2015 DOE Hydrogen and Fuel Cells Program Annual Merit Review

Hydrogen Delivery Infrastructure Analysis

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Overview

Timeline

- Start: FY 2007
- End: Determined by DOE
- % Complete (FY15): 70%

Barriers/Challenges

- Lack of hydrogen infrastructure options analysis
- Cost and efficiency of delivery components
- Lack of appropriate models and analytical capability
- Conduct unplanned studies and analyses

Budget

- FY14 Funding: $200K
- FY15 Funding: $200K
- 100% DOE funding

Partners and Collaborators

- PNNL, NREL, SNL, LLNL
- Fuel Science
- Boyd H2
- Industry Stakeholders

Relevance/Impact

- Assess impacts of delivery and refueling options on the cost of dispensed hydrogen
  - ✓ Model refueling cost in early FCEVs markets
  - ✓ Evaluate impact of design and economic parameters
  - ✓ Identify cost drivers of current technologies
  - ✓ Develop estimates of delivery and refueling cost reduction with market penetration
- Assist FCTO planning
  - ✓ Assist with setting cost and performance targets in MYRD&D
  - ✓ Identify R&D areas with potential to meet cost and performance targets
- Support existing DOE-sponsored tools (e.g., H2A , JOBS, GREET, MSM)
  - ✓ Collaborate with other model developers and lab partners
  - ✓ Support other DOE sponsored activities (e.g., H2FIRST – Reference Station Design Project)
  - ✓ Interact with experts from industry for input and review

Approach:

Model near-term hydrogen delivery and refueling cost

- **Acquire** current cost and design of refueling and delivery components
  - ✓ Collaborated with industry (station developers, OEMs, experts)

- **Develop** modeling structure to evaluate the impact of key market, design, and economic parameters on hydrogen cost

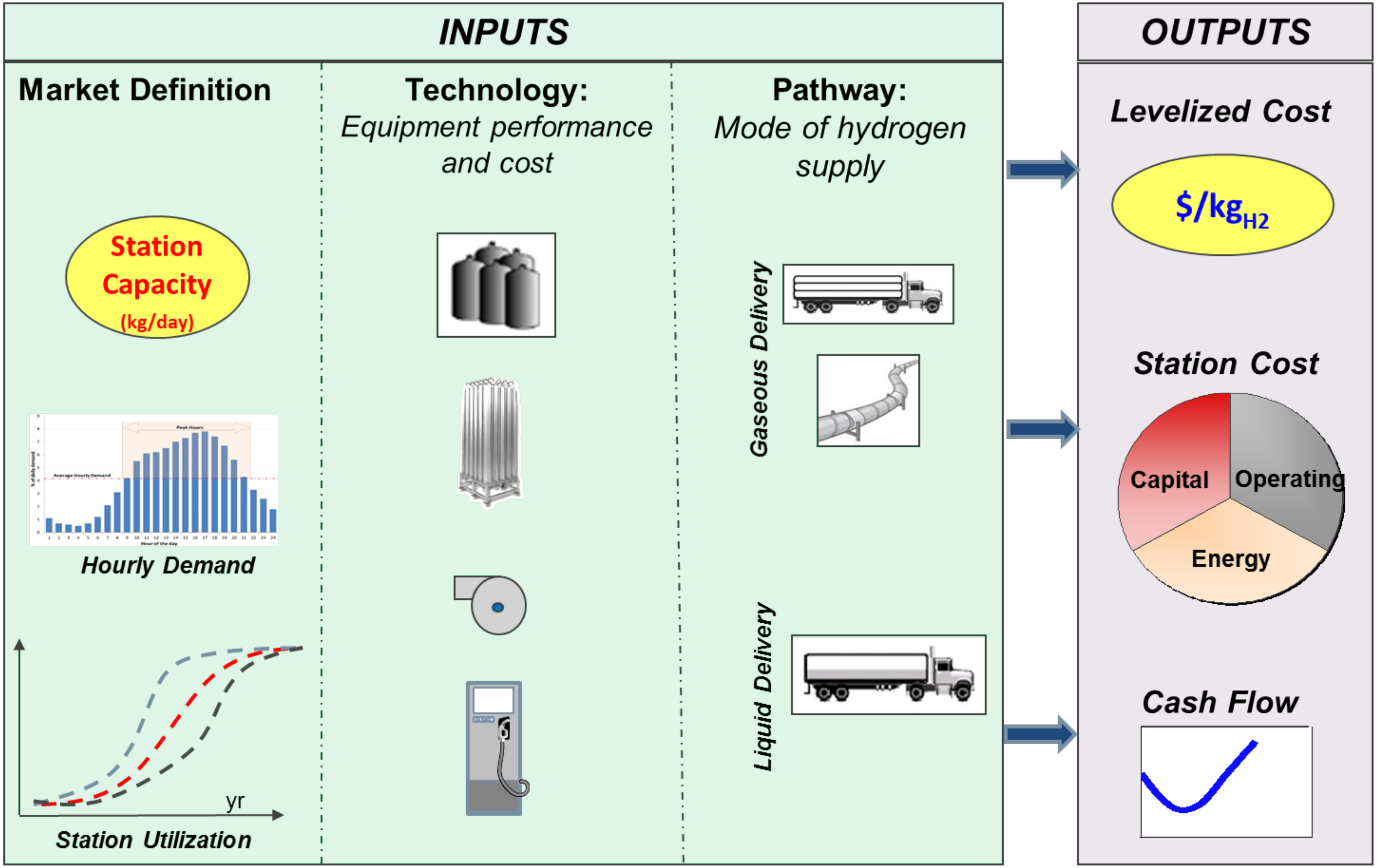
- **Evaluate** performance of various hydrogen supply options and station design configurations

