Analysis of Optimal On-Board Storage Pressure for Hydrogen Fuel Cell Vehicles

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Timeline

- Start: Oct 1, 2012
- End: Sep 30, 2013
- 70% complete

Barriers & Targets

- Barriers of Storage
  - B. System Cost
  - F. Codes and Standards
  - K. System Life-Cycle Assessments
- Barriers of Market Transformation
  - B. High hydrogen fuel infrastructure capital costs for PEM fuel cell applications

Budget

- Total funding: $80k
  - DOE share: 100%
- FY13: $80k

Partners

- Argonne National Laboratory
  - Station cost estimation
- Industry
  - Data and assumptions

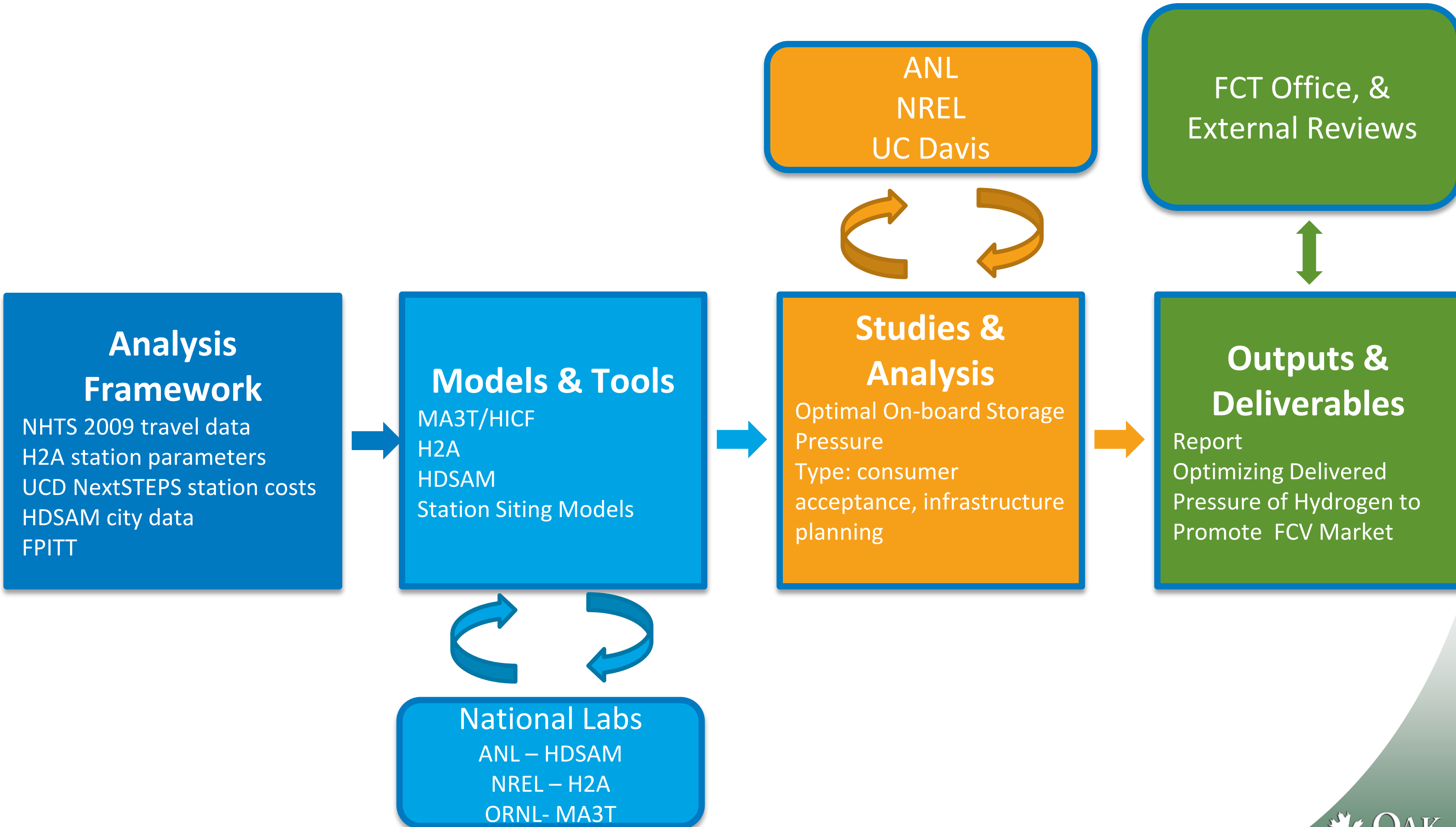
Analytical framework needed for complicated relationships between on-board H2 pressure and range, costs, consumer acceptance, and industry risks

