H2FIRST

Hydrogen Fueling Infrastructure Research and Station Technology

Reference Station Design, Phase II

Comparison of conventional vs. modular hydrogen refueling stations, and on-site production vs. delivery

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DOE Hydrogen and Fuel Cells Program Annual Merit Review

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Project ID: PD139

Timeline

- Task start date: Feb. 2016
- Task end date: March 2017
- Percent Complete: 100%

Budget

- Total Task Budget: $200k
  - DOE share: $200k
    - SNL: $140k
    - NREL: $60k

Barriers (Delivery)

A. Lack of Hydrogen/Carrier and Infrastructure Options Analysis
E. Gaseous Hydrogen Storage and Tube Trailer Delivery Costs
I. Other Fueling Site/Terminal Operations
K. Safety, Codes and Standards, Permitting

Partners

- NREL
- H2USA Hydrogen Fueling Station Working Group

Relevance – Overall Project Objectives, and FY17 Impact

- ✓ **Provided near-term economic assessment** of the cost of hydrogen to the customer for stations supplied by centrally produced, delivered hydrogen and those with hydrogen produced on-site (*Barrier: A*)
- ✓ **Illustrated the economic drivers** for hydrogen delivery costs (*Barrier: E*)
- ✓ **Showed how to reduce capital and operating costs** through design decisions and operating methods (*Barrier: I*)
- ✓ **Demonstrated footprint reduction methods** while maintaining compliance with current Codes (*Barrier: K*)

Approach: Consider the current market and technology for station designs

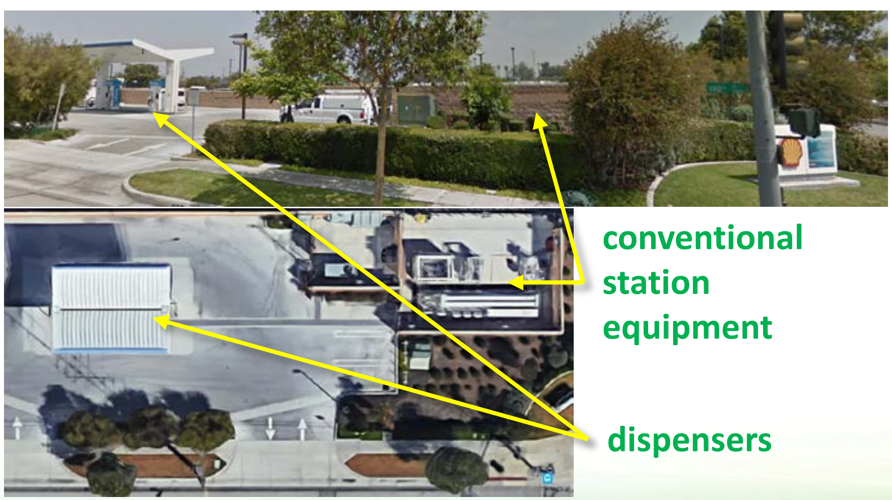
Builds on the Phase 1 reference station project to include the cost of producing and delivering (if necessary) hydrogen, with 5 concepts considered (at 100, 200 and 300 kg/day):

Conventional (assemble-on-site) stations with hydrogen:

1. delivered as compressed gas from a centralized, already operational production facility (baseline)
2. produced on-site through steam methane reforming (SMR)
3. produced on-site through electrolysis

Modular (containerized) fueling stations with hydrogen:

4. delivered as compressed gas from a centralized production facility
5. produced on-site through electrolysis

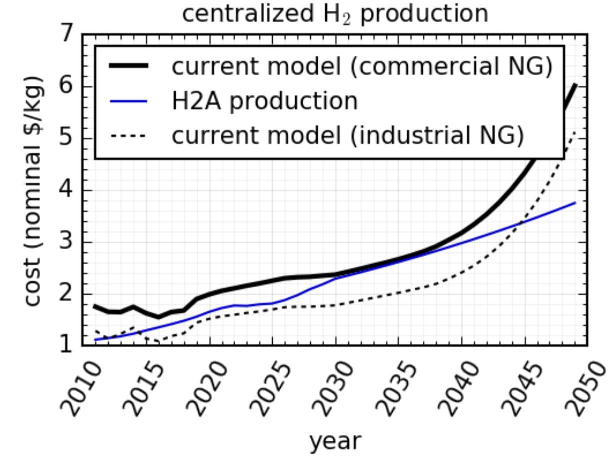


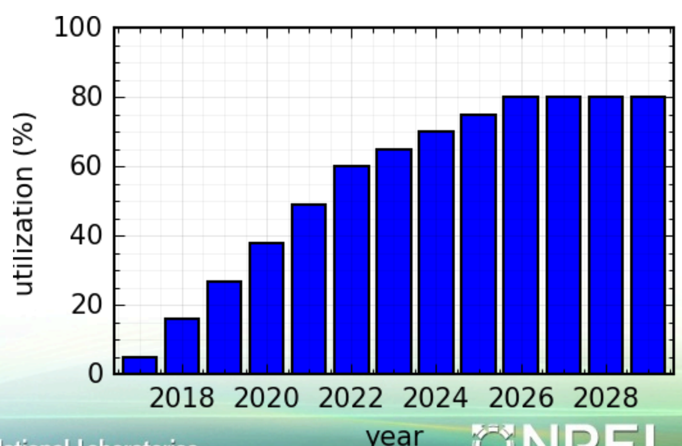
Street and overhead view of Shell hydrogen station at 2015 W 190th St, Torrance CA. Images from google maps.

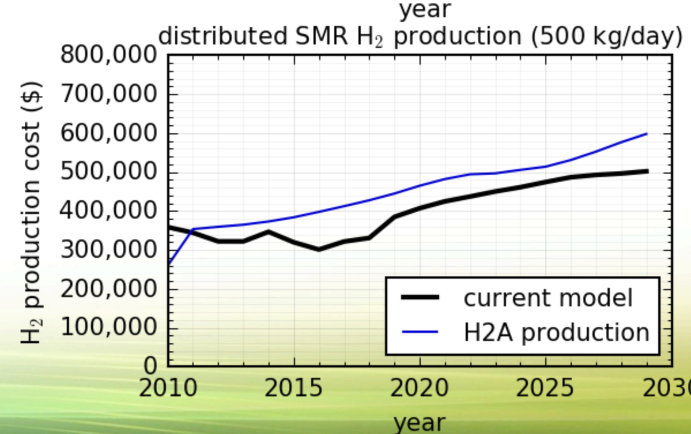
Modular station coupled to an electrolyzer at Proton OnSite's station in Washington D.C.
image source: http://www.protononsite.com/hydrogen-fueling