- **Identify** major cost drivers for hydrogen delivery/refueling

- **Review** modeling approach and results
  - ✓ Internally via partners
  - ✓ Externally, via collaborators and through briefings to Tech Teams, early releases to DOE lab researchers, and interaction with experts from industry
  - ✓ Checked against cost data in 24 proposals submitted to four California Energy Commission (CEC) solicitations from 2010 to 2014

Accomplishment:

Developed Hydrogen Refueling Station Analysis Model (HRSAM) to simulate near-term station costs



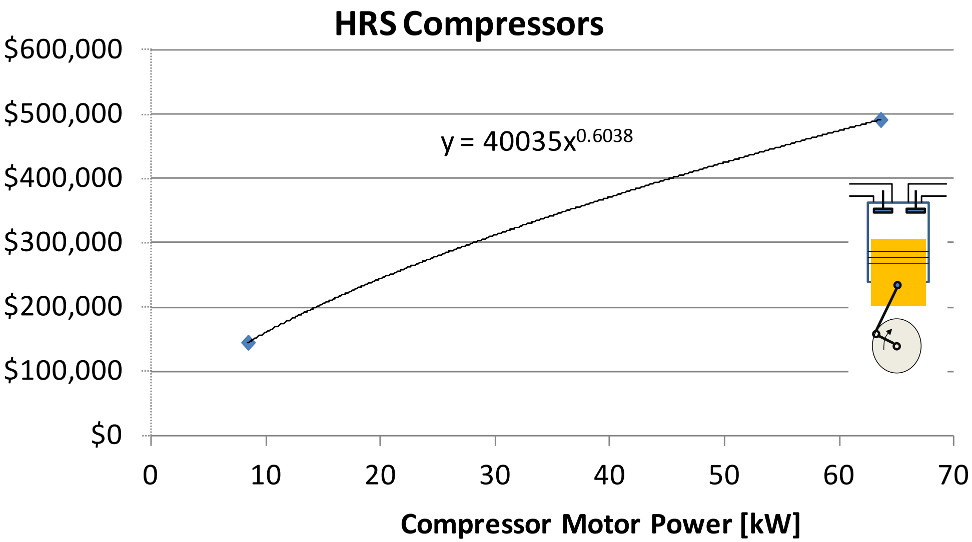
Accomplishment:
Evaluated the impacts of key parameters on HRS cost:

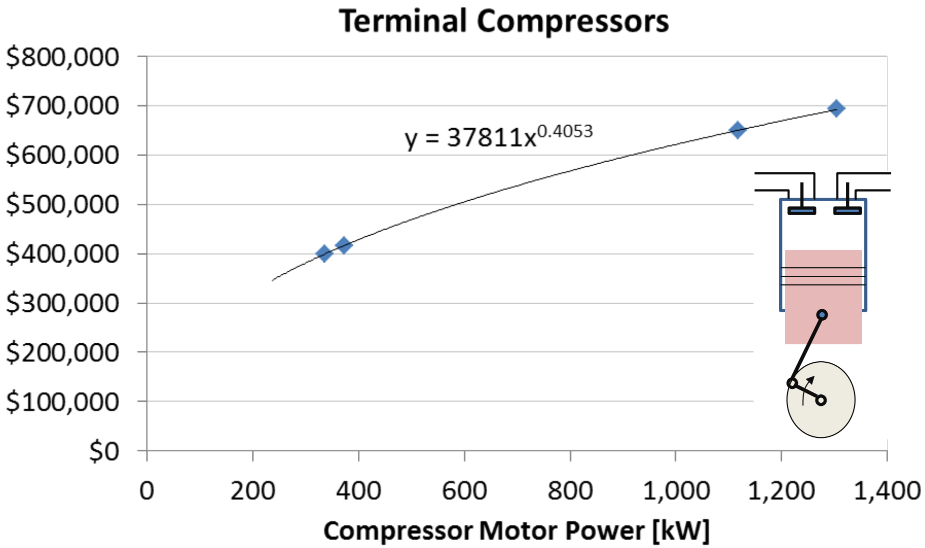
– Station Design
  - ✓ Size (capacity)
  - ✓ Utilization rate (esp. given slow vehicle deployment)
  - ✓ Configuration (e.g., gaseous vs. liquid supply, cascade vs. booster fueling)
  - ✓ Desired station performance (e.g., fill speed and back-to-back fill capability)

