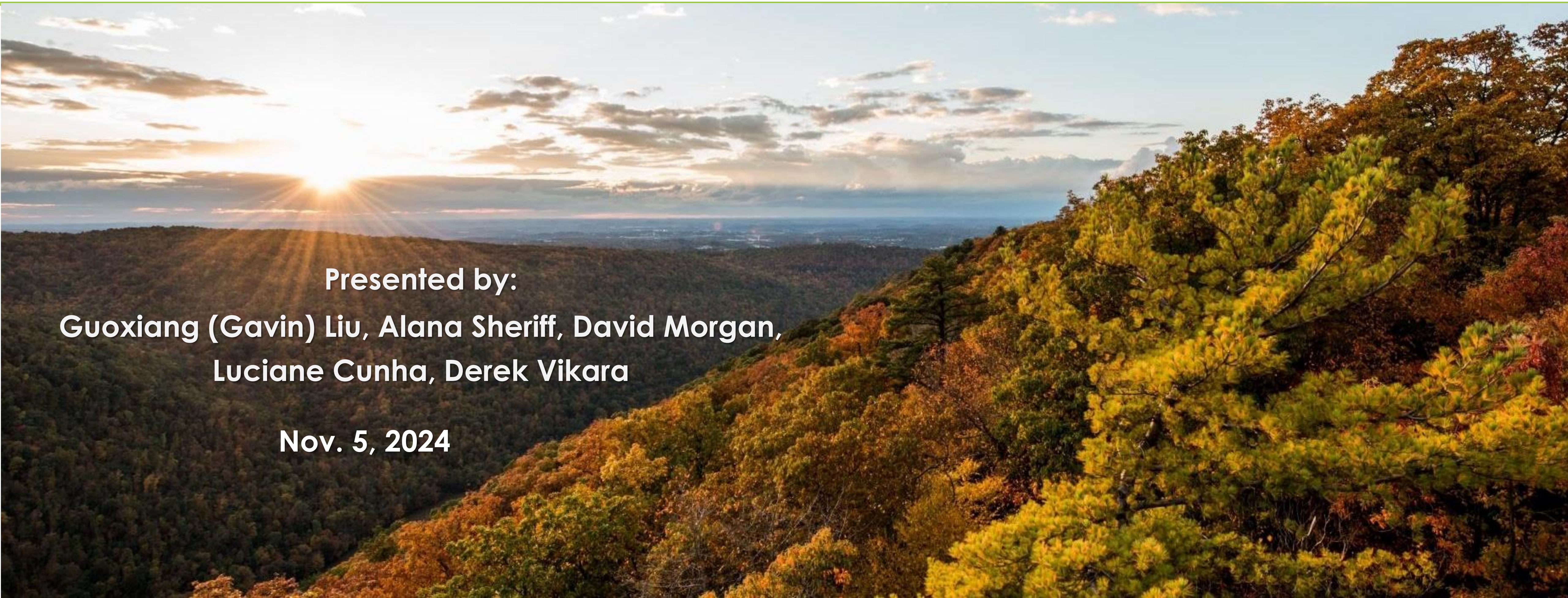
U.S. Department of ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

Techno-Economic Pipeline Models for Transporting Pure Hydrogen and Blends of Natural Gas and Hydrogen

USAEE 2024 meeting, Baton Rouge, LA, Nov. 3-6, 2024



Presented by:
Guoxiang (Gavin) Liu, Alana Sheriff, David Morgan, Luciane Cunha, Derek Vikara

Nov. 5, 2024

Background and Introduction

- Part of the Fossil Energy and Carbon Management (FECM) program entitled Natural Gas Decarbonization and Hydrogen Technologies. Two models include:

✓ Model 1: FECM/NETL Hydrogen Pipeline Cost Model (Pure hydrogen model: **H2_P_COM**)

✓ Model 2: Blend with existing natural gas pipelines so they can transport mixtures of natural gas and hydrogen (Blend hydrogen Model: **NG-H2_P_COM**)

