# Hydrogen Station Economics and Business (HySEB) -- Preliminary Results


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**Project: AN046**

Center for Transportation Analysis

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OAK RIDGE NATIONAL LABORATORY

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# OVERVIEW

## Timeline

- Project start date: Oct. 2013
- Project end date: Oct 2014

**Project continuation and direction determined annually by DOE*

## Barriers (System Analysis)*

- A. Future Market Behavior
- B. Stove-piped/Siloed Analytical Capability
- D. Insufficient Suite of Models and Tools

**from 2011-2020 FCTO MYPP*

## Budget (DOE share)

- FY14 funding: $100k
- Total DOE Project Value: $100k

## Partners/Collaborators

- University of Tennessee
- University of California, Davis
- Ford
- Argonne National Laboratory
- National Renewable Energy Laboratory
- US Department of Transportation

# Objective: develop a tool to analyze profitability, risk and public-private partnership in hydrogen station deployment.

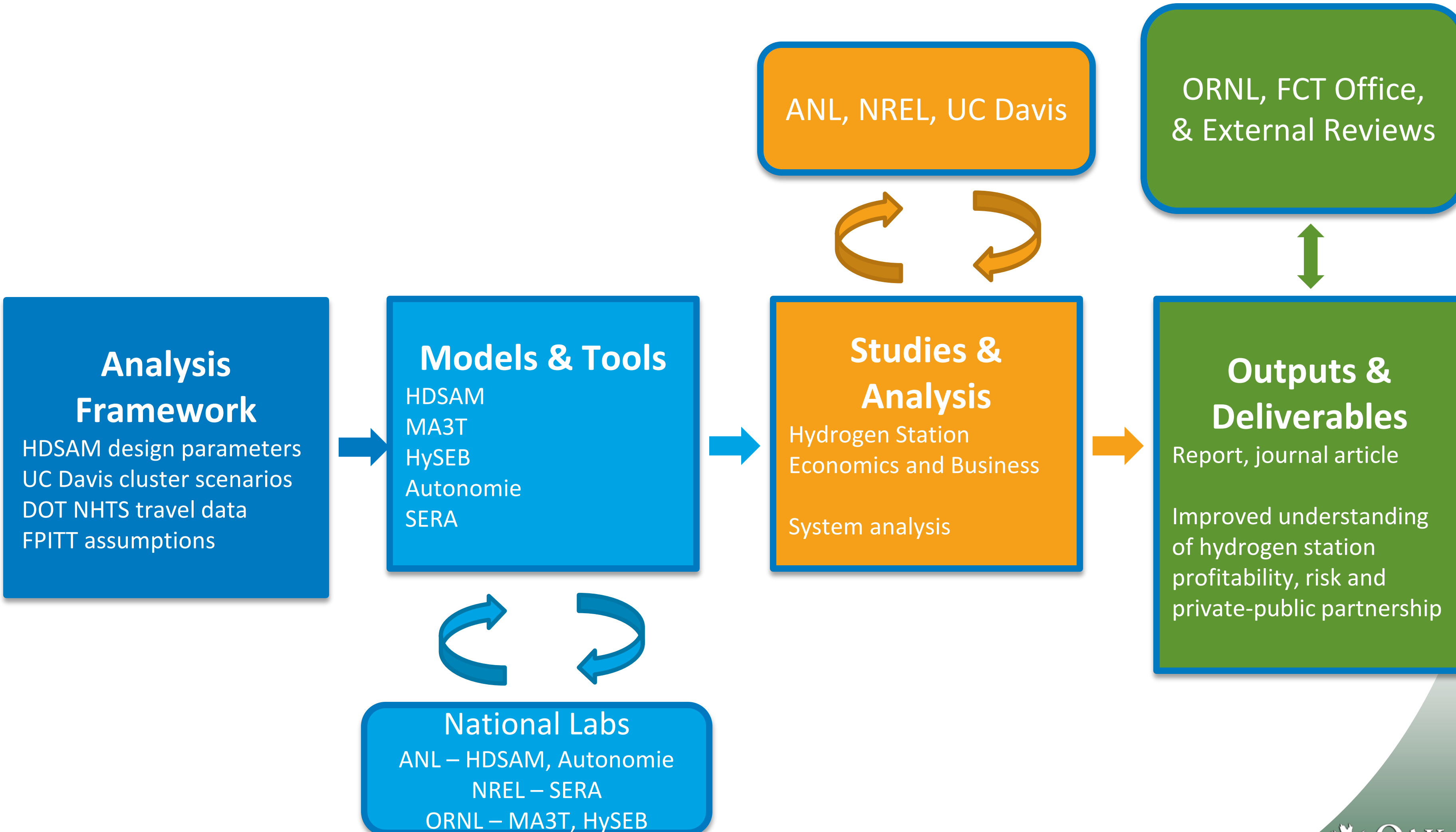
| Barriers | Project Goals |
| --- | --- |
| Future market behavior | Develop more understanding to the supply of H2 infrastructure and the interplay between infrastructure and FCV* demand |
| Stove-piped/Siloed Analytical Capability | Integrate relevant outputs from UC Davis, ANL, NREL; Support H2USA activities; provide insights to designing public-private partnership policies that can motivate private investment with efficient use of government subsidy. |
| Insufficient suite of models and tools | Develop a model that optimizes H2 station deployment and provides insights on station economics and business models under public-private partnership |

* acronyms are listed and defined in technical backup slides.

# Analytical framework needed for analyzing private profitability and risk of hydrogen station deployment.

- Problem complexity
  - early adopters of FCVs requires sufficient fuel availability (% of stations), but increased number of stations reduces station utilization, or reduces economy of scale and thus inflates delivered H2 cost
  - Refueling inconvenience can be theoretically compensated, if the required compensation can be justified by station cost savings
  - Required government subsidy is related to industry perception of market prospect, investor patience, infrastructure cost, and transition optimality.
- Issues of interest
  - At what level and by how soon can government subsidy realize market-driven station deployment?
  - What are the uncertainties, barriers and opportunities in identifying early adopters with the cluster strategy?
  - What is the profitability and risk faced by investors?
  - How to design the public-private investment partnership?

# Hydrogen Station Economics and Business (HySEB)



## The Hydrogen Station Economics and Business (HySEB) model optimizes key deployment decisions to maximize profitability in consideration of investment risks.