Approach: Developed a new economic model to output the data of interest

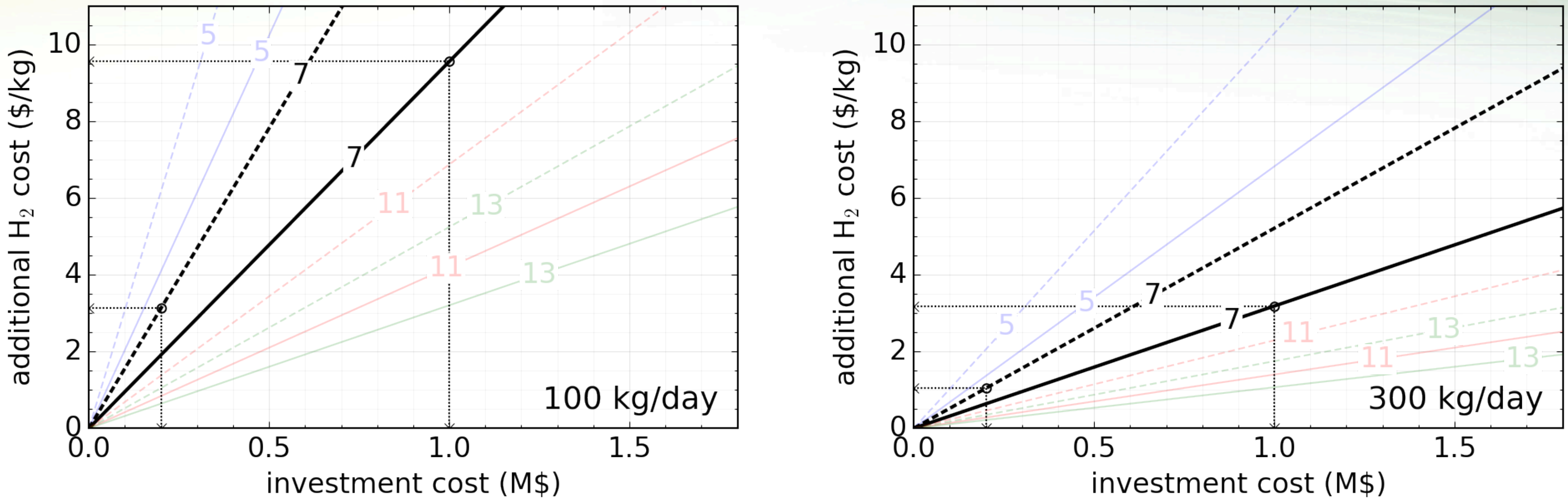
- Developed Python model to calculate cost of hydrogen for station developer/operator to break even on investments in given timeframe
  - H2A Refueling Station Analysis Model (HRSAM) does not include the cost of hydrogen
  - H2A Delivery Scenario Analysis Model (HDSAM) is for a higher volume, mature market delivery scenario with tractor/trailer sharing for a network of stations
  - Hydrogen Financial Analysis Scenario Tool (H2FAST) lacks an interface for varied production/delivery methods
  - Benchmarked against accepted models, where possible
- Informal industry surveys for component costs
- Calculated 7-year break-even point for different station designs
  - Assume no major components replaced in this timeframe
  - Assume 7-year depreciation schedule on equipment
  - Utilization model from CARB with delayed onset







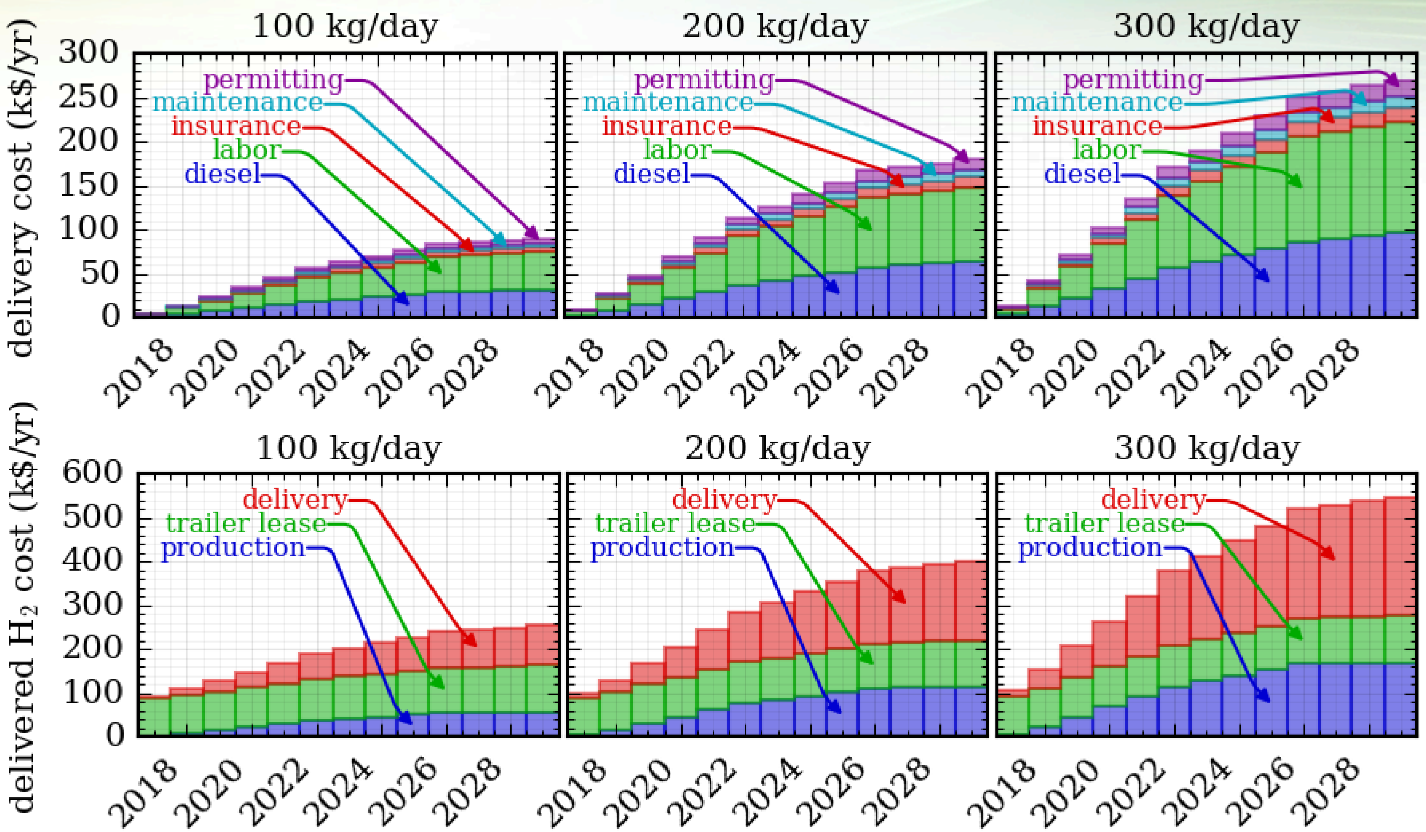
Accomplishment: Developed graphical method to calculate the change in hydrogen cost from change in capital cost



- Solid lines are for depreciable asset (e.g. electrolyzer)
- Dashed lines for non-depreciable asset (e.g. land purchase)
- Numbers are years required to break even on investment (black lines are the 7-year case break-even case used in this analysis)

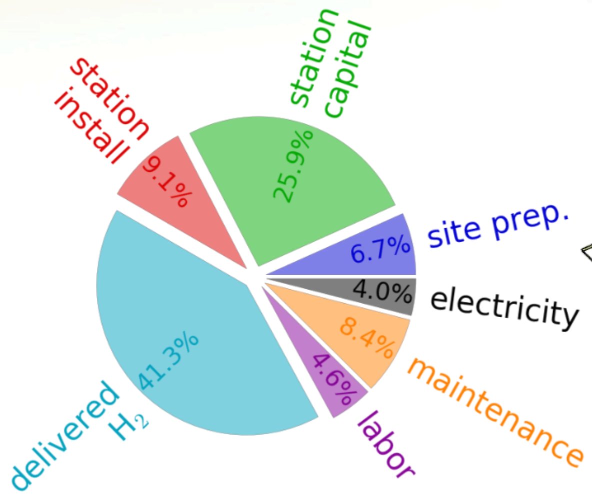
➢ Makes it possible to limit capital costs based on a desired cost of hydrogen

