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The Business Case for Hydrogen-powered Passenger Cars: Competition and solving the Infrastructure Puzzle

Subproject 2: The Business Case for Hydrogen Fueling Stations: The 101th-of-a-kind case

Project ID # SA052

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Overview

Timeline of Subproject

Start date: 01 March 2016

End date: Ongoing project

Budget

FY15 DOE Funds: $70K

FY16 DOE Funds: $72k

- Including partners

Barriers

1. Uncertain future market behavior (viz., fuel costs, # of H_2-powered cars sold in target markets)
2. Lack of existing market experience for H_2-powered passenger vehicles – and the as-yet unanswered question of market acceptability for H_2-fueled passenger vehicles
3. Inconsistent data, assumptions and guidelines in existing literature, for both H_2 filling station construction and operating costs
4. Unanticipated technological developments

Partners/Collaborators

Funded partners:

Univ. of Chicago faculty: Energy Policy Institute at Chicago [EPIC]*

Univ. of Chicago Senior Research Associate: Carlo Graziani

Univ. of Chicago student: Chuan Yin

Argonne National Laboratory

Collaborator for this subproject:

NREL

* A joint program of the Booth School of Business, the Harris School of Public Policy and the Department of Economics, all at the University of Chicago

Relevance of this subproject

- A key question for the success of H_2-fueled vehicles is whether a plausible business case can be make for building out the H_2 filling station network, once the initial subsidies phase out
  - This will be needed to have VCs consider investing in this market
  - This is a key economic milestone for the DOE Hydrogen & Fuel Cells Program
- A complete business case analysis requires
  - Consideration of the various schemes for distributing H_2
  - Analysis of the various cost components for building out H_2 filling stations
    - Analysis of the opportunities for "learning"
    - Analysis of the cost savings accruing from operating H_2 filling station networks at scale
    - Probabilistic analysis of risk
  - **This document provides a progress report on our 1st two months of study of this subproject**

Approach: 1 – Steps and Status

1. Establish
Build our team; identify data sets; and and our approach
(2015, December)

- Discuss approach with ANL and DOE-FCTO
- Identify and hire collaborating students
- Hire collaborating research associate (part-time)

2. Prototype
Gather cost data sets for construction and operation
(2016, March-April)

- Discuss with ANL, NREL, H_2 providers
- Collect initial data set for costs for building out 101st H_2 filling station and its operation

3. Prototype
Develop first-cut 101st H2 station deployment strategies
(2016, April)

- Develop analysis approaches for identifying and evaluating “learning opportunities” (e.g., “learn by doing”) for cost reductions
- Identify cost reduction opportunities by operating at scale

3. Refine
Vet data, carry out analyses, consider risk issues
(2016, May-September)

- Execute and validate data and analyses with stakeholders, including commercial vendors
- Results framed as a business analysis for VC community
- Sensitivity & uncertainty (risk) analyses

Approach: 2 – Program Interconnections and Deliverables

Analysis Framework

- H2A design parameters
- HDSAM design parameters
- OEM capital & O&M costs
- H2FAST input parameters
- Stakeholder experience/data
- 3rd party H2 vendor analyses

Models & Tools

- H2A
- H2FAST
- HDSAM/HRSAM
- UChicago business analysis tools

National Labs

ANL – HDSAM/HRSAM

NREL/SNL – H2FIRST

Stakeholder Analyses

- Station component manufacturers & operators
- Air Liquide
- Air Products

3rd Party Studies & Analyses

- NREL and ANL H2 station analyses

Stakeholders, FCTO & External Reviews

Outputs & Deliverables

- Independent assessment of costs and their uncertainties
- Business case statement for VC community