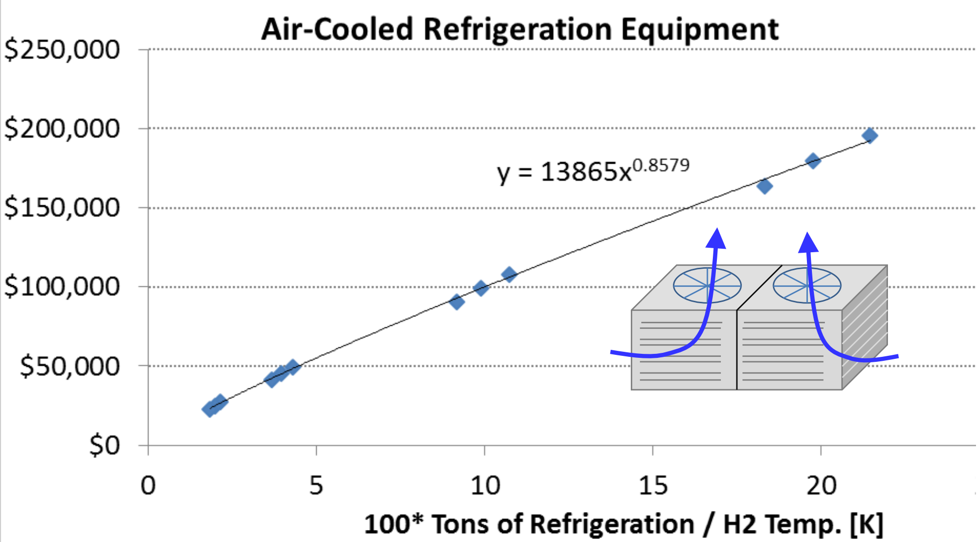
– Economics
  - ✓ Rate of return (discount rate)
  - ✓ Analysis period
  - ✓ Debt/equity ratio
  - ✓ Components life/depreciation schedule

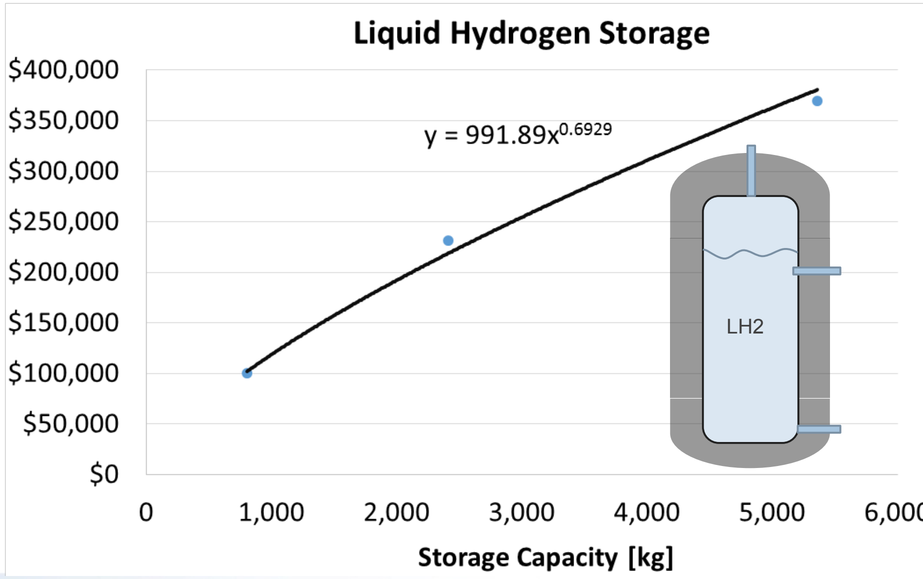
– Other
  - ✓ Setback distances (cost of land)
  - ✓ Reliability of components (operating cost)
  - ✓ Efficiency of equipment (energy cost)

Accomplishment: Developed formulas for today's cost of delivery and refueling components