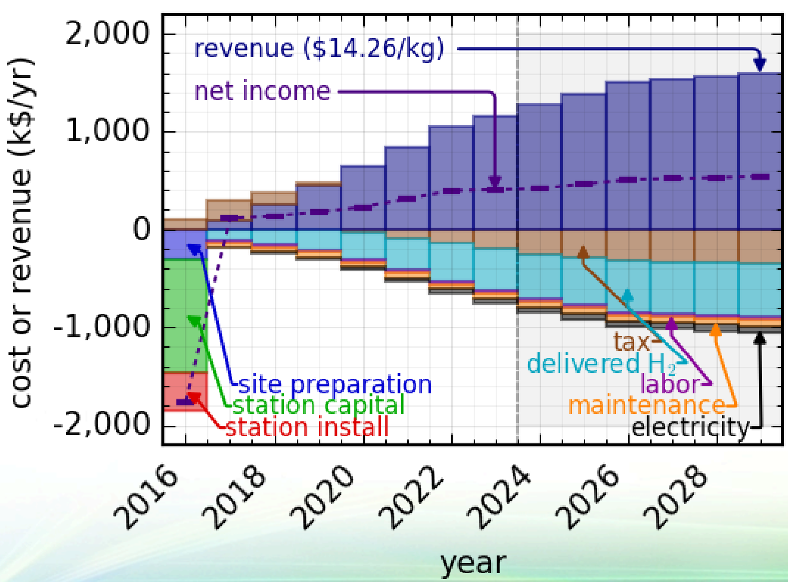
Accomplishments: Determined contributions to costs of delivered hydrogen

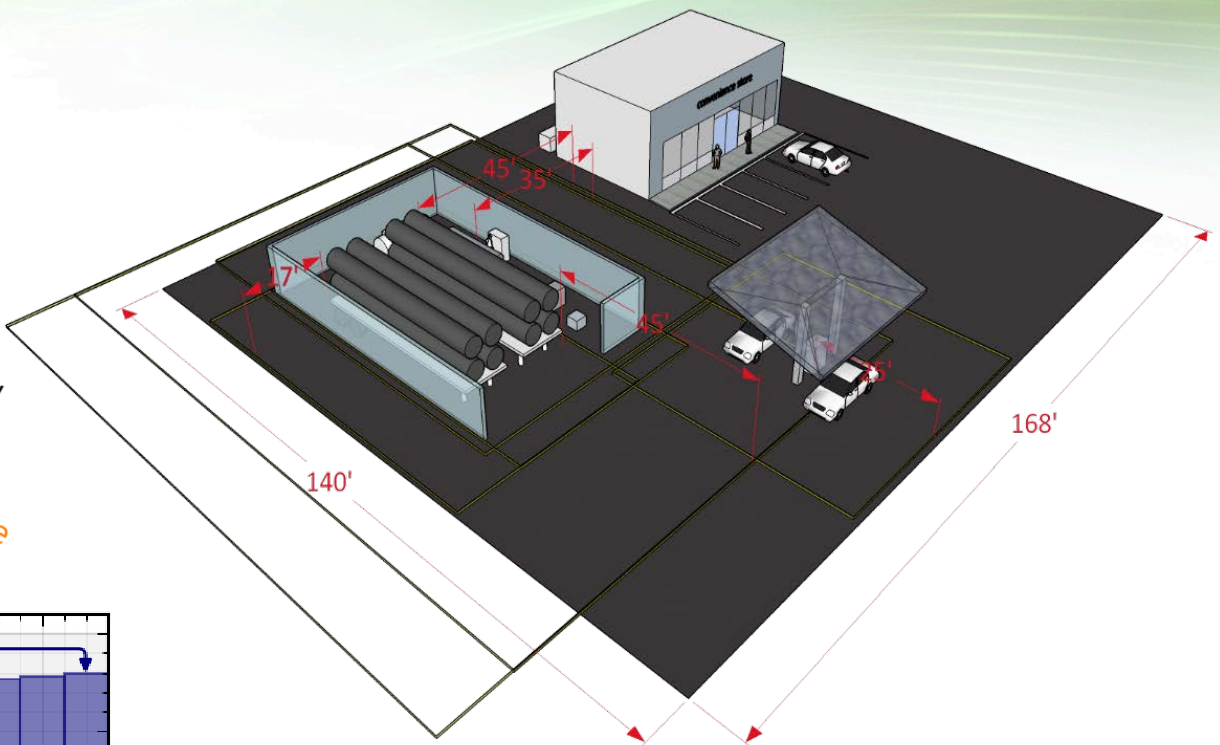


- Delivery, on-site storage in tube-trailers, and production are all significant contributors to the cost of delivered hydrogen
  - Adds $9.95/kg (32.6%), $6.90/kg (37.6%), $5.89/kg (41.3%) to costs for 100, 200, 300 kg/day stations
  - Without trailer lease, delivered hydrogen adds $3.87/kg for all station sizes

Accomplishments: Developed economics and layout for delivered, centrally-produced hydrogen station stored in tube-trailers







- Delivered hydrogen and station capital are largest contributors to hydrogen cost
- Footprint is large due to tube trailer storage

Accomplishments: Replacing conventional station equipment with modular station equipment does little to change economics or layout ($14.26 -> $14.25/kg for 300 kg/day)

