Techno-economic Analysis of Blending Hydrogen into Natural Gas Transmission Networks

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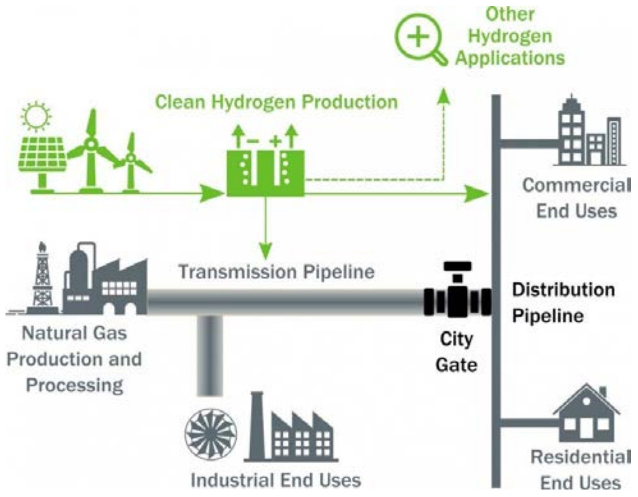
HyBlend™ initiative is multi-party consortium to address technical barriers in blending hydrogen into natural gas pipelines

- Key initiative objectives in:
  - Understanding how H_2 impacts pipes and pipeline components
  - Assessing a pipeline's capability of H_2 blending and benefit on a case-independent basis
- R&D conducted by four national labs (with focuses)
  - National Renewable Energy Laboratory (Techno-Economic Analysis)
  - Argonne National Laboratory (Lifecycle Analysis)
  - Sandia National Laboratory (Metals Compatibility)
  - Pacific Northwest National Laboratory (Polymer Compatibility)
- Co-funded by U.S. Department of Energy (DOE) and industry:
  - $15M R&D portfolio
  - 17+ industry partners



Utilizing existing natural gas infrastructure may enable low-cost H_2 transport and facilitate private sector uptake

- The U.S. possesses an extensive natural gas network consisting of 2.44 million miles of pipe
- **Leveraging this existing infrastructure for hydrogen blending advances clean energy adoption by:**
  - Offering a pathway *with incremental steps* towards cost-effective pure hydrogen transportation
  - Promoting *early-market access* for hydrogen technology adoption
  - Enabling *short-term carbon emissions reductions* (with low-carbon H_2) with the potential for long-term emissions reductions for hard-to-decarbonize sectors
  - Potentially providing *lower cost* H_2 transport than new-built H_2 pipes or truck delivery
  - Facilitating a *smooth transition* for natural gas workforce into clean energy jobs
  - Utilize existing infrastructure right-of-way to *avoid environmental and social impacts* of developing new energy infrastructure

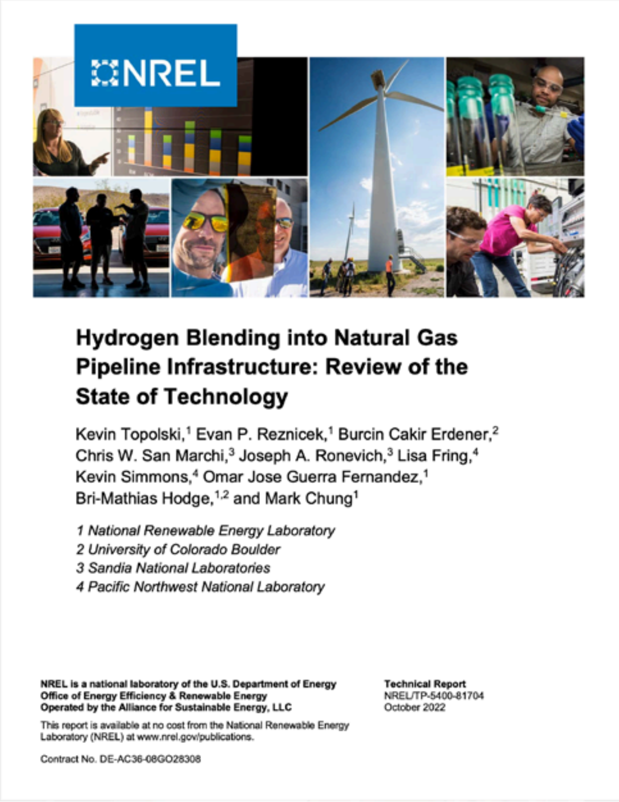
NREL's primary task is in assessing what upgrades may be required for pipelines to blend hydrogen and the respective costs