- Current status and assumptions
  - All station costs based on Ogden 2013 AMR and H2A
  - 1st station is 100kg/d mobile refueler; capacity and timing of subsequent stations are to be optimized
  - FCV sales estimates based on ZEV mandate
  - Clustering strategy based on Ogden and Nicholas (2010)
  - Detailed modeling of station deployment at a city level
    - Scenarios: small stations first, uniform size, large stations first
    - Trade off between station cost and fuel accessibility cost
  - Incorporate daily travel patterns to more accurately reflect fuel demand at home stations in the context of cluster strategy
    - Mix and daily distance distributions of 6 driver types: Frequent Long Commute (FLC), Frequent Short commute (FSC), Average Long Commute (ALC), Average Short Commute (ASC), Modest Long Commute (MLC), Modest Short Commute (MSC)
  - Capability of modeling fuel cell PHEVs
  - Cash flow analysis of home stations
    - Capital, O&M, revenue, fuel accessibility
    - Hydrogen price subsidy, capital cost subsidy
    - System NPV, investor NPV, buy-down cost, next-N-years NPV
- On-going efforts
  - implementing optimization algorithm
  - more uncertainty analysis

# Assumption—clustering strategy is our starting point and we focus on station network economics at one cluster (a small city)

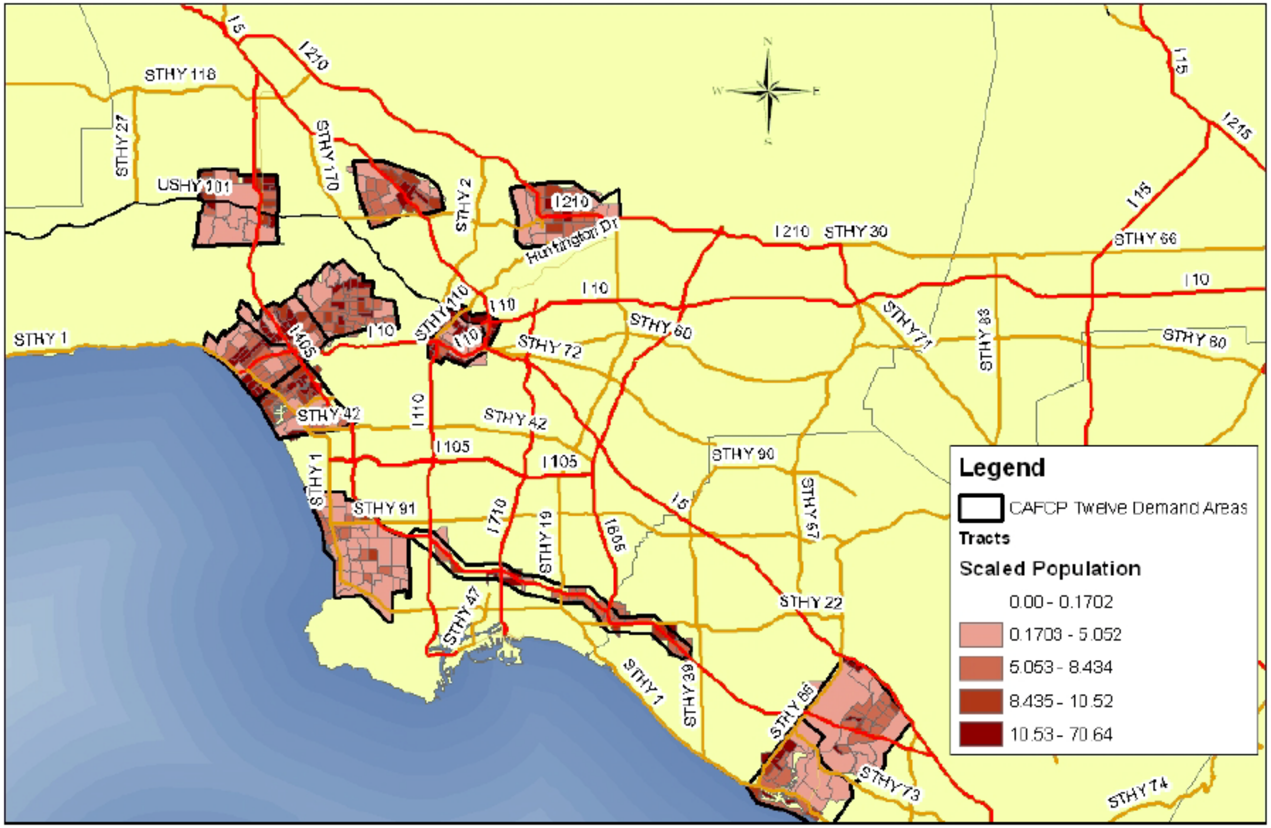



**Figure 3** Scaled population distribution within the clusters so that each cluster represents the same number of people. Population is a proxy for attractiveness of vehicle placement. Having each cluster represent the same number of vehicles implies that each cluster is equally attractive.

Source: J. Ogden, M. Nicholas, 2010. Energy Policy, 39(4), Pg 1923-1938

# Travel time to the nearest station for clustered consumers varies among clusters, but generally is lower than that for region-wide random consumers.

Home station fuel accessibility cost is a function of fuel availability (% of stations), FA curve that reflects city density, travel time value that reflects income level, and number of FCVs on road.

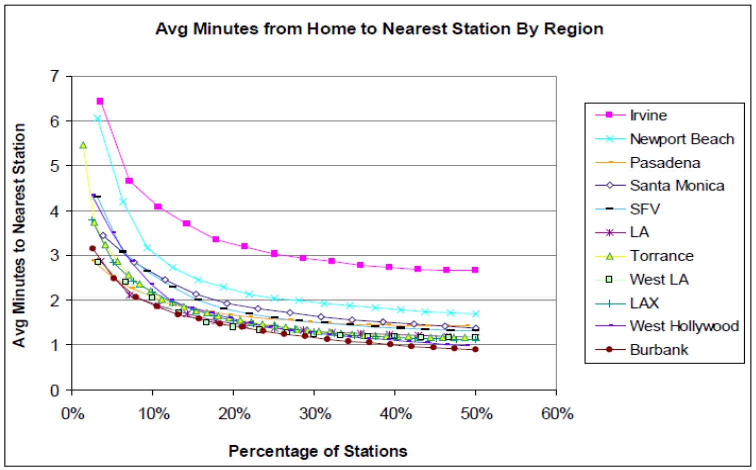
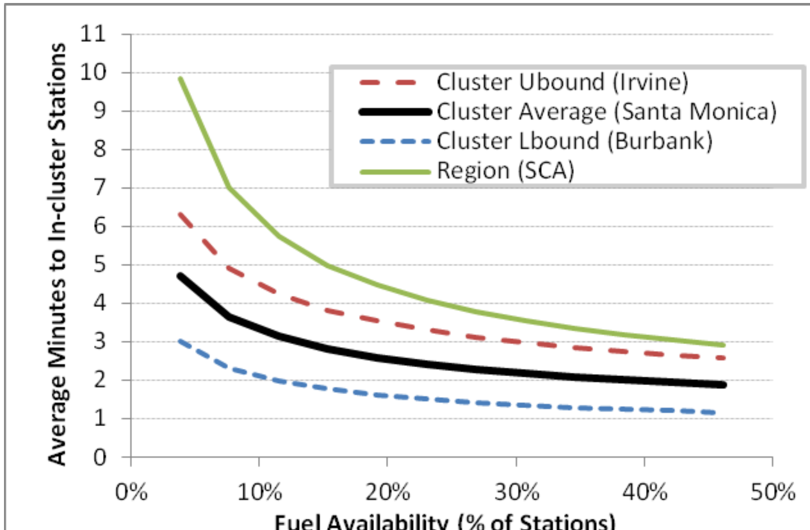



**Figure 6** Due to the varying number of stations per cluster, the average minutes to the nearest station is plotted as a function of the percentage of gasoline stations that offer hydrogen. Each dot signifies a hydrogen station. One station is signified by the leftmost dot in each line. Subsequent dots signify additional stations. Irvine, as defined by the cluster boundary, shows poorer access to fuel than other clusters. If there were 50% as many hydrogen stations as gasoline stations, most clusters would average a little over a minute to the nearest station.

Source: J. Ogden, M. Nicholas, 2010. Energy Policy, 39(4), Pg 1923-1938

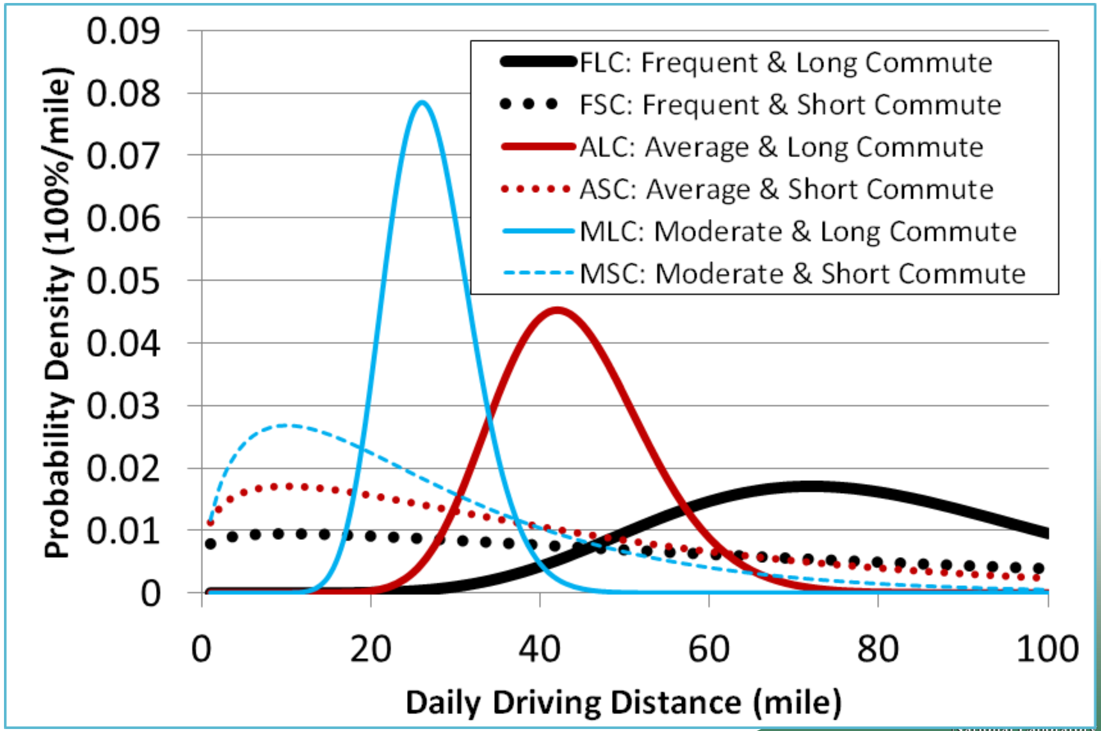



note: fitted curves based on (Nicholas & Ogden 2010).

# Driving pattern heterogeneity affects home station business and is captured with a set of daily distance probability density curves.

- 6 California drivers were selected from NHTS 2009 as data source to capture driving pattern heterogeneity. Driver shares are calibrated for an average driving intensity of 13k miles/year based on California.
- A higher share of frequent drivers with long commute distance is expected to contribute more to home station business.
- For each driver group, fuel demand at home stations are calculated (refueling at connector stations if daily driving distance > a threshold value )
- The daily long distance threshold is assumed to be 100 miles.

| | Miles /year | miles to work | % of miles on home stations | H2 demand from home stations (kg/d) | % of drivers |
|---|---|---|---|---|---|
| FLC | 29250 | 36 | 72% | 0.93 | 2% |
| FSC | 31107 | 5 | 34% | 0.49 | 2% |
| ALC | 14263 | 21 | 100% | 0.73 | 25% |
| ASC | 12500 | 5 | 73% | 0.53 | 25% |
| MLC: | 9850 | 13 | 100% | 0.45 | 23% |
| MSC | 9849 | 5 | 96% | 0.43 | 23% |



# We developed HySEB, an Excel/VBA model, to optimize clustering deployment decisions under a wide range of user-specified market and technological parameters, and to inform public-private investment decisions.

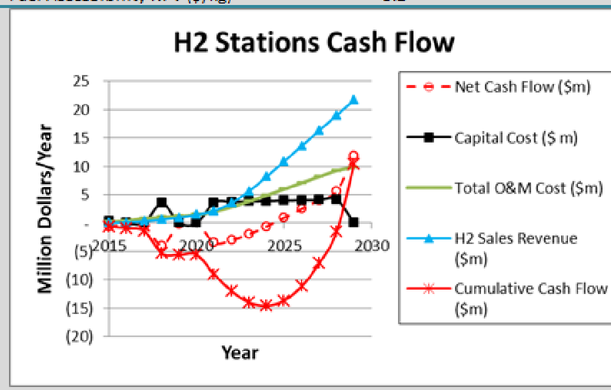
- 4 groups of inputs: City-Vehicle, Driver, Infrastructure, Market Scenario.
- Optimization algorithm is under development.
- Users can use the interface to examine in real-time how system NPV, next-N-years NPV, and cashflows respond to input changes.

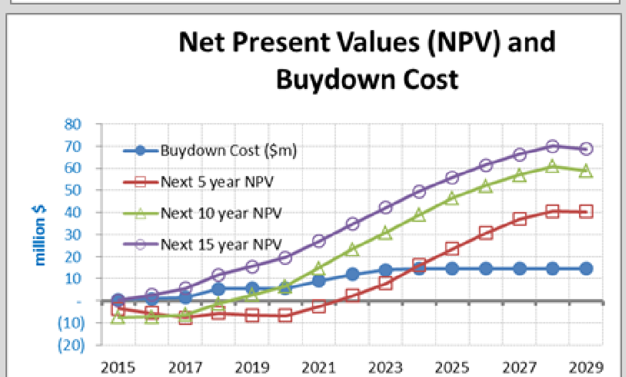
**Hydrogen Station Economics and Business (HySEB)**

