

An aerial night photograph of a hydrogen fueling station. A white Linde truck is parked at a station, with its tank labeled "Making our world more productive" and the Linde logo. The station is illuminated by bright yellow lights, and several cars are visible in the background. The truck is positioned in front of a building with a glass facade.

High Rate Liquid Hydrogen Fueling for HD Rail

**Sean Kelly
Linde Inc.**

DOE project award: EE0011105

DOE Hydrogen Program
2024 Annual Merit Review and Peer Evaluation Meeting

May 6th -9th , 2024
AMR Project ID:SDI016

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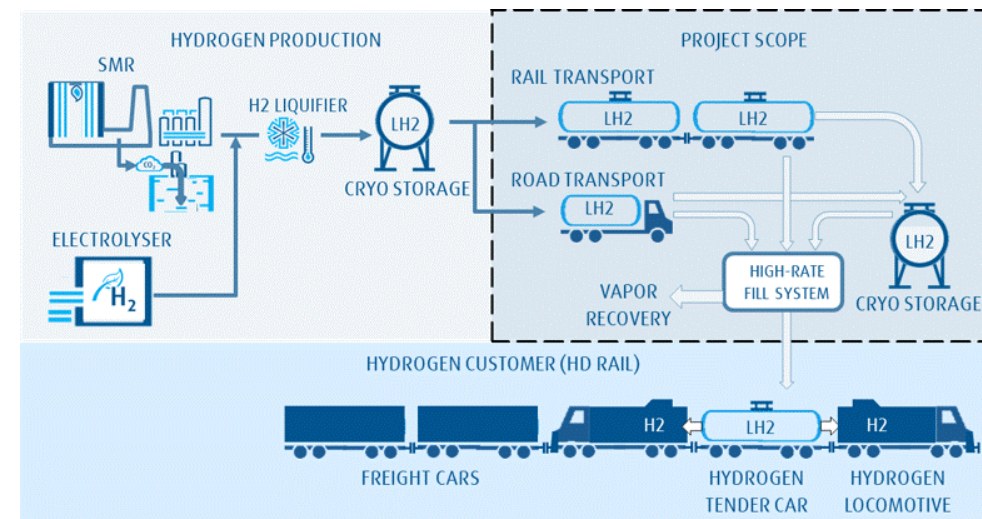
Project Goal

A system targeted for HD Rail Application LH2 Fueling

- Demonstrate the feasibility of a high flow rate, cost effective and safe transfer of LH2 into a rail tank car and a strategy for mitigating the impact of the resulting losses.
- Design, construct and test in a relevant environment a high fill-rate prototype at industrial scale

Technical Targets:

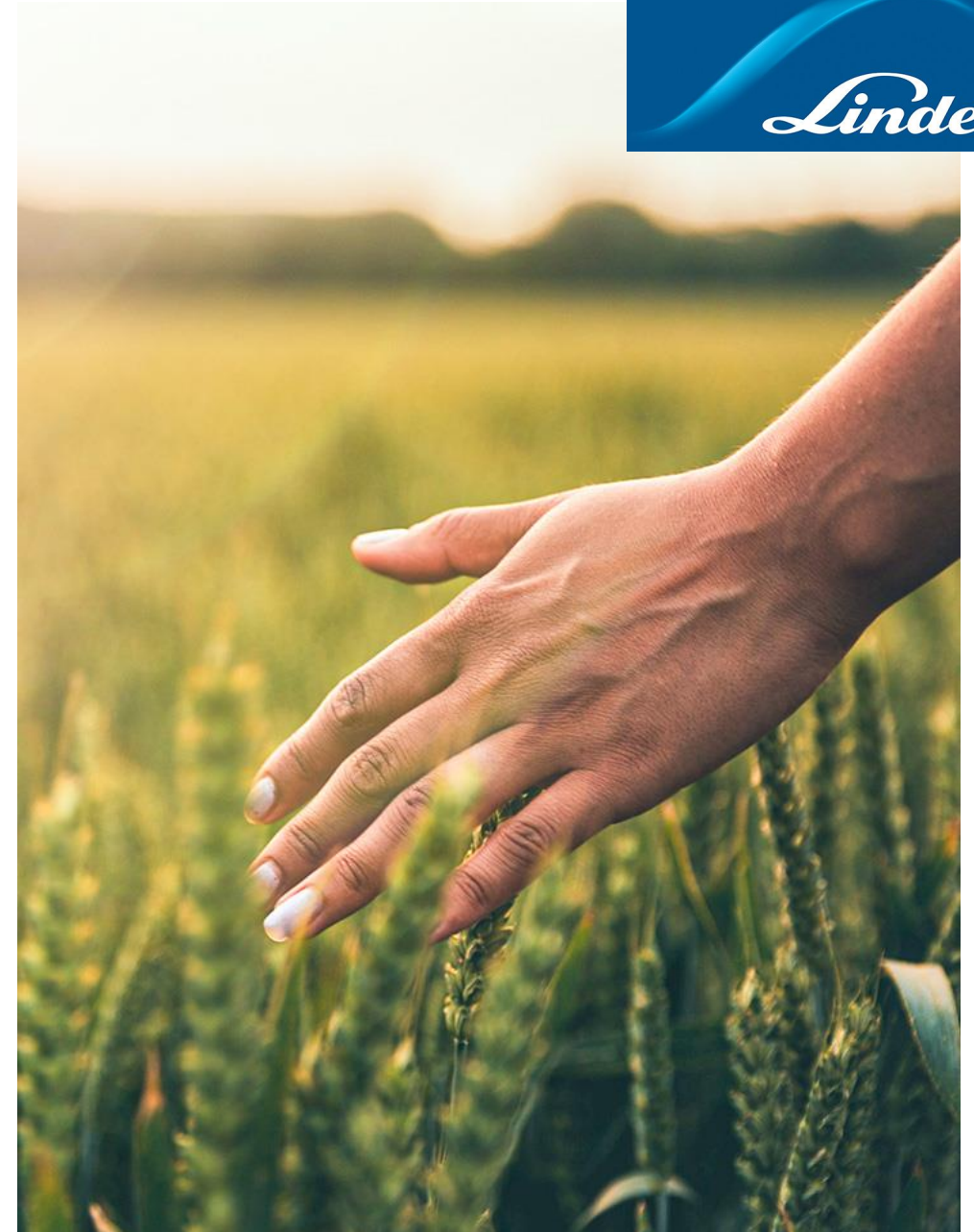
- Minimum 1500 kg LH2 at 100 kg/min flowrate
- Less than 4% hydrogen vapor losses in transfer



Potential Impact

Accelerating the transition of HD Rail to Hydrogen Fuel

- Eliminate a key hurdle to the adoption of H₂ technology in the rail industry while ensuring safe fuel handling
- Help drive adoption by serving as the basis for the currently undefined codes and standards for rail refueling systems and practices.
- Enabler for economical large-scale shipment of LH₂ by rail.
- Positively impact project underserved and underrepresented communities.



Overview



Timeline and Budget

- Project Start Date: 04/01/24
- Project End Date: 04/01/27
- Total Project Budget: \$7,087,481
- Total DOE Share: \$5,669,984
- Total Cost Share: \$1,417,497
- Total DOE Funds Spent*: \$0
- Total Cost Share Funds Spent*: \$0

* As of 03/01/2024

Partners

- Sean Kelly (PI, Linde Engineering N.A.)
- Christopher Homison (Co-PI, Wabtec)
- Brian Ehrhart (Hydrogen Safety, Sandia National Laboratory)
- Jeniffer Flagg (State University of New York at Buffalo, Community Benefits)

Targets

- Design and fabrication of LH2 fueling system targeting HD Rail requirements, anticipated standards, operability and hydrogen safety.
- Achieve Fill Rates of greater than 100 kg/min with a minimum transfer of 1500 kg
- Complete LH2 Transfer to target tank with less than 4% hydrogen vapor loss