- Develop a Pipeline Preparation Cost Analysis Tool (PPCT) that:
  - Is flexible, open-source and can estimate the system cost to blend hydrogen on a case-by-case basis
  - Captures key natural gas infrastructure elements (e.g compressors, piping, materials, etc.) in techno-economic analysis
  - Uses and improves underlying gas network models to understand hydrogen concentration along the network and its impact on upgrade costs

- Apply analysis to evaluate pipeline network upgrade costs over a range of hydrogen blending scenarios and pipeline networks

- Benchmark hydrogen blending economics (with Argonne National Laboratory) against alternative natural gas decarbonization pathways

NREL's initial efforts in the Pipeline Blending CRADA involved developing a comprehensive literature review



NREL

Hydrogen Blending into Natural Gas Pipeline Infrastructure: Review of the State of Technology

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- Result of a collaborative effort between U.S. Department of Energy Hydrogen and Fuel Cell Technology Office, 3 National Labs and 17 consortium partners

- Key Review Takeaways:
  - Consensus is emerging on H_2 impacts on steel materials and pipeline performance
  - More research is needed on polymers, components, and economics
  - Demonstrations have primarily been conducted on low-pressure distribution systems with residential and commercial end users
  - There are numerous active blending projects today, many applied to the transmission network and some attempting up to 100% H_2

- Ability to blend H_2 in a pipeline is dependent on numerous factors such as end user compatibility, pipeline design and operating conditions; a **case-by-case approach to evaluation is necessary**

NREL developed a Pipeline Preparation Cost Analysis Tool (PPCT) that provides case-by-case TEA capabilities

- The PPCT is a Python tool that answers the following:
  - What % of H_2 in pipeline gas can be achieved from blending without major capital investment?
  - What incremental capital investment and operating expense is required to upgrade the natural gas pipeline network for *X*% of hydrogen in pipeline gas?
- This model targets application at the initial project assessment stage
- Intent is to provide the user with an understanding of <u>most promising opportunities</u> before proceeding with more detailed pipeline inspections based on "probable" economic outcome

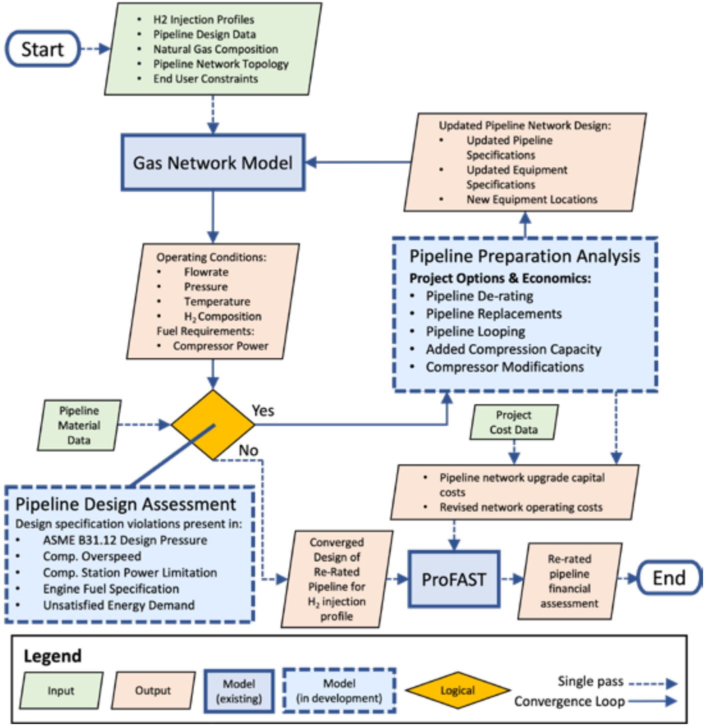

Figure 1: Pipeline Preparation Cost Analysis Tool framework.