Contact: Zhenhong Lin,linz@ornl.gov, Oak Ridge National Laboratory

| City-Vehicle | | |
|---|---|---|
| units | FCV volume 15-17 | 159 |
| units | FCV volume 18-20 | 574 |
| units | FCV volume 21-23 | 2083 |
| % | Clustering Scale | 100% |
| units | City vehicle volume | 65000 |
| persons | City population | 90000 |
| mpkg | FCV CS Fuel Economy | 60 |
| Wh/mi | FCV CD Electricity Rate | 235 |
| miles | FCV CD Range | 0 |
| kg | H2 On-board Capacity | 5.0 |
| kg/day | Per-vehicle H2 Use | 0.55 |
| **Driver** | | |
| % | FLC Share | 2% |
| % | FSC Share | 2% |
| % | ALC Share | 25% |
| % | ASC Share | 25% |
| % | MLC Share | 23% |
| % | MSC Share | 23% |
| min | Value of travel time | 20 |
| | anoyance multiplier | 3 |
| | early adopter AM factor | 5 |
| | Consumer discount rate | 7% |
| | Investor discount rate | 12% |
| **Infrastructure** | | |
| kg/day | Min H2 Supply Capacity | 6,600 |
| | Minimum Sta No. | 7 |
| | DV--Station No. | 10 |
| kg/day | Avg Station Size | 722 |
| kg/day | Smallest Station Size | 444 |
| kg/day | 2nd Station Size | 444 |
| kg/day | Incre Size | 69 |
| | Roll-out Scenario | SmallFirst |
| year | Station Lifetime | 15 |

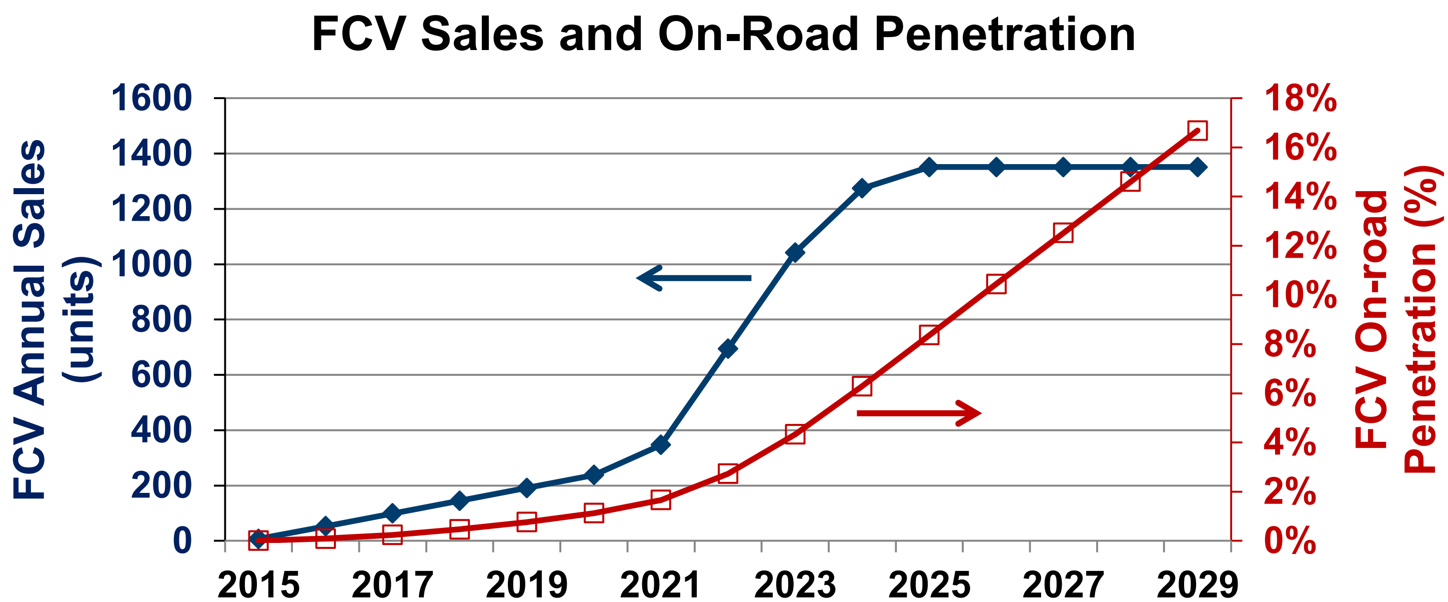
| Output | |
|---|---|
| System Cost NPV ($/kg) | 12.3 |
| Infrastructure NPV ($/kg) | 9.1 |
| Fuel Accessibility NPV ($/kg) | 3.2 |




| | Market Scenario and Infrastructure Deployment | | | |
|---|---|---|---|---|
| | Year | 2015 | 2022 | 2029 |
| | Time Step | 1 | 8 | 15 |
| | FCV Sales | 7 | 694 | 1351 |
| | FCV Volume | 7 | 1774 | 10845 |
| | FCV On-road Penetration | 0.01% | 2.73% | 16.68% |
| | **Station On Line** | 1 | 4 | 10 |
| 1 | #1 | 1 | 1 | 1 |
| 2 | #2 | 0 | 1 | 1 |
| 3 | #3 | 0 | 1 | 1 |
| 4 | #4 | 0 | 1 | 1 |
| 5 | #5 | 0 | 0 | 1 |
| 6 | #6 | 0 | 0 | 1 |
| 7 | #7 | 0 | 0 | 1 |
| 8 | #8 | 0 | 0 | 1 |
| 9 | #9 | 0 | 0 | 1 |
| 10 | #10 | 0 | 0 | 1 |
| | **Station Capacity (kg/day)** | | | |
| | #1 | 100 | 100 | 100 |
| | #2 | 0 | 444 | 444 |
| | #3 | 0 | 514 | 514 |
| | #4 | 0 | 583 | 583 |
| | #5 | 0 | 0 | 653 |
| | #6 | 0 | 0 | 722 |
| | #7 | 0 | 0 | 792 |
| | #8 | 0 | 0 | 861 |
| | #9 | 0 | 0 | 931 |
| | #10 | 0 | 0 | 1000 |
| | City H2 Supply Capacity (kg/da | 100 | 1641 | 6600 |
| | City H2 Demand (kg/day) | 4 | 972 | 5940 |
| | City H2 Station Utilization | 0.04 | 1 | 1 |
| | Station Output (kg/day) | 4 | 972 | 5940 |
| | #1 | 4 | 59 | 90 |
| | #2 | - | 263 | 400 |

