Effects of Hydrogen Blending & Hydrocarbon Permeation on Plastic Pipe

Presented by
Chris Ampfer, P.E., of WL Plastics

On behalf of
Randy Knapp, Director of Engineering
Plastics Pipe Institute Energy Piping Systems

2022 Public Service Commission of Wisconsin
Pipeline Safety Seminar
February 9-11, 2022
Chula Vista, Wisconsin Dells
Hydrogen Blending

- Effects to PE Pipe
- Initiatives and Research
Changing Landscape for Energy Piping

- Worldwide push to reduce greenhouse gas emissions – carbon neutral by 2050
- PHMSA’s Methane mitigation efforts
  - Advisory bulletin (ABD-2021-01) – update inspection and maintenance plans by YE 2021
  - NPRM likely later this year dealing with methane mitigation and monitoring
- Responsibly Sourced Gas (RSG) certification by 3rd party is the latest trend
- Push to use alternative gas is accelerating
  - Renewable Natural Gas (RNG) from decomposition of waste
  - Synthetic Natural Gas (SNG) from coal or coke
  - Hydrogen (H2)
- Can the existing natural gas piping infrastructure support H2?
HYDROGEN PRODUCTION

Hydrogen can be produced via:

- **Steam methane reforming (SMR)** – natural gas (CH₄) is heated to between 700–1100 °C in the presence of steam and a nickel catalyst to split hydrogen from carbon. Nearly 50% of the world's hydrogen is being produced by this method.

- **Biomass gasification** - heat, steam, and oxygen are used to convert organic waste to hydrogen and other products, without combustion.

- **Electrolysis** - electricity is used to split water into H₂ and O₂.

- **Direct solar water splitting** - light energy is used to split water into H₂ and O₂.

- **Biological processes** - microbes such as bacteria and microalgae can produce hydrogen through biological reactions, using sunlight or organic matter.
### H₂ Heating Value

<table>
<thead>
<tr>
<th>Gas</th>
<th>Gross Heating Value (Btu/FT³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Gas</td>
<td>149</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>323</td>
</tr>
<tr>
<td><strong>Hydrogen (H₂)</strong></td>
<td><strong>325</strong></td>
</tr>
<tr>
<td>Coke Oven Gas</td>
<td>574</td>
</tr>
<tr>
<td>Landfill Gas</td>
<td>476</td>
</tr>
<tr>
<td>Sewage Digester Gas</td>
<td>690</td>
</tr>
<tr>
<td><strong>Natural Gas</strong></td>
<td><strong>950 to 1150</strong></td>
</tr>
<tr>
<td>Methane</td>
<td>1011</td>
</tr>
<tr>
<td>Propane</td>
<td>2572</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gas Mixture</th>
<th>%H₂</th>
<th>%Natural Gas</th>
<th>Gross Heating Value (Btu/FT³)</th>
<th>Required Pipe Size Increase to Carry same BTU Value as NG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>100%</td>
<td>1000</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>95%</td>
<td>966</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>90%</td>
<td>933</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>85%</td>
<td>899</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>80%</td>
<td>865</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>75%</td>
<td>831</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>30%</td>
<td>70%</td>
<td>798</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>60%</td>
<td>730</td>
<td>37%</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>50%</td>
<td>663</td>
<td>51%</td>
</tr>
<tr>
<td></td>
<td>60%</td>
<td>40%</td>
<td>595</td>
<td>68%</td>
</tr>
<tr>
<td></td>
<td>70%</td>
<td>30%</td>
<td>527</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>20%</td>
<td>460</td>
<td>117%</td>
</tr>
<tr>
<td></td>
<td>90%</td>
<td>10%</td>
<td>392</td>
<td>155%</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>0%</td>
<td>325</td>
<td>208%</td>
</tr>
</tbody>
</table>
Critical Role of Pipelines

