# XI.1 Worldwide Status of Hydrogen Fuel Cell Vehicle Technology and Prospects for Commercialization

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## Overall Objectives

- Describe the worldwide status of automotive fuel cell technology.
- Estimate the likely costs of automotive fuel cell systems and components.
- Assess current worldwide plans for deployment of hydrogen refueling infrastructure.

## Fiscal Year (FY) 2013 Objectives

- Document the status of automotive fuel cell technology based on discussions with experts at automobile manufacturers, public presentations, and the published literature.
- Estimate the likely costs of automotive fuel cell systems and components in 2015 and 2020 at low (20,000/year) and high (200,000/year) production volumes.
- Describe current plans for deployment of hydrogen refueling infrastructure and expectations for early sales of hydrogen fuel cell vehicles (FCVs).
- Obtain thorough review by original equipment manufacturers (OEMs) of the information they provided. Publish a final report as an ORNL Technical Memorandum summarizing confidential information in such a way that manufacturer-specific data is not identified.

## Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(A) Future Market Behavior

(C) Inconsistent Data, Assumptions and Guidelines

## Contribution to Achievement of DOE Systems Analysis Milestones

This project contributes to achievement of the following DOE milestones from the Systems Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

- Milestone 1.12: Complete an analysis of the hydrogen infrastructure and technical target progress for technology readiness. (4Q, 2015)
- Milestone 1.16: Complete analysis of program performance, cost status, and potential use of fuel cells for a portfolio of commercial applications. (4Q, 2018)
- Milestone 1.17: Complete analysis of program technology performance and cost status, and potential to enable use of fuel cells for a portfolio of commercial applications. (4Q, 2018)
- Milestone1.18: Complete life cycle analysis of vehicle costs for fuel cell electric vehicles compared to other vehicle platforms. (4Q, 2019)
- Milestone 1.19: Complete analysis of the potential for hydrogen, stationary fuel cells, fuel cell vehicles (FCVs), and other fuel cell applications such as material handling equipment including resources, infrastructure and system effects resulting from the growth in hydrogen market shares in various economic sectors. (4Q, 2020)

By documenting the current status of automotive fuel cell technology in terms of performance and cost, this study provides an updated benchmark of progress toward program research and development (R&D) targets that explains progress to date and informs analyses of future market potential.

## FY 2013 Accomplishments

- Completed a written review of the current status of automotive fuel cell technology performance and cost based on published and publicly available sources.

- Obtained input from U.S., Japanese, Korean and German OEMs about status of fuel cell technology.
- Published final report on status and prospects for worldwide automotive fuel cells and deployment of hydrogen refueling infrastructure, after thorough review.

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## INTRODUCTION

At least eight of the world's largest automobile manufacturers have plans to bring FCVs to market sometime between 2013 and 2020. Governments in the Members of the European Union (EU), United States, Japan and Korea have developed plans to deploy hydrogen refueling infrastructure to support the early market introduction of hydrogen FCVs. This study assesses the current status of automotive fuel cell technology and the plans for deploying of refueling infrastructure.

## APPROACH

Interviews with the leading OEMs and with governmental agencies and non-governmental organizations in the United States, Japan, South Korea and Germany were conducted in late summer and fall of 2012. The information obtained was combined with data from the open literature and public meetings, and analyzed with the objective of providing a comprehensive view of the current status of the industry and its future prospects.

## RESULTS

The performance of FCVs with respect to durability, cold start, packaging, acceleration, refueling time and range has progressed to the point where vehicles that could be brought to market in 2015 will satisfy customer expectations. However, cost and the lack of refueling infrastructure remain significant barriers. Costs have been dramatically reduced over the past decade, yet are still about twice what appears to be needed for sustainable market success. While all four countries have plans for the early deployment of hydrogen refueling infrