HyBlend: Pipeline CRADA Cost and Emissions Analysis

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National Renewable Energy Laboratory

Argonne National Laboratory

WBS 8.6.2.1

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Project ID: IN034

DOE Hydrogen Program
2022 Annual Merit Review
and Peer Evaluation
Meeting

Project Goal: Assess opportunities, costs, and lifecycle emissions benefit for blending hydrogen into natural gas pipelines

Vision

Develop tools to quantify the economic and environmental impacts of blending hydrogen into the U.S. natural gas pipeline system

What

- **Model the economic impact and lifecycle emissions** associated with blending hydrogen into the U.S. natural gas pipeline system
- Evaluate user-defined scenarios to blend hydrogen to achieve $X\%$ composition into a pipeline network

How

- Leverage DOE/lab tools (H2A, HDSAM, GREET®, RODeO) to estimate value proposition of blending
- **Design and analyze scenarios** to evaluate the hydrogen blending's application across different sections of the U.S. natural gas pipeline system

Why

- **Quantify the value proposition** of hydrogen blending to accelerate early-market hydrogen technology adoption and achieve short-term emissions reduction
- Provide natural gas pipeline operators a pathway to convert existing assets into clean infrastructure

Overview: Pipeline Blending CRADA

Timeline and Budget

Start: October 2021
End: September 2023

15% complete (NREL's TEA tasks)*
*As of April 25th, 2022

Overall CRADA project budget: $15 MM
- DOE Share: $11 MM
- Cost Share: $4 MM

NREL's total project budget: $1.85 MM
- DOE funds spent**: $172.2k
- Industry cost share funds spent**: $76.6k

ANL's total project budget: $1.6 MM
- DOE funds spent**: $176k

**as of ~03/01/2022

Partners

National Labs *(Role)*
National Renewable Energy Laboratory - Mark Chung, PI (Techno-economic Analysis)
Argonne National Lab – Amgad Elgowainy, PI (Lifecycle Analysis)
Sandia National Lab – Chris San Marchi, PI (Metals Compatibility)
Pacific Northwest National Lab – Kevin Simmons, PI (Polymer Compatibility)

Industry Partners *(alphabetical)*
Air Liquide, Chevron, DNV, Enbridge, EPRI, ExxonMobil, GTI, Hawaii Gas, Hydril, National Grid, NJNG, ONEGAS, PRCI, SMUD, Southern Company, Stony Brook University and SWRI

Relevance: Utilizing existing natural gas infrastructure might enable low-cost H$_2$ transport and facilitate private sector uptake

- The U.S. possesses an extensive natural gas (NG) network consisting of 2.44 million miles of pipe
- **Leveraging this existing infrastructure for hydrogen blending advances DOE goals 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

Approach (1/5): Pipeline Blending CRADA Techno-economic Analysis Objectives

What upgrades may be required for pipelines? What's the cost?

Pipeline Upgrade Cost Model

- Flexible open-source tool to estimate the system cost to blend on a case-by-case basis.

- Captures key NG infrastructure elements (e.g., storage, compressors, piping, materials)

- Use and improve gas network models to understand hydrogen concentration along network and its impact on upgrade costs

- Incorporated materials research from SNL, PNNL to identify and prioritize

What revenue opportunities exist with blending?

Hydrogen Blending Value Model

- Internal tool integrating electrolyzers in power production cost and natural gas network models to estimate the revenue opportunities for hydrogen blending (e.g., sales, grid management, demand response, emissions credits)

- Journal article on use and improve integrated electricity grid and natural gas operational models and hydrogen representation

- Establish metrics for blended system operation

What are the alternative decarbonization pathways?