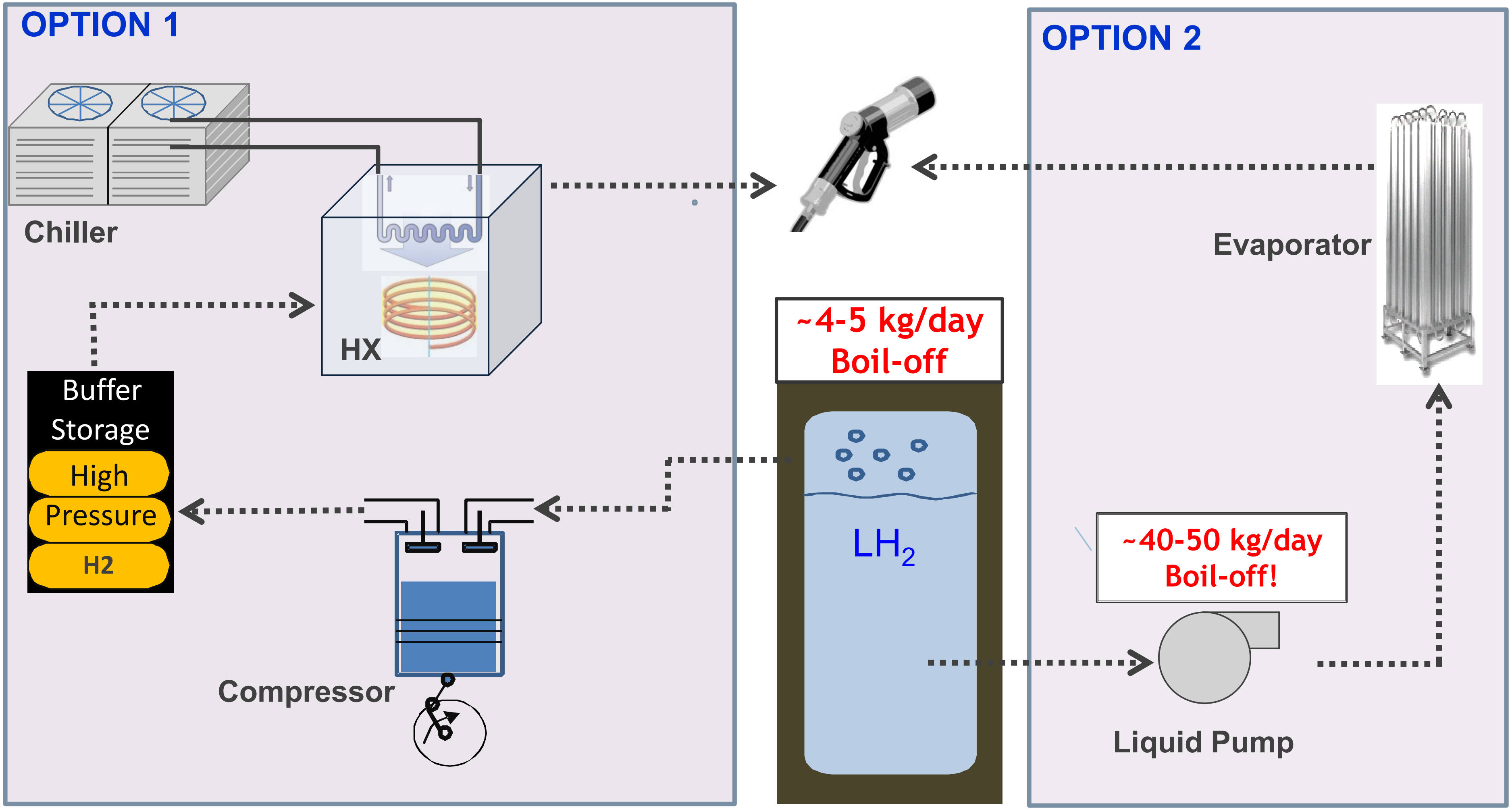






Accomplishment:

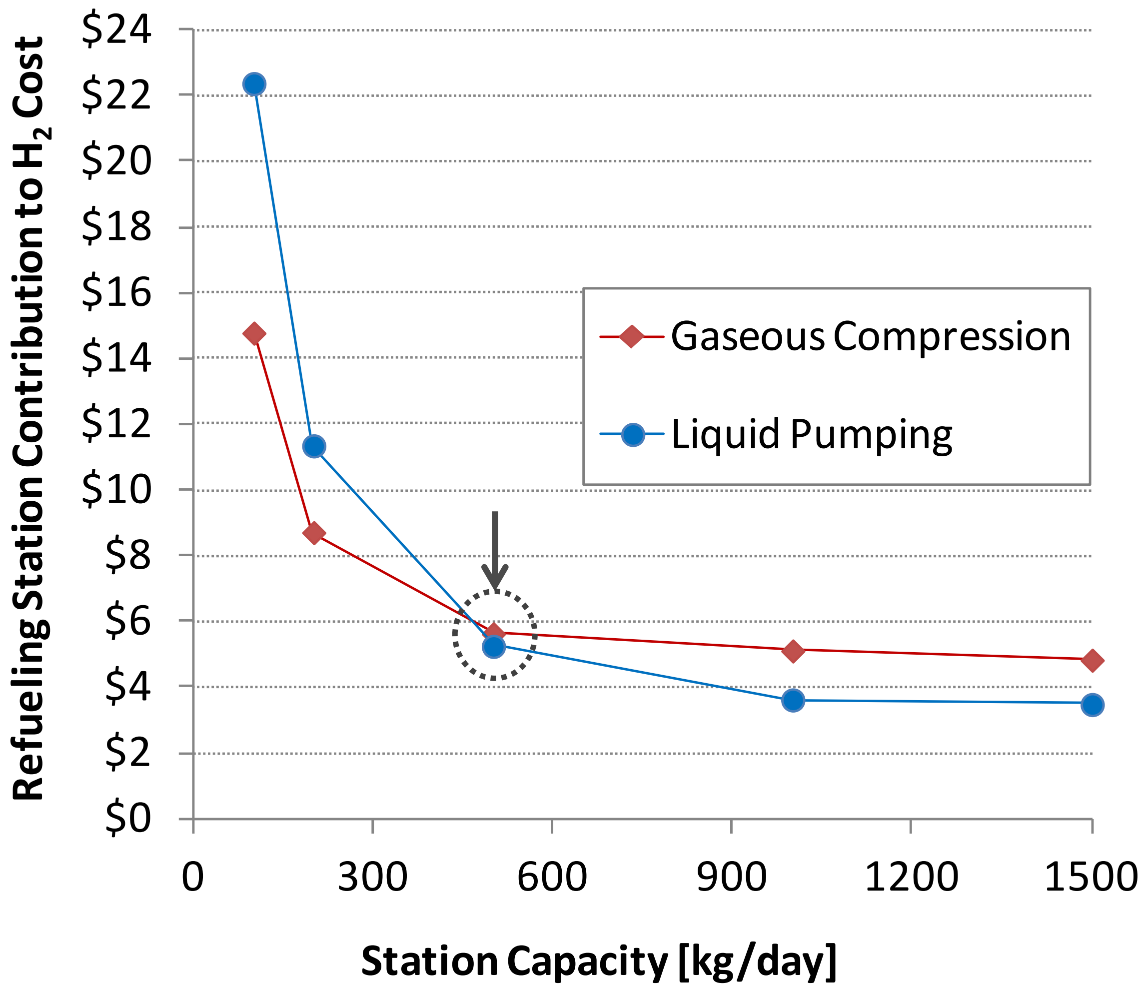
Determined that gaseous compression is preferable to liquid pumping in early markets due to boil-off in small and under-utilized stations



Thermal parasitics and low demand result in excessive boil-off in option 2

Accomplishment:

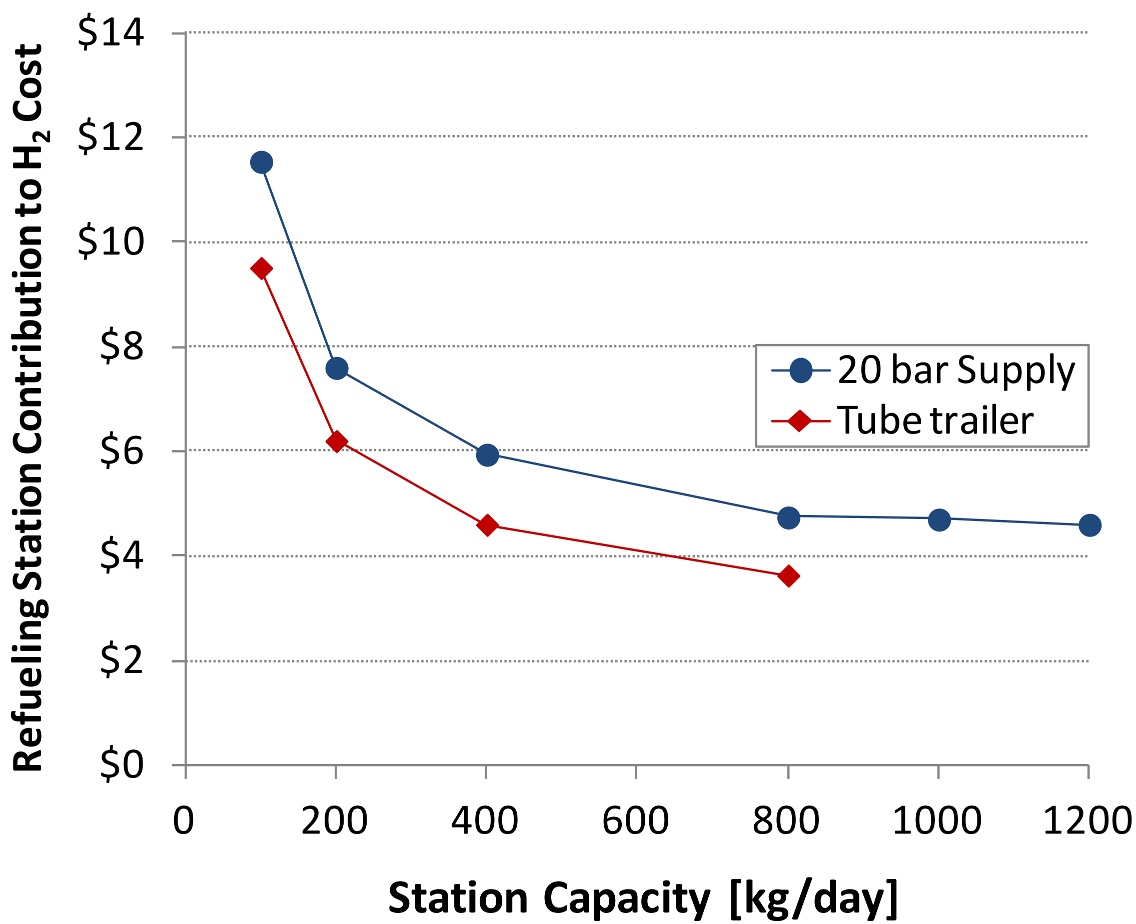
Determined that liquid pumping is favorable to gas compression at large LH2 station capacities