Accomplishments and Progress: Background

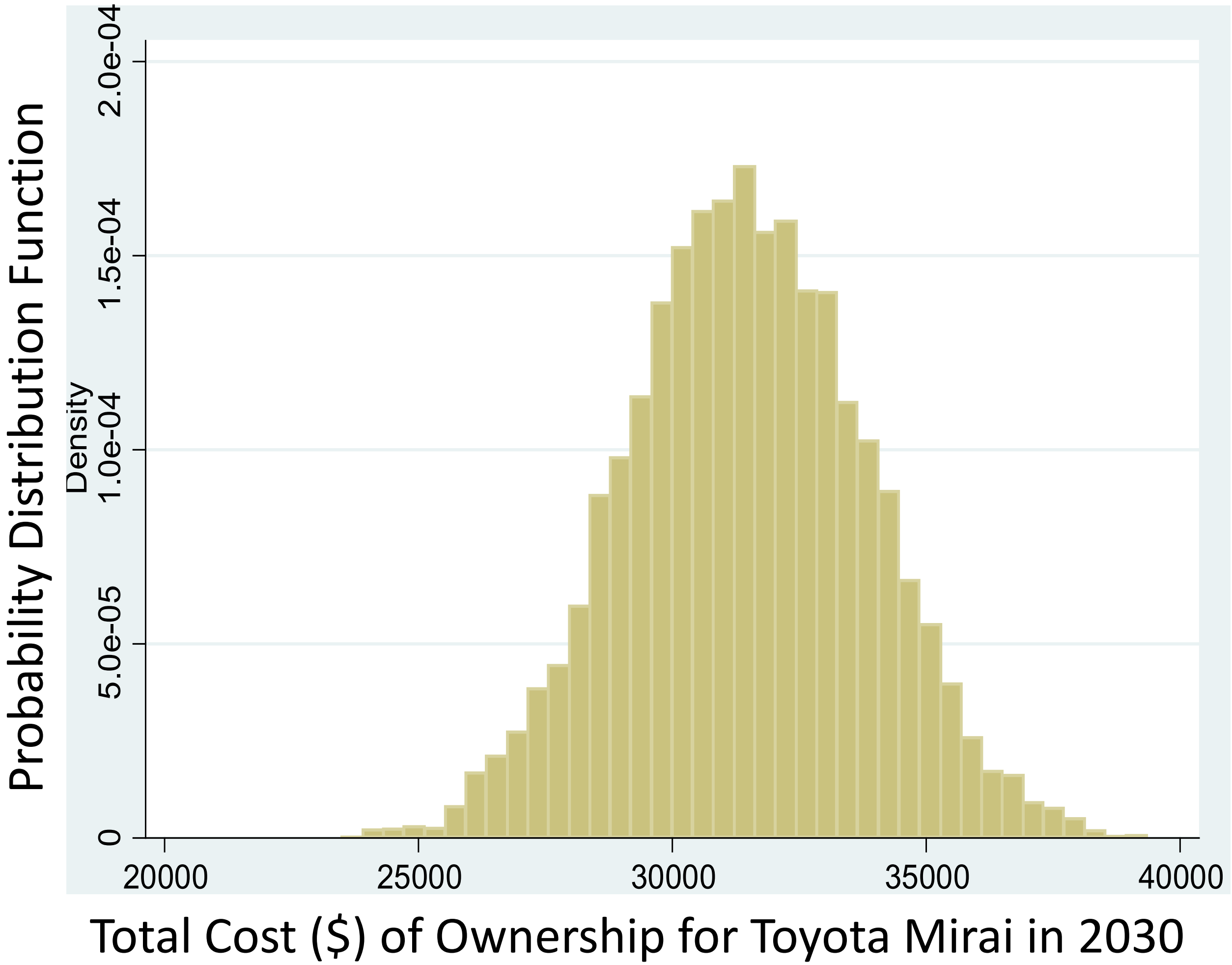
- Our overall project aims to establish the business case for investing in the HFCV market place for the VC community.
  - *First stage: Examine the competitive outlook for HFCVs, based on existing data for fossil-fueled passenger vehicles, hybrids, BEVs and HFCVs*
    - *Focus on extant data* – including provenance and uncertainties
    - *Adopted a "learn-by-doing" paradigm* for estimating future cost reductions in the various competing car technologies
    - *Used a probabilistic risk framework*, based on estimated uncertainties of the various cost component of the competing vehicles, in order to develop uncertainties for our vehicle cost predictions.
    - The next 3 slides provide examples of our results from this study.
  - *Second stage: Focus on ROI for fueling infrastructure for HFCVs; this is the current study (started 1 March 2016), and is described in detail in subsequent slides.*
  - *Third stage: Monitor the H_2 vehicle market (principally in California) in order to probe whether we can confirm (or contradict) our various assumptions of "learn by doing" and "cost reductions at scale"*

Accomplishments and Progress:
Summary of results of our stage 1 study

- The essence of our competitive market analysis is illustrated by the two figures following slides.
  - *Figure 1: Probability distribution function (PDF) for estimated Total Cost of Ownership of a Mirai HFCV in 2030, based on our estimated cost component uncertainties and the estimated effects of "learn-by-doing".*
  - *Figure 2: Composite estimated Total Cost of Ownership for the competing vehicle technologies, together with uncertainties (obtained from the computed PDFs), for years 2020 through 2050, assuming no carbon tax or any other market interference by government.*

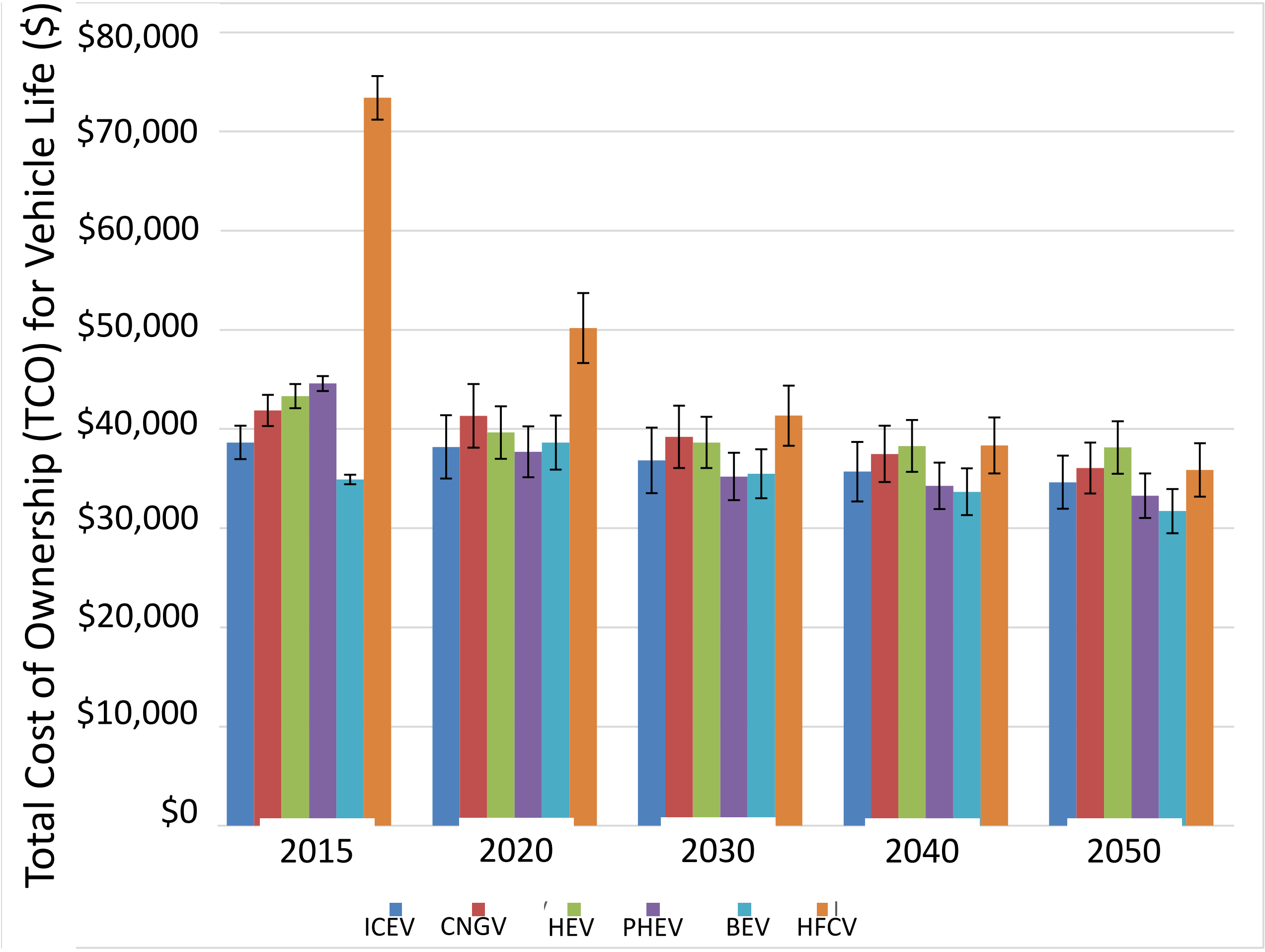
- *Key conclusion*: In the absence of government interventions, HFCVs will not be competitive – as measured by the Total Cost of Ownership – until roughly the 2030s.

