas infrastructure may require changes in operations, engineering design, system maintenance procedures, etc, and limits must consider end use equipment tolerances.

Hydrogen Needs & Gaps

GTI ENERGY

- Embrittlement and other H2 material impact concerns for LDC; a lot of emphasis for transmission companies but what about distribution operating conditions?
  - H2 impacts based on pressure, material type and age, and H2%.
- What are the actual impacts of H2 on GHG emissions?
- Operational impacts/changes for H2/NG blends and 100% H2.
  - Welding, joining, hot tapping, stopping, squeeze-off, and purging, etc.
- Efficacy of internal pipe coatings to mitigate hydrogen impacts
- Leaks grading; how will categorization of leaks be different with hydrogen?
- Development and/or evaluation of interior pipe coatings to act as a barrier for H2
- New education and training will be required for workforce, contractors, and first responders

GTI ENERGY

solutions that transform

Questions / Comments

GTI Energy develops innovative solutions that transform lives, economies, and the environment

Dennis Jarnecke
Sr. Director R&D
djarnecke@gti.energy
847-768-0943

www.gti.energy