Economic impact of boil-off losses diminishes with station capacity

Accomplishment:

Identified HRS cost reduction opportunity with tube-trailer deliveries due to pre-compression at terminal

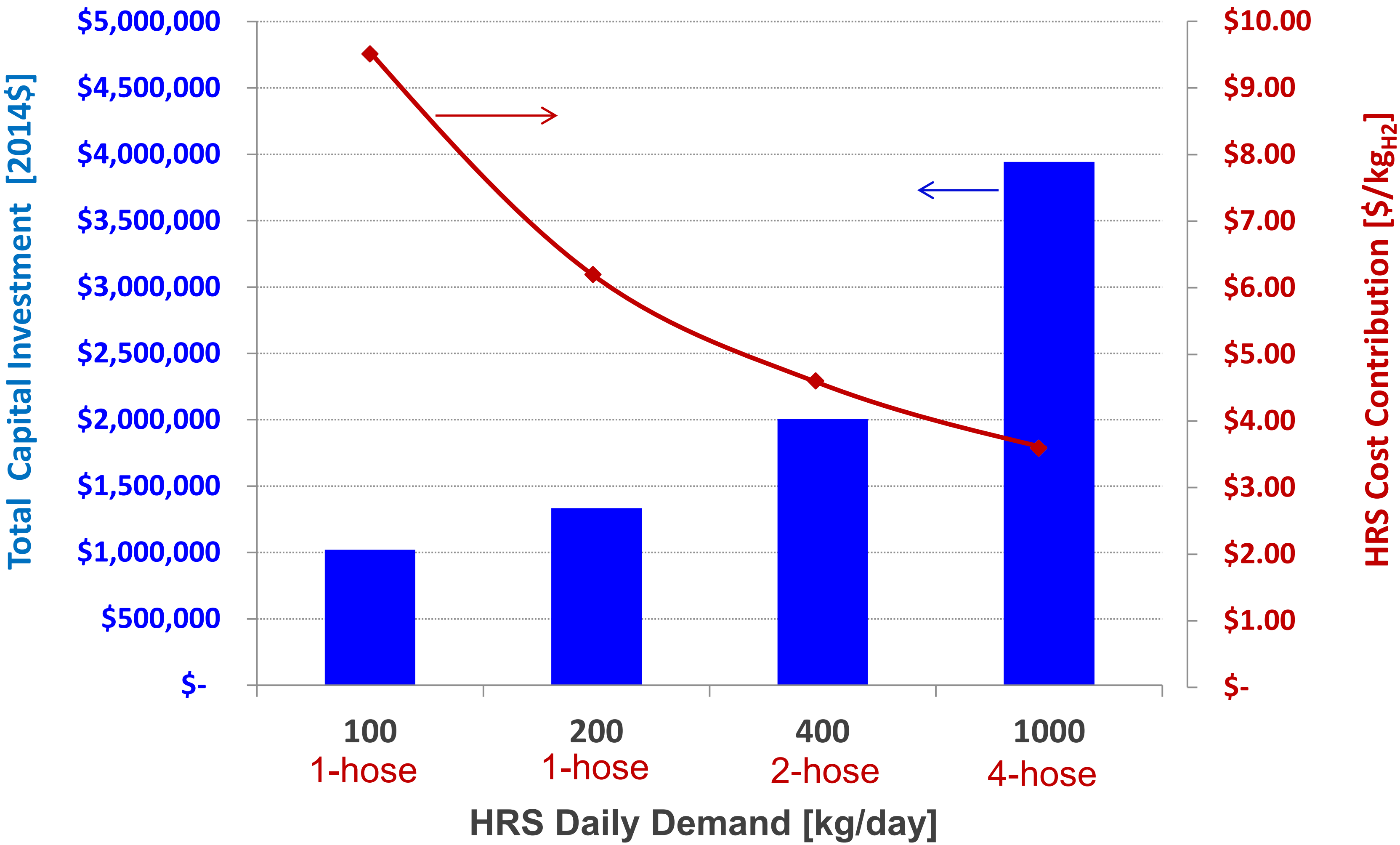


Capacity of stations supplied by tube-trailers is limited by frequency of delivery (< one delivery per day)