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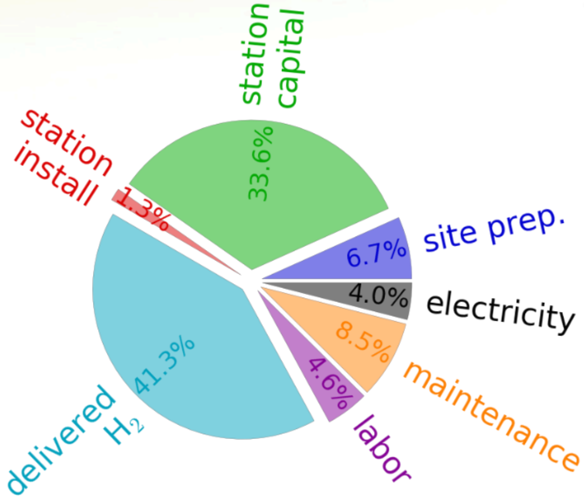
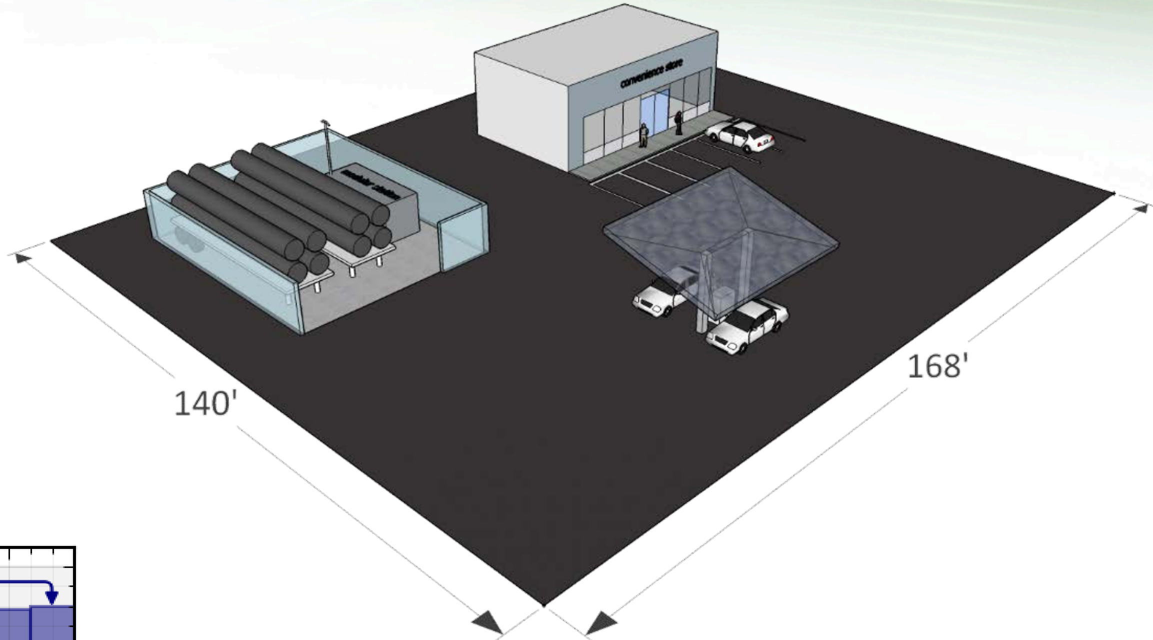
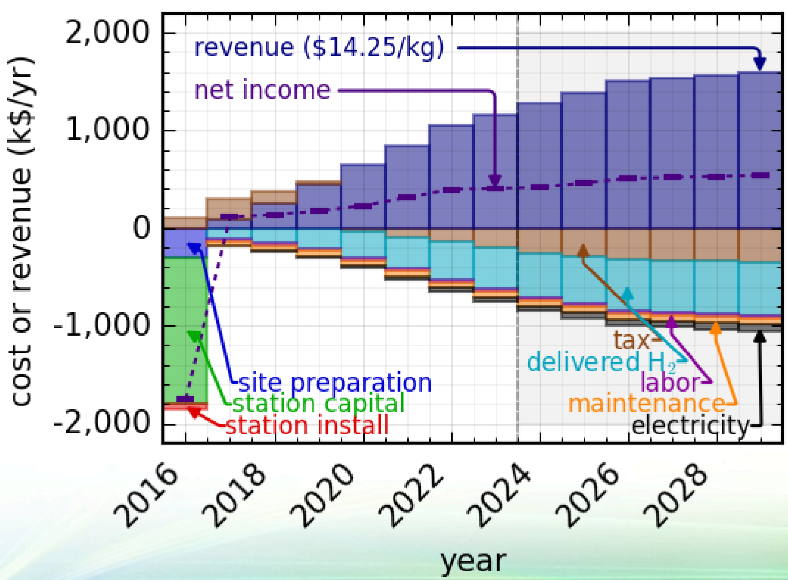




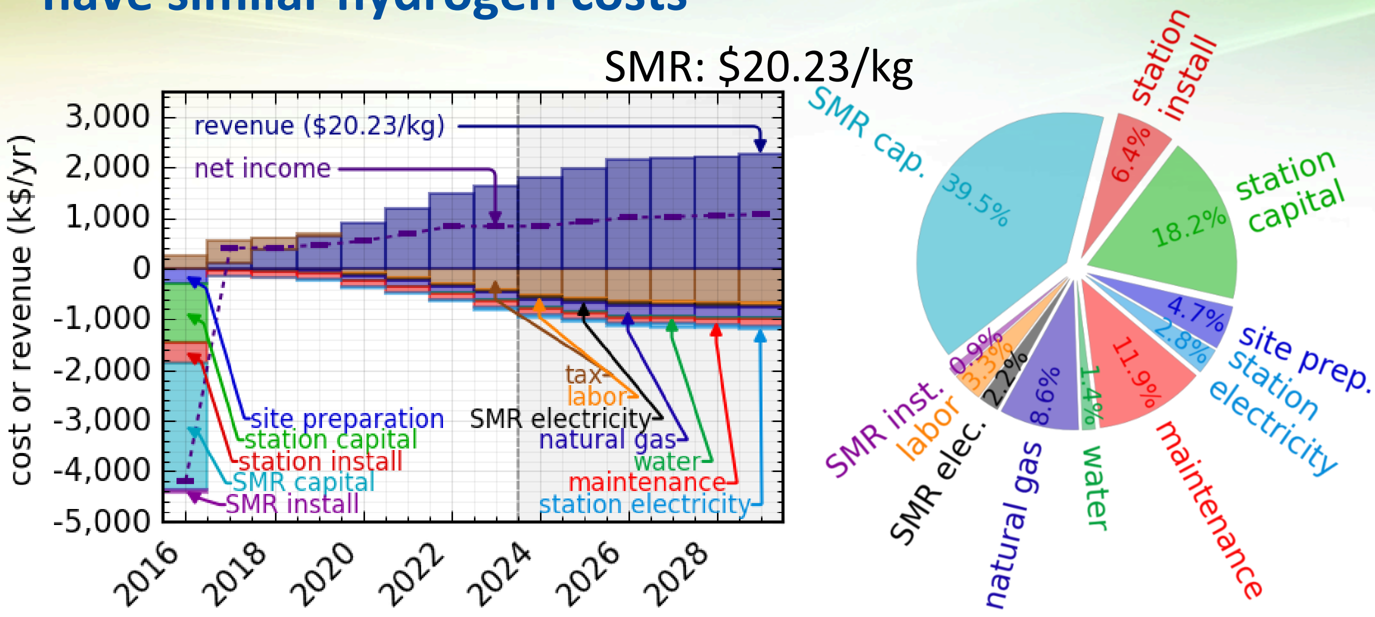


- Higher station capital costs are offset by lower installation costs

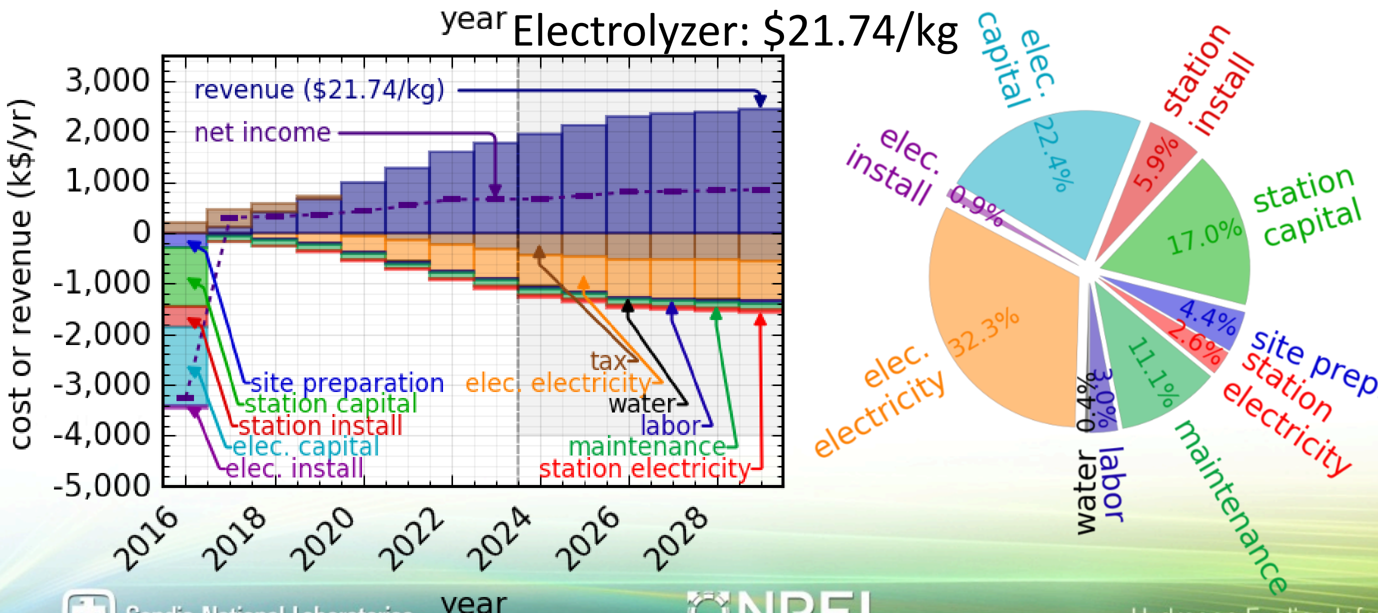
- Future modular costs may decrease with:
  - Parts standardization
  - Improved reliability (decreased maintenance)