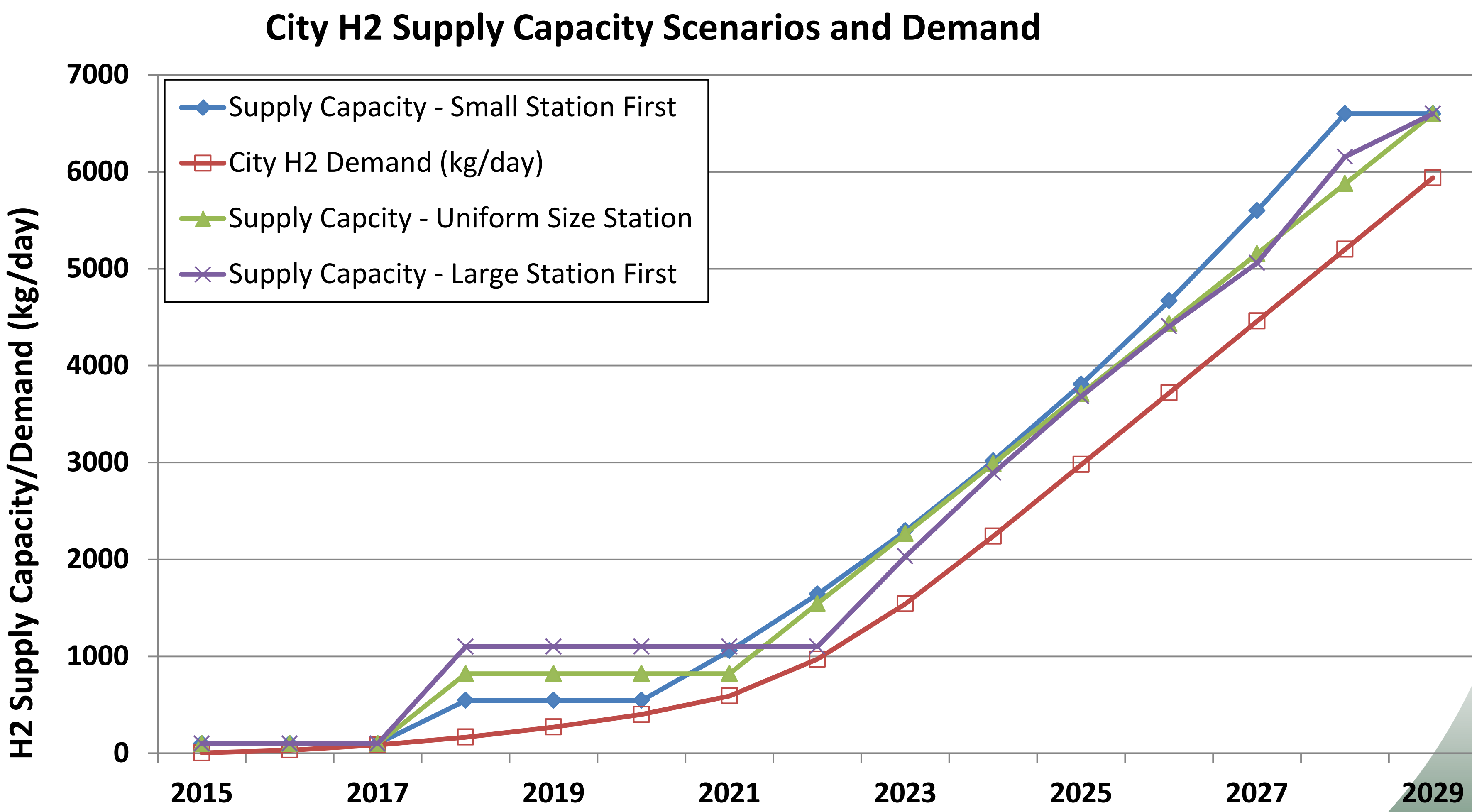
# To estimate H2 use, clustered FCV volume is assumed to grow rapidly during 3 ZEV-compliance periods and then stabilize.




**Assumptions**

- Use Santa Monica as the clustering context. In 2007, city vehicle volume about 65000, city population about 90000, a total of 159 FCVs sold during 2015-2017, 574 during 2018-2020, and 2083 during 2021-2023, consistent with ZEV-compliance scenarios in (Ogden, Nicholas, 2010); 3 years to stabilize the annual sales.
- A 100 kg/day mobile refueler is assumed as the 1st station; all subsequent stations are onsite SMR with varied sizes.
- All station capital, O&M costs and efficiency data are consistent with (Ogden 2013 AMR) and H2A.

# Three H2 station roll-out scenarios are considered to examine the significance of station economy of scale and timing.



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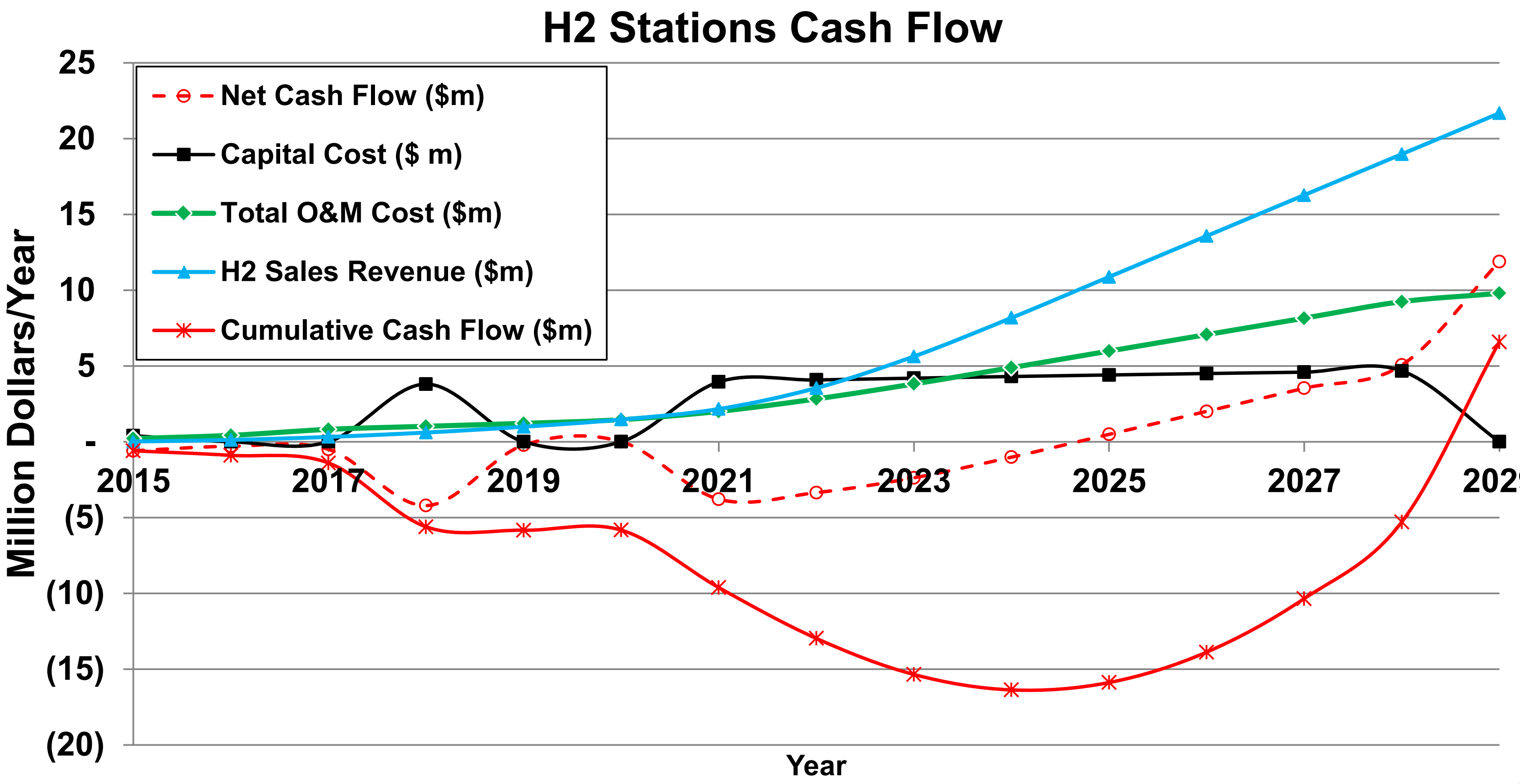
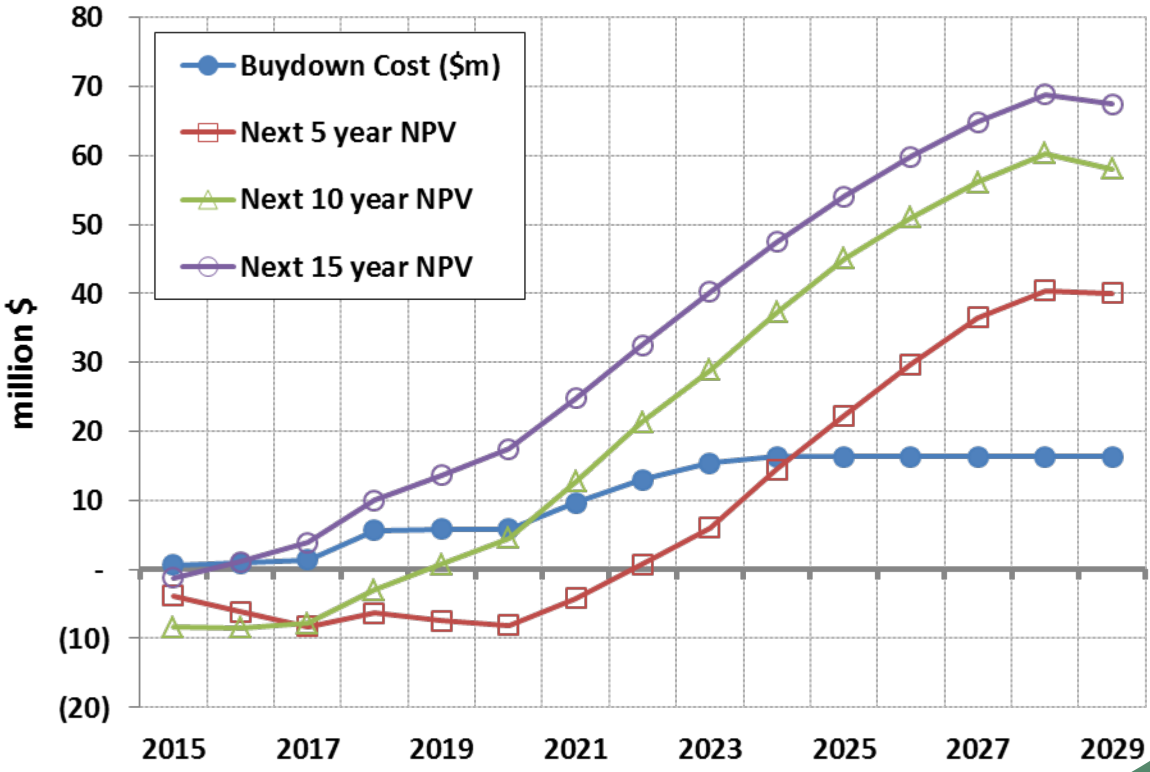
# Base Case: build small stations first. System NPV is $12.4/kg (33.5 $m), including $9.2/kg for infrastructure cost and $3.2/kg for fuel accessibility cost.




