V.G Cross-Cutting

V.G.1 Existing Natural Gas Pipeline Materials and Associated Operational Characteristics*

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Objectives

Assist DOE in defining criteria for a cost-effective and energy-efficient hydrogen delivery infrastructure for transitional and long-term use of hydrogen for transportation and stationary power by determining the feasibility of co-transporting hydrogen and natural gas in existing pipelines and completing a future trade-off analysis to determine the best hydrogen delivery approach(es) in Pennsylvania.

- Document the materials used in construction of the existing natural gas pipelines in the United States, including their operational characteristics.
- Provide information on pipeline construction materials and operational characteristic data in Pennsylvania.
- Document technical and operational factors to consider when evaluating hydrogen and co-transport delivery scenarios.
  - Integrate results of this study into an ongoing trade-off analysis with technical and economical parameters.
  - Identify the best delivery scenarios and prepare report describing such conclusions.
  - Determine the feasibility of separating hydrogen from hydrogen/natural gas blends at the point of use.
  - Construct prototype materials for pipelines and compressed gas storage tanks.

- Establish capability of hydrogen-specific sensors to determine percent level hydrogen in feed gas and ppm-level hydrogen for leaks.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- A. Lack of Hydrogen/Carrier and Infrastructure Options Analysis
- D. High Capital Cost and Hydrogen Embrittlement of Pipelines
- H. Storage Tank Materials and Costs
- I. Hydrogen Leakage
- J. Safety, Codes and Standards, Permitting and Sensors

Technical Targets

This report provides existing natural gas infrastructure information to provide insights into cost reduction to meet the following DOE 2010 hydrogen pipeline delivery targets:

- Transmission Total Capital Cost: $1M/mile
- Distribution Total Capital Cost: $0.25M/mile

Additionally, the subject report provides reliability information on natural gas transmission and distribution pipeline operations, as potentially applicable to pipeline transport of hydrogen and hydrogen/natural gas blends.

Approach

- Provide data from the United States and Pennsylvania on materials of construction used in the existing natural gas pipelines including operational characteristics
- Determine if material or operational incompatibilities are readily apparent when comparing the existing natural gas infrastructure to a possibility of co-transporting hydrogen with the natural gas
- Outline the factors and operational input parameters affecting the use of natural gas pipelines for use in co-transporting natural gas and hydrogen

Accomplishments

- Evaluated construction materials and operating conditions for existing natural gas pipeline the United States and compared it to that in Pennsylvania.
- Acquired baseline, natural gas pipeline information for input to an ongoing trade-off analysis study to determine the best delivery scenarios for Pennsylvania.
- Recommended technical factors and operational input parameters to consider when developing hydrogen delivery scenarios.

Future Directions

- Continue trade-off analysis for hydrogen delivery scenarios.
  - Continue discussions with Federal Energy Regulatory Commission (FERC), Gas Appliance Manufacturers Association (GAMA), local distribution companies (LDCs) and transmission system operators to verify operational parameters and capacities.
  - Complete economic delivery trade-off analysis.
- Conduct separation technology analysis.

  - Build on baseline assessment as starting point for a comparative analysis of separation technologies.
    - Review applicability of Savannah River National Laboratory's hydrogen separation technologies.
    - Assess carbon molecular sieve membranes entering the market.
    - Identify new separations technologies that have appeared in the past year.
- Conduct pipeline material development and testing.
  - Initiate testing of existing materials to feed into lifing model.
  - Evaluate existing pipeline materials using models.
  - Explore use of the NASA MAC/GMC code for evaluating the performance of composite structures.
- Identify new tooling designs for gas storage tanks using new composite structures.
  - Conduct trade-off study of various fibers, resins, liners and coatings.
  - Design experiments to establish capability of proposed tank.
  - Conduct permeation testing on non-metals.
  - Develop tooling design for fabricating the proposed tank.
- Investigate hydrogen sensor developments.
  - Continue assessment of commercially available sensors or pre-commercial sensors, capturing new developments.
  - Select three fully functional sensors, which potentially meet the established specifications, to evaluate and test.
  - Conduct testing of the developed sensor systems including:
    - performance testing under laboratory conditions
    - durability testing over a 1-3 month period in a natural gas environment.