The design assessment module models existing pipeline, identifies pipe segments, and calculates design pressures

1. Given network data (pipe topology, length, diameter, schedule) and desired hydrogen fraction, model the existing pipeline network to identify necessary operating pressures and flowrates to meet demand

2. Identify independent pipe segments:
   - Separated by compression stations or pressure reduction stations for line-packing
   - Separated by changes in pipe diameter for in-line inspection
   - May have multiple pipes within one segment with different age, grade, elevation, etc.
   - Can have an offtake mid-segment if it does not result in change in diameter

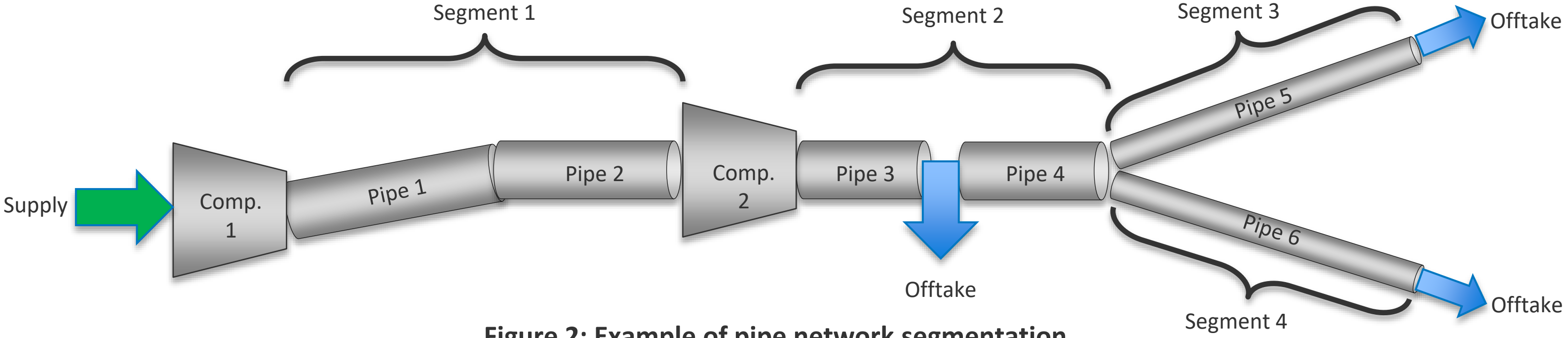

Figure 2: Example of pipe network segmentation.

3. Choose an ASME B31.12 design option and calculate MAOP for existing network for desired hydrogen blend

The design modification module models three independent methods for accommodating hydrogen

- **Method 1: Directly replace existing pipes that cannot meet required pressure**
  - Identify pipes that violate ASME B31.12 requirements for a chosen design option
  - Replace those pipes with new pipes of the same diameter (presumably use design option B for new pipes)
  - *Modify or replace compressors necessary to meet required operating pressure*
  - *Replace valves and meters as necessary to handle hydrogen*
  - This method requires removing existing pipe, but we assume no new right-of-way costs

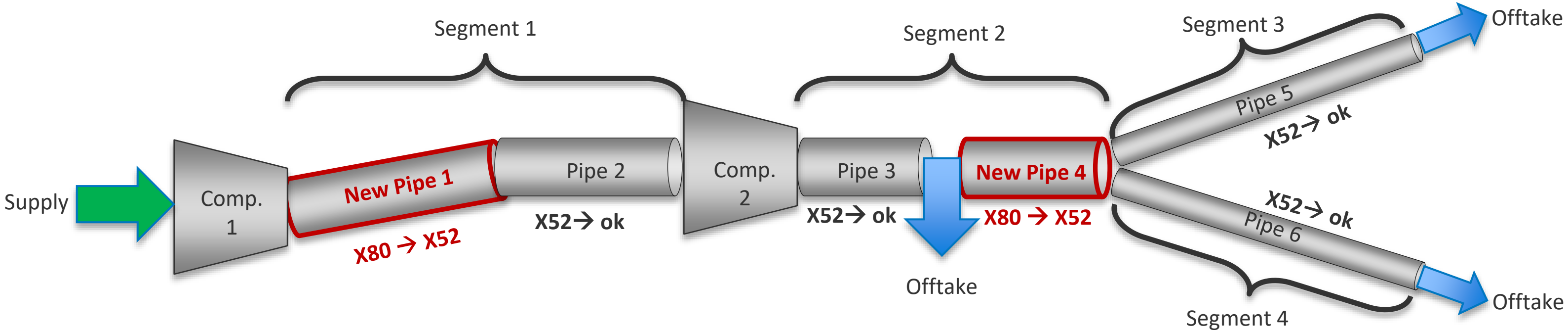

Figure 3: Example of pipe network modification with direct pipe replacements.