Accomplishments: Steam methane reforming and electrolysis have similar hydrogen costs

SMR: $20.23/kg

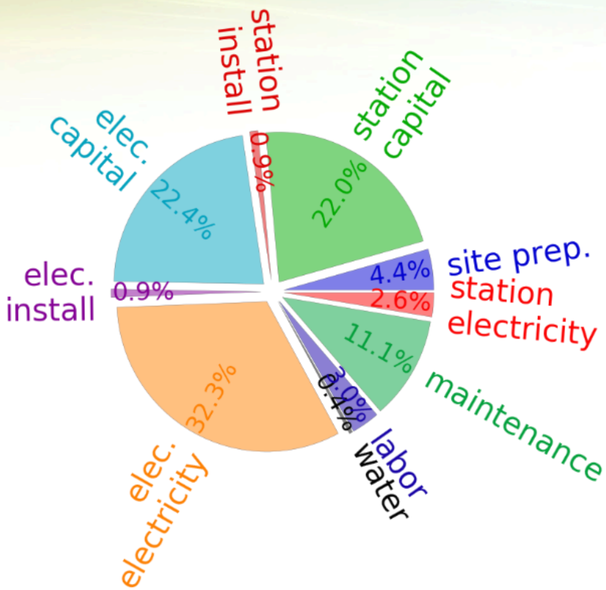


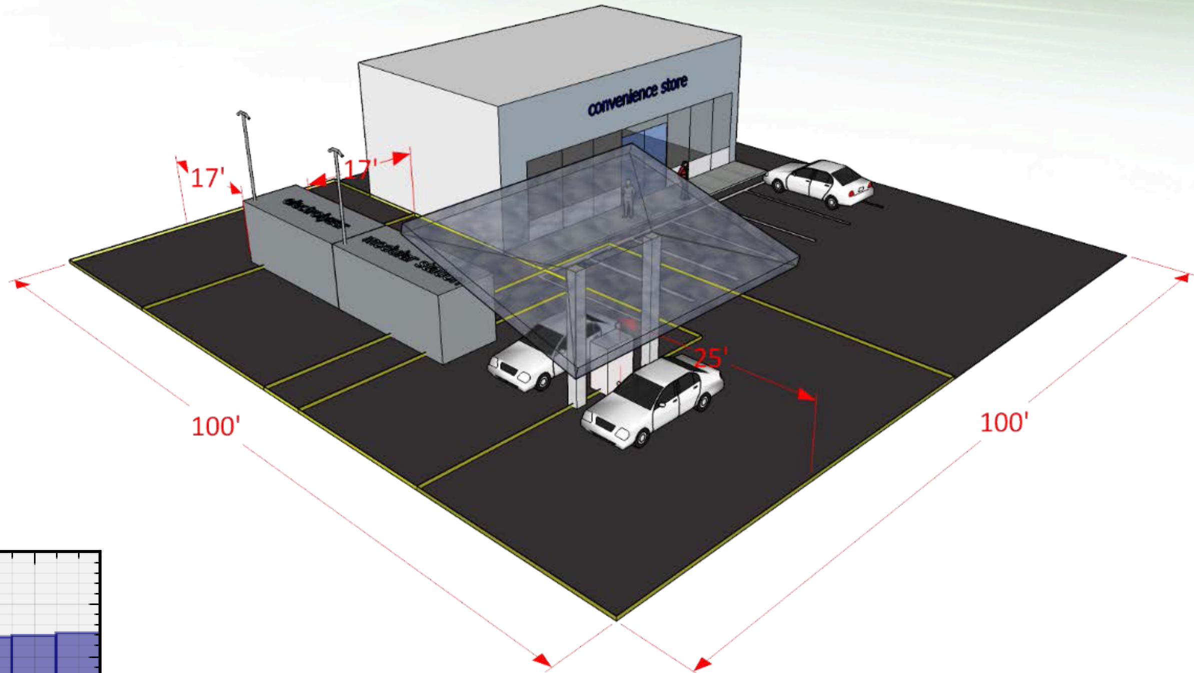
Electrolyzer: $21.74/kg

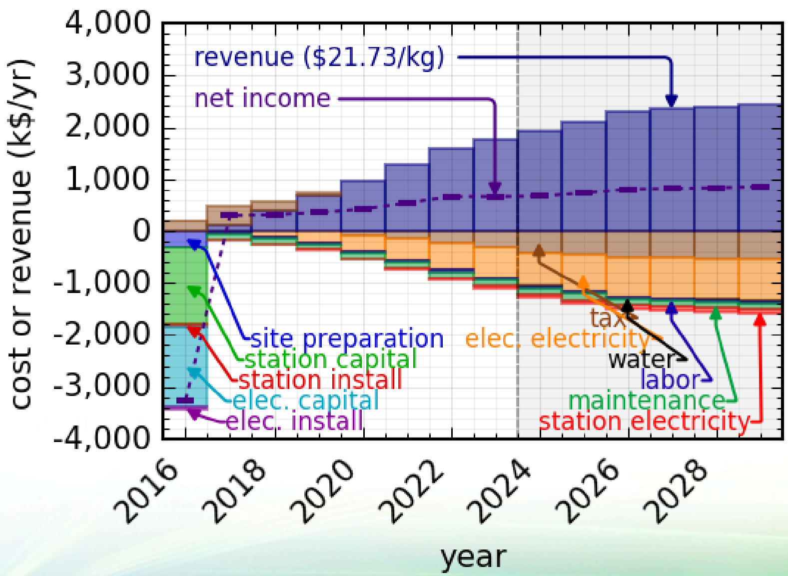


- Hydrogen producer (either electrolyzer or SMR) have large capital costs
- Higher SMR capital costs are offset by lower utility operation costs

Accomplishments: Developed economics and layout for modular station with hydrogen produced on-site