Benchmarking Alternative Pathways

- Internal tool to analyze the economics of alternative pathways to pipeline decarbonization (e.g., estimate USD/tonne-CO_2 avoided cost in collaboration with ANL's LCA modeling)

- Journal article evaluating potential decarbonization pathways including
  - Synthetic natural gas from renewable H2 + captured CO2
  - 100% hydrogen pipelines

Materials Research Tasks

Sandia National Laboratories · Pacific Northwest NATIONAL LABORATORY

Building and Improving on Prior Efforts

NREL

Integrating with LCA Task

Argonne NATIONAL LABORATORY

NREL Transforming ENERGY — **Cross-laboratory collaboration *facilitates* learning and *improves* feedback loop** — NREL Transforming ENERGY

Note: indicates key deliverable
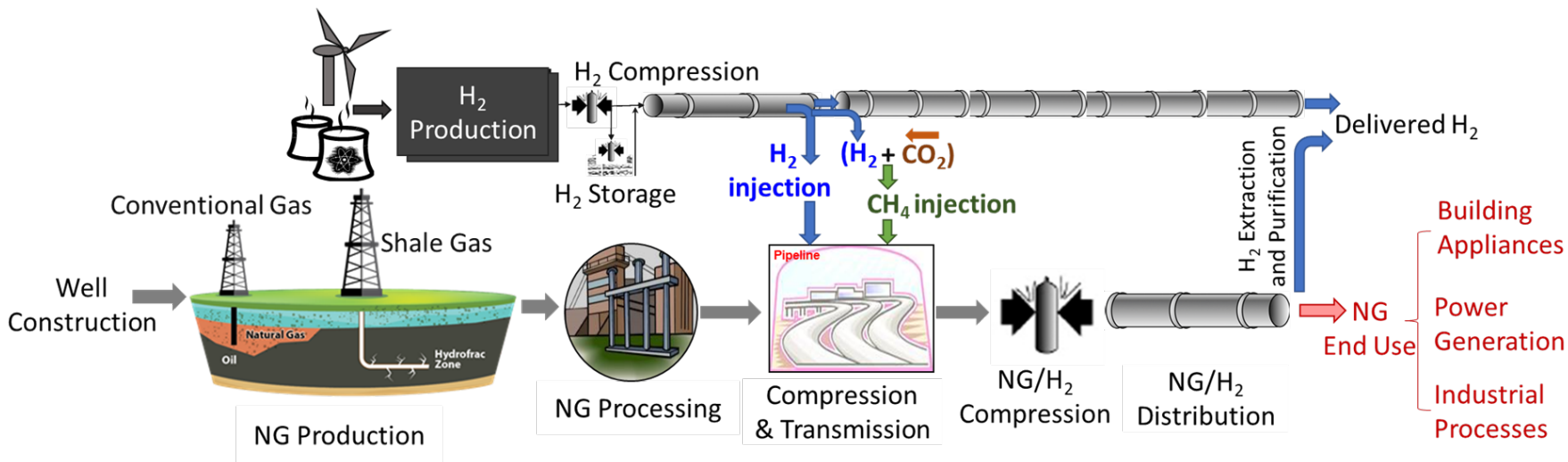
- Identify the GHG emissions associated with each stage across the full supply chain of H_2/NG blend, e.g., NG recovery and transport, hydrogen production and injection, the compression and transmission and final application of H_2/NG blend.

Approach (3/5): Pipeline Blending CRADA Analysis Milestones

Due Date	Lab	Description	Status
December 2021	NREL	Draft NREL report providing an updated literature review of the global research and experience of operating hydrogen blends	Complete
March 2022	ANL	Evaluation of energy use and emissions of H_2 production pathways to injection point	Complete
March 2022	NREL	Status memorandum detailing how the techno-economic pipeline preparation tool will be integrated with the natural gas and electric grid modeling framework.	Complete
June 2022	ANL	Evaluation of cost, energy use and emissions of capturing, purifying and transportation of CO_2 from various sources	On Track
June 2022	NREL	Status memorandum the key components of the natural gas supply-chain to be prioritized	On Track

Approach (4/5): Pipeline Blending CRADA Analysis Milestones

Due Date	Lab	Description	Status
September 2022	NREL	Status memorandum and presentation to DOE and industry parties summarizing the status of (1) techno-economic pipeline preparation model, (2) natural gas and electricity infrastructure models, (3) alternative decarbonization benchmark pathways, (4) potential data and method improvements and (5) initial inputs/output results	Not Started
September 2022	ANL	Evaluation of energy and emissions of delivering NG/H_2 blends from injection point to end use applications	In Progress
September 2022	ANL	Model of CH_4 synthesis process	In Progress
December 2022	ANL	Integrating life cycle assessment with techno-economic analysis of synthetic NG production	In Progress
December 2022	NREL	Draft journal article of initial techno-economic pipeline preparation tool and results of a case-study application of the tool.	Not Started