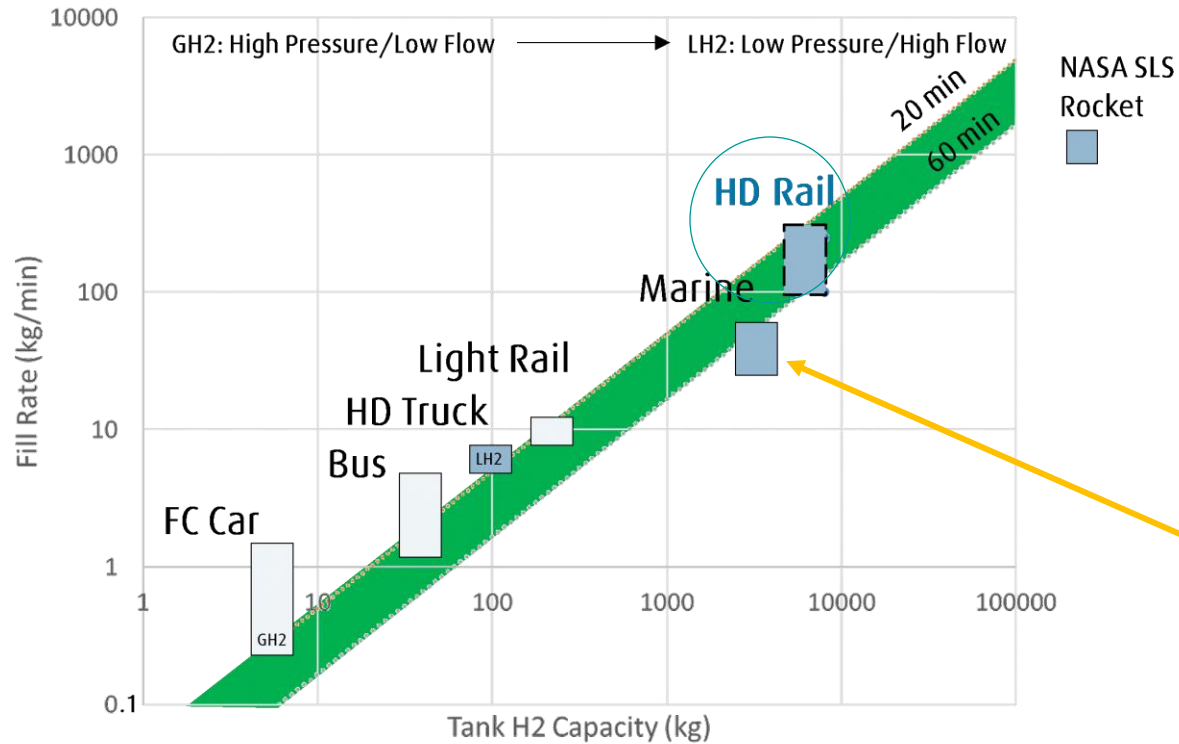
Barriers

- Confirmation of target demonstration location (Linde LH2 plant, Ontario CA.)
- Adaptation of codes and standards for hydrogen use in the rail industry
- Capital cost of LH2 equipment meeting HD Rail requirements