The design modification module models three independent methods for accommodating hydrogen

- **Method 2: Build parallel loops to increase capacity at reduced operating pressure**
  - Reduce operating pressure of existing pipe to that allowed by ASME B31.12 given design option employed
  - Build pipe parallel to existing pipe to accommodate higher volumetric flow at lower operating pressure
    - Calculate loop length for different diameters
    - Select least-cost loop diameter and schedule that allows network to meet all demand
  - *Modify or replace compressors as necessary to meet required operating pressure*
  - *Replace valves and meters as necessary to handle hydrogen*
  - This method keeps existing pipe but incurs additional right-of-way costs for added new parallel pipe

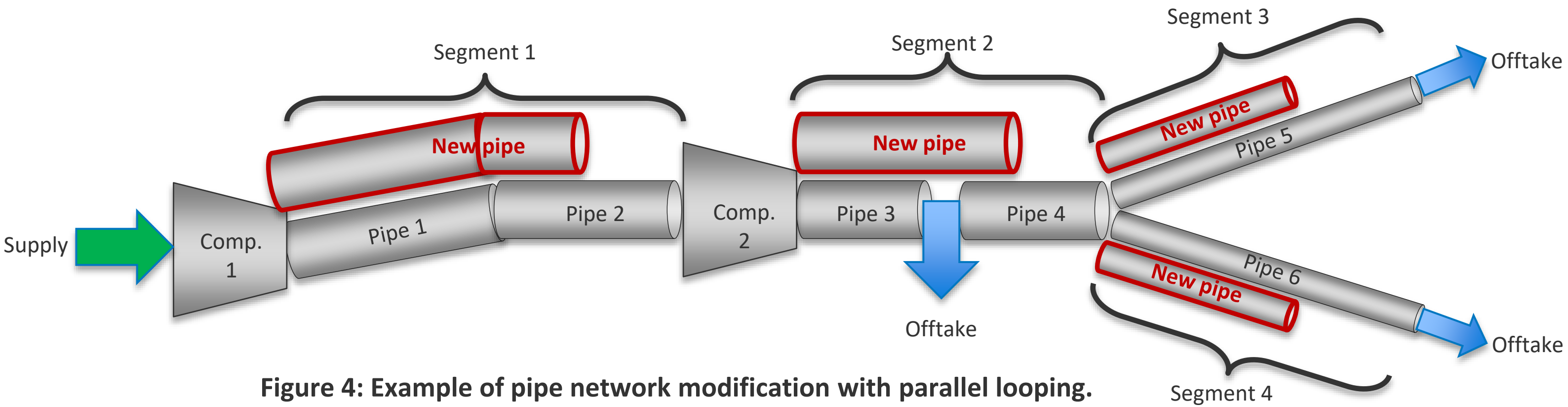

Figure 4: Example of pipe network modification with parallel looping.

The design modification module models three independent methods for accommodating hydrogen

- **Method 3: Build new compressor stations along existing pipeline and operate at reduced pressure**
  - Reduce operating pressure of existing pipe to that allowed by ASME B31.12 given design option employed
  - Calculate number and placement of additional compression stations to increase volumetric flow through existing pipeline at reduced operating pressure
  - *Modify or replace existing compressors necessary to meet required operating pressure*
  - *Replace valves and meters as necessary to handle hydrogen*
  - This method keeps existing pipe but requires more frequent compression stations

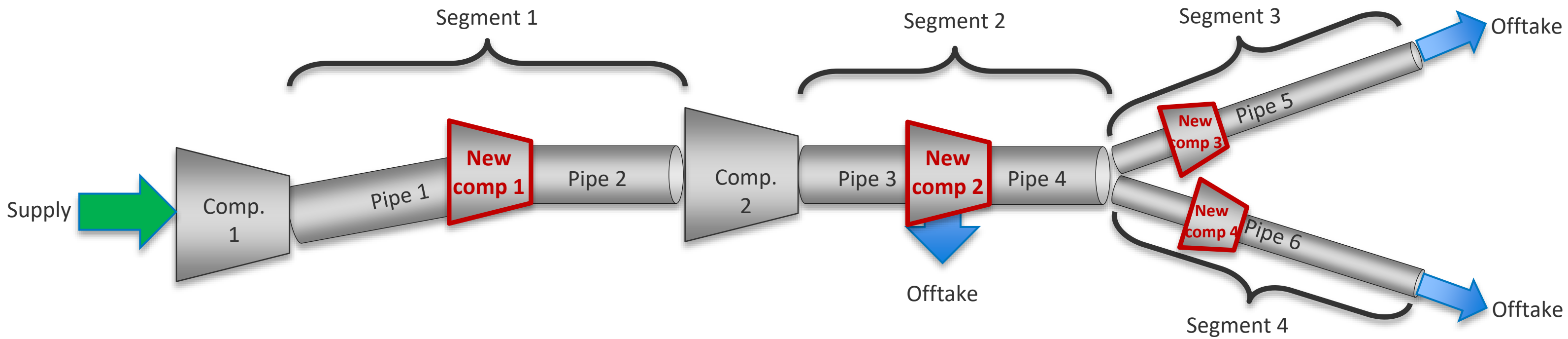

Figure 5: Example of pipe network modification with additional compression capacity.