- Columbia University Center on Global Energy Policy found that investing in the natural gas pipeline network could be crucial to helping the U.S. reach the 2050 zero emission goals
  - Fortifying and upgrading the system could prepare the infrastructure to transport zero-carbon fuels and, in the mean-time, reduce methane leaks
  - A 20% H2 blend rate would require more capacity than is currently available in the U.S. pipeline network – we will need more pipelines!
- The existing network of gas piping provides a vast system for storing and delivering energy produced from a variety of sources
- Plastic used in gas distribution continues to grow and can help future-proof the system
As of 2020
~ 787,424 miles of plastic mains
~ 718,815 miles of plastic services
~ 52.3 MM plastic services

Source: AGA 2021 (using PHMSA 2020 Annual Data)
H2 and Plastic Piping

- PE and PA 12 pipes can transport H2 safely and reliably
- H2 does not change short or long-term mechanical properties of PE and PA12
  - No Hydrogen embrittlement
  - No change in long-term strength
  - No change in SCGR
- EF joining:
  - Normal electrofusion procedure can be followed without issue.
- Squeeze off testing on PE pipes showed that H2 exposure does not compromise the pipeline’s integrity to be isolated
- Permeation
  - Permeation rate of H2 through PE is about 5 to 8 times greater than methane
  - Economic impact is negligible
  - A 32mm (1.26” OD) MDPE pipe operating at 58 psig could lose 54 Cf of natural gas per mile per year
H2 and Plastic Piping

Approximate Gas Permeation Rate Through Polyethylene at Ambient Temperature

<table>
<thead>
<tr>
<th>Piping Material</th>
<th>Methane</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE2XXX *</td>
<td>4.2x10^{-3}</td>
<td>2.1x10^{-3}</td>
</tr>
<tr>
<td>PE3XXX *</td>
<td>2.4x10^{-3}</td>
<td>1.6x10^{-3}</td>
</tr>
<tr>
<td>PE4XXX *</td>
<td>1.9x10^{-3}</td>
<td>1.4x10^{-3}</td>
</tr>
</tbody>
</table>

*PE 2XXX, PE3XXX and PE4XXX denotes all PE's that comply, respectively, to the density cell classification 2, 3, or 4 in accordance with ASTM D3350.

Table 14. The Permeation Coefficient and the Calculated Gas Loss from a 32 mm (1.26") PE80 Pipe Under the Pressures of (58 psig (4 bar), 116 psig (8 bar) and 174 psig (12 bar))*

<table>
<thead>
<tr>
<th>Gas</th>
<th>Pressure (psig)</th>
<th>Time-Lag (day)</th>
<th>Permeation Coefficient ((x10^{-8} ft^3-mil/ft^2/day/psig))</th>
<th>Gas Loss ((ft^3/mile/year))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(CH_4)</td>
<td>(H_2)</td>
</tr>
<tr>
<td>Pure CH(_4)</td>
<td>58</td>
<td>6.46</td>
<td>NA</td>
<td>0.18</td>
</tr>
<tr>
<td>90% CH(_4) + 10% H(_2)</td>
<td>58</td>
<td>4.31</td>
<td>0</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>116</td>
<td>6.39</td>
<td>0</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>174</td>
<td>5.69</td>
<td>0</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Note:
* The original data in this table are from the experimental test results in the paper of “Evaluation of the Permeability to \(CH_4\) and \(H_2\) of PE Currently Used in Gas Distribution Networks” [18], and are converted to the English unit.
• Currently 1600 miles of H2 pipeline (700 miles under PHMSA jurisdiction)
• PHMSA in cooperation with DOE, DOC, NIST, and others developing a national hydrogen energy roadmap
• Gas utilities looking at blends using natural gas as a carrier gas for delivering hydrogen - starting with small amounts of H2 (1%, 2%, 5%) to test effects on the systems and operating procedures
• Hawaii Gas has been using 10-12% hydrogen blending with SNG for almost 50 years!
• Open hydrogen code questions: gas quality requirements, blend percentages, material compatibility (especially high strength steel), monitoring (permeation rates) inspection, maintenance/repair, and system safety considerations
U.S. Department of Energy (DOE) initiative that brings together stakeholders to advance affordable hydrogen production, transport, storage, and utilization to enable decarbonization and revenue opportunities across multiple sectors.
Utility Hydrogen Initiatives

Selective Early-Stage Hydrogen Initiatives at U.S. Gas Utilities

Natural gas pipelines can serve as the necessary and widespread delivery infrastructure for hydrogen.

