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

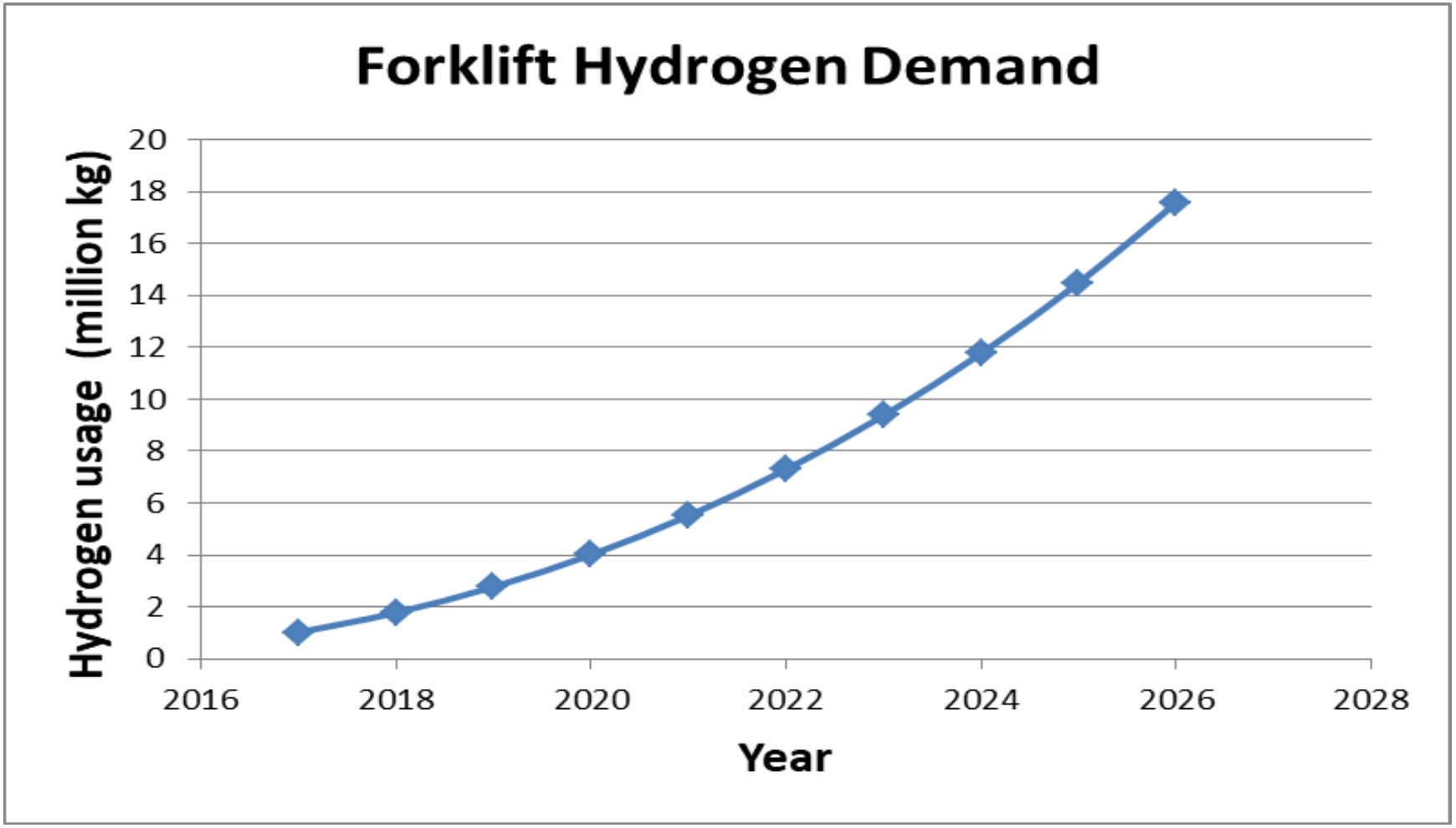
TRUs

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