H2 price is assumed to be $10/kg.

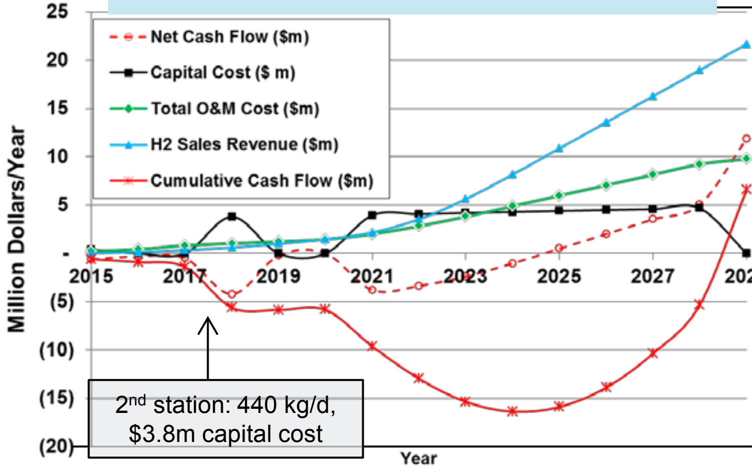
# The "term-limited buydown" public-private partnership

- buydown cost of year i = the cumulative sum of negative cash flows in year 1, 2… i.
- The next-N-years NPV of year i = NPV of the cash flows during the next N years starting from year i+1, discounted to the end of year i.
- E.g, in year 2020, the return to a $5.5 million of 2015-2020 buydown (public investment) is a local hydrogen station business that is worth $6.6 million for the next 10 years.
- But is 10-year investor patience too much to ask? Should we use 5 years, 15 years or something else?

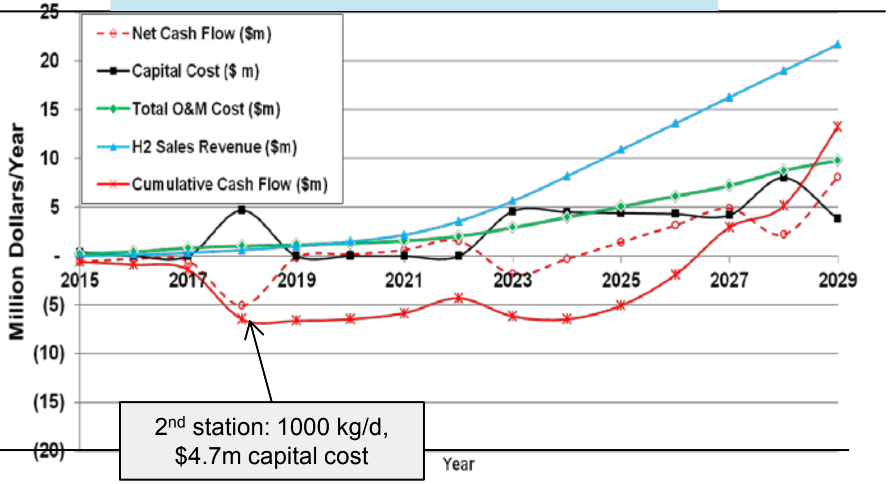


# Building large stations first could reduce system cost NPV due to near-term economy of scale.

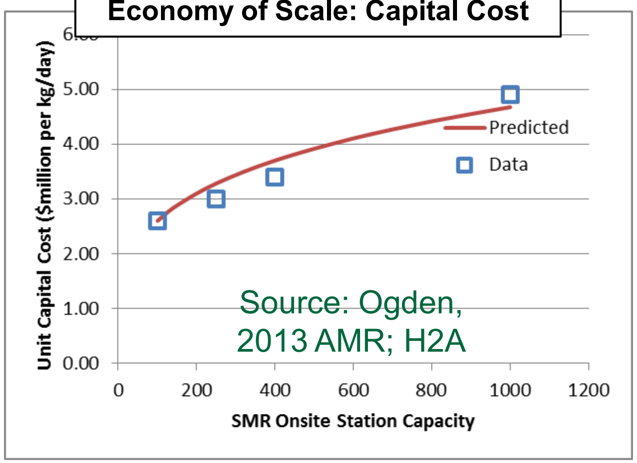
H2 Station Cash Flow: Small Station First