**Sempra Energy California**
- Announced plans to introduce a 1 percent blend of green hydrogen into its natural gas stream, with aspirations to reach a 20 percent blend at its two California utilities.

**NW Natural Oregon**
- Developing a project to produce green hydrogen and pair the locally produced supplies with carbon dioxide to create synthetic natural gas.

**CenterPoint Energy Inc. Minnesota**
- Preparing to launch a pilot project to produce green hydrogen and flow a less than 1 percent blend to customers through its gas distribution system.

**Dominion Energy Inc. Utah**
- Conducting a demonstration project to test hydrogen blends in pipeline systems, with plans to distribute synthetic natural gas made from green hydrogen.

**New Jersey Resources Corp. New Jersey**
- Developing a renewable hydrogen demonstration project to study natural gas blending and raise awareness among policymakers and regulators.

**Southern California Gas Co., One Gas Inc. Texas**
- Participating in the U.S. Energy Department H2@Scale project to demonstrate commercial hydrogen production, distribution, storage and consumption.

**National Grid PLC New York**
- Participating in a hydrogen blending study with Stony Brook University and the New York State Energy Research and Development Authority.

Hydrogen Activity

- **AGA PMC**
  - Formed a TG to develop a White Paper on the impact of H2 blending
  - TG reviewing all potential material impact (non-operational aspects)
    - Steel, PE/PA, Meters & Regulators, Fusion, Valves, etc.
  - Sub-TG focused on PE/PA systems
  - Coordinating efforts with CGA

- **Canadian Standards Association (Z662 and B137.4)**
  - Part of a larger CGA/CSA effort to implement H2 blending in Canada
    - Also looking at RNG
  - Review of CSA Z662 and B137.4 to propose changes that provide for the use of blended gas distribution
  - Sub-TG focused on plastic materials including elastomers
  - Supporting research efforts

**DRAFT STANDARD**

Z662
Oil and gas pipeline systems
PPI Hydrogen Task Force

• PPI has formed a new H2 TF
  • Increase understanding of potential impacts of H2 on plastics and polymers
  • Provide support for ongoing industry efforts at CSA and AGA
  • Develop Q&A and technical documents
  • Support research efforts
National Hydrogen Research

- HyBlend Project to Accelerate Potential for Blending Hydrogen in Natural Gas Pipelines
  - National Renewable Energy Lab (NREL) – provides H2 data, tools, and maps
  - Pacific Northwest National Labs (PNNL) – focus on plastics
  - 18 other labs and university partners

- Sandia National Labs: H-Mat: DOE/EERE Energy Materials Network to address material compatibility questions

- Pipeline Research Council International (PRCI): State of the Art Analysis (SOTA) and Gap analysis on blending hydrogen into natural gas systems (Nov. 2020)
Ongoing Hydrogen Research

- Existing research and experience using plastic piping (PE and PA) in hydrogen blended systems is positive
- Critical pipeline system components, end-user equipment tolerances, and operating considerations are key areas of investigation
- Gas Technology Institute (GTI) is a subcontractor for the University of California Riverside, conducting a project for the California Public Utilities Commission
  - Long-term hydrostatic strength (LTHS) testing of a common MDPE with three hydrogen/methane blend ratios (5%, 12.5%, 20%) and 100% methane.
  - LTHS testing will include testing of Nitrile rubber (NBR) elastomers.
  - Vintage materials - Impact of hydrogen blending on Aldyl-A and HDPE pipes - Remaining life when exposed to 20% hydrogen blend.
Liquid Hydrocarbon Permeation