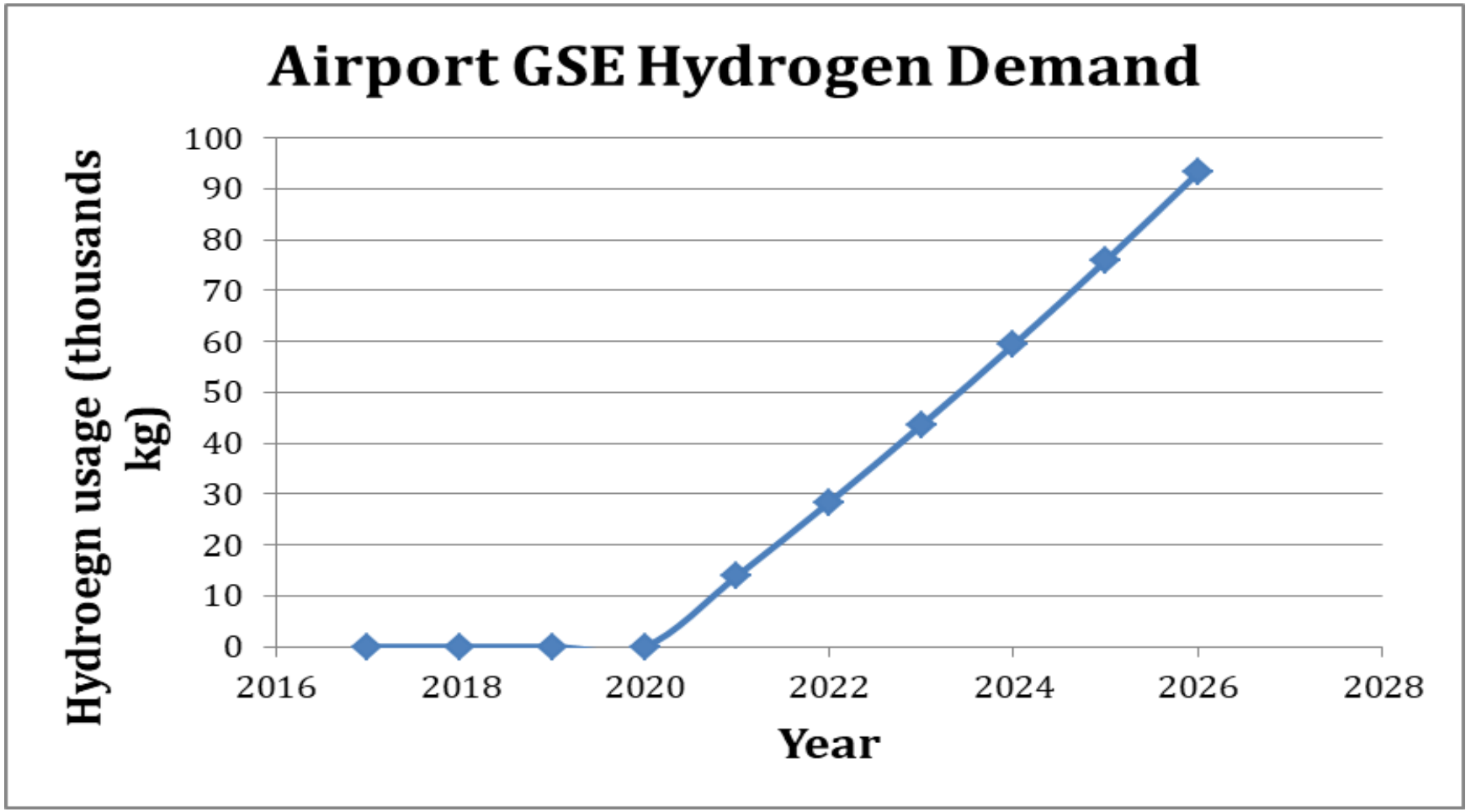
TRU Size	Electric Power (kW)
< 11 hp	2.3
11 – 25 hp	6
> 25 hp	10
Out-of-state	10