Approach



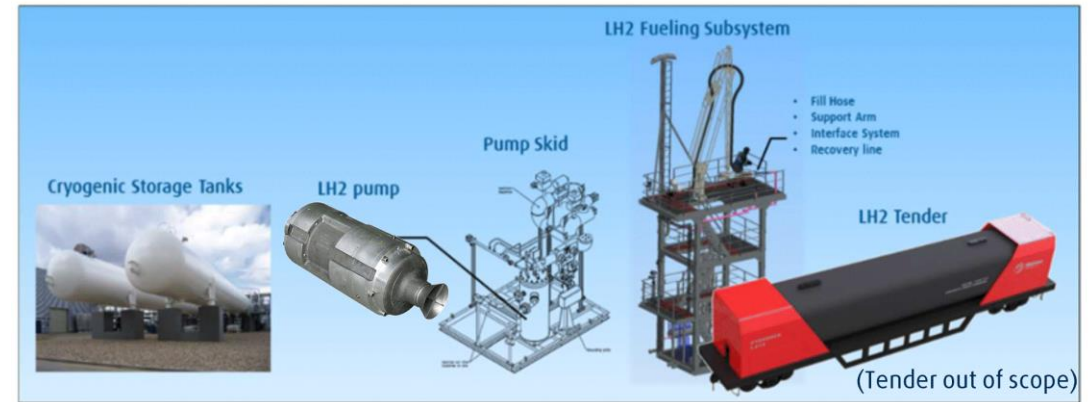
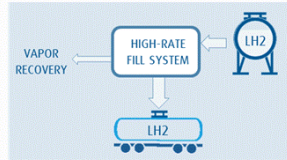
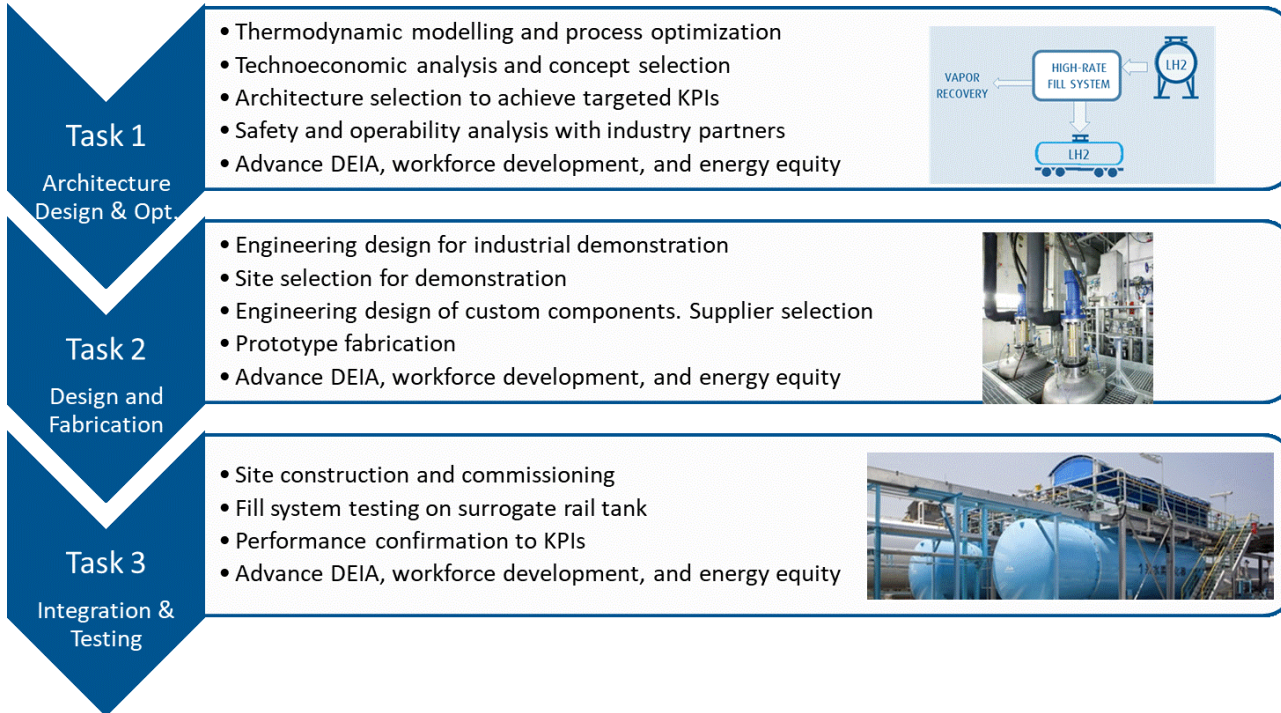
Utilize Linde commercial experience for world-first LH2 Ferry application for HD Rail



Approach



A phased development approach: Process Design and Verification, Engineering and Procurement, Construction and Demonstration