✓ User's manuals for both models and benchmark testing

Links of the Model and Documentations

- H2_P_COM: Excel spreadsheet model and user's manual were released through NETL's website in March 2024. The link to the collection of these two files is:
  https://netl.doe.gov/energy-analysis/search?search=HydrogenPipelineCostModel2024

- NG-H2_P_COM: Excel spreadsheet model, user's manual and comparison study were released through NETL's website in August 2024. The link to the collection of these three files is:
  https://netl.doe.gov/energy-analysis/search?search=NatGasHydrogenPipelineCostModel2024

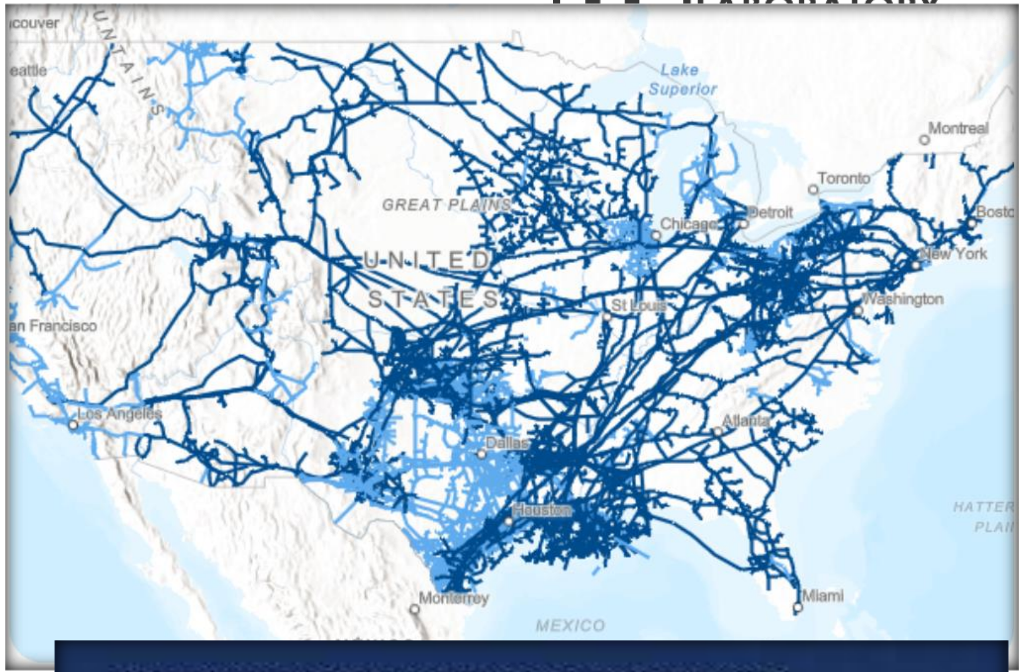
Project Justifications

- Existing pipeline and demands of the growing

- Blending hydrogen into natural gas reduces the carbon intensity of natural gas.

- The U.S. has a large network (305,000 miles) of natural gas transmission pipelines. Reusing these pipelines to transport mixtures of natural gas and hydrogen will reduce the cost of incorporating hydrogen into the US energy economy.

- Potential uses of H2_P_COM and NG-H2_P_COM:
  - ✓ Can be used in system studies for Hydrogen Hub and similar projects
  - ✓ Can be used in regional and national analyses of pipeline networks for building a hydrogen energy economy