Illustrative result for Stage 1: PDFs



Key assumptions:
- No gov't market interventions
- Learn-by-doing
- All data input uncertainties accounted for

Illustrative result for Stage 1:
Total cost of ownership comparisons



We assume:

- No gov't market interventions
- Error bars derived from variance of computed PDFs
- "Learn-by-doing" applied, but differentially, depending on maturity of propulsion technology

ICEV: Toyota Camry SE	PHEV: Chevrolet Hatchback Premier
CNGV: Honda Civic NG Hatchback	BEV: Ford Focus Electric 4-door
HEV: Toyota Camry Hybrid XLE	HFCV: Toyota Mirai

N.b.: All vehicles listed have a range in excess of 300 miles, except for the BEV. The 2016 BEV chosen has a nominal range of 76 miles, which is believed to increase to 100 miles for the 2017 model year.

Accomplishments and Progress: Background of 2nd Stage Study

- The present subproject focuses on H_2 fueling of HFCVs, and in particular entails examination the "101th-of a-kind" business case
  - *We focus on the business opportunities for delivering H_2 to the ultimate H_2-powered vehicle customer, assuming 100 H_2 fueling stations have already been established*
    - Analysis of extant data – including provenance, uncertainties, and technological readiness
      - Data include cost of constructing a H_2 fueling station as well as its operating costs
    - Identification of cost savings opportunities and economic and technical risks
    - Develop probabilistic risk framework
  - Two key assumptions will govern this work
    - First, the number of H_2-fueled vehicles in the target area will be known
    - Second, extant data will confirm (or contradict) our assumptions of "learn by doing" and "cost reductions at scale"
- Subproject started 1 March 2016; we report progress as of late April 2016
  - **We have finished** the 'first-cut' data gathering, including first cuts at identifying saving opportunities

Accomplishments and Progress: Results

BASED ON EARLIER WORK BY NREL AND ANL, OUR INITIAL CONCLUSIONS ARE:

•A 101th station only makes economic sense if the H_2 vehicle market shows evidence of accelerating

- *In that case, an appropriate target delivery rate for the 101st station is 200-300 kg/day.*

•At this fill rate, the *H2FIRST Reference Station Design* study (Pratt et al. 2015) strongly supports going with the "High Use Commuter" station model, based either on a 1-hose gaseous, or a 2-hose liquid H_2 filling station design.

•Since the 101st station will be built after considerable experience with the various alternative station designs has been gained, we assume that the target station designs for this study correspond to station numbers 1 (gaseous, 1-hose, 300 kg/day) and 5 (liquid, 2-hose, 300 kg/day) of Table 9 shown in Pratt et al. (2015).

Station Design Number	Delivery Method	Daily Capacity (kg/day)	Number of Fill Hoses	Back-to-Back Fill Capacity	Fill Configuration
1	Gaseous	300	1	6	Cascade
5	Liquid	300	2	5	Cascade

- Note 1: Station design #5 requires a high-pressure cryo pump. Unfortunately, as Pratt et al. (2015) note, such a pump is not yet commercially available. We are consulting with cryo pump manufacturers to determine likely cryo pump costs, which are currently not known.
- Note 2: Current set-back distance restrictions on liquid H_2 stations lead to site size requirements economically inconsistent with high-capacity urban environments. We plan to investigate relaxation of these restrictions.