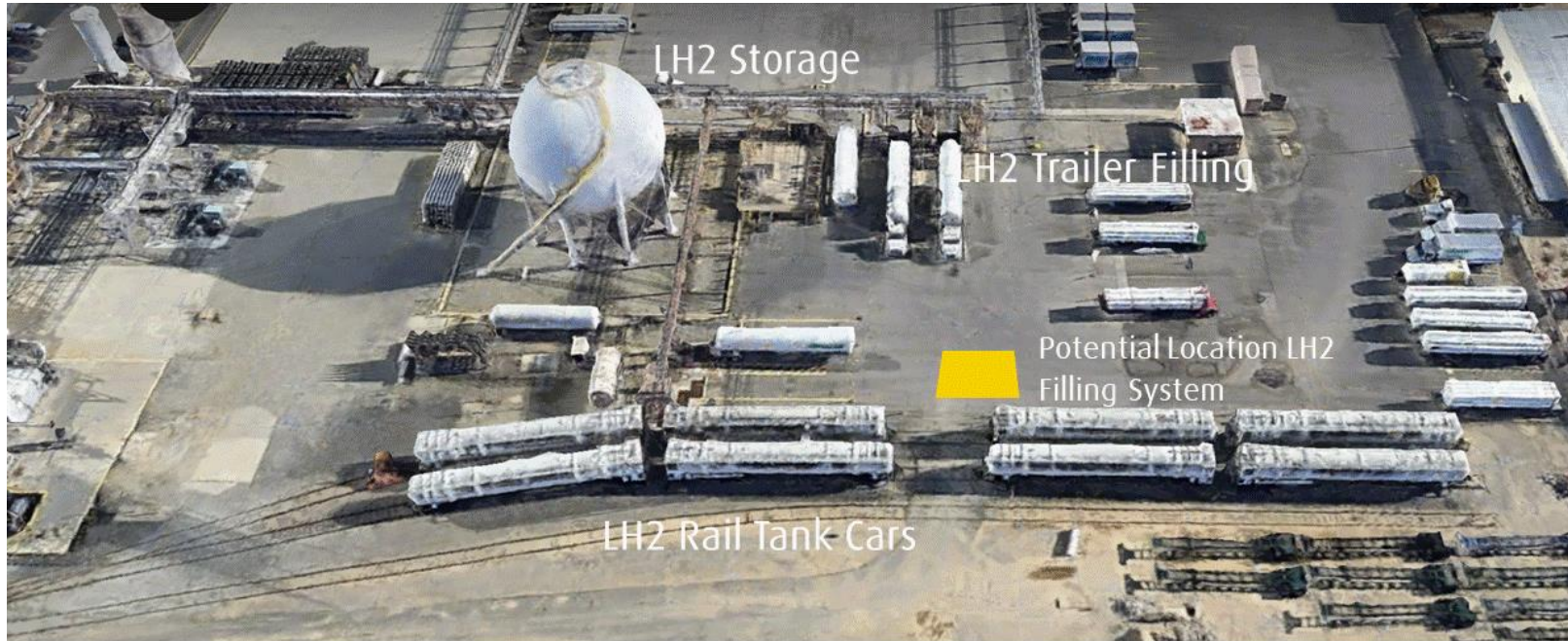


- Linde has core expertise in hydrogen production, LH2 trans-filling, hydrogen for mobility and hydrogen safety
- Linde Engineering has core product competence in LH2 tanks, cryogenic pumps, and filling systems for mobility applications (cars, buses, HD trucks, light rail, and marine)
- Wabtec has locomotive industry experience and is pursuing hydrogen powertrains for HD locomotives.
- Sandia has expertise in hydrogen safety standards, and safe operation protocols
- UB has broad community benefits capability

Approach



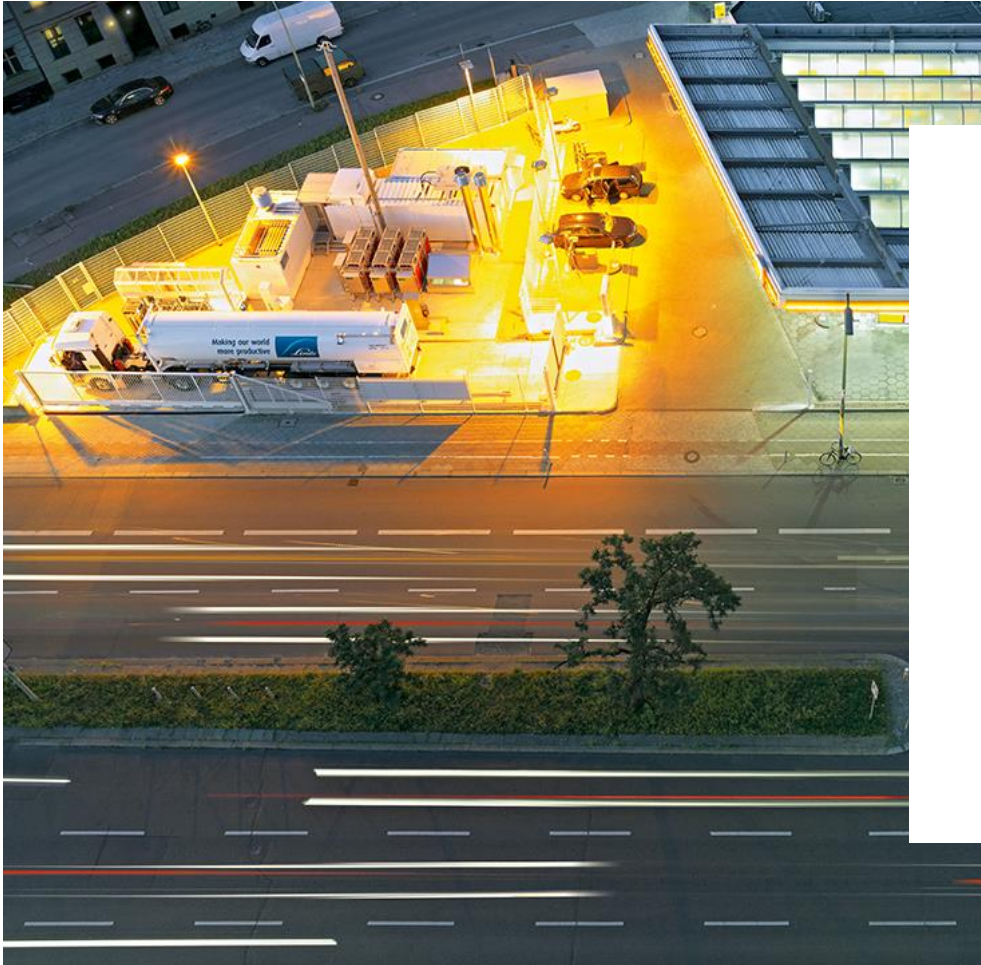
Full-Scale Demonstration Planned at Linde LH2 Production Plant (Ontario CA)