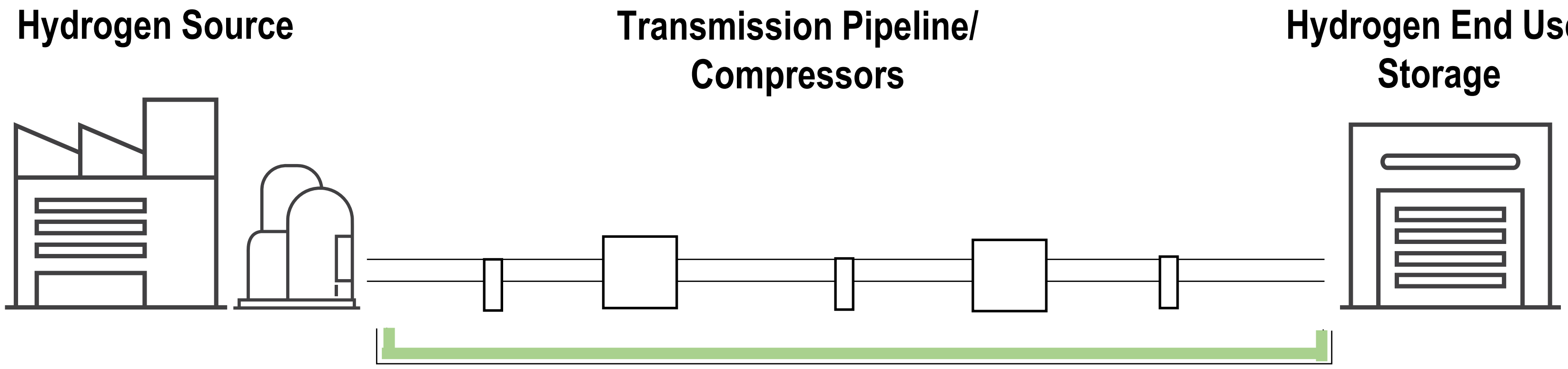
[Regional Clean Hydrogen Hubs Selections for Award Negotiations | Department of Energy]

H2_P_COM Assumptions

NATIONAL ENERGY TECHNOLOGY LABORATORY

Model 1

- Hydrogen is transported in a gaseous state.
- Costs are calculated for a point-to-point pipeline from a hydrogen source to end use location (storage or fuel distribution).
- Natural gas pipeline capital costs are calculated using either Brown et al. (2022)[1], Parker (2004), Rui et al. (2011), or McCoy and Rubin (2008) for natural gas pipelines.
  - Natural gas pipeline capital costs are adjusted to be applicable to hydrogen pipelines using a material cost factor and labor cost modifier from Brown et al (2022)[1].
- Hydrogen density and compressibility calculated using Lemmon et al. (2008).
- Hydrogen viscosity calculated using Muzny et al. (2013).
- Compressor technical calculations and costs from ANL's Hydrogen Delivery Scenario Analysis Model (HDSAM).



Ref.: Brown, D., K. Reddi and A. Elgowainy, 2022. The development of natural gas and hydrogen pipeline capital cost estimating equations, Intl. J. Hydrogen Energy, Vol. 47, pgs. 33813-33826, Elsevier.

H2_P_COM Calculations

Model 1

- **Inputs**
  - **Operational inputs** such as H_2 mass flow-rate (max. and annual avg.), pipeline length, number of compressor stations, elevation change across pipeline and pressure drop between compressor stations
  - **Financial parameters** such as fraction debt (remainder is equity), escalation rates, interest rate on debt and minimum desired return on equity
  - **Planning inputs** such as duration of construction, duration of pipeline operation and price for transporting hydrogen
- **Technical calculations**
  - Model assumes pipeline is divided into **equal length segments** with a compressor at start of each segment except the first segment
  - Model calculates **smallest standard pipe diameter that can sustain the maximum hydrogen mass flow rate** given the pressure drop and elevation change across the segment
- **Costs**
  - Model calculates **capital costs for pipeline and compressor stations**
  - Model calculates **annual operations and maintenance (O&M) costs** for pipeline and compressors

H2_P_COM Functionalities

Model 1

- **Given the number of compressor stations and a price for hydrogen**
  - Model calculates cash flows for revenues, capital costs and O&M costs
  - Model depreciates capital costs and calculates taxes
  - Model calculates net earnings excluding payments for principal and interest on debt and returns to equity
  - Model sum the present value net earnings to give net present value (NPV) for project