Approach (5/5): Pipeline Blending CRADA Analysis Milestones

Due Date	Lab	Description	Status
March 2023	ANL	Evaluation of emissions of NG/H$_2$ combustion at various end use applications	Not Started
March 2023	ANL	Life cycle assessment of synthetic NG production	In Progress
March 2023	NREL	Draft journal article on the economic assessment of alternative pathways for natural gas decarbonization	Not Started
June 2023	ANL	Life cycle assessment of various NG/H$_2$ blending pathways	Not Started
June 2023	NREL	Draft journal article on the integrated techno-economic pipeline preparation model with the natural gas and electrical grid optimization models	Not Started
September 2023	ANL	Final technical report draft for DOE and public webinar	Not Started
September 2023	NREL	Open-source techno-economic pipeline preparation model provided on NREL's website with supporting documentation (NREL Report). Public webinar completed after publication	Not Started

Accomplishments and Progress (1/9):
Literature review summary

Consensus is <u>emerging</u> on H$_2$ impacts on steel materials* and pipeline performance

- Suitability of steel natural gas transmission pipelines for hydrogen depends on several factors
  - Condition of pipeline (design, construction methods, fatigue, defects, etc.)
  - Pipeline operating conditions (pressure, transmission capacity factor, etc.)
  - Hydrogen has a pronounced affect on fatigue and fracture properties*
    - However, impact of increased hydrogen concentration is relatively modest
    - Design guidelines (ASME B31.12) exist for steel pipes with >10% hydrogen

- Theoretical impacts of hydrogen blending on transmission pipeline transport and compression performance are well documented
  - 100% hydrogen with equivalent ΔP: reduces energy transmission capacity by 15-20%
  - Compressing hydrogen to equivalent pressure requires substantially more energy
  - Compressors may be limited by power and speed rating (especially centrifugal compressors)

*For more information on hydrogen impact on materials, please attend in035_san marchi_2022 for HyBlend materials research.

> ## **More research is needed on polymers*, components, and economics**

- Need more data on impact of hydrogen on polymer pipe mechanical properties and life*
- Currently no design guidelines for plastic pipes

- Need more research on hydrogen's impact on valves, flow-meters, and pressure regulators
- Lower Wobbe Index, faster flame speed, and wider flammability limits all impact end-use appliance compatibility; modifications likely necessary at some point

- Literature contains many studies of simulation and optimization of gas networks with hydrogen
  - Many focus on blending for increasing renewables penetration and decarbonization
  - Most target low blending levels (<20% vol.)
  - Few consider costs of upgrading pipelines, equipment, and appliances for hydrogen
  - Economics of blending are case dependent; tools for evaluation are lacking

*For more information on hydrogen impact on materials, please attend in035_san marchi_2022 for HyBlend materials research.

Literature review summary

> **Demonstrations have primarily been conducted on low-pressure distribution systems with residential and commercial end users**

- Handful of blending demonstrations in the U.S. to-date
  - Hawaii Gas: 12%-15% hydrogen in low-pressure transmission and distribution systems is the longest-running demonstration (>50 years)
  - Pipeline network and end-use appliances (primarily residential and commercial appliances such as water boilers and cooktops) have not needed significant upgrades
- Several ongoing demonstration projects globally
  - Low-pressure distribution networks with a limited number of end users
  - High-pressure transmission networks with multiple end-users
  - Testing on residential and commercial end-use appliances
- Limited demonstrations of blending for industrial applications such as power generation, petrochemical or steel manufacturing, etc.
  - Likely due to their high sensitivity to inlet gas quality.

Literature review summary

There are numerous active blending projects today, many applied to the transmission network and some attempting up to 100% hydrogen

- High-pressure transmission line active demonstration projects: MosaHYc*, FenHYx*, Jupiter 1000, HyNTS FutureGrid, Snam Contursi and H21*.