Effects on PE and PA Pipes
Liquid Hydrocarbon Permeation

- Gas composition effects
- Chemical resistance of PE
- Impact on design pressure
- Impact on fusion joining
- Industry guidance – CSA and GPTC
Liquid Hydrocarbon Sources

- Pipe installed where the soil surrounding the pipe is contaminated with liquid hydrocarbons
  - May be from fuel spills or other ground contamination

- Liquid hydrocarbon condensates can form in gas pipelines from “drop out” from the natural gas
Absorption – Desorption Rates

GTI (2016) performed testing to determine the rate and depth that heavy hydrocarbons can permeate into the PE matrix, and also desorb under ambient conditions. PE samples were soaked in a 100% HHC mix at three test temperatures: 23°C, 60°C, and 80°C.

Tests concluded:

- HHC permeation rate increases as temperature increases. The rate increase is approximately 10x faster for material at 60°C (140°F) vs 23°C (73°F)
- Absorption rates are greater than desorption rates
- Desorption rates decrease as you move further into the pipe wall.
- HDPE absorbs and desorbs HHC slower than MDPE
- Bimodal MDPE absorbs and desorbs HHC slower than unimodal MDPE

Further research is needed. GTI is using these results to develop a risk calculator.
Effect on LTHS & SCG

Lang (2014) pressure tested PE100 and PEX pipe materials with mixtures of liquid hydrocarbon (LHC; 90/10 w-% i-octane/toluene) and deionized water for varying time durations up to 10,000 hours and at two test temperatures (35 °C and 60 °C). Results revealed:

- Reduction in long-term hydrostatic strength (LTHS) by approx. 50 % for LHC samples compared to samples tested with water
- LHC saturated samples indicate a superior SCG resistance compared to samples tested in water
- Pipes under severe media environment such as oil and gas (condensate) applications should be monitored in specified time frames

Note: GTI (2016) study indicated a 20% decrease in LTHS and that the softening effect of the HHC is equivalent to an increase in ambient temperature of 20° C
Chemical Resistance

PPI publication TR–19 (2020) lists the resistance of polyethylene to many chemicals. Data in TR-19 is based on fluid immersion tests followed by strength tests.

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Adversely Effects PE</th>
<th>Pressure Rating Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqueous solutions of salts, acids, and bases</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Sewage &amp; Wastewater</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Detergents, alcohols, glycols</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Oxidizers / Disinfectants (chlorine, chloramine)</td>
<td>Dependent on concentration, operating pressure &amp; temperature</td>
<td>See PPI TN-44 &amp; TN-49</td>
</tr>
<tr>
<td>Inert Gases (H, N, CO2, Air)</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Low MW Hydrocarbon gases (Methane, Hydrogen Sulfide)</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Liquified Petroleum Gas Vapors</td>
<td>Some softening/solvating</td>
<td>0.8</td>
</tr>
<tr>
<td>High MW hydrocarbons (LPG, crude oil, fuel gas condensate, gasoline, diesel fuel, kerosene)</td>
<td>Some softening/solvating</td>
<td>0.5</td>
</tr>
<tr>
<td>Aromatic hydrocarbons (benzene, toluene)</td>
<td>Yes, do not use PE pipe</td>
<td>NA</td>
</tr>
</tbody>
</table>
Pressure Rating (PPI PE Handbook, Ch. 6)

1. Dimensional Ratio (DR) Correlates Pressure Rating
2. DR = OD / t
3. Lower DR (Thicker Wall) equates to Higher Pressure Rating

\[ PR = \frac{2 \times HDS \times F_T \times A_F}{(DR-1)} \]