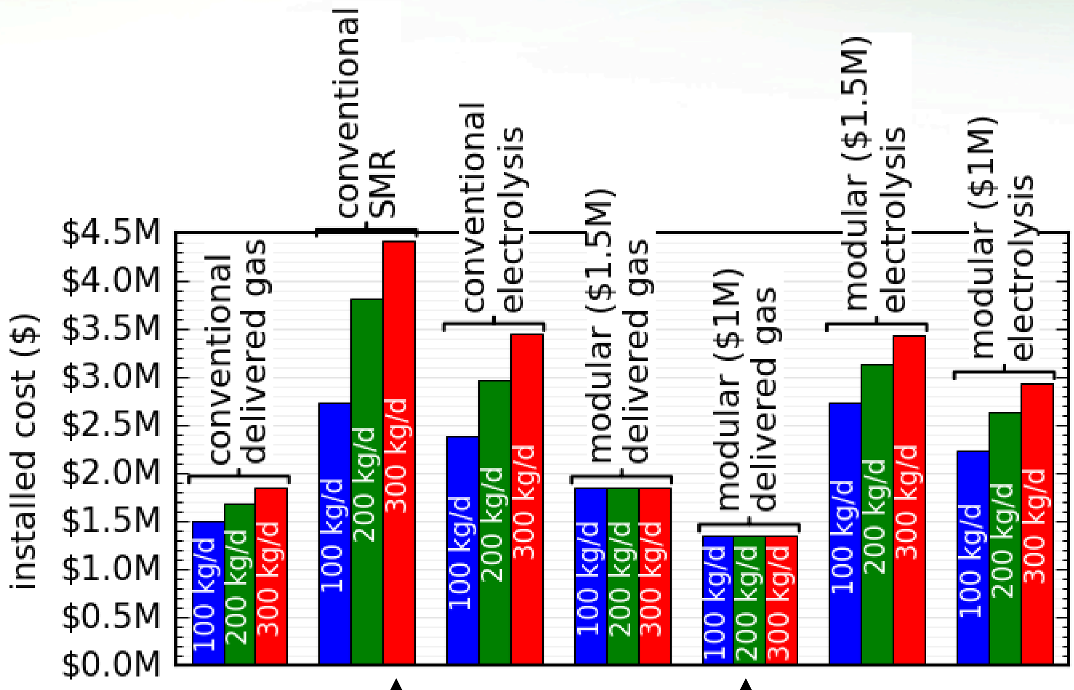




- Utilities for production are high cost
- Eliminating electricity cost reduces hydrogen cost by $7.02/kg

> ➢ Footprint can be reduced by building fire-rated walls into containers (and eliminating tube-trailer deliveries)

Accomplishments: Compared the capital costs of all 5 scenarios, with 2 costs of modular stations

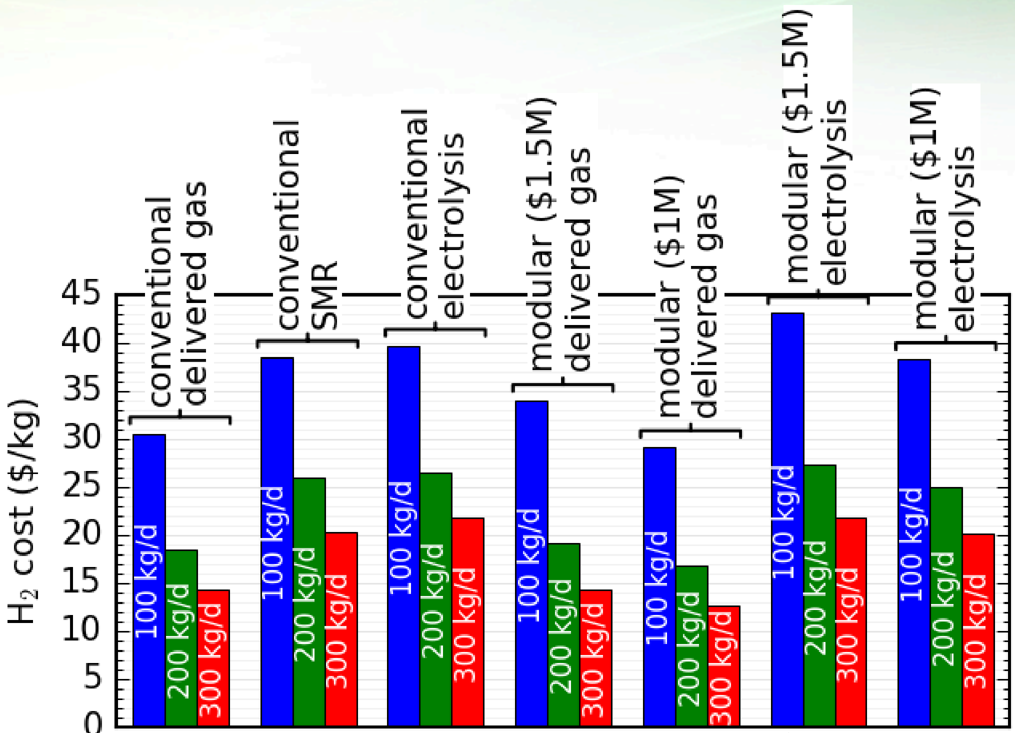


highest installed cost ($4.43M)

lowest installed cost ($1.36M)

➢ Centrally produced, delivered hydrogen results in lowest capital cost

Accomplishment: Compared the hydrogen costs of all 5 scenarios, with 2 costs of modular stations

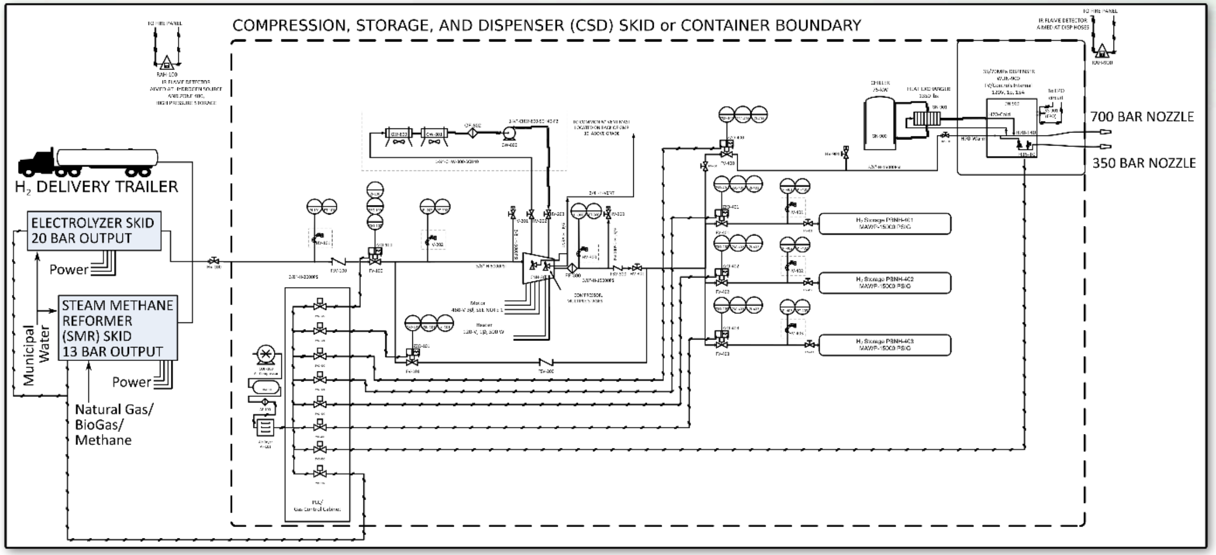


lowest cost hydrogen ($12.65/kg)

highest cost hydrogen ($43.03/kg)

- Centrally produced, delivered hydrogen results in lowest hydrogen cost
- Increased hydrogen throughput at larger stations reduces hydrogen cost

Accomplishments: Developed Piping and Instrumentation Diagrams (P&IDs) and equipment specifications for the different station concepts



Capacity	100 kg/day	200 kg/day	300 kg/day
Compressor power	25 kW	60 kW	100 kW
Electrolyzer power	260 kW	510 kW	770 kW
Electorlyzer water	110 l/hr	220 l/hr	330 l/hr
SMR power	16 kW	33 kW	49 kW
SMR water	400 l/hr	800 l/hr	1200 l/hr
SMR gas	34 Nm^3/hr	68 Nm^3/hr	101 Nm^3/hr

- Approximate utility requirements can be used in economic evaluations and siting screening

Collaborations

H2FIRST itself is a **SNL-NREL** co-led, collaborative project and members of both labs contributed heavily to this project.