Tube-trailers can carry up to 1000 kg payload at 500 bar

Accomplishment:

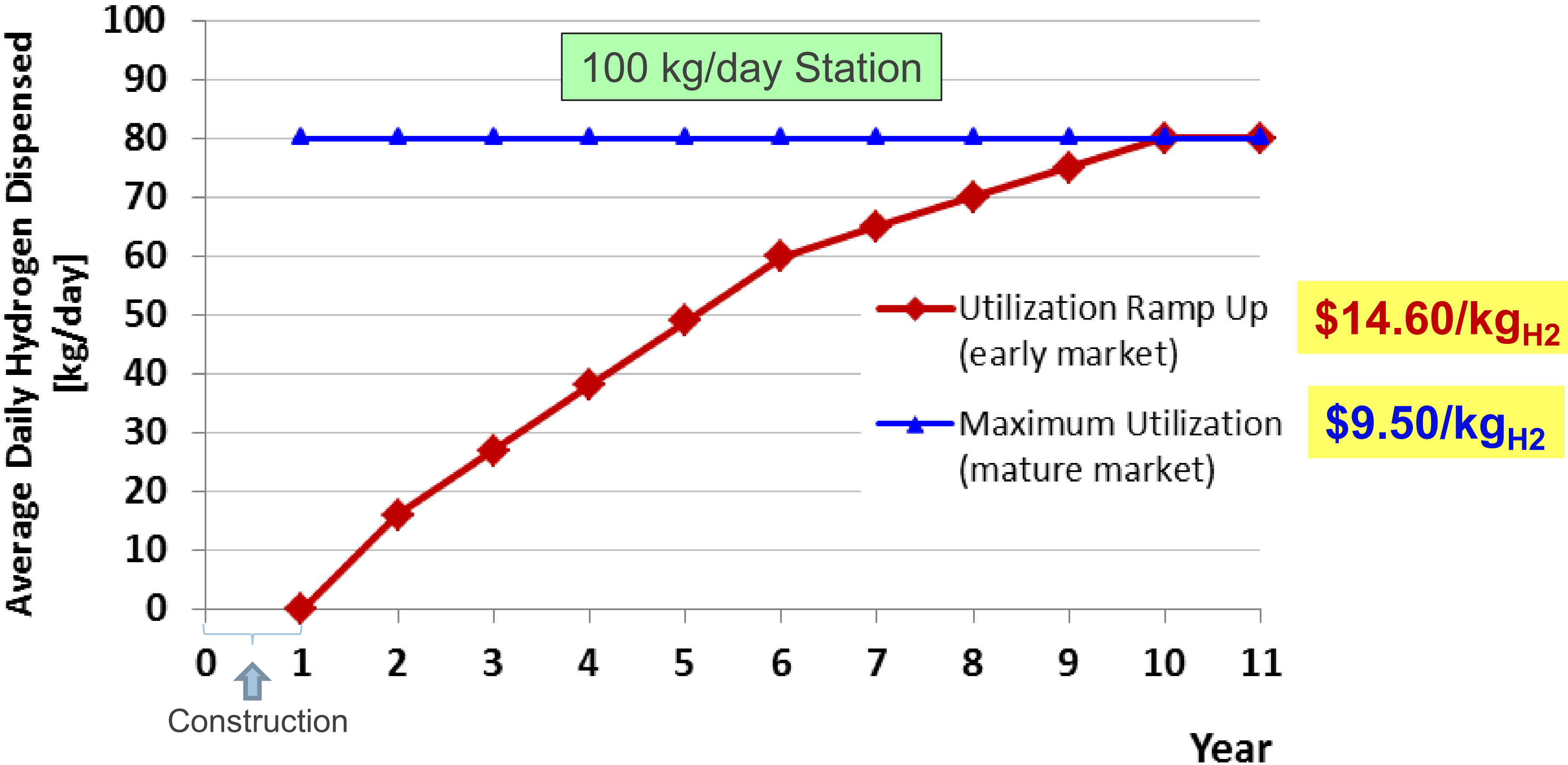
Station economies of scale strongly impacts H_2 cost



Large station capacities are not suitable for early FCEV markets because they are only viable with high utilization

Accomplishment:

Station utilization ramp up is the single most important factor that impacts H_2 cost in early markets



FCEV deployment rate is critical to market success because underutilization of HRS in early years strongly influences station economics

Summary

- The model HRSAM has been developed to examine near-term refueling cost in early FCEVs markets
  - Developed formulas for today's cost of delivery and refueling components
  - Identified station utilization ramp up as the single most important factor that impacts H_2 cost in early markets
  - Demonstrated the strong impact of station economies of scale on H_2 cost
  - Tube-trailer supply to HRS is favorable in early FCEV markets, but are limited to station capacities smaller than delivered payload (a practical limitations on frequency of delivery)
  - Evaluated impact of boil-off losses associated with liquid H_2 deliveries in early markets
    - ✓ Impact of boil-off losses diminishes with large station capacities and frequency of fueling
- The model has been peer-reviewed by partners and industry experts
  - Released in public domain for use by researchers and stakeholders
    - ✓ Available at: http://www.hydrogen.energy.gov/h2a_delivery.html