Alliance Pipeline serves as a preliminary PPCT case study demonstration

- Alliance Pipeline is a well-documented, large-scale pipeline representative of future potential blending scenarios

- Case study covers 327 mi segment of U.S. pipeline; simulated to transport 64,345 MMBTU/hr of gas to end users

- Demonstrated each model method to assess preliminary economic impacts for blending up to 10% vol H_2

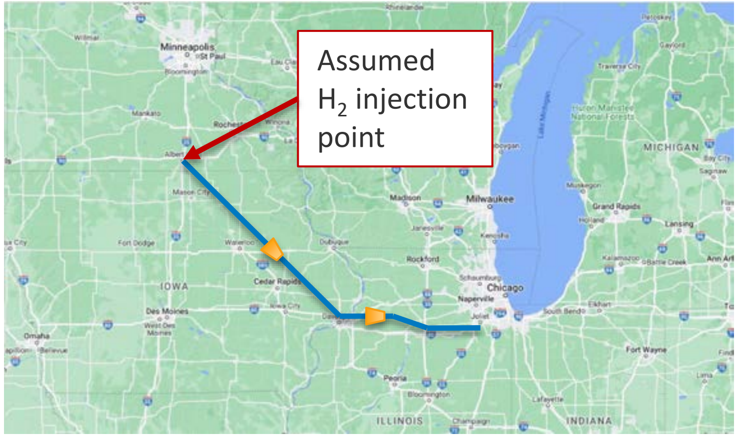

Figure 6: Segments of Alliance Pipeline (—) and compressor stations (▶) represented in case study

Table 1: Preliminary key performance indicator results for each modification method applied for blending to 10% by vol. hydrogen in pipeline gas case

Applied PPCT Modifcation Method	ASME B31.12 Design Pressure	Required length of added new pipe	Compressor stations (CS) added	Required increase in CS rated power	Transported gas used as fuel
Direct pipe replacement	1740 psig	327 miles	-	-	0.58%
Parallel looping	678 psig	295.5 miles	-	17.6%	0.8%
Additional Compressors	678 psig	-	16	909%	6%

Due to the low ASME B31.12 design factor, all methods require significant equipment investments for hydrogen blending

- Direct replacement method requires approximately $932 million in new pipe across all blending scenarios ($9.80/ton-mile)
- Parallel loop method with the 10% vol. H_2 in pipeline gas scenario requires
  - $723 million in new pipe ($7.59/ton-mile)
  - $25.3 million in new compression capacity
  - $57.8 million in compression station refurbishments
- Additional compressor method with the 10% vol. H_2 in pipeline gas scenario requires
  - $778 million in new compressor stations
  - $57.8 million in compression station refurbishments

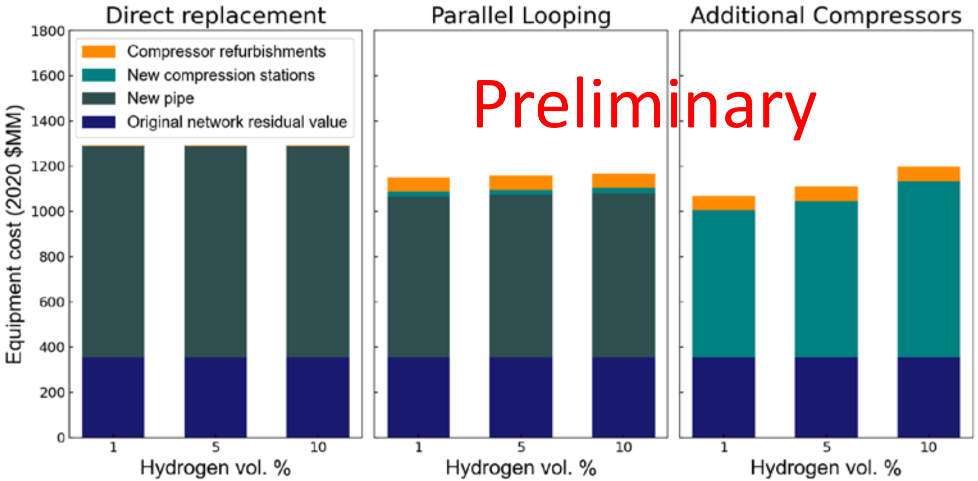

Figure 7: Installed capital expense for each pipeline modification method at 1%, 5% and 10% vol. H_2 in pipeline gas