- Alternatively, model can find the hydrogen price that makes **NPV for the project equal to zero**
  - This is the **break-even price** for hydrogen (also called **levelized price** for transporting hydrogen)
  - This is the lowest price the pipeline owner can charge and cover all costs
  - Project is viable at this price but just barely

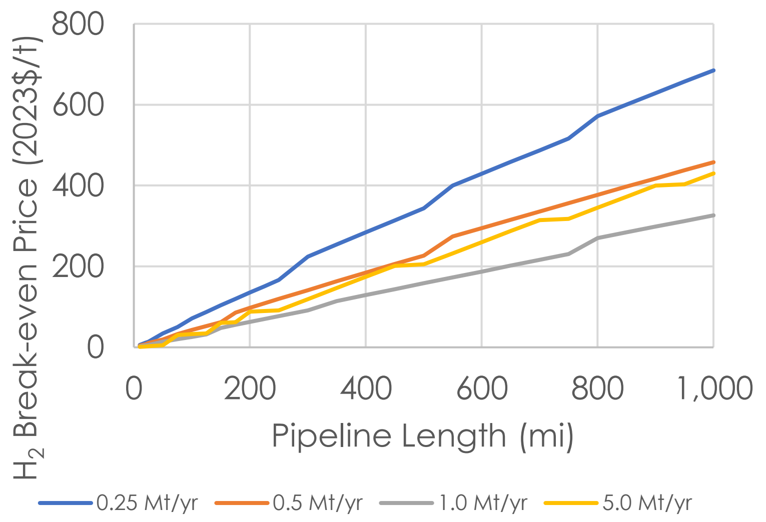
- Or, rather than specifying the number of compressor stations, model can find the number of compressor stations that **gives the lowest break-even hydrogen price**
  - As the number of compressor stations increases, the smallest diameter pipe will decrease so there is a trade-off between pipe diameter and number of compressor stations

H2_P_COM Example Results

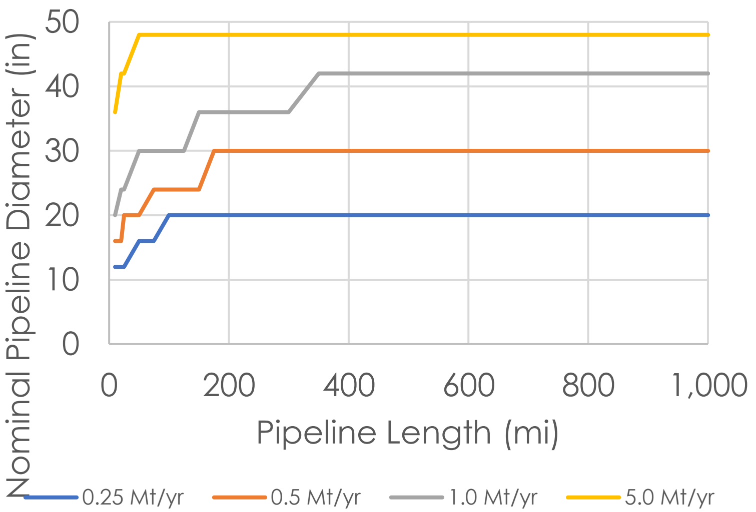
Model 1

- H2_P_COM results for finding **break-even prices** for H_2 (minimum price for H_2 to achieve a barely positive NPV) based on pipeline distance and flow rate, with associated nominal pipe diameter and optimal number of compressor stations.