- Low-pressure distribution system demonstrations

  - Many initially target 3-5 vol.%, and incrementally increase over time up to 20%

  - Consensus in literature that 5% is tolerable (without significant device tuning or capital expenditure) by both the network and many end-use appliances.

  - Very few projects have tested above 20%

  - HyDeploy project is an exception: tested blends of up to 28.4%

  - The H21 Leeds City Gate project (started 2016) plans to implement 100% H_2 in distribution network in Phase 3 (timing unknown)

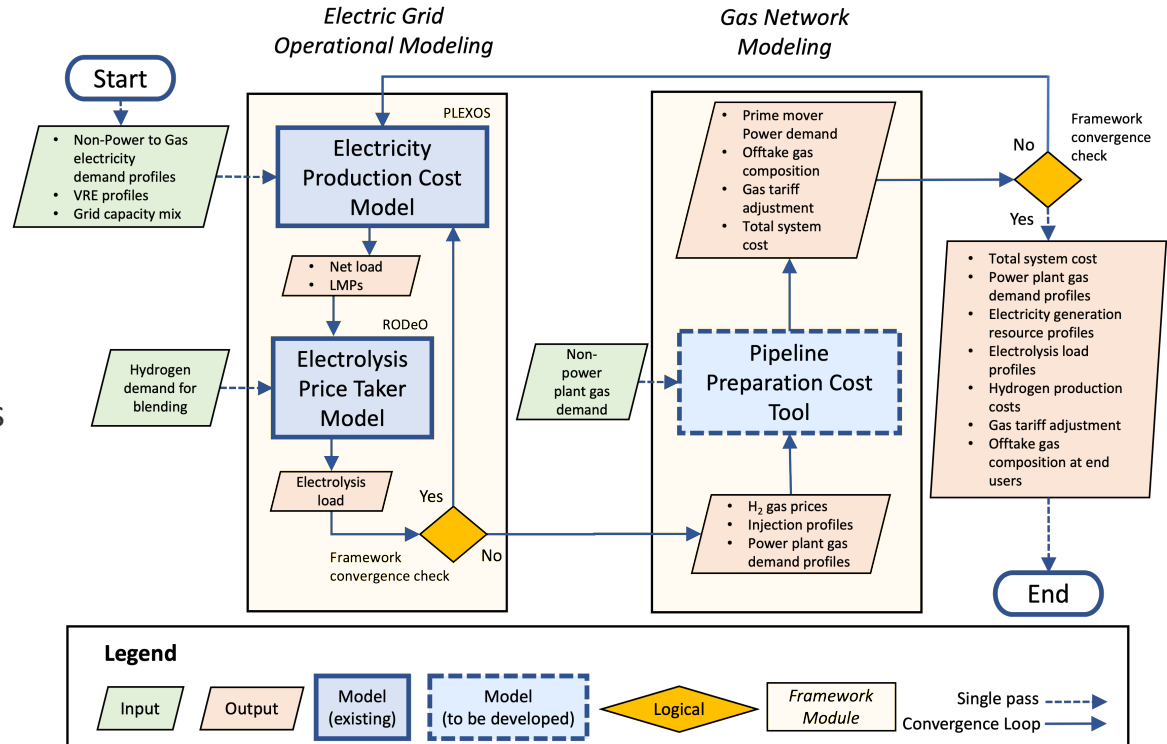*Denotes demonstration projects testing higher hydrogen concentrations of up to 100%