Future work:
Updates to Hydrogen Delivery Scenario Analysis Model (HDSAM)

- Develop improved understanding of tube trailer terminal design and cost, and update HDSAM accordingly
- Update station footprint evaluation (size and cost) in collaboration with Codes and Standards Tech Team (CSTT)
- Update pipeline modeling and cost information through interaction with pipeline working group
- Update cost of major refueling equipment (i.e., compression, storage, refrigeration/HX, and dispensing)
  - Develop a modeling option for components cost reduction with market penetration
    - ✓ Cost reduction factors will be a function of technological improvements, and manufacturing economies of scale
    - ✓ HRS market penetration will be used as a proxy for cumulative production volume
- Continue to provide technical support to FCT Office, hydrogen community, and industry stakeholders

Collaborations and Acknowledgments

Collaborators and Partners:

– Daryl Brown, Pacific Northwest National Laboratory: provided updated refueling components cost estimates and price indices

– Neha Rustagi, ORISE Fellow: provided modeling information and conducted model reviews

– SNL, Joseph Pratt: provided critical input in the model development phase and conducted thorough model reviews

– NREL, Danny Terlip: provided critical input in the model development phase and conducted thorough model reviews

– LLNL, Salvador Aceves and Guillaume Petitpas: provided critical input on modeling impact of boiloff losses at liquid stations

– Boyd H2, Bob Boyd: provided information on configuration of current refueling stations and conducted model reviews

– Fuel Science, George Parks: conducted thorough model reviews

Project Summary

- **Relevance:** Model near-term refueling cost in early FCEVs markets. Evaluate impact of design and economic parameters of various hydrogen refueling station (HRS) configurations. Identify cost drivers of current technologies for hydrogen delivery and refueling. Develop estimates of delivery and refueling cost reduction with market penetration. Assist FCTO with setting cost and performance targets in MYRD&D planning. Investigate delivery pathways and identify R&D areas with potential to meet cost and performance targets.
- **Approach:** Collaborate to acquire/review model inputs and examine/review model and results. Acquire current cost of refueling and delivery components from vendors and industry experts. Checked against cost data in California Energy Commissions (CEC) solicitations. Develop modeling structure to evaluate the impact of key market, design, and economic parameters on hydrogen cost. Evaluate performance of various hydrogen supply options and station design configurations. Identify major cost drivers for hydrogen delivery/refueling. Review modeling approach and results with partners, Tech Teams, and experts from industry.
- **Collaborations**: Collaborated with researchers from other national labs and interacted with experts from the industry with knowledge and experience on delivery and refueling components relevant to this project. Acquired information needed for the simulations and received valuable input and suggestions to complete our project.
- **Technical accomplishments and progress:**
  - Developed a modeling framework (HRSAM) to examine near-term refueling cost in early FCEVs markets
  - Developed formulas for today's cost of delivery and refueling components
  - Identified station utilization ramp up as the single most important factor that impacts H2 cost in early markets
  - Demonstrated the strong impact of station economies of scale on H2 cost
  - Tube-trailer supply to HRS is favorable in early FCEV markets
  - Released the model in public domain for use by researchers and stakeholders
- **Future Research**: Update station footprint evaluation (size and cost) in collaboration with Codes and Standards Tech Team (CSTT). Update pipeline modeling and cost information through interaction with pipeline working group. Update key statistics for calculating market demand of hydrogen with vehicle penetration scenarios. Develop a modeling option for components cost reduction with production volume. Post an updated version of HDSAM.

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Acronyms

- ANL: Argonne National Laboratory
- APRR: Average Pressure Ramp Rate
- DOE: Department of Energy
- FCEV: Fuel Cell Electric Vehicle
- FCTO: Fuel Cell Technologies Office
- GREET: Greenhouse gas, Regulated Emissions, and Energy in Transportation
- H2: Hydrogen
- H2A: Hydrogen Analysis
- H2SCOPE: Hydrogen Station Cost Optimization and Performance Evaluation
- HDSAM: Hydrogen Delivery Scenario Analysis Model
- HRSAM: Hydrogen Refueling Station Analysis Model
- HRS: Hydrogen Refueling Station
- H.T.: Heat Transfer
- HX: Heat Exchanger
- LH2: Liquid Hydrogen
- LLNL: Lawrence Livermore National Laboratory
- MSM: Macro-System Model
- MYRD&D: Multi-Year Research, Development, and Demonstration
- NREL: National Renewable Energy Laboratory
- PNNL: Pacific Northwest National Laboratory
- SAE: Society of Automotive Engineers
- SNL: Sandia National Laboratory
- SOC: State Of Charge