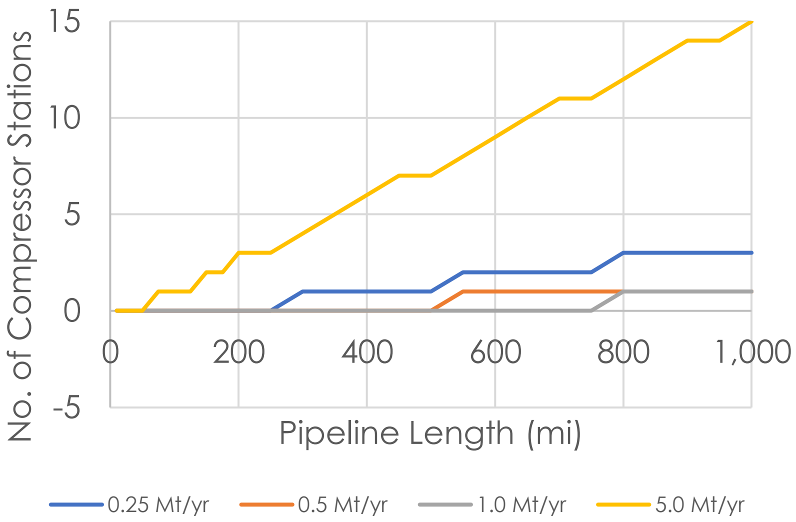
Break-even H_2 Price



Nominal Pipeline Diameter



Optimal No. of Compres. Stations



0.25 Mt/yr = 106 Bscf/yr; 0.50 Mt/yr = 212 Bscf/yr; 1.0 Mt/yr = 423 Bscf/yr; 5.0 Mt/yr = 2,120 Bscf/yr

Pipe segment inlet pressure: 1000 psig Pipe segment outlet pressure: 705 psig

NG-H2_P_COM (Blend Transportation)

Model 2: Approach, Model Description, and Methodology

- **Approach**
  - Performed literature review to identify infrastructure modifications, best practices, and cost data related to repurposing existing natural gas infrastructure for transporting natural gas with different fractions of hydrogen
- **Description**
  - NG-H2_P_COM is a screening level Excel-based model that estimates costs for transporting gaseous phase NG and H_2 blends by pipeline.
- **Methodology**
  - The energy throughput of original gas stream is held constant
    - Allows for the evaluation of costs and benefits of hydrogen blending projects compared to alternative decarbonization strategies
    - Crucial for meeting energy demands and ensuring a consistent energy supply to end-users
  - First year breakeven price is calculated at the volumetric flow rate of the blend

NG-H2_P_COM Assumptions

NATIONAL ENERGY TECHNOLOGY LABORATORY

Model 2

- NG-H_2 blend is transported in a gaseous state.
- Costs are calculated for a point-to-point transmission pipeline from a blending station to end user (e.g., city gate).
- Natural gas pipeline capital costs are calculated using either Brown et al. (2022)[1], Parker (2004), Rui et al. (2011), or McCoy and Rubin (2008) for natural gas pipelines.
- NG-H_2 blend density and compressibility calculated using **AGA8 method** (American Gas Association Report).
- NG-H_2 blend viscosity calculated using **Lee gas viscosity correlation**.
- Compressor technical calculations and costs from ANL's Hydrogen Delivery Scenario Analysis Model (HDSAM).

[1]Brown, D., K. Reddi and A. Elgowainy, 2022. The development of natural gas and hydrogen pipeline capital cost estimating equations, Intl. J. Hydrogen Energy, Vol. 47, pgs. 33813-33826, Elsevier.

NG-H2_P_COM Calculations

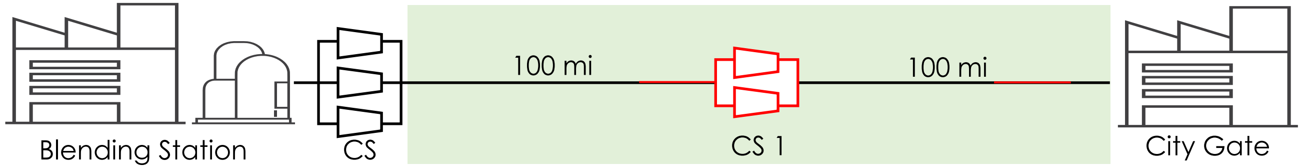
Model 2

- **Inputs**
  - User specifies key technical inputs such as current volumetric flow-rate of NG pipeline, **percentage of H_2 (vol%) to be blended into the gas stream**, pipeline length, number of compressor stations, **number of compressor stations reusing**, and **percentage of pipeline being reused**
  - User specifies key financial parameters such as fraction debt (remainder is equity), escalation rates, interest rate on debt and minimum desired return on equity
- **Technical calculations**
  - Model calculates the new volumetric flow rate with the same energy throughput at the **specified hydrogen percentage**
- **Costs**
  - Model calculates capital costs for pipeline (new and reuse) and new compressor stations
  - Model calculates annual operations and maintenance (O&M) costs for pipeline and compressors
  - Model calculates the **first-year breakeven price of the NG-H_2 blend** which is the price that makes NPV for the project equal to zero