HDS = Hydrostatic Design Stress = HDB*DF
HDB = Hydrostatic Design Basis = 1600psi @73F for PE4710
DF for water and non-regulated gas = 0.63
DF for regulated gas pipe made after 1/22/19 = 0.4
DF for regulated gas pipe made before 1/22/19 = 0.32

Example:
What is the pressure rating of 6" DR11 PE4710 process water pipe if water temperature is 100°F and contains 5% solvating hydrocarbons by volume?

\[ PR = 2 \times 1600 \times 0.63 \times 0.78 \times 0.5 / (11-1) = 78 \text{psi} \]

### Maximum Sustained Pipe Temperature (°F) and HDPE Temperature Factor, \( F_T \)

<table>
<thead>
<tr>
<th>Maximum Sustained Pipe Temperature (°F)</th>
<th>HDPE Temperature Factor, ( F_T )</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>1.25</td>
</tr>
<tr>
<td>50</td>
<td>1.17</td>
</tr>
<tr>
<td>60</td>
<td>1.1</td>
</tr>
<tr>
<td>73</td>
<td>1</td>
</tr>
<tr>
<td>80</td>
<td>0.94</td>
</tr>
<tr>
<td>90</td>
<td>0.86</td>
</tr>
<tr>
<td>100</td>
<td>0.78</td>
</tr>
</tbody>
</table>

Note: Pressure Rating of PA12 is not impacted by HHC
GRI (1997) performed butt and EF saddle fusions on 2” & 4” MDPE and HDPE pipe submerged in 100% liquid propane for different soak times. Fittings were not exposed to propane. Propane was used because it is usually the largest hydrocarbon in natural gas and is often mixed with air to supplement natural gas.

The results concluded:

- Thermal mitigative measures used to remove propane permeation in the pipe before fusing were not effective.
  1. Radiant pre-heating by positioning heat about 1” from pipe for 45 seconds to 5 minutes
  2. Radiant pre-heating pipe for 5 minutes then waiting 5 minutes
  3. Preheating the pipe using heater (150F & 200F) and conduction for 30 to 60 seconds
  4. Preheating the pipe convectively for about 2 minutes using a hair dryer

- 2” MDPE joint strength degrades after ~30 hours of immersion and was almost non-existent after 200hrs of immersion.
- 4” MDPE joint strength degraded after ~10 hours of immersion and was almost non-existent after 200hrs of immersion.
- HDPE butt joints retain more strength than MDPE joints for the same exposure time
- Joining delays after propane immersion of up to two days do not increase joint strength

GTI (2016) performed 105 butt fusion on MDPE & HDPE pipe samples permeated with heavy hydrocarbons to 0%, 50%, and 100% saturation and performed long-term creep testing, bend-back testing, and HSLTT testing on ASTM D638 type V dog bone specimens.

The results showed:

- 50% tensile strength reduction for fully saturated specimens at 23°C
- A fully saturated pipe wall reduces the likelihood of a successful butt fusion by a factor of 2/3 and increases the likelihood of a poor fusion by a factor of 4 relative to the non-saturated condition.
- There may be potential operating windows to mitigate HHC effects on fusion, but they are material and temperature dependent.
- The current industry practice of not allowing permeated pipe to be heat fused is well advised.

Further research is needed. GTI is using these results to develop a risk calculator.
GTI Project - Influence of HHC Permeation on mechanical couplings

• GTI conducted a test program in cooperation with RW Lyall to evaluate the influence of swelling and softening of PE on mechanically coupled pipe due to HHC permeation.