Introduction

Concurrent Technologies Corporation has initiated the Hydrogen Regional Infrastructure Program in Pennsylvania [1] to address the specific R&D needs related to the delivery and storage of H_2, as defined in the Department of Energy's (DOE's) Multi-Year Research, Development and Demonstration Plan (MYRDDP) for the Hydrogen, Fuel Cells & Infrastructure Technologies Program [2]. The areas of focus entail materials science and engineering, simulation and modeling, and H_2 separation and sensor technologies. The Statement of Objectives (SOO) for this project consists of three main tasks: (1) H_2 Delivery (co-transport, separation, and trade-off), (2) New Material Development (pipeline and storage tank), and (3) H_2 Sensor Development. The overall goal is to advance the state-of-the-art technologies required to adapt and build on the existing natural gas infrastructure for use in the H_2 economy.

The present work, as part of Task 1 stated in the SOO, summarizes the construction materials for the existing natural gas pipelines and the associated operating characteristics (feed gas composition, pressure, temperature, and ambient conditions) in the United States and in the state of Pennsylvania. In addition, some of the technical and operational considerations for delivering H_2/natural gas blends are also addressed in this study. According to the MYRDDP, pipelines offer the lowest-cost option for H_2 delivery at high volumes, and it may be possible to mix H_2 with natural gas in the existing natural gas pipeline infrastructure without modifications to the pipeline. However, the potential impacts of H_2 leakage and damage must be understood and mitigated in order to make this a viable option. The purpose of this work is to assess the feasibility of co-transporting H_2 and natural gas in existing pipelines to reduce necessary investment. Information from this study will be input to a H_2 delivery trade-off analysis to determine the most attractive pathway for delivering H_2 fuel in consideration of Pennsylvania-specific resources and constraints associated with transmission and distribution.

Approach

Pipeline data were grouped into four categories: (1) materials, (2) operating parameters, (3) piping components, and (4) losses and leakage. Much of the data on the distribution line for Pennsylvania was not readily available; therefore, telephone interviews were conducted with local distribution companies (LDCs) and the Pennsylvania Public Utility Commission (PUC) to enhance the level of detail. Factors affecting the feasibility of co-transporting natural gas and H_2 were identified based on data from the regulatory agencies, existing H_2 delivery companies, and LDCs. These factors will be used along with economic considerations in evaluating and selecting the most feasible delivery scenarios for Pennsylvania.

Results

Analyze natural-gas infrastructure in the United States

Information on the mileage of transmission pipelines was drawn from the 2003 Annual Data compiled by the Office of Pipeline Safety (OPS) at the Department of Transportation (DOT) [3]. To date, qualified carbon steels have been used almost exclusively for the transmission pipeline system of natural gas and account for over 98% of the total mileage. Both steel and plastic materials are used for natural gas distribution mains. Over a half of the total mileage in distribution pipelines is steel and the other third is plastic, primarily polyethylene (PE). The remainder consists of aging cast, wrought and ductile iron pipes. Typical steel grades for the main distribution pipeline include A, B, X42, and X46. The higher-strength grades (X52, X56, X60, X65, and X70) are primarily used for the transmission pipeline. Grade A is no longer qualified for use as the replacement pipe. It is an ongoing effort in the industry to use X80 or develop even higher-performance grades for increased pressure requirements for the transmission pipeline. These steel grades conform with the American Petroleum Institute (API) specification 5L [4], which is referenced in Title 49 Code of Federal Regulations Part 192 (49 CFR 192) [5] issued by DOT-OPS. None of the transmission systems currently uses PE pipes. On the other hand, more and more of the distribution pipelines are constructed with PE pipes. PE pipes are increasingly being used to replace the aging iron and steel pipes in the low-pressure distribution system because of lower construction and maintenance costs. There are also ongoing initiatives to apply PE to the transmission pipeline system albeit only at an experimental stage and in a small scale. Other components, such as valves and fittings, in the pipeline are made of the same material as the pipe.

The Gas Technology Institute (GTI) performed numerous experimental studies at its three pipeline test loops in 1970s and 1980s [6] [7] [8] [9]. The GTI studies did not show any degradation in the mechanical and physical properties of steel, cast iron, and copper pipes and components such as valves and fittings after six months of operation in hydrogen delivery/storage applications. Results from tests conducted by GTI indicate that current pipeline materials may be suitable for hydrogen transport. However, lifing has not been evaluated for these materials and additional testing is needed for PE pipe.