- The Pipeline Upgrade Cost Model is developed to answer the following:
  - What % of hydrogen 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
  - Leverages pipeline and equipment records
  - Avoids need for costly inspections in later project assessment stage
- Intent is to provide the user with an understanding of most promising opportunities before proceeding with more detailed pipeline inspections based on "probable" economic outcome
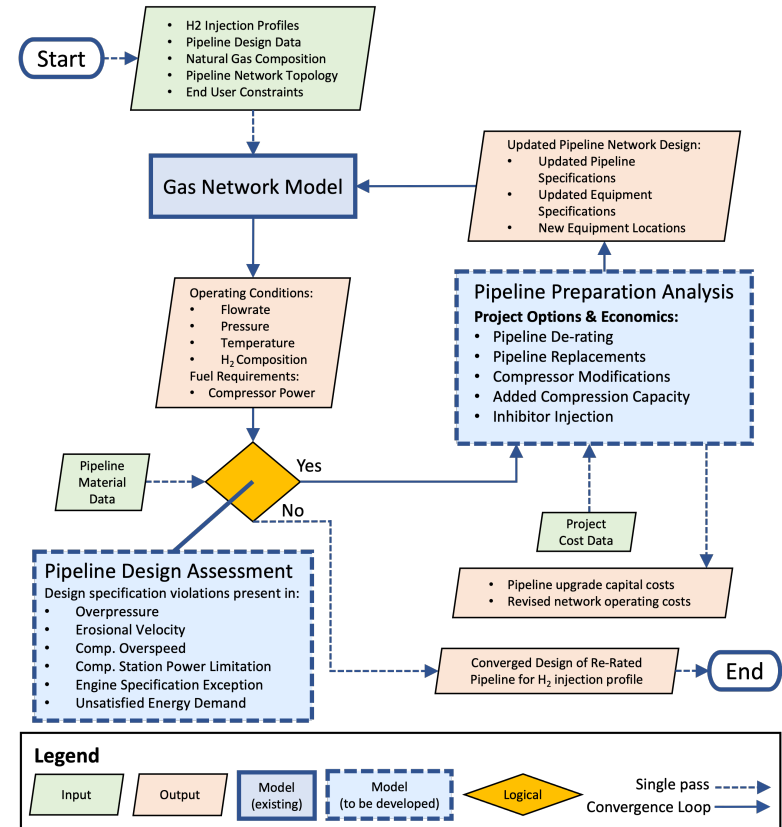
- Assessing the value of blending electric grid-derived hydrogen into a natural gas pipeline network requires:
  - Modeling both electric grid and gas network
  - Multiple feedback loops
- Framework is designed for market coordination approach
- Iteration may be necessary for framework models to observe mutual constraints

- Evaluation of the GHG emission of various H$_2$ production pathways to injection point

- Compression emissions were calculated considering US electricity mix (2020)