To be as relevant and useful as possible, the project tightly integrated input, learnings, and feedback from many stakeholders, such as:

- H2USA's Hydrogen Fueling Station Working Group
- California Fuel Cell Partnership
- California Energy Commission
- California Air Resources Board
- UC Berkeley
- Argonne National Lab
- H2 Logic
- Hydrogenics
- ITM Power
- Linde
- Nuvera
- PDC Machines
- Proton OnSite
- Siemens AG
- First Element

Remaining barriers and challenges:

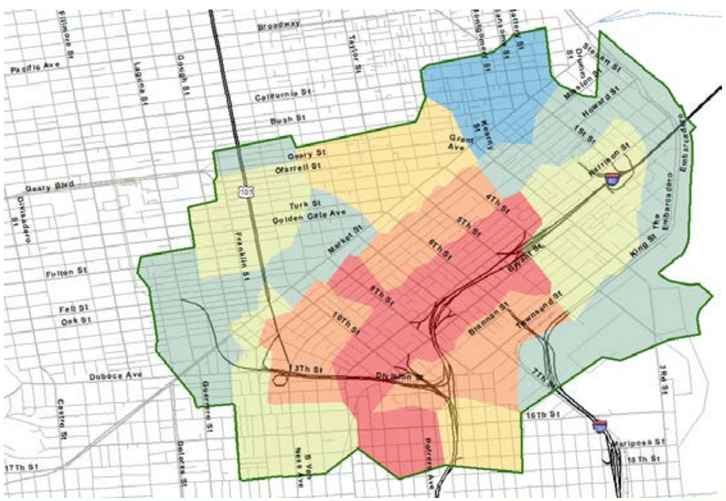
- On-site production eliminates delivery and can reduce space but suffers from higher capital and, especially, higher operating expenses
  - Utility cost reduction through innovative business models may be one solution
- Modular-type stations offer installation cost reduction potential but is not yet being fully realized.
  - Factory build costs are still significant
  - High capital costs of fundamental station equipment and components inhibits cost reduction potential of any station, including modular
- Increasing need to site even larger capacity fueling stations in urban centers as more vehicles are on the roads
  - Unique strategies for compact stations including liquid hydrogen storage

Future work: Reference Station – Urban Sites

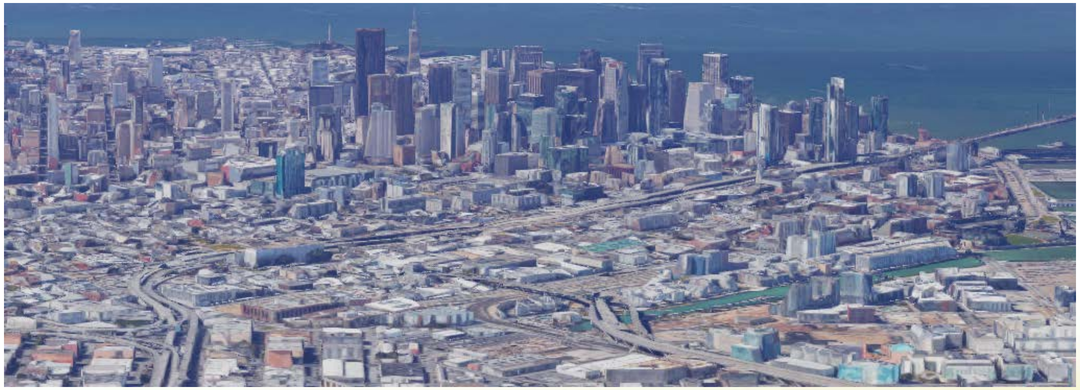
Origin: H2USA HFSWG identified station footprint reduction for urban areas as the *#1 priority* FY17 H2FIRST project.

Goal: Identify and evaluate methods of footprint reduction and associated costs for stations in urban areas.

- New delivery concepts
- Potential changes to NFPA 2
- Underground storage
- Rooftop Storage



Preferred location of stations in San Francisco
← CHIT map, aerial view ↓



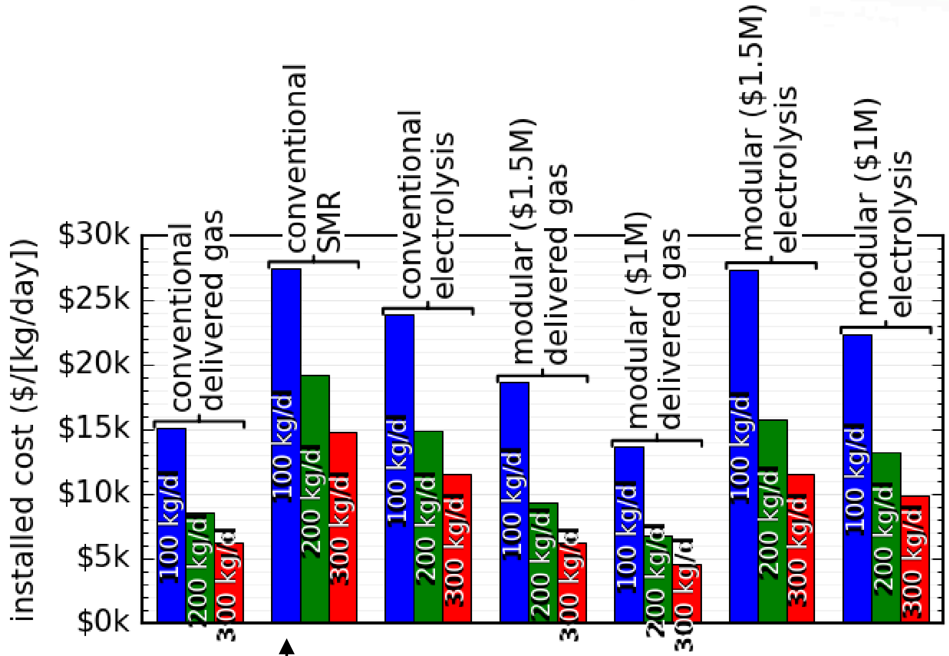
Any proposed future work is subject to change based on funding levels

Summary

- **Relevance**: Deliver publically available, transparent details of hydrogen fueling station equipment, designs, and economics
- **Approach**: Apples-to-apples cost comparison of entire hydrogen delivery chain with various station scenarios using data from industry collaborators to determine overall hydrogen cost
- **Technical Accomplishments**:
  - Economically evaluated five station concepts for 3 station capacities
    - Lowest cost hydrogen for 300 kg/day modular station with centrally produced, delivered gaseous hydrogen
  - Produced layouts of different station concepts
    - Smallest footprint of 10,000 ft^3 for modular station with on-site produced hydrogen (either electrolysis or SMR)
  - Identified new barriers and challenges of current station infrastructure rollout effort
- **Future work**:
  - Identify and evaluate methods of footprint reduction and associated costs for stations in urban areas