- Lower-pressure H2 is cheaper, but reduces vehicle range.
- Reduced range can be compensated with more stations, but then lower station utilization will increase H2 costs.
- Low-pressure stations require less capital. Are many low-pressure stations better than a few high-pressure ones?
- What is the optimal strategy for station deployment, timing, size, location, delivery pressure?
- What are the implications for consumer acceptance, industry risks, R&D and deployment policies?

Objective—to develop a method of optimizing delivered H2 pressure to maximize market acceptance of FCVs

- Key issues addressed
  - Why analyze and optimize pressure? How significant is negative impact of a wrong/sub-optimal pressure?
  - How to logically model the relationships among the many factors related to delivered pressure?
  - What are typical patterns of interactions between these factors?
  - How sensitive is the optimal pressure to these factors?
  - Specifically, for the CaFCP 2017 deployment plan, between 350bar and 700bar, which one?

Analysis of Optimal On-Board Storage Pressure for Hydrogen Fuel Cell Vehicles



Optimal Delivered Pressure reflects tradeoff between consumer refueling convenience and infrastructure costs

- Higher pressure increases hydrogen storage and driving range between hydrogen refills, but increases the cost of delivery infrastructure, and the cost of hydrogen.
- Assume high pressure-capable tanks with FCVs
- Assume region-wide (i.e., Los Angeles) availability rather than cluster strategy.

Method: Marginal value of increased range due to increased pressure = marginal H2 delivered cost due to increased pressure.

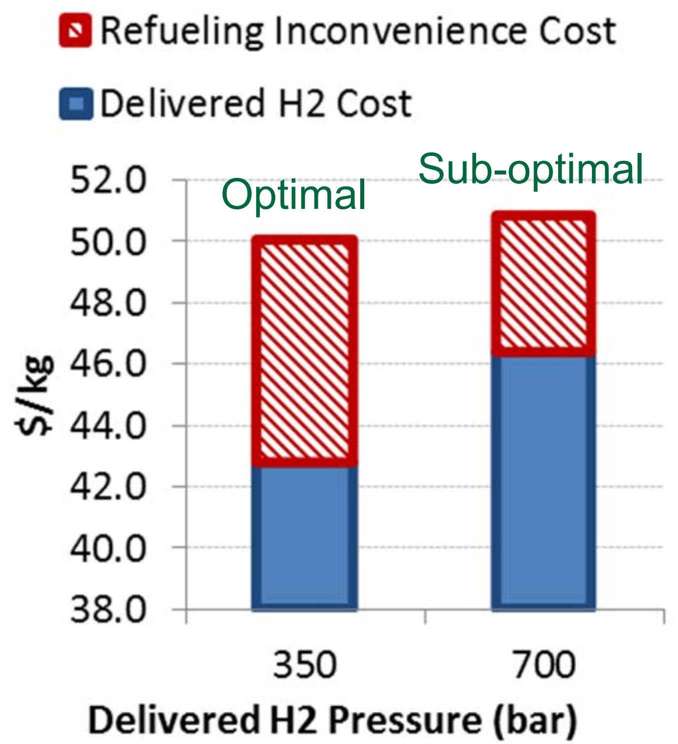
- **Equivalent to minimization of combined costs of refueling inconvenience and station**
- **Marginal value of increased range**
  - Measured by reduction of net present value of total refueling time over 5 years; also called reduction of refueling inconvenience cost
  - Refueling time includes access time to station (depends on availability) and refueling time at station
- **Marginal cost of increased pressure**
  - Increased cost of pumps, tanks
  - Increased cost of energy
  - Approximated by H2A delivered costs at 350 & 700 bar (500-bar is under consideration)

Case study assumptions are mostly based on FPITT consensus, national lab models and published data

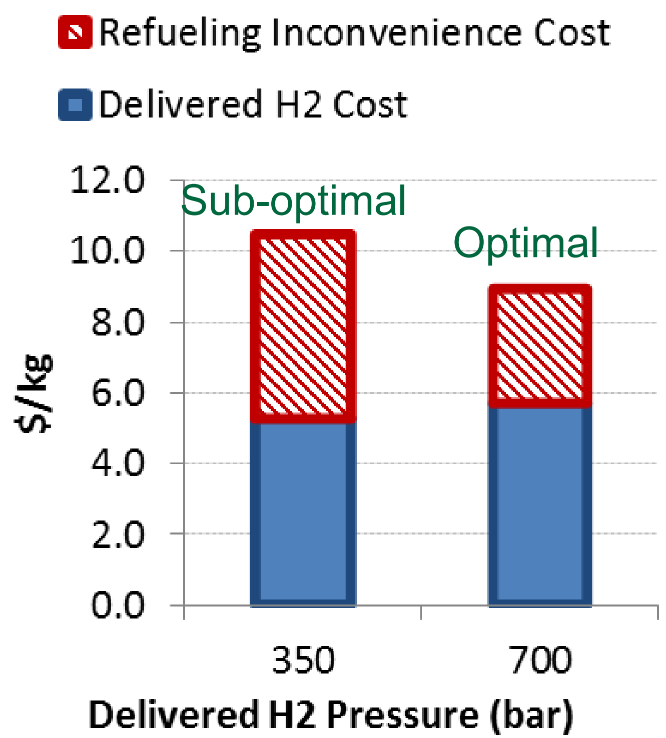
- Vehicle
  - Midsize car, 60 mpgge (low 48, high 68, for sensitivity analysis), tank refill point 25%, 5-yr life for analysis
- Driver
  - 12.8k mi/yr (10k/15k), dispenser linger time 2.4 min
- Infrastructure
  - H2 fill time 1.6 kg/min, value of time $50/hr ($25/$75)
  - $4.50/kg of delivered H2 cost at 700bar and $4.00 at 350bar
- Regional context
  - Southern California: 6k gas stations, 8.6m vehicles on road

Sub-optimal pressure leads to higher total cost and bigger barrier for market acceptance.