- When H$_2$ is blended with NG, the environmental benefit is highly dependent on the H$_2$ production pathway
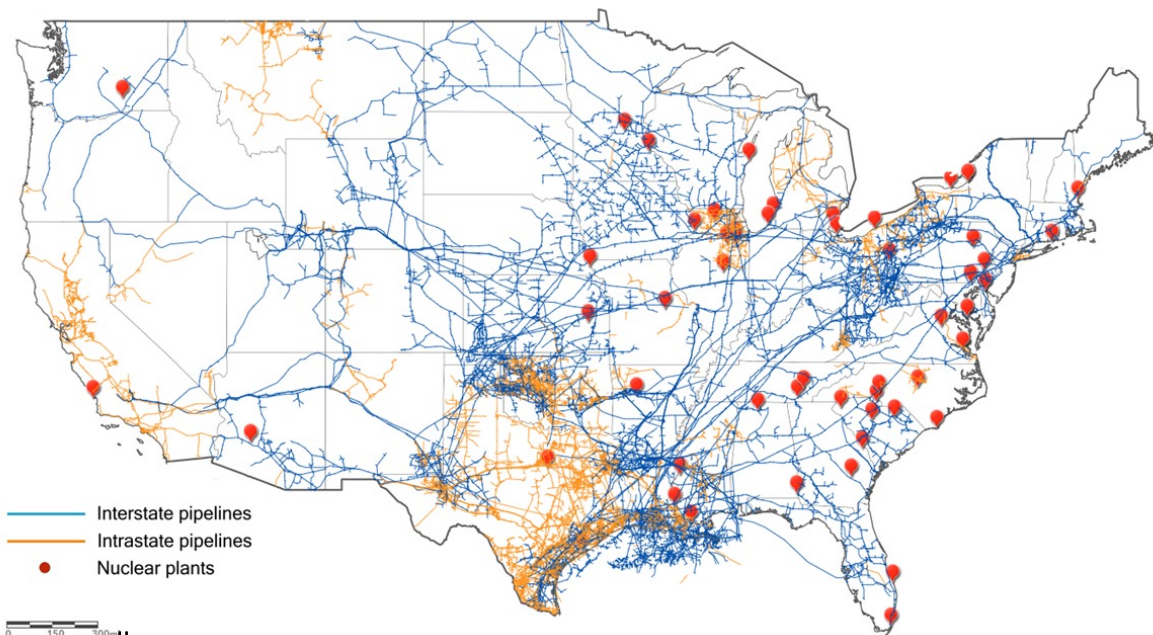
■ Injection emissions were calculated considering US electricity mix (2020) on a higher heating value (HHV) basis
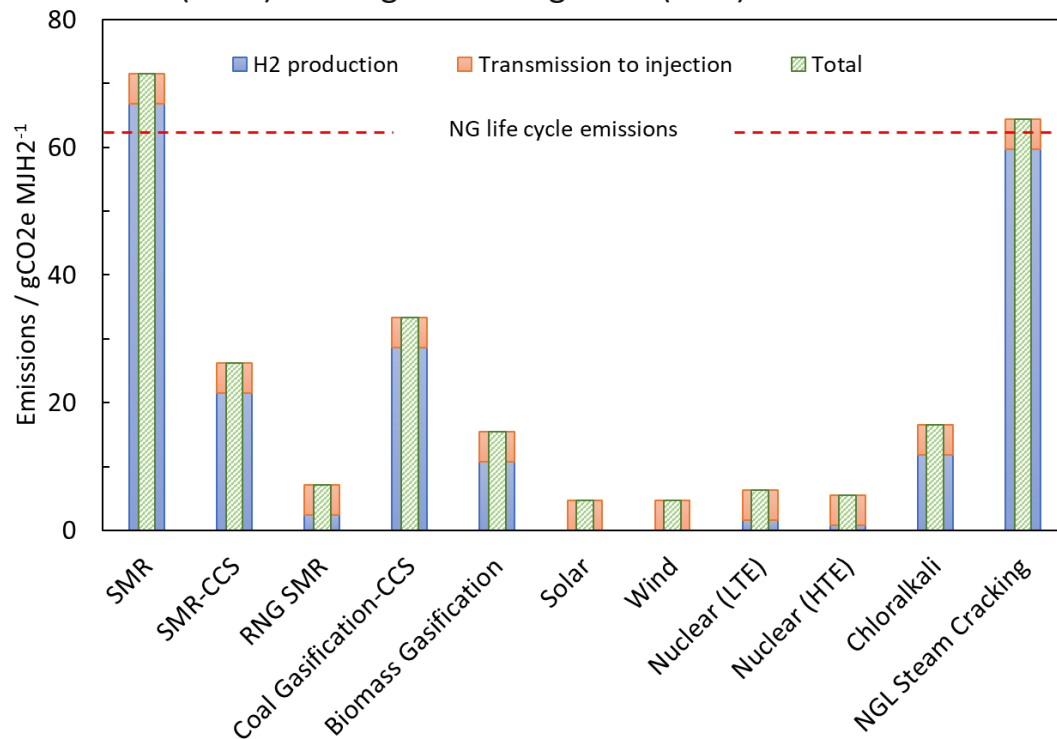
Interstate pipelines		
Intrastate pipelines		
Nuclear plants		

Average distance to NG pipeline	10	miles
Average nuclear power	1750	MW
Max H2 capacity (HTE, 71.4%)	1000	MT/day
	423	MMscfd
Average NG pipeline capacity	2360	MMscfd

- We consider H$_2$ production in proximity of NG pipeline for blending

- Example: we found nuclear power plants for hydrogen production are within ~10 mile radius from an NG transmission pipelines

- 55 nuclear plants with an average power of 1750 MW, can produce up to 1000 MT H$_2$/day