Technical Back-up Slides

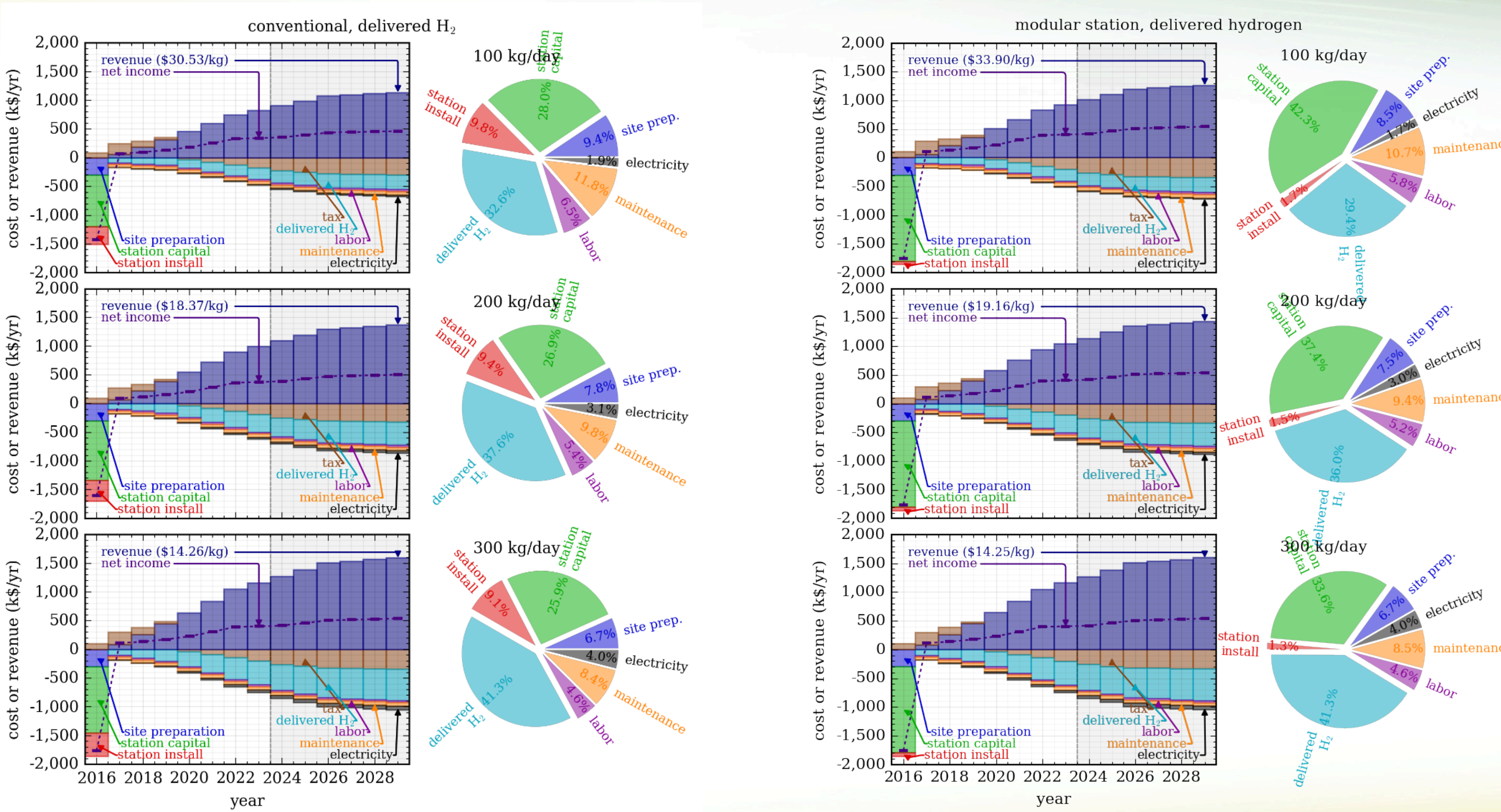
For less than 300 kg/day stations, economics always improve with capacity



highest cost/capacity ($27,420/[kg/day])

lowest cost/capacity ($4,530/[kg/day])

Economic results for all stations, and all capacities are included in the report



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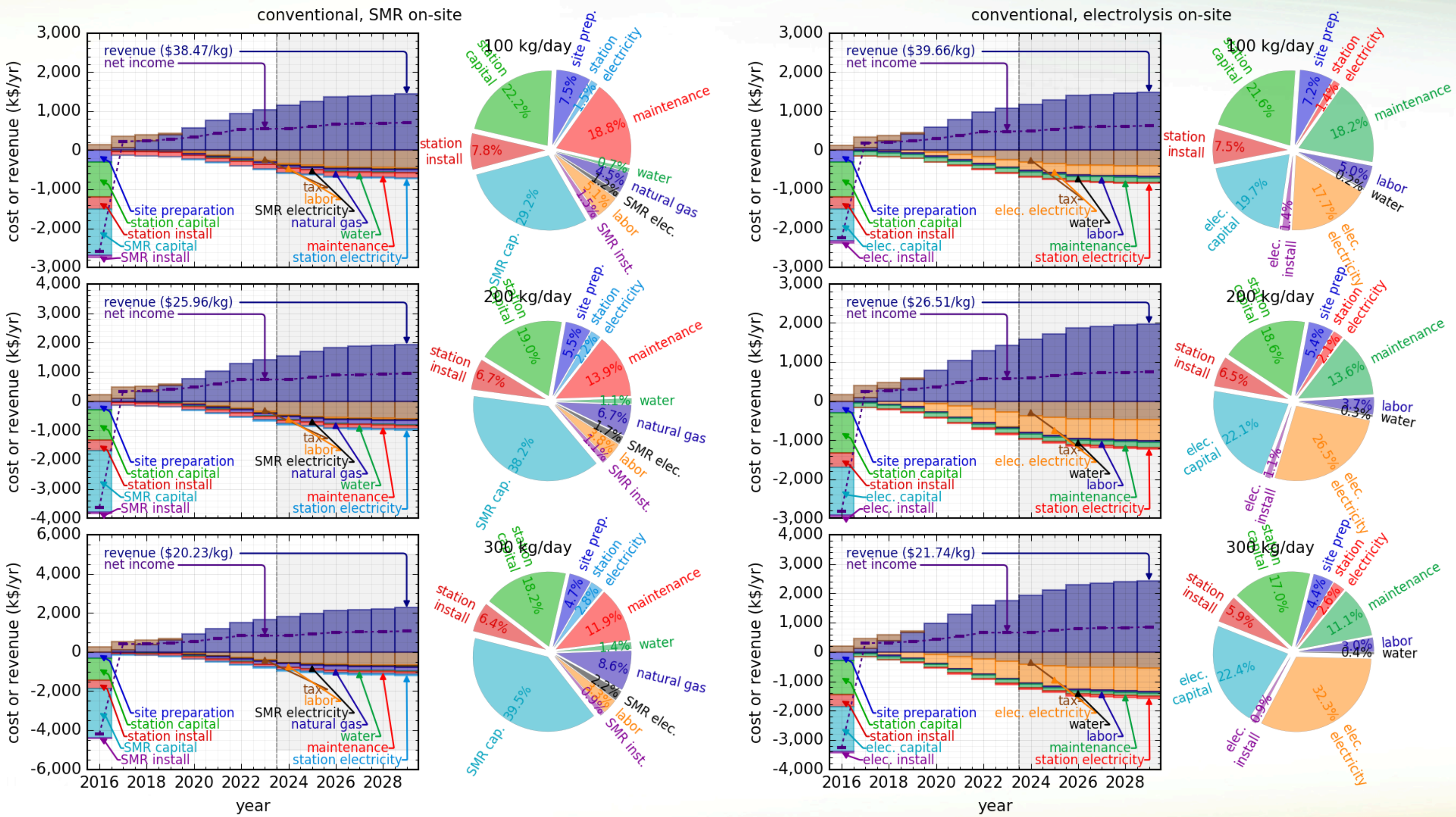

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