NG-H2_P_COM Example Results

Constant Reuse Parameters Case Study

- Varied H_2 blend percentage from 5% to 25% for 200-mile and 500-mile pipeline lengths
  - Constant pipeline reuse percentage – 75%
  - Constant reuse cost factor – 30%
- CAPEX remains constant but OPEX increases
  - To maintain the same energy throughput, higher volumetric flow rates are necessary, resulting in increased compression costs



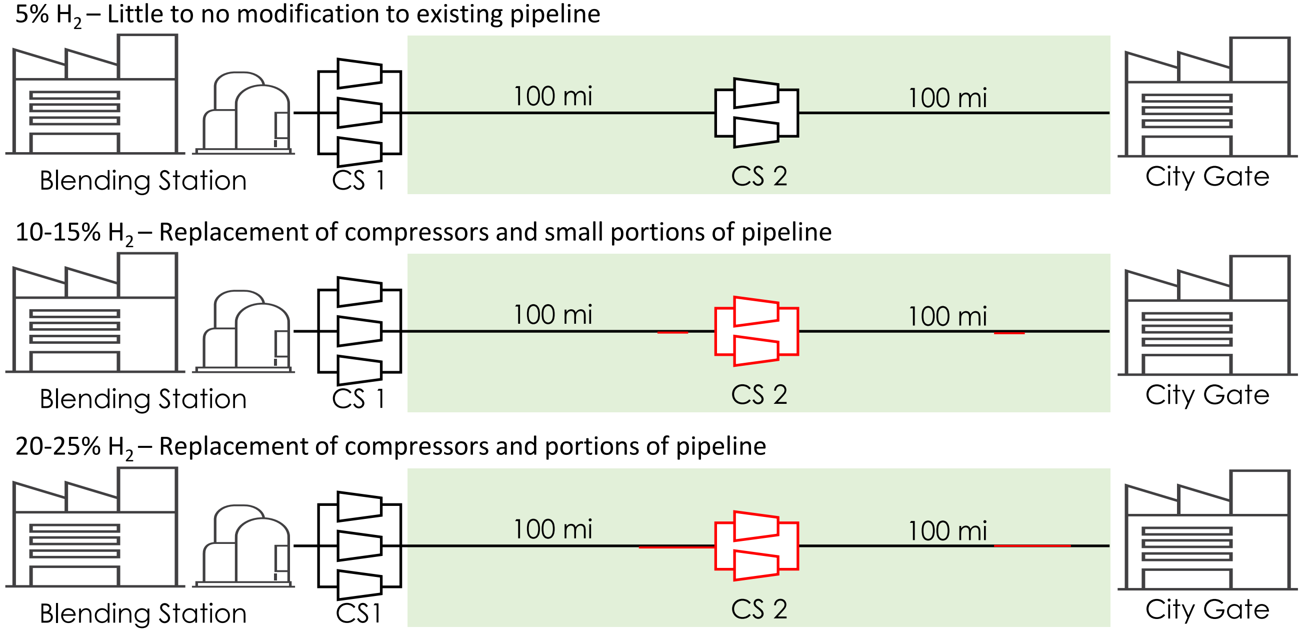
Modifications modeled in the constant reuse parameter case study for the 200-mile example.