Levelized cost of transport (LCOT) is estimated using ProFAST and high-level cost estimation

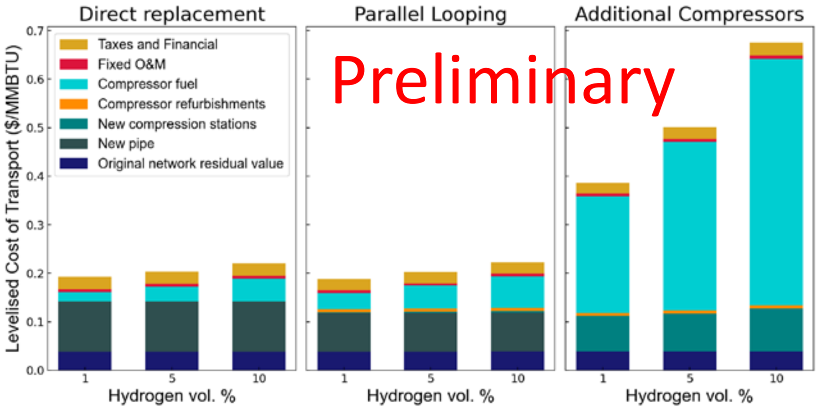

Figure 8: Levelized cost of transport for each pipeline modification method at 1%, 5% and 10% vol. H_2 in pipeline gas

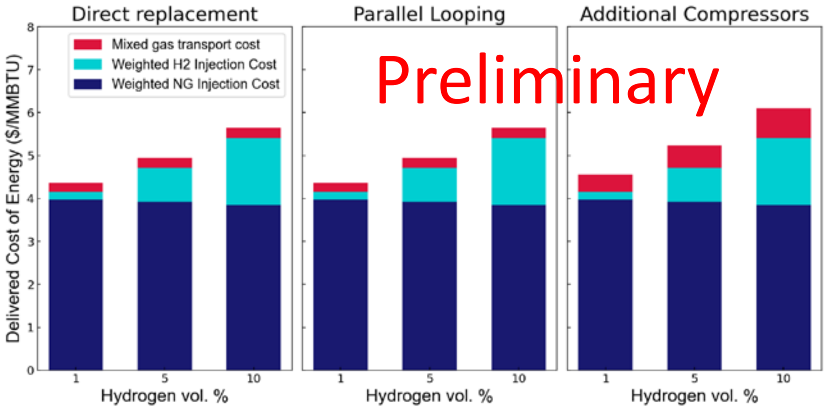

Figure 9: Delivered energy cost for each pipeline modification method at 1%, 5% and 10% vol. H_2 in pipeline gas

- Direct replacement and parallel looping modifications are favored for this case study
  - Direct replacement has highest pipe costs, lowest compressor costs
  - Parallel looping has lower pipe costs, higher compressor capex and fuel costs
- Additional compressors method has no pipe costs but very high compressor capex and fuel costs

- LCOT is a small portion of delivered cost of energy
- Delivered energy increases with increasing H_2 blending (at $6 - $7 per kg H_2)
- Added capital associated with low levels of blending may not necessarily translate to significant increases in cost of delivered energy

Summary

- NREL's key tasks in the Pipeline Blending CRADA covers the challenges and economic costs of blending hydrogen into natural gas pipelines

- NREL developed the PPCT with key objectives of:
  - Assessing a pipeline's compatibility to blend hydrogen without major capital investment
  - Identifying potential pipeline system upgrades to blend hydrogen to *X%* in pipeline gas
  - Estimating capital and operating expenses associated to pipeline system upgrades

- Levelized cost of transporting hydrogen blends are estimated for three design modification methods applied to a preliminary transmission pipeline case study

Future research will refine the PPCT to explore higher blend ratios and additional case studies

- Use the PPCT to explore higher blend ratios and/or other potential network case studies
- Explore economic impact of potential revisions to design guidelines based on materials research
- Improve PPCT framework automation and cost estimation (pending available data)
  - Compressor refurbishment costs and dependence on pressure, hydrogen blend, etc.
  - Valve and meter costs
- Adding messaging to inform model user of additional requirements for pipeline testing before hydrogen blending project implementation to ensure safe pipeline operation
- Improve user interface/accessibility of model framework

Thank You

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