Source: Google Earth

Safety:

- Linde produces and distributes >150 tpd LH2 in the U.S. from 5 production plants
- Linde has supplied more than 200 hydrogen refueling systems worldwide, including a large LH2 fueling system for marine application
- This project will adhere to Linde best-practices around process safety, safe operations, and safe handling of cryogenic hydrogen
- Sandia National Laboratory experts are project participants focused on LH2 fueling safety protocols and required standards



Accomplishments and Progress

Target Project Start April 1st, 2024

- New Award September 2023
- Team participation confirmed
- Contract negotiations and budget justifications complete
- Project start planned April 2024

Collaboration and Coordination



A multi-disciplinary expert team focused on process, safety, operability, equipment design, performance, and community benefits



Linde Inc. / Linde Engineering N.A.

R&D (US): Prime Recipient

- Process design & transient simulations
- Thermodynamic analysis
- Integration and operation at test site

Engineering/Manufacturing (DE)-Contractor

- LH2 vacuum insulated tanks
- LH2 supply system and interface

Cryostar (FR + US)-Contractor

- High flow rate submersible LH2 pumps



Wabtec (US)- Sub-Recipient

- Hydrogen locomotive and rail industry operability, standards, and safety input

State University of New York at Buffalo (US)

- Community benefits program

Sandia National Laboratory (US)-FFRDC

- Hydrogen safety analysis
- Recommendations for new and revised standards for use of hydrogen

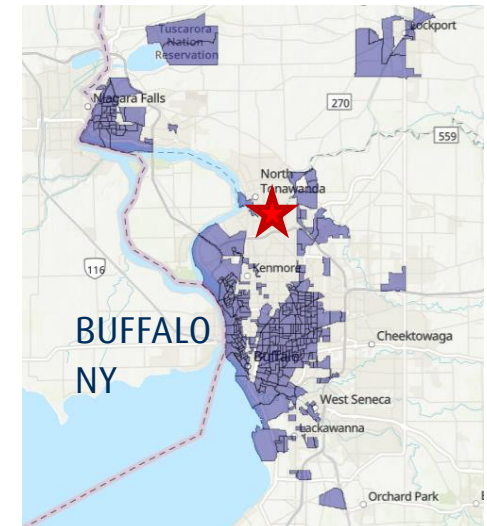
Community Benefits Plan (CBP)



Plan designed to maximize the positive impact of the project in relation to affected communities, with special emphasis on workers and disadvantaged communities.