- **Higher total cost also means more subsidy difficulty.**

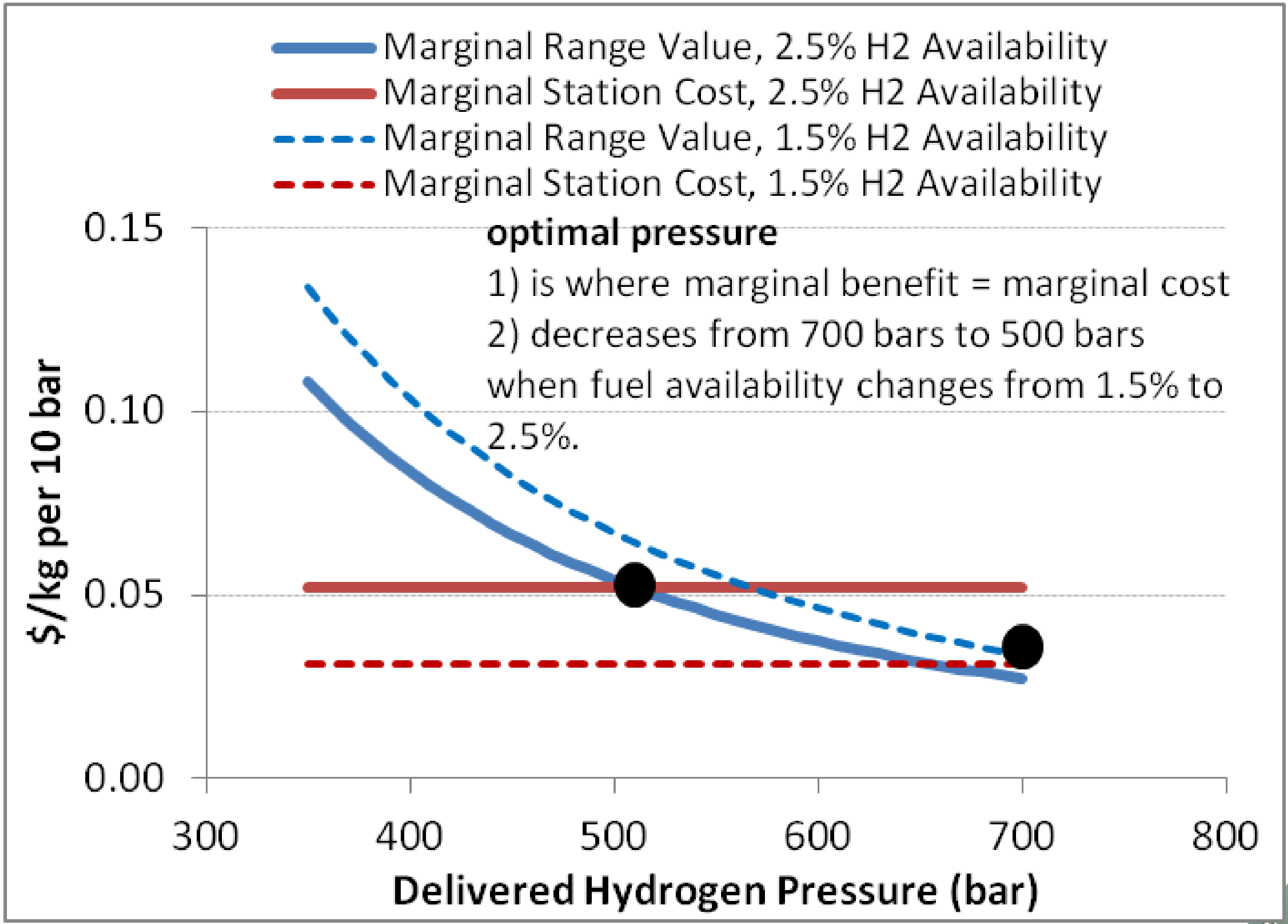


assume 60 stations, 500 kg/day, 5000 FCVs; resulting in 10% station utilization



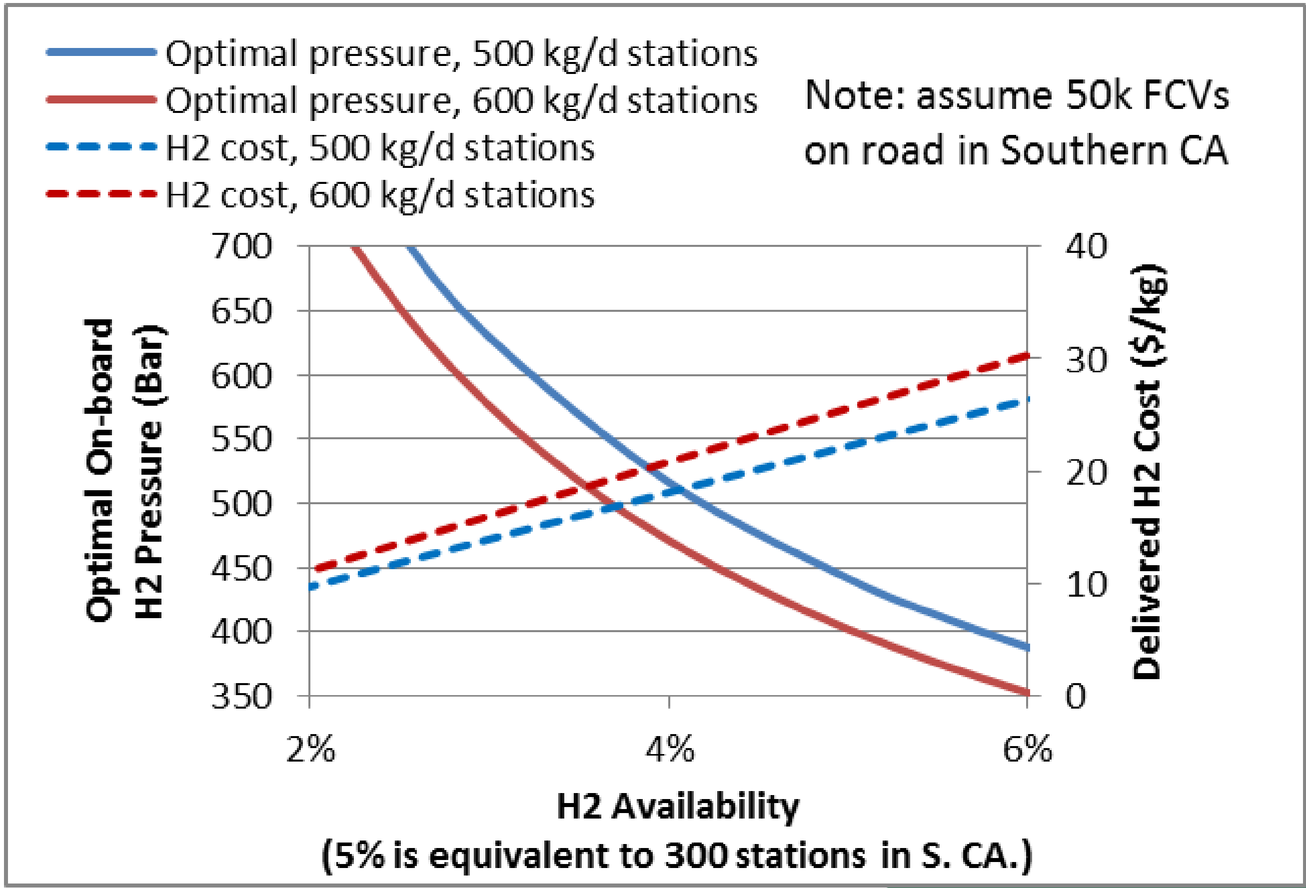
assume 145 stations, 500 kg/day, 100k FCVs; resulting in 81% station utilization

Lower hydrogen availability calls for higher pressure



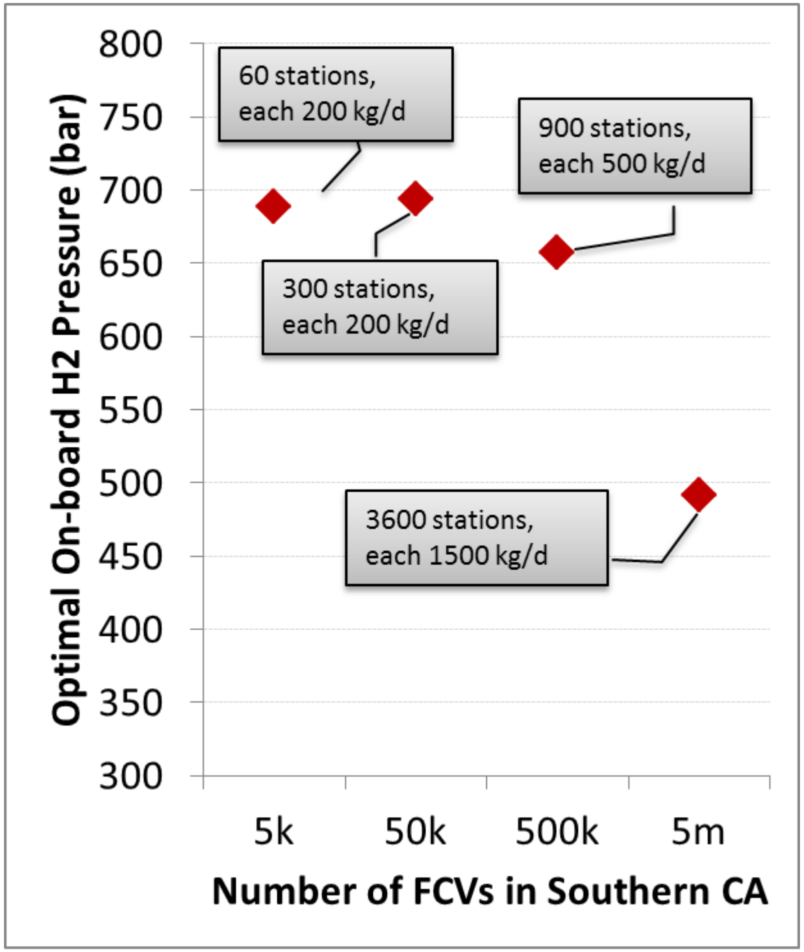
Optimal pressure and H2 cost can change with station size and number

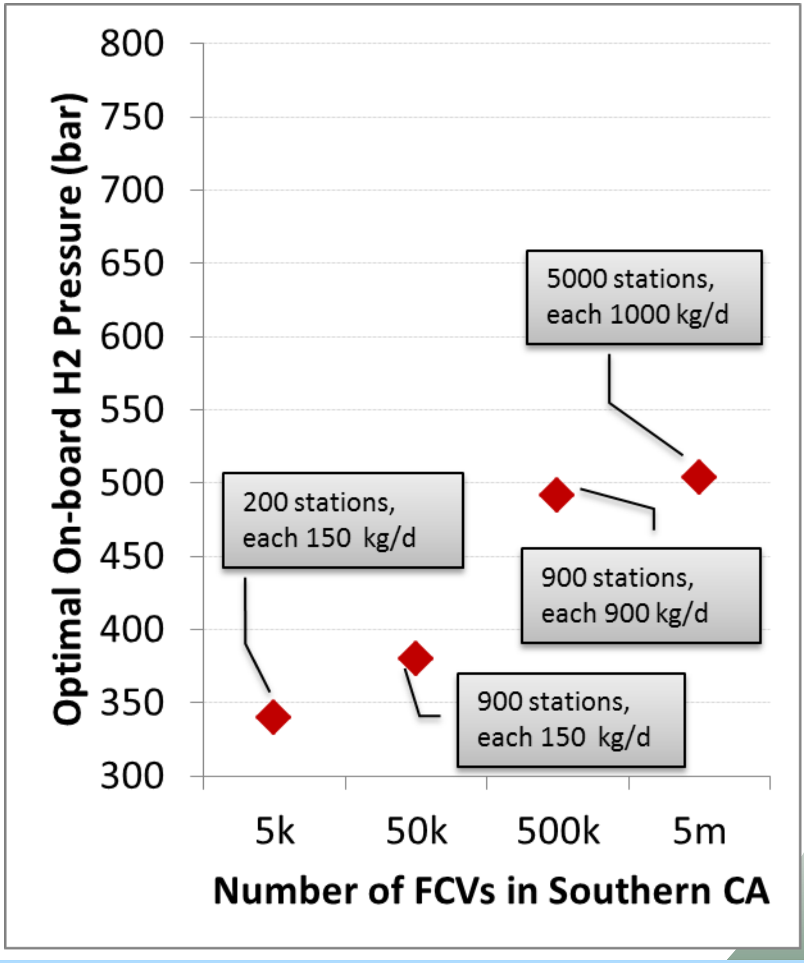
- **For a given station size, more stations (higher H2 availability) allow lower pressure, but result in higher H2 cost due to lower station utilization**
- **For a given station number (same H2 availability), smaller stations call for higher pressure, as the resulting higher utilization makes pressure upgrade cheaper and also lowers H2 cost.**



H2 pressure may evolve with market, but the trend is unclear and depends on other evolving factors.