• Testing of two types of mechanical joints subjected to full HHC saturation has shown:
  • The tested joints met short-term strength requirement (25% pipe elongation)
  • Saturated PE behaves similarly to non-saturated PE at an elevated temperature: 15-25°C (27-45°F) increase
  • Swelling from HHC permeation can exceed pipe dimension tolerances (OD and WT), thus hindering installation of standard-size mechanical couplings
What to Look for

- Pipe Discoloration (sometimes visible on non-black pipe)
- Pipe Swelling
- Bubble-like formation on PE surface when fusion heater plate applied
- Possible hydrocarbon fuel odor
Joining Guidance

CSA Z662 and GPTC TR17-39 (in process)

- Suspect pipe has been exposed to HHC (Internal or external)
- Perform a Heat Fusion Melt pattern (saddle) test on the pipe or butt fusion
- Visual inspection – do you see bubbles after the test or a rough pockmarked surface in the fusion bead (butt fusion)?
  - Bubbles caused when liquid hydrocarbons vaporize into the melt zone
  - May be an indication of hydrocarbon permeation
- If conditions exist
  - Assess operating conditions and determine if an adjustment to the design pressure is needed
  - Consider using mechanical fittings since voids within the joint can adversely affect fusion joint strength – note potential swelling issues (GTI work with RW Lyall)
- Note: Electrofusion provides no ability to see potential bubbles
- It’s also possible to see bubbles from moisture if glycerin used in pipe processing – ask your pipe manufacturer for guidance
Repairing LHC Permeated Pipe

- Mechanical fittings are recommended for use on HC permeated pipe
- Measure the pipe OD of permeated pipe and check it against fitting manufacturers maximum OD
- If mechanical fitting will not work, pipe section may have to be replaced
PPI LHC R&D Plans

• PPI is working with Oil & Gas Advisory Board to determine primary objectives to aid the industry

• Need to better understand saturation and desaturation rates in different environments
  • Rates at different temperatures
  • Natural vs. forced convection

• Provide practical guidance and education on joining and repair
  • Heat fusion – at what level can this method be effective
  • Electrofusion – effects of internal exposure to HHC
  • Mechanical fittings – impact of swelling (Note: GTI work with RW Lyall)
PPI Tools & Resources
Component ID Update

- Component ID.org
  - Launched Fall 2021!
  - Features:
    - Easier registration process
    - Provides encoding and decoding functions for F2897 codes
    - Allows manual entry or barcode scan
    - Provides downloadable list of registered manufacturer IDs
Gas Calculator Tool
- Provides online gas flow rate calculation
- Allows user to define parameters such as: gas composition, pipe roughness, and elevation
- Will have accompanying Engineering Help document
- Launched Fall 2021

PPI Historical Gas Component Database
More PPI Resources

Position Papers

Renewable Energy and the Role of Pipeline Transportation

Importance of Pipelines
The natural gas and pipeline industry is under attack, and the enviro community is doing everything possible to restrict and even phase out the use of natural gas as well as the pipelines that safely transport it.

So these position papers make the case that 1) natural gas actually enables the increased use of renewable energy, and 2) use of some renewable energy sources will definitely need pipelines to move it safely. Those getting a lot of attention are:

- Hydrogen and
- What they call “carbon capture” where they capture carbon dioxide before it is emitted into the atmosphere and sent to locations where it can be put to industrial use and/or stored in an environmentally safe way.

Position
The Plastics Pipe Institute (PPI) is the leading trade association representing more than 150 companies involved in the production of plastic pipe in our nation's infrastructure. PPI members produce plastic pipe, composite pipe, fittings, and components used in our

Carbon Capture
Carbon capture, use and storage (CCUS) efforts have gained significant attention in the debate about America’s “Energy Future.” Capturing carbon dioxide (CO2) from sources of emission and delivering it to locations where it can be used effectively and/or...
Other PPI Publications

• Helpful PPI Technical Documents
  • TN 54 2017 General Guidelines for Squeeze Off of PE Pipe
  • TR-19 2020 Chemical Resistance of Plastic Piping Materials
  • TR-30 2020 Investigation of Temperatures Attained by Plastic Fuel Gas Pipe inside Service Risers
  • TR 49 2020 Generic Electrofusion User Guide for Field Joining of Polyethylene Gas Piping
  • TR 50 2020 Generic Butt Fusion Joining Procedures for PA12
QUESTIONS?