- University at Buffalo is leading the effort with the support of the project industrial partners.
- A multi-discipline Community Benefits Tasks Force to further develop, implement and maintain the CBP, including Subject Matter Experts (SMEs) from the project Team.
- Three CBP components incorporated into the overall project scope, schedule and budget:
 1. Diversity, Equity, Inclusion and Accessibility (DEIA)
 2. Energy Equity
 3. Workforce Impacts and Opportunities

#	CBP Specific Project Objectives
1	Continuous evaluation of performance metrics for improvement effectiveness in relation to the three components of the CBP by incorporating and building upon lessons learned.
2	Increase and promote DEIA fostering an inclusive environment, advancing equity and encouraging the inclusion of individuals from disadvantaged communities.
3	Advance energy equity by promoting clean and affordable transportation options, and engaging equity and justice stakeholders
4	Design a plan to support education and training of workforce to address needs related to LH2 fueling



- >52.42% in *urban area* members of minority groups
- >26.28% in *rural area* members of minority groups
- >22.82% household incomes below the federal poverty level

Proposed Future Work

FY 2024



Process and Safety

- Project kick-off with partners
- Identification of HD rail application requirements for safety and operability
- Identification of required modes of operation (standby, fill, purge, safety interlock etc.)
- Identification of baseline fill process and process alternatives
- Transient analysis of proposed processes with predicted fill rates and losses.
- Initial equipment cost estimates and process selection
- Identify location(s) at demonstration site and any specific constraints

Equipment

- Confirmation of target LH2 pump performance and requirements for operation (NPSHR, etc.)
- System conceptual design meeting Rail operability and safety considerations
- Initial equipment definition and sizing
- Equipment supplier identification and initial cost estimates

Community Benefits

- Project kick-off with SUNY Buffalo and project partners
- Identification of community benefit opportunities for project
- Initiation of 2024 activities

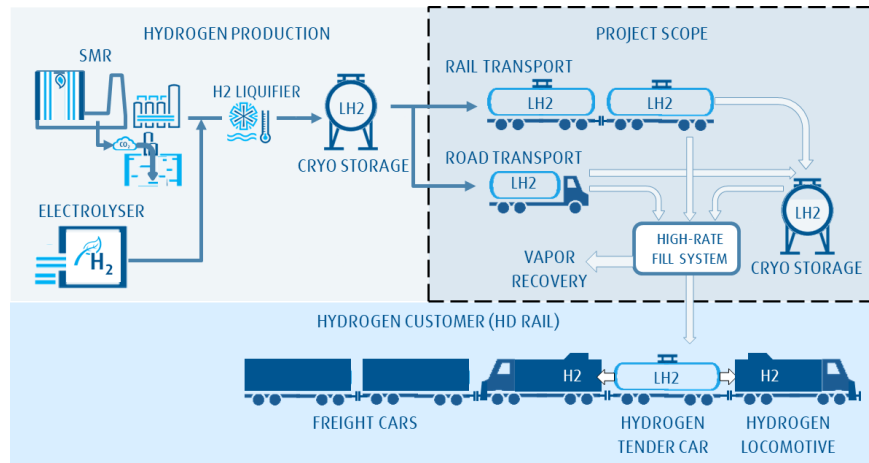
Any proposed future work is subject to change based on funding levels

Project Summary: High Rate LH2 Fueling for HD Rail



Technology Summary

The project will demonstrate the feasibility of a high flow rate, cost effective and safe transfer of LH₂ into a rail tank car and a strategy for mitigating the impact of the resulting losses. To achieve this goal, the project will design, construct and test in a relevant environment a high fill-rate (100 kg/min) prototype at industrial scale.



Key Personnel

Sean Kelly (Linde) - PI

Christopher Homison (Wabtec) - Co-PI

Program Summary

Federal funds:	\$5,669,984
Period of performance:	Cost-share: \$1,417,497
36 months	Total budget: \$7,087,481

Key Milestones & Deliverables	
Year 1	<ul style="list-style-type: none"> Industry gap analysis Techno-economic analysis Safety assessment Community Benefits milestones
Year 2	<ul style="list-style-type: none"> Fill system and recovery design Community Benefits milestones
Year 3	<ul style="list-style-type: none"> Fill system testing Performance evaluation Community Benefits milestones

Technology Impact

- 1) Eliminate a key hurdle to the adoption of H₂ technology in the rail industry while ensuring safe fuel handling.
- 2) Help drive adoption by serving as the basis for the currently undefined codes and standards for rail refueling systems and practices.
- 3) Enabler for economical large-scale shipment of LH₂ by rail.
- 4) Positively impact project underserved and underrepresented communities.

Decarbonizing the freight rail sector in the US