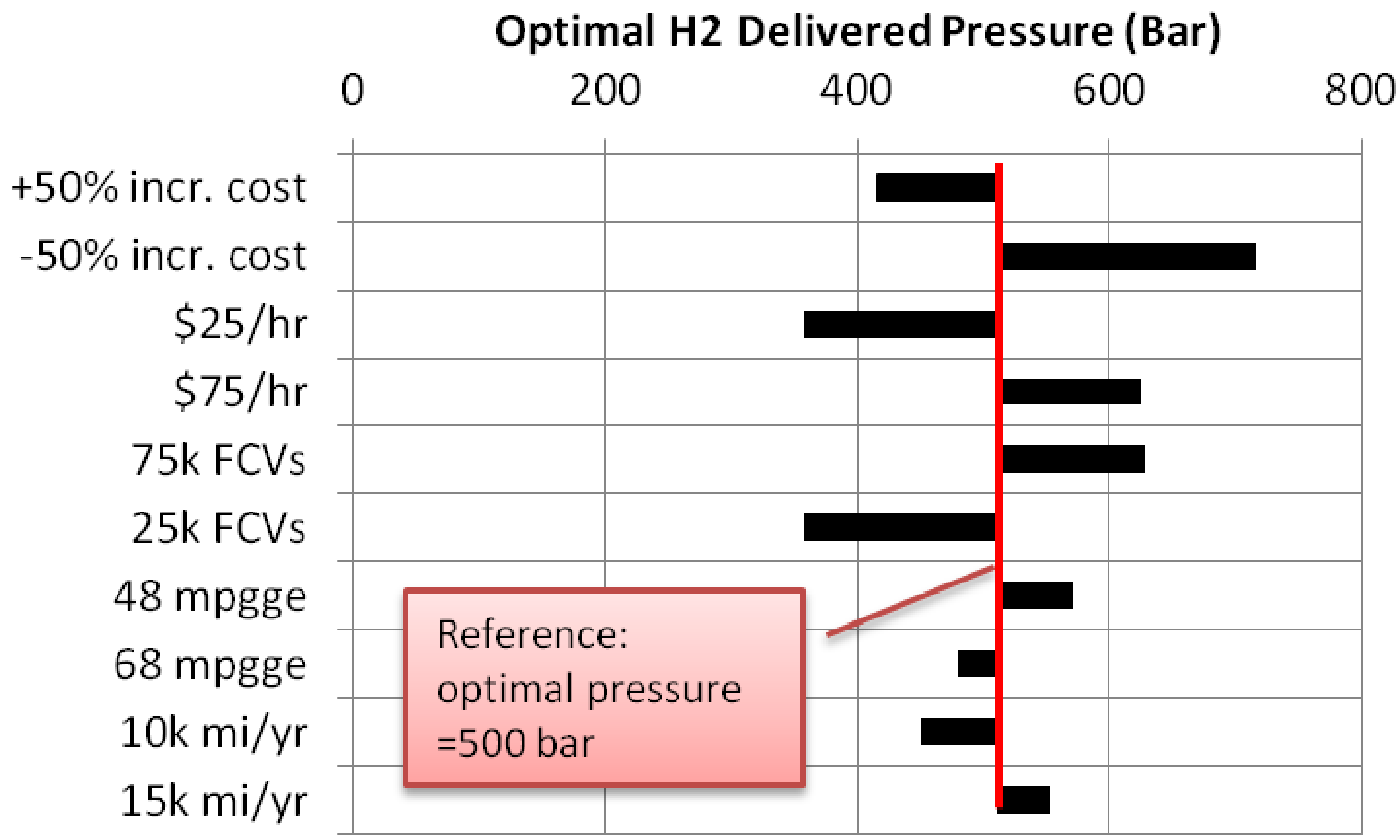
- Including station size, station number, value of time, station cost





So what is the optimal adaptive infrastructure roll-out strategy?

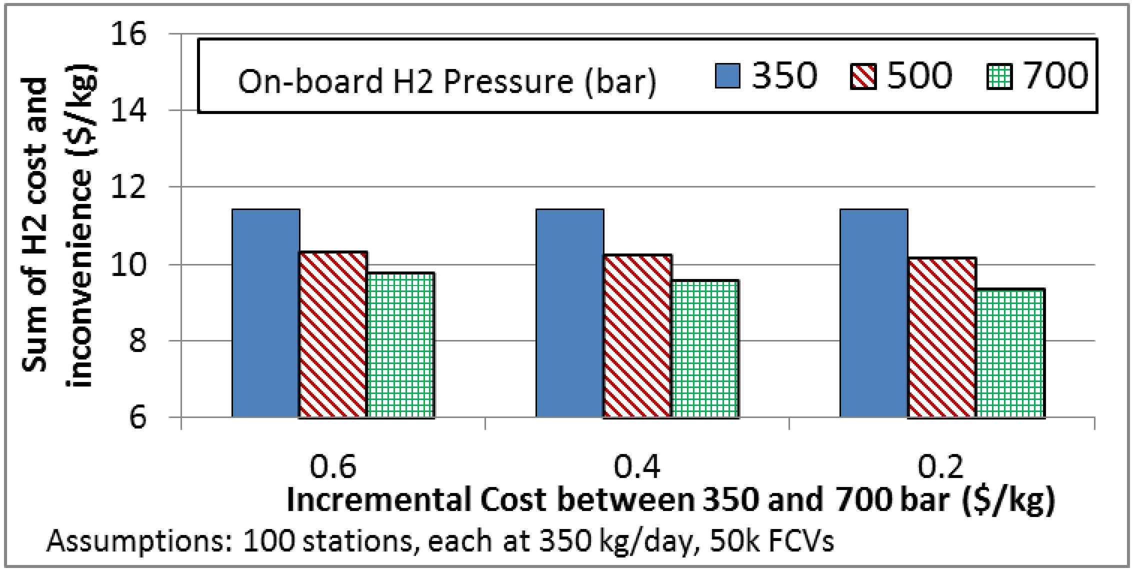
Optimal pressure is more sensitive to value of time, incremental cost, and number of FCVs