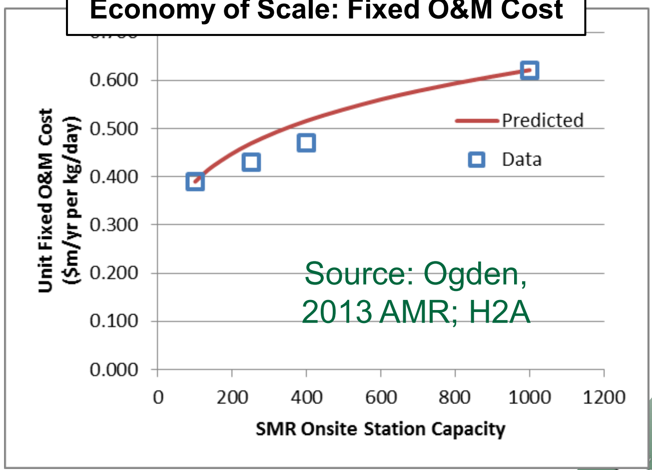

H2 Station Cash Flow: Large Station First



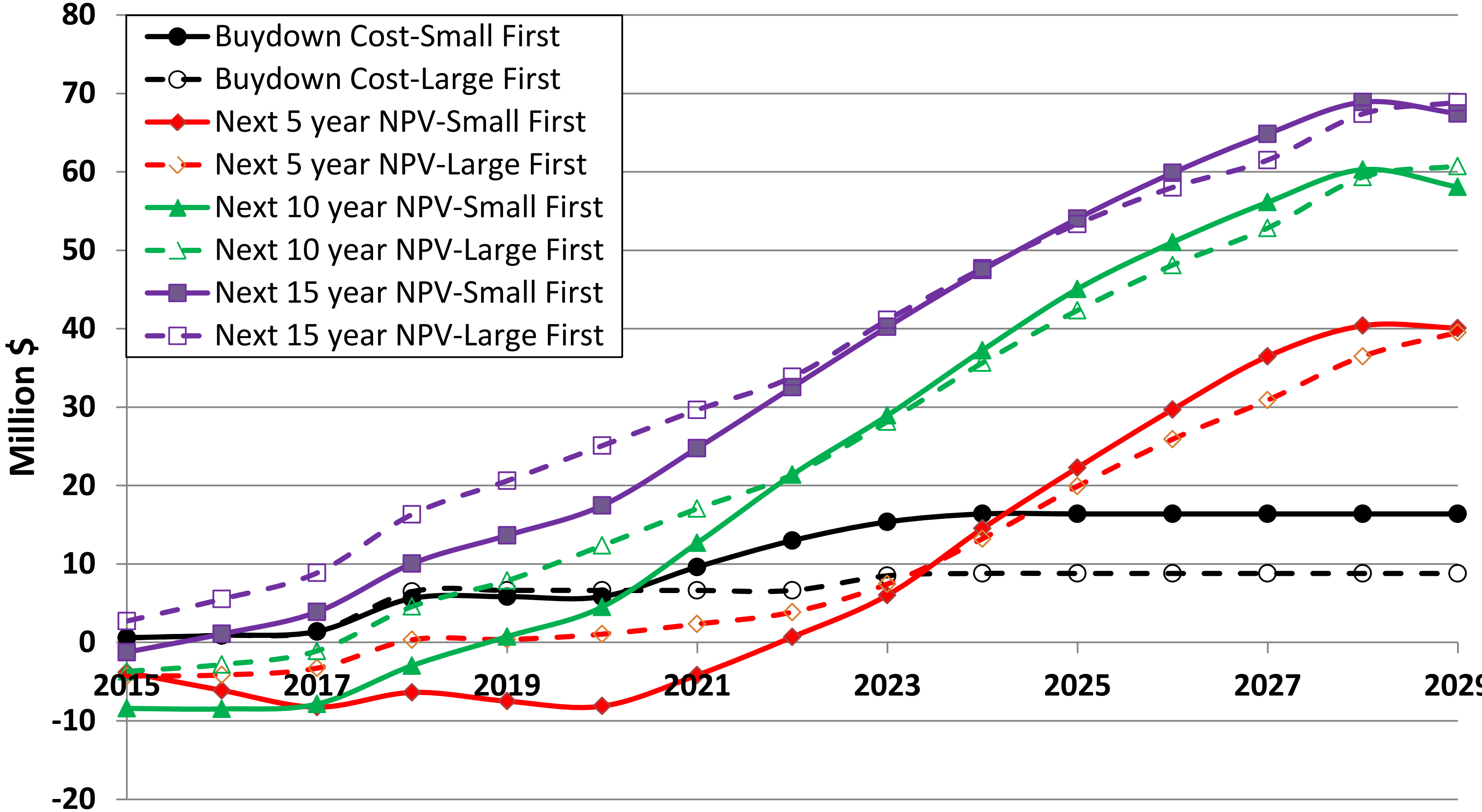

Economy of Scale: Capital Cost




Economy of Scale: Fixed O&M Cost



# Balancing station economy of scale with fuel availability can be important for private-public partnership.




Caution: how accurate is the estimated economy of scale?

# Combining cluster strategy with station scale economy and favorable travel patterns can significantly lower system cost.

The table shows scenario system NPV in $/kg and the number within the parenthesis shows the infrastructure cost component.

| | Small Station First | Large Station First |
|---|---|---|
| Ref. Case (2/25/23% mix) | 12.4 (9.2) $/kg | 11.4 (7.8) $/kg |
| 100% FLC | 9.4 (5.9) $/kg | 9.7 (6.4) $/kg |
| 100% MSC | 14.7 (11.7) $/kg | 12.3 (8.5) $/kg |

- System cost NPV = infrastructure cost NPV + fuel accessibility cost NPV. System cost is independent of hydrogen price, which only affects wealth transfer between consumers and fuel providers.
- On the other hand, frequent outside-network travelers with high time value would be a challenge for business viability of cluster strategy.
- Limiting public subsidy would require more investor patience, Investors may be more patient if they perceive less technological and policy risk.