The operating parameters for the natural gas pipeline usually include gas composition, pressure and temperature, and ambient conditions. A refined natural gas for commercial and industrial applications typically contains 87–96% of methane to meet the requirement for heating value in Joules per standard cubic meter (or Btu per standard cubic foot). In the transmission pipeline system, gas pressure can range from 200 psig to 1,500 psig. The pressure in the distribution lines is generally below 100 psig, with most systems operating below 30–60 psig. However, some distribution lines between the major transmission line and the first regulator at the city gate operate at 100–250 psig. Most of the small lines (two inches or less) operate at less than 2 psig. Federal regulations govern the maximum allowable operating pressure (MAOP), which is the maximum pressure at which a pipeline or segment of a pipeline may be operated, under 49 CFR 192. In general, the temperature of the natural gas exiting a compressor station ranges from 100°F to 120°F. Once the natural gas leaves the compressor and travels underground, the temperature of the gas falls rapidly and approaches the ambient underground temperature. In the winter, pipelines located above the frost line may have flowing gas temperatures less than 32°F, while the gas temperature in pipelines buried below the frost line is not likely to fall below freezing and will remain fairly constant. The ground below the frost line maintains an average temperature between 50°F and 54°F.

Natural gas storage facilities help to offset seasonal fluctuations in demand and to ensure uninterrupted gas supplies at all times. In summer when demand is low, natural gas is pumped into the underground storage facilities. At peak times on very cold winter days, when demand can be five or six times as high as on warm summer days, the natural gas is withdrawn from the storage facility. The underground facilities are depleted gas and mine fields, salt caverns, and aquifers. Michigan has the largest storage capacity (close to 13% of total in the United States), followed by Illinois (12%) and then Pennsylvania (9%). Transmission companies usually own the storage facilities.

On a federal level, the safety and security of the nation's pipelines are controlled by two agencies. The Transportation Security Administration (TSA), located within the Department of Homeland Security, holds responsibility for pipeline security (i.e., protection against deliberate attacks), while DOT-OPS is mainly responsible for pipeline safety and regulations related to worker and equipment safety issues. Currently, there is only an informal division between TSA and OPS. The primary regulatory force behind pipeline safety and security issues is the Pipeline Safety Improvement Act of 2002, which reauthorizes OPS funding through fiscal year 2006.

Evaluate natural-gas infrastructure in Pennsylvania

The natural gas pipeline infrastructure in Western Pennsylvania is different from the pipeline in Eastern Pennsylvania, mainly because of the local production as well as the historical ownership of the pipelines. Historically in Western Pennsylvania, because of local natural gas production, many local utilities supplied small municipalities and rural communities. In this early infrastructure, some pipelines served both as gathering and distribution lines. Today, about 40% of the natural gas used in Western Pennsylvania is from local production, while the other 60% is from the transmission pipeline system. Per discussions with the Pennsylvania PUC, local utilities have conjectured that it is due to the multiple natural gas sources and existing integrated infrastructure, that Western Pennsylvania has an adequate supply of natural gas all year round. Eastern Pennsylvania does not have local natural gas production facilities. Instead, natural gas delivery is from the transmission pipeline system through dedicated local utility service areas. Local utility companies have indicated that during the winter Eastern Pennsylvania does not always have an adequate supply of natural gas. To meet the demands, utilities will peak-shave the natural gas supply with propane. If necessary, the utilities will cut off the supply of natural gas to their larger industrial customers.

The gas produced in the Gulf Coast area travels in transmission pipeline over one thousand miles interstate, and hundreds of miles more intrastate, to the local city-gates in Pennsylvania, where it passes into smaller distribution pipes for regional and local distribution. There were a total of some 9,500 miles of transmission pipeline and 35,900 miles of distribution pipeline in Pennsylvania in 2003. Almost 50% of the existing transmission pipeline was installed between 1950 and 1969. A small amount, less than 5%, of the existing pipeline dates to a time before 1940, followed by 9% from 1940 to 1949. Over 98% of the total transmission pipeline length in Pennsylvania was constructed with steels. The remaining portion was comprised of plastic and cast or wrought iron. Approximately 82% of the steel pipeline was externally coated to prevent corrosion; while over 95% of the steel pipes (coated and bare) had cathodic protection against corrosion. The deterioration or corrosion of pipes caused nearly 72% of all leak repairs. Another 19% of leaks were caused by materials or welds. The remaining 9% of leaks fell into the category of other and force leaks. Table 1 compares the transmission pipeline data between the United States and the state of Pennsylvania. It is noted that Pennsylvania has much higher corrosion occurrences than the nation as a whole.

