The Development of Lifecycle Data for Hydrogen Fuel Production and Delivery

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Project Tasks 1

- Life Cycle Analysis (LCA)
  - Identify renewable hydrogen production pathways anticipated to be available in the short, mid, and long term (20 years)

- Technological Assessment
  - Perform lifecycle analyses to determine energy use and greenhouse gas emissions for the hydrogen pathways

- Economic Assessment
  - Estimate the costs of each potential hydrogen pathway to determine the most cost-effective options
Project Tasks 2

• Leveraging Natural Gas Infrastructure
  – Assess the potential for blending hydrogen with natural gas in the current natural gas infrastructure in renewable hydrogen fuel pathways for vehicles

• Potential Markets for Hydrogen
  – During early commercialization of fuel cell vehicles, hydrogen demand is expected to be modest
  – Identify potential fuel cell hydrogen markets in the off-road transportation or non-transportation sectors that could increase overall hydrogen demand and estimate the demand
  – Identify barriers to commercialization and strategies to overcome those barriers
Leveraging Natural Gas (NG) Infrastructure

• Hydrogen can be produced locally, but significant hydrogen may require distribution to fueling stations

• Some benefits of utilizing the natural gas pipeline infrastructure (blending hydrogen with natural gas)
  – Reduction in the cost of hydrogen distribution through bypassing the need to build expensive dedicated hydrogen pipelines
  – Injecting hydrogen in natural gas pipelines can reduce the need to build hydrogen storage systems
  – Increasing the availability of hydrogen can accelerate the introduction of pure hydrogen applications
Safety Issues

• Gas buildup of blends similar to natural gas up to 50% concentrations by volume
• Severity of confined vented explosions – modest increase compared to pure NG for blends up to 20%
• Risk from failure of pipeline: Gas Technology Institute (GTI) 2010 study
  – Failure modes considered: corrosion, material defect, natural forces, excavation, equipment malfunction, operations, etc.
  – Risk increases with hydrogen percentage
  – Risk not significant higher than pure NG for blends up to 20%
  – Blends > 20% can have significant risk in service lines (more confined spaces)
  – Risk unacceptable for blends > 50%
Leakage

- Hydrogen leakage rates greater than NG due to size of molecules
- Leakage primarily through threads or mechanical joints
- 20% blends in distribution lines can ~ double gas losses
- Higher concentrations increase leakage
- Losses in service lines (lower pressures) will be lower
- Measured loss at 20% concentration economically insignificant (NREL 2015)
Durability

- Hydrogen can degrade pipeline materials through physical or chemical processes (lower tensile strength, ductility)
- Operators must inspect, maintain, and assess pipeline (integrity management programs)
- Degradation depends on pipeline materials, hydrogen concentration, pressure, temperature
- Increase in cost of integrity management programs generally less than 10% for hydrogen concentrations below 50%, pressures < 66 bar, and system design life < 50 years (GTI 2010)
Hydrogen Extraction for Use in Fuel Cell Vehicles

- Fuel cell vehicles require hydrogen extraction and purification
- Pressure swing adsorption (PSA), Membrane separation, Electrochemical separation (uses fuel cells)
  - Works better at high partial pressures
  - Generally sacrifice recovery rate for purity
- NREL study
  - PSA 80% recovery, 10% concentration: $3.3 – 8.3/kg depending on volume (100-1000 kg/day), 20% concentration: $2.0-7.4/kg
  - Cost reduction if hydrogen extracted at pressure reduction facility (NG not recompressed): $0.3-1.3/kg
End Use Issues

- After hydrogen extraction, some hydrogen remains in NG
- Systems that operate on NG will be fed a blend of hydrogen and NG
- Blend can adversely affect end uses such as boilers, stoves, power generation equipment
  - Composition of NG
  - Type of appliance
  - Age of appliance
  - Stationary NG engines likely would require modifications to control strategy
- Acceptable range without requiring modifications to equipment ~ 5-20% concentrations
Leveraging Natural Gas Infrastructure - Summary

• Based on safety, durability, end use applications, 5-15% concentrations

• Wide range of parameters for NG pipelines (NG composition, temperature, pressure, materials) may require individual analysis to determine appropriate concentrations

• Modifications to integrity management programs are necessary

• Caution must be exercised in utilizing concentrations above 15%
Leveraging Natural Gas Infrastructure - Recommendations

- Make funding available for detailed analyses of the distribution cost for hydrogen blended into natural gas pipelines. This cost should be compared to other distribution options.
- Given the wide variability of pipeline conditions, conduct studies of the necessary modifications to natural gas pipelines to allow hydrogen blending at various percentages.
- Conduct studies to understand the effect of various blend percentages on end-use equipment.
Potential Markets for Hydrogen

• Markets considered in analysis
  – Material handlers (forklifts)
  – Airport ground support equipment (GSE)
  – Transport Refrigeration Units (TRUs)
  – Backup power / telecommunications
    • Fuel cell market for telecommunications potentially large
    • Hydrogen usage insignificant due to reliability of grid power
    • Not considered in analysis
Methodology to Estimate Demand

- Determine fleet stock for each sector (forklift, airport GSE, TRUs)
- Project stock out for 10 years (2017-2026) based on macroeconomic projections for California GSP (average increase ~ 2.3%/year)
- Estimate maximum market share for fuel cells in each market based on reports and stakeholder discussions (greatest uncertainty)
- Estimate fuel cell hydrogen usage based on energy usage, activity (hours) and average power, and fuel cell efficiency (assume 50%)
Material Handlers

- Industrial Truck Association (ITA) Market Intelligence report gives forklift sales in US
- Use data to estimate current stock in CA (12% of population) and estimate future stock based on CA GSP projections
- Assume 15% of future projected ICE forklifts (Class 4 and 5) will be purchased as Class 1 and 2 forklifts by 2026
- Estimates of electric forklift energy usage
  - 6000-8000 lb ~ 18.3 MWh/year
  - 19,800 lb ~ 52.8 MWh/year
  - Class 3 ~ 5.2 MWh/year
- Stakeholder discussions upper limit of fuel cell sales - 30% by 2026
Airport GSE

• Airport Cooperative Research Program Report – stock of GSE at US airports. Roughly 11% of enplanements in CA (FAA data)

• Los Angeles World Airports Environment & Land Use Planning Division report gives energy usage for electrical GSE
  – Tugs, belt loaders, cargo tractors, forklifts, lifts, passenger stands, other GSE (carts, sweepers, etc.)

• Fuel cell GSE currently in demonstration phase focusing on cargo tractors.

• Maximum market penetration by 2026
  – 5% cargo tractors
  – 2% other GSE
TRUs

- Stock and activity determined from CARB TRU emissions inventory database
- California Transportation Electrification Assessment and discussions with ARB personnel gave average power

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<th>TRU Size</th>
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<td>&lt; 11 hp</td>
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<tr>
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<td>&gt; 25 hp</td>
<td>10</td>
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<tr>
<td>Out-of-state</td>
<td>10</td>
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- Fuel prices (diesel and H2) make commercialization difficult
- Stakeholder discussions suggest max 5% sales in 2026
- Incentives likely focus on in state so assume Out-of-State sales 0%
Material Handler (Forklift) Demand

Forklift Hydrogen Demand

Hydrogen usage (million kg)

Year

2016 2018 2020 2022 2024 2026 2028

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Airport GSE Hydrogen Demand

Hydrogen usage (thousands kg)

Year

2016  2018  2020  2022  2024  2026  2028

Airport Ground Support Equipment Demand
Transport Refrigeration Unit Demand

TRU Hydrogen Demand

Hydrogen usage (thousands kg)

Year

2016 2018 2020 2022 2024 2026 2028

0 100 200 300 400 500 600 700
Total Off-Road and Non-transportation Demand

Total Non-transportation Hydrogen Demand

Hydrogen usage (millions kg)

2016 2018 2020 2022 2024 2026 2028

Year

- Total Non-transportation Hydrogen
- Hydrogen usage (millions kg)
- Year
Barriers to Commercialization

- Major barrier is cost
  - fuel cell
  - Hydrogen
  - Infrastructure
- Fuel cell TRU range
  - Lack of infrastructure may limit TRUs to fleets that return to base for refueling
- Uncertainty
  - Fuel cell forklifts have significant sales
  - Airport GSE and TRUs have uncertain reliability, cost, and performance
- Competition from battery electric designs
  - Battery electric designs have head start in commercialization
Strategies to Overcome Barriers

- The emissions standard for off-road diesel engines could be lowered over time. Stricter standards could make zero emission technologies more attractive to companies considering new purchases.

- To reduce the concerns about the reliability and performance of these new fuel cell technologies, demonstration programs could be closely monitored, and information relating to successful outcomes could be widely disseminated.

- Locate fuel cell products near already existing markets (hub and spoke).

- Incentives/subsidies.
Thank You