# Responses to Previous Year Reviewer Comments

- **The project is new and has not been reviewed before.**
- **We look forward to your comments, recommendations and advice.**

# Collaborations/Contributions

| Institution | Role |
|---|---|
| Oak Ridge National Laboratory (ORNL)<br>Zhenhong Lin (PI), Changzheng Liu | Prime, oversee the project, model formulation and implementation, data collection, analysis |
| University of Tennessee<br>David Greene | Comments on methods and issues of interest |
| University of California, Davis<br>Joan Ogden, Michael Nicholas | Provide station costs, generate cluster roll-out scenarios, fuel accessibility analysis |
| Ford<br>Mike Tamor | Travel pattern analysis; daily distance distribution |
| Argonne National Laboratory<br>Amgad Elgowainy | Execute the H2A model and provide delivered H2 costs for various station sizes and pressures |
| National Renewable Energy Laboratory<br>Marc Melaina, Brian Bush, Yongling Sun, Jennifer Melius | Generate hydrogen station roll-out scenarios at various spatial levels |
| US Department of Transportation<br>Danielle Gray, Rick Goeltz (ornl), Tim Reuscher (contr) | Provide and explain household travel survey data |

# Future work will focus on model upgrade, uncertainty, and public-private cost share mechanisms

- Develop an optimization algorithm that finds station placing and sizing strategy to minimize system cost.
- Uncertainties, especially of demand and station cost
- Integrate with consumer choice model and analyze the interplay between infrastructure and vehicle penetration by representing investor patience, risk, and hydrogen pricing.
- Business viability for connector stations
- More analysis of public-private cost share mechanisms

# Summary

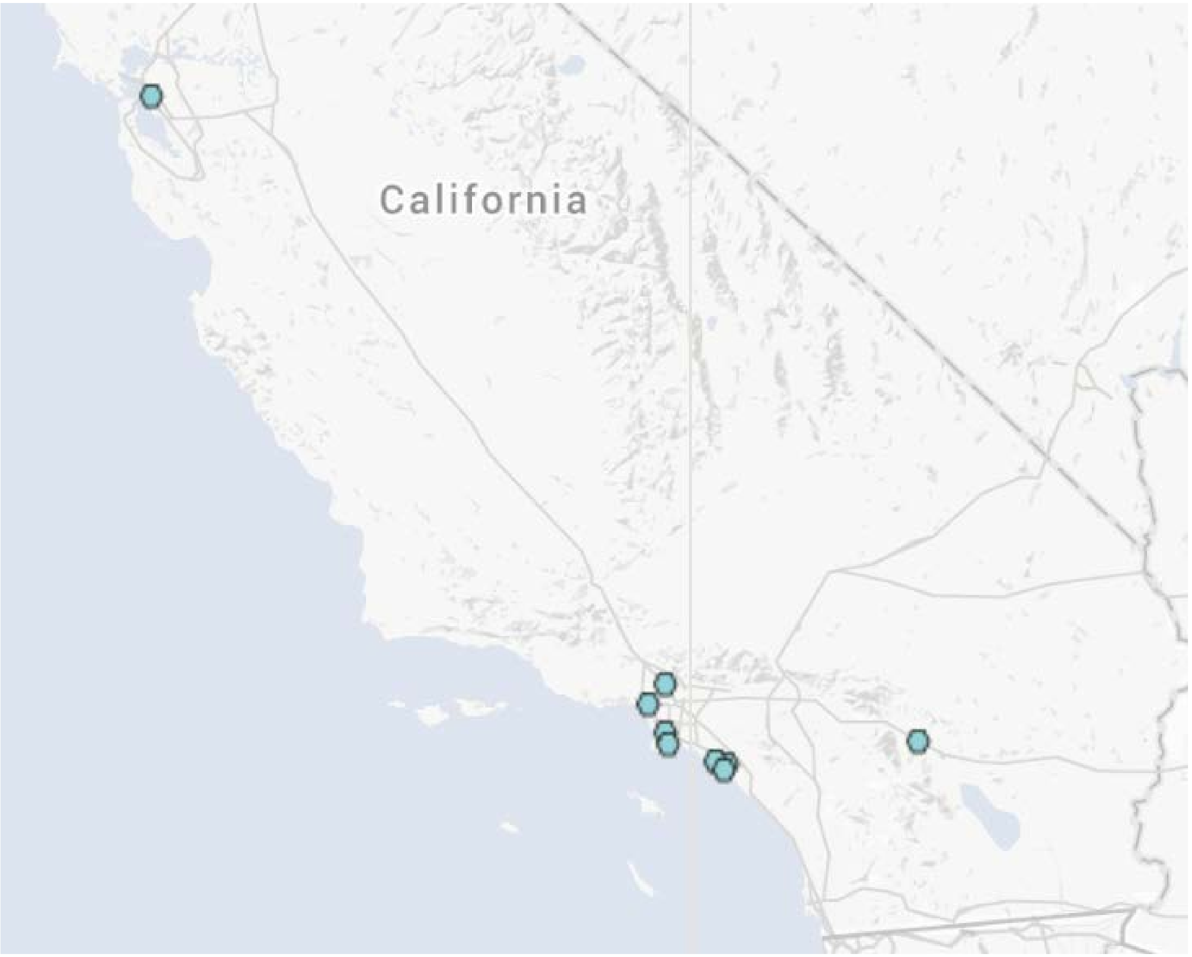
- The project aims at analyze profitability, risk and public-private partnership in hydrogen station deployment.
- Toward this goal, we developed HySEB to analyze business viability and risk of home stations under cluster strategy, with some unique features:
  - Optimal roll-out decisions (expected); minimize sum of infrastructure cost and fuel accessibility cost
  - Travel pattern heterogeneity (daily variation and driver mix)
  - "Term-limited buydown + next-N-year NPV" allows public-private cost share analysis
- Preliminary results suggest the importance of station economy of scale and travel patterns.
- Future work will focus on model upgrade, uncertainty, and public-private cost share mechanisms.

# THANK YOU

# Acronyms

| | |
|---|---|
| ALC | Average Long Commute |
| AOP | Annual Operating Plan |
| ASC | Average Short Commute |
| FA | Fuel availability |
| FCV | Fuel cell vehicle |
| FLC | Frequent Long Commute |
| FPITT | Fuel Pathway Integration Tech Team |
| FSC | Frequent Short commute |
| H2A | Hydrogen Analysis |
| HySEB | Hydrogen Station Economics and Business |
| MA3T | Market Acceptance of Advanced Automotive Technologies |
| MLC | Modest Long Commute |
| MSC | Modest Short Commute |
| MYPP | Multi-year Program Plan |
| NHTS | National Household Travel Survey |
| NPV | Net present value |
| O&M | Operation and Maintenance |
| OP | Optimal pressure |
| ZEV | Zero-emission vehicle |

# A total of 9 hydrogen stations exist in California, most in SCA




Source: afdc.energy.gov, accessed on April 2, 2014



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# Driving pattern heterogeneity is found to be significant, which affects the business viability and risk of hydrogen stations.

- NHTS 2009 Filtering criteria: State=CA, vehicle age<5, household per-driver vehicle >1, detached home, full-time worker (N=2512)

- NHTS 2009 is used to obtain California driving pattern with the validated ORNL Gamma method. 6 sampled drivers were selected from the 2512 drivers to represent a wide range of driving intensity and pattern. Their shares are calibrated to the average driving intensity of California drivers.

| | Annual distance driven (miles) | Distance to work (miles) |
|---|---|---|
| Mean | 13,739 | 14 |
| Median | 12,501 | 11 |
| Mode | 15,000 | 5 |
| St. Deviation | 7,031 | 11 |
| Std/Mean | 0.51 | 0.75 |
| Count | 2,512 | 2,512 |