Data from 2003 shows that steel was the most common construction material for the natural gas distribution pipeline in Pennsylvania at 55% of the total mileage. This is not nearly as prevalent as the transmission pipeline in Pennsylvania at 98.5%.

Table 1. Comparison of US and PA Transmission Pipeline[1]

Category	US	PA
Material	Percent of Total Miles	Percent of Total Miles
Steel	99.73	98.5
Other	0.27	1.5
Total	**100(291,704 mi)**	**100(9,501 mi)**
Steel Corrosion Protection	Percent of Steel Miles	Percent of Steel Miles
CP Steel	96.6	81.9
BP Steel	2.4	13.7
CU Steel	0.1	0.2
BU Steel	0.9	4.2
Diameters of Steel Pipe	Percent of Steel Miles	Percent of Steel Miles
Diameter > 28”	23	23.1
28” ≥ Diameter > 20”	16	20.4
20” ≥ Diameter > 10”	31	35.4
10” ≥ Diameter > 4”	23	17.8
Diameter ≤ 4”	7	3.3
Decade of Installation	Percent of Steel Miles	Percent of Steel Miles
Unknown	2.9	0
Installed Pre-1940	5.1	4.5
Installed 1940-1949	8.7	9.3
Installed 1950-1959	24.5	28.7
Installed 1960-1969	24.6	19.5
Installed 1970-1979	10.8	7.8
Installed 1980-1989	9.3	16.6
Installed 1990-1999	10.6	10.2
Installed 2000-Present	3.5	3.4
Leaks	% Leak Repairs	% Leak Repairs
Corrosion Leaks	44.7	71.8
Mat’l/Welds Leaks	19.4	18.8
Other/Forces Leaks	35.9	9.4

[1] Based on 2003 Data

Plastic constituted over one third of the total mileage, about 35% or over 12,000 miles. Nearly the entire plastic pipeline system was made of PE, with just a fraction of a percent (0.3%) made of polyvinyl chloride (PVC). The remaining approximately 9% of the distribution pipeline was made of chiefly of cast, wrought and ductile iron, copper, and other materials. Some of these were over fifty years old and were originally used to transport town gas. Of the 55% of distribution pipelines composed of steel, about 55% had cathodic protection while the remainder were unprotected. Bare and unprotected pipeline length accounted for 38% as compared to less than 7% for coated and unprotected. Corrosion was still the leading cause of leaks at 63%, but undefined outside forces increased to nearly 17%. Material, third party, and construction defects totaled to only 7% of leaks. The remaining 13% was classified as other. The steel pipeline size distribution was divided into the following groups, with plastic pipeline distribution information shown in parentheses: (1) 23% (50%) for diameter less than or equal to 2 inches, (2) 35% (37%) greater than 2 inches and less than or equal to 4 inches, (3) 31% (13%) greater than 4 inches and less than or equal to 8 inches, (4) 8% greater than 8 inches and less than or equal to 12 inches, and (5) remaining 3% greater than 12 inches. The trend for higher corrosion incidents for the main distribution pipeline system in Pennsylvania, as compared to the nation, is seen in Table 2.

Survey governing codes, regulations, and standards

Besides pipeline materials, other factors influencing the use of the existing natural gas infrastructure to transport or co-transport H_2 include codes and regulations, experience from operating existing H_2 pipelines, which exist from conversions of petrochemical pipelines, and end-user concerns (i.e., operating conditions). The main codes, regulations, standards and enforcement bodies are: (1) 49 CFR 192, (2) Federal Energy Regulatory Commission (FERC), (3) Pennsylvania PUC, and (4) various standards set by the American Society of Mechanical Engineers (ASME), the American National Standards Institute (ANSI), and API.