Pipeline Length	Number of Compressor Stations	Hydrogen Volume	Transport Capacity	FYBE Price	Increase in Electricity Costs Compared to Original NG
mi	#	%	bscf/d	$/MMBtu (2023)	$/yr (2023)
200	1	5	0.2071	0.37	239,372
		10	0.2148	0.37	491,821
		15	0.2231	0.37	759,206
		20	0.2320	0.37	1,043,614
		25	0.2417	0.39	1,347,440
500	4	5	0.2071	0.98	957,489
		10	0.2148	1.00	1,967,286
		15	0.2231	1.02	3,036,825
		20	0.2320	1.04	4,174,455
		25	0.2417	1.05	5,389,758

NG-H2_P_COM Example Results (Cont.)

Varied Reuse Parameters Case Study (1)

- Varies retrofitting parameters to align with infrastructure requirements based on H_2 percentage
- Input variables varied
  - H_2 percentage
  - Pipeline reuse percentage
  - Reuse cost factor
  - Number of compressors reused



Pipeline Length	Pipeline Diameter	H_2 by Volume	Cost Factor for Pipeline Reuse	Pipeline Reuse	Number of Compressor Stations	Number of Compressor Stations Being Reused	NG-H_2 Blend Energy Content (Pipeline Transport Capacity)		FYBE CAPEX	FYBE OPEX	FYBE Electricity Costs	FYBE Transport Price of NG-H_2 Blend
mi	in.	%	%	%	#	#	MMBtu/day	bscf/d	$/MMBtu (2023)			
200	24	5	10	100	1	1	209,000	0.2071	0.05	0.02	0.07	0.14
		10	20	90	1	0		0.2148	0.14	0.05	0.07	0.26
		15	20	90	1	0		0.2231	0.14	0.05	0.09	0.28
		20	30	75	1	0		0.2320	0.23	0.07	0.09	0.39*
		25	30	75	1	0		0.2417	0.23	0.07	0.09	0.39

*FYBE price is $0.02 higher than in the constant reuse parameter case due to rounding the FYBE of each cost category to the nearest cent.

NG-H2_P_COM Example Results (Cont.)

NATIONAL ENERGY TECHNOLOGY LABORATORY

BlendPATH Comparison Case Study (Benchmarking)

- Designed to **compare levelized cost of transport (LCOT)** using NREL's BlendPATH and first year breakeven price of transport using NG-H2_P_COM
  - BlendPATH is a Python tool developed by NREL that estimates the LCOT for NG-H_2 blends
- 15 key operational and financial parameters were matched between the two models.
- NG-H_2 Blend Transportation Costs in the year of 2020 $/MMBtu
  - **BlendPATH: $0.21**
  - **NG-H2_P_COM: $0.25 (19% higher relative to BlendPATH)**
- Differences in transport costs likely due to modeling parameters that could not be matched
  - Pipeline steel grade: X60 (BlendPATH) vs X70 (NG-H2_P_COM)
  - Pipeline diameter: 26 in. (BlendPATH) vs 30 in. (NG-H2_P_COM)

BlendPATH (Blending Pipeline Analysis Tool for Hydrogen) [SWR-24-10] (Software) | OSTI.GOV

Links of the Model and Documentations

NATIONAL ENERGY TECHNOLOGY LABORATORY

- H2_P_COM: Excel spreadsheet model and user's manual were released through NETL's website in March 2024. The link to the collection of these two files is:

  https://netl.doe.gov/energy-analysis/search?search=HydrogenPipelineCostModel2024

- NG-H2_P_COM: Excel spreadsheet model, user's manual and comparison study were released through NETL's website in August 2024. The link to the collection of these three files is:

  https://netl.doe.gov/energy-analysis/search?search=NatGasHydrogenPipelineCostModel2024

THANK YOU!

VISIT US AT: **www.NETL.DOE.gov**

@NETL_DOE

@NETL_DOE

@NationalEnergyTechnologyLaboratory

CONTACT:

Guoxiang (Gavin) Liu
Strategic Systems Analysis & Engineering (SSAE)
412-386-7386
guoziang.liu@netl.doe.gov

David Morgan
SSAE
412-386-7405
david.morgan@netl.doe.gov