Collaborations

- Argonne National Laboratory
  - Prime contractor for UChicago activities and primary collaborator, inside the DOE Hydrogen and Fuel Cells Program
  - Is serving as our main technical support for H_2 fueling technology information
  - We work directly with the key ANL staff (including M. Mintz and M. Wang)
- Related collaboration
  - We have discussed our approach to the H_2 filling station market analysis with key NREL staff (including M. Melaina and M. Penev)

Remaining Challenges and Barriers

- Learning curves for constructing and operating H_2 filling stations are uncertain – however, at the time the 101^{st} station is to be build, sufficient data for developing such learning curves may be in hand in order to allow a more fact-based construction of
- H_2 costs remain highly uncertain
  - Optimal H_2 production technology is not yet established
  - Learning curve (“learn by doing”) is highly uncertain, and will depend on the nature of the H_2 production and distribution path chosen (cost reductions because of scale-up will not matter at this stage since H_2 volumes due to H_2 vehicle market remains relatively small)
- The dominant investment risk depends on the longer-term viability of H_2-fueled vehicles in the context of a concerted marketing effort on the part of battery-powered vehicles (BEVs)
  - The market segment, e.g., the retail price point at which H_2 vehicles are marketed, will be critical, esp. as BEVs selling for MSRP in the mid-$30K range come on market
  - A second significant investment risk is market acceptance: Safety concerns about H_2-fueled vehicles remain, and are likely to be stoked in the marketing competition with BEVs.

Proposed Future Work

- FY 16: Completion of business case analyses
  - Vetting of all input cost data
  - Bayesian analysis of construction and operation costs of two versions of high-capacity H_2 filling stations – one gaseous and one liquid
    - Our analysis will supplement the existing analyses of Pratt et al. (2015), replacing point estimates with probability distributions
- FY 17: Validation of business case analyses
  - Market analyses of roll-out of (a) alternative fuel vehicles (including BEVs and H (b) first-generation H_2 fueling stations during the FY15-17 period
    - Examine early evidence for "learn-by-doing"
    - Examine early evidence for gaining cost reductions from increasing scale of effort
    - Examine market acceptance

Summary Slide: Progress and Accomplishments in current fiscal year

1. **In the 1st two months** (03-04/2016) of our project, **we have completed** a "first cut" data gathering of the various cost components for the construction and operation of H_2 filling stations
2. **We are developing** a "first cut" analysis framework for a Bayesian analysis of the H_2 filling station total construction and operation costs
   1. This will allow replacement of point estimates with distributions
   2. Together with an analysis of the projected costs of H_2 delivered to a given station, this will allow us to compute the ROI as a function of the volume (kg/day) of H_2 sold, together with its uncertainties
   3. We also consider "learn-by-doing" opportunities for cost reduction. Key examples of such opportunities are offered by the build-out of supply chains for assembling H_2 filling station equipment, as well as the experience gained in the various means of producing and delivering

Technical Back-up Slides

Data Sources and References

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- Melaina, M., & Penev, M. 2013, *Hydrogen Station Cost Estimates*, Technical Report NREL/TP-5400-56412
- Quin, N., Brooker, P., & Srinivasan, S. 2014, *Hydrogen Fueling Stations Infrastructur*e (Univ. of Central Florida EVTC Report No. EVTC-RR-02-14)
- Penev, M., Melaina, M., Bush, B., & Zuboy, J. 2015, *Hydrogen Financial Analysis Scenario Tool (H2FAST): Spreadsheet Tool User's Manual* (Draft version 05/08/15).
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- Ramsden, T., Ruth, M., Diakov, V., Laffen, M., & Timbario, T.A. 2013, *Hydrogen Pathways*, Technical Report NREL/TP-6A10-60528.
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Acronyms

ANL	Argonne National Laboratory
EPIC	Energy Policy Institute at Chicago
BEV	Battery-powered Electric Vehicle
FCTO	Fuel Cell Technology Office
H_2	Molecular hydrogen (often written in the automotive industry in the form H2), e.g. hydrogen is a diatomic molecule in its usual gaseous phase
H2A, HDSAM, H2FIRST	FCTO program analysis tools
HFCV	Hydrogen Fuel Cell Vehicle
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturer
O&M (costs)	Operation and Maintenance (costs)
UChicago	The University of Chicago
VC	Venture Capitalist