- 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%

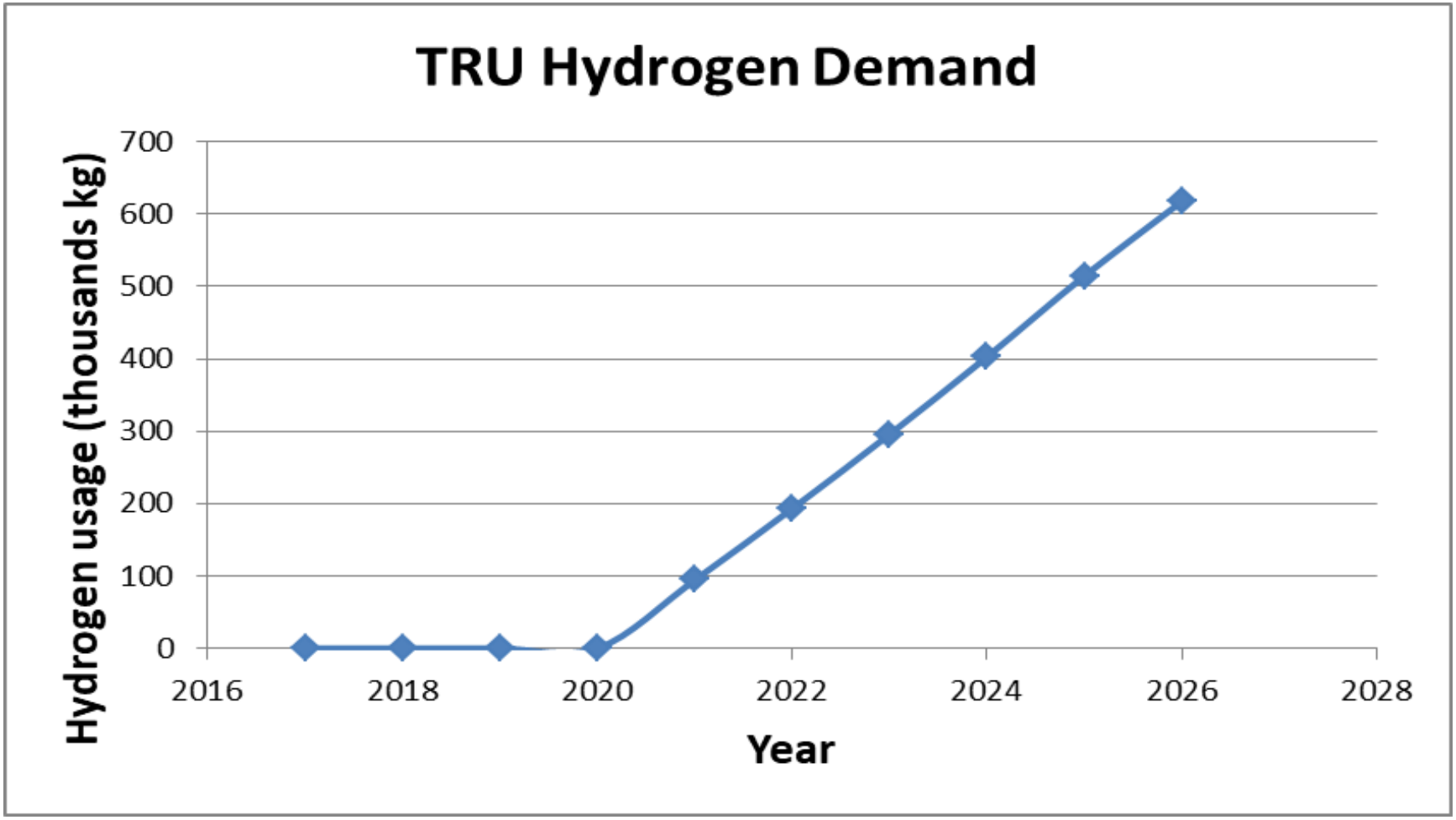
Material Handler (Forklift) Demand



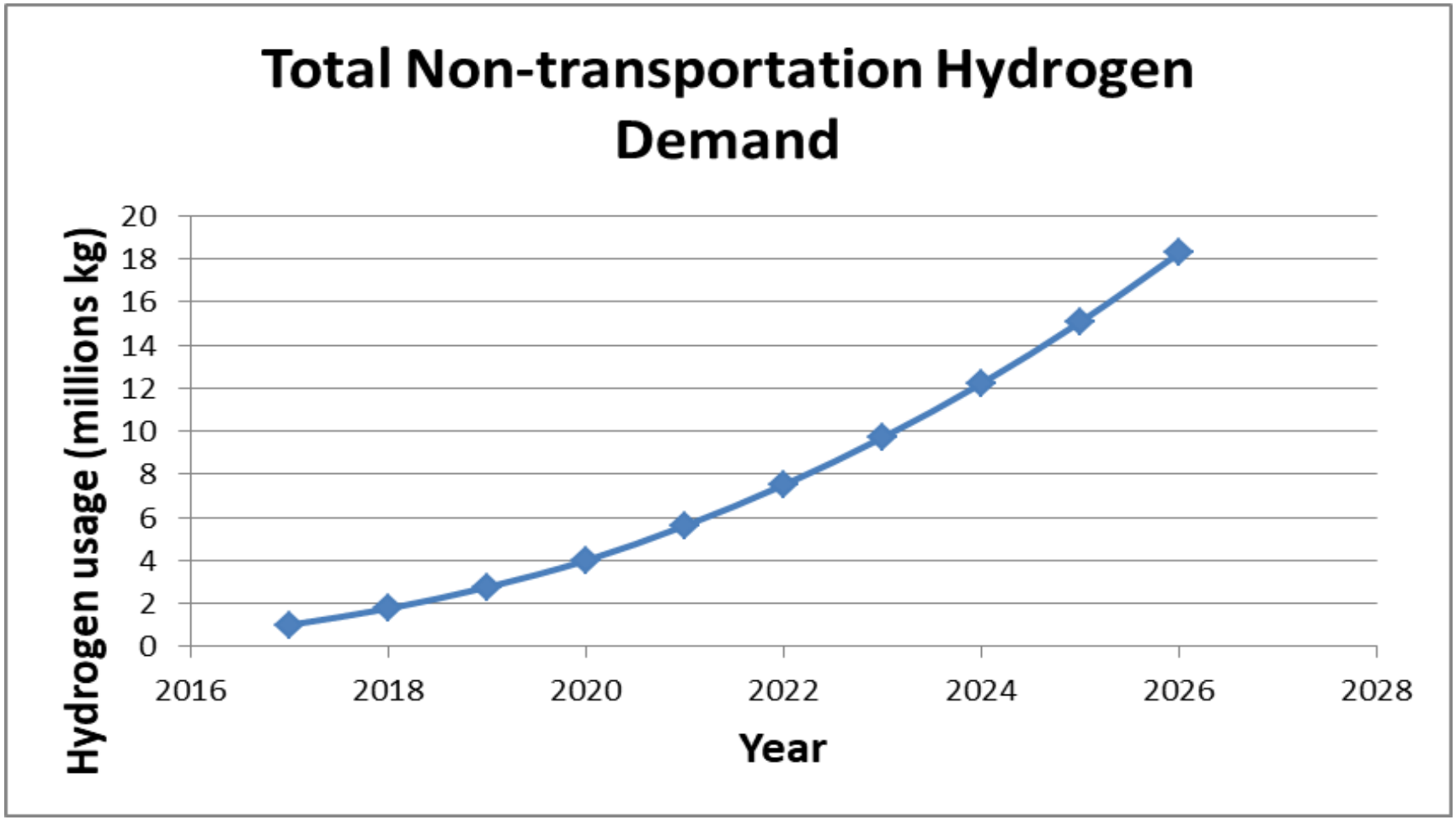
Airport Ground Support Equipment Demand



Transport Refrigeration Unit Demand



Total Off-Road and Non-transportation Demand



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