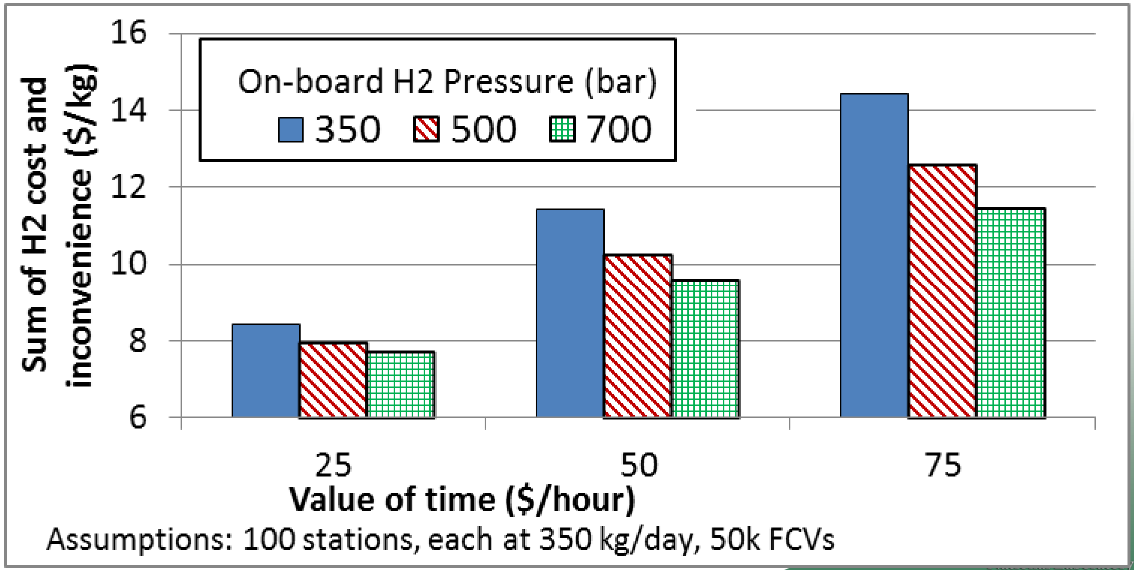


Reference: 4% H2 Availability, 50k FCVs, station size 500 kg/day
60 mpgge, 12.8k mi/yr, time value $50/hr, $0.4/kg incremental cost at full

With 100 stations and 50k FCVs in S. CA, 700 bar offers lower combined cost

- **Even if consumers value time at $25/hr or the incremental cost is as high as $0.6/kg**
- **Caveat—not the cluster strategy as in the CaFCP 2017 plan**





Collaboration with colleagues in the field has made the progress of the project possible.

- **Estimating storage capacity and station costs under different pressures with help from Amgad Elgowainy (ANL) and Joan Ogden (UC Davis)**
- **Working on parameter assumptions with the Fuel Pathways Integration Technical Team (FPITT), which includes representatives from Air Products, ExxonMobil, Phillips 66, Shell, Chevron, NREL, and DOE**

We propose a study to estimate the optimal delivered pressure that maximizes station profitability, FCV acceptance and minimize investment risks.

- Limitation of this study
  - No representation of demand response to H2 cost and pressure
  - Limited analysis on uncertainty
  - No consideration of cluster roll-out strategy
- Proposed for FY14
  - Refine the optimization model based on reviewer comments
  - Define and measure station profitability and investment risk
  - Model cluster roll-out strategies
  - Integrate with consumer choice models (e.g. MA3T)
  - Estimate required subsidy and analyze station business models
  - Conduct comprehensive uncertainty analysis

Summary

- The goal of the project is a better understanding of optimal delivered H2 pressure.
- Toward this goal, we made FY13 progress on question definition, method development, parameter assumptions, case studies, and sensitivity analysis.
- Typical patterns of factor interactions are identified.
- Results strongly suggest 700bar (as opposed to 350) for the 2017 CaFCP deployment scenario in California.

THANK YOU