Pennsylvania gas companies are required by the Pennsylvania PUC regulations to deliver gas at a minimum higher heating value of 950 BTU per standard cubic foot. The BTU value of hydrogen is 320 BTU per standard cubic foot. As H_2 is mixed with the natural gas, the BTU value of the mixture will decrease, until at a point, the mixture of H_2 and

Table 2. Comparison of US and PA Main Distribution Pipeline[1]

Category	US	PA
Material	Percent of Total Miles	Percent of Total Miles
Steel	50.4	55
Plastic	45.7	35
Other	3.9	10
Total	100(1,097,994 mi)	100(9,501 mi)
Steel Corrosion Protection	Percent of Steel Miles	Percent of Steel Miles
CP Steel	84.4	53.9
BP Steel	2.7	1.3
CU Steel	3.2	6.5
BU Steel	9.7	38.3
Diameters of Steel Pipe	Percent of Steel Miles	Percent of Steel Miles
Diameter > 12"	23	23.1
12" ≥ Diameter > 8"	16	20.4
8" ≥ Diameter > 4"	31	35.4
4" ≥ Diameter > 2"	23	17.8
Diameter ≤ 2"	7	3.3
Diameters of Plastic PE Pipe	Percent of Steel Miles	Percent of Steel Miles
12" ≥ Diameter > 8"	0.1	0.1
8" ≥ Diameter > 4"	4.8	12.8
4" ≥ Diameter > 2"	22.6	36.7
Diameter ≤ 2"	72.5	50.4
Leaks	% Leak Repairs	% Leak Repairs
Corrosion	35	62.8
Outside Force	8.6	16.8
Third Party	17.9	4.1
Material Defect	6.3	2.4
Construction Defect	3	0.5
Other Causes	29.2	13.4

[1] Based on 2003 Data
[2] 93.5% of all plastic pipe used in the US is made of PE plastic. (468,681 mi.)
[3] 99.7% of all plastic pipe used in PA is made of PE plastic. (14,528 mi.)

natural gas will be below the minimum calorific. value set by the Pennsylvania PUC. To add greater amounts of H_2, thus lowering the calorific value below 950 BTU per standard cubic foot, will require a policy change.

Another potentially relevant issue is the Wobbe index. The Wobbe index defines the heating value of a quantity of gas that will flow though a hole of a given size in a specified amount of time. The index of a fuel gas is calculated by dividing the higher heating value by the square root of its specific gravity with respect to air. The higher the Wobbe number, the greater the heating value of the quantity of gas that will flow though a hole of a given size in a given amount of time. In most natural gas applinaces, the gas flow is regulated by an orifice. Therefore, the Wobbe index indicates the interchangability of fuel gases. FERC, in conjunction with the utilities and the GAMA, is working to standardize the Wobbe Index in the United States. For a given orifice, gases with the same Wobbe number will deliver the same amount of heat. Most natural gas appliances operate with a Wobbe index between 1310 and 1390. Injecting hydrogen into natural gas will lower the Wobbe Index. Increase in H_2 beyond 11% may require burner changes in the natural gas appliances.

Conclusions

In this part of Task 1, we thoroughly analyzed the natural-gas pipeline data as of 2003 for the United States and Pennsylvania along with the operating parameters. We also surveyed the current codes, regulations, standards, and energy requirements (higher heating value and Wobbe Index) for natural gas pipelines. The findings are summarized below.

- The natural gas pipeline in the United States and Pennsylvania are similar both in materials and operating conditions.
- The natural gas composition in the United States can vary greatly and varies according to its source, but the calorific value of the natural gas in Pennsylvania tends to be more consistent than in the United States as a whole.
- The operating pressures in Pennsylvania distribution pipelines are similar to those in other parts of the United States. The majority is below 100 psig with many of the lines operating below 60 psig and 30 psig.

- The pipelines in the United States and in Pennsylvania meet most of the flow requirements for the current natural gas needs. Western Pennsylvania tends to have an adequate flow of natural gas year round, while Eastern Pennsylvania does not always have an adequate flow during peak demands.
- Petrochemical pipelines have been converted to hydrogen service. This experience provides information that can be used to convert natural gas lines to hydrogen or hydrogen/natural gas services.
- Other parameters that will influence the feasibility of co-transporting hydrogen and natural gas include:
  – Heating value
  – Wobbe index
  – End-user equipment such as natural gas-powered appliances
  – Thermodynamic properties of H_2-natural gas mixtures
  – Odorants.
- A number of delivery scenarios can be developed by taking into account location of H_2 production, location of H_2 injection, ratio of hydrogen to natural gas transport as a function of demand, and end-user requirements. These will have to be evaluated in determining the economic feasibility of co-transport.

FY 2005 Publications/Presentations

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