Response to Previous Year Reviewers' Comments

- This is a new project and has not been reviewed before at AMR

Collaboration and Coordination

- **U.S. DOE National Laboratories**
  - NREL: Project Lead, Techno-economic analysis (TEA)
  - ANL: Life cycle assessment (LCA) and emissions analysis; LCA/TEA of Synthetic Natural Gas (SNG) production
  - PNNL: Polymeric material testing and analysis
  - SNL: Metallic material testing and analysis; supporting polymeric material testing
- **Industry stakeholders**
  - Guide and inform research to yield insights to better inform industry-wide solutions
  - Help identify most economically critical natural gas supply chain segments
  - Provide insight or guidance on how NREL-developed economic tools can be most useful

Remaining Challenges and Barriers

- **Techno-economic analysis:**
  - Computational complexity of modeling and optimization of multiple sectors
    - Achieving a tractable solution time, convergence of multiple iterative feedback loops
    - Work with industry partners to select the most relevant scenarios
  - Uncertainty in materials and cost data
    - Work with SNL and PNNL to incorporate the latest material performance data
    - Work with industry stakeholders to obtain the best cost data for the most economically impactful components
- **Lifecycle assessment:**
  - Identification of storage needs and distance to injection point
    - Depends on available low carbon electricity for H_2 production and proximity to NG pipelines
    - Interact with project team for potential scenarios and inputs

Proposed Future Work

- **Planned tasks for FY22**

  - Continued development on pipeline upgrade and coordinated gas-electric models with key scenario case studies

  - Pathway comparison between hydrogen blending, pure hydrogen pipelines, and SNG production

  - Evaluation of energy and emissions of delivering H_2/NG blends from injection point to end use applications

  - Evaluation of cost, energy use, and emissions of capturing, purifying and transportation of CO_2 from various sources

  - Model of CH_4 synthesis process, estimate the production cost and GHG emission. This is an alternative scenario to injection with tradeoff between upstream and downstream costs

- **Planned work beyond FY22**

  - FY22 task refinement and research publication

  - Proposed tasks to build on FY22 progress by

    - Improving pipeline upgrade model

    - Electric grid capacity expansion modeling with consideration of hydrogen for natural gas blending

    - Comparing options for managing blend ratio in dynamic conditions due to variations in renewable output and gas demand

    - Investigating impact of H_2 storage option and transportation distance on GHG emissions

Summary

- Hydrogen blending into natural gas networks necessitates case-by-case assessment approach
- Knowledge gaps in pipeline material mechanical properties and equipment performance warrants additional research

- Existing literature establishes foundation for operational modeling of hydrogen blending
- Previous techno-economic assessments are often narrow in focus
- More comprehensive economic modeling frameworks are proposed to estimate blending value

- Environmental benefit of using H_2/NG blends is highly dependent on H_2 production pathway
- The usage of renewable electricity or low-carbon power (e.g., solar, wind, nuclear) is key for the generation of low carbon H_2 needed for blending
- Synthetic natural gas is proposed as an alternative to blending

Thank You

NREL/PR-5400-82564

HyBlend

U.S. DEPARTMENT OF ENERGY

Technical Backup and Additional Information

Technology Transfer Activities

- **Pipeline Upgrade Cost Model** is being developed will be released as open-source (target end in 2023)

- **RODeO** is a publicly available open-source optimization model. Access to **RODeO** is provided in the following link: (https://github.com/NREL/RODeO)

Publications and Presentations

Publications

- Kevin Topolski, Evan P. Reznicek, Burcin Cakir Erdener, Omar Jose Guerra Fernandez, Bri-Mathias Hodge, Chris W. San Marchi, Joseph A. Ronevich, Lisa Fring, Kevin Simmons, and Mark Chung. "Hydrogen blending into natural gas pipeline infrastructure: review of the state of technology." National Renewable Energy Laboratory, Golden, CO. NREL/TP-5400-XXXXX. *In Press, 2022.*

Presentations

- Evan Reznicek, Kevin Topolski, and Mark Chung. "Pipeline Blending CRADA – A HyBlend Project." Federation of Indian Petroleum Industry webinar on Gas-H_2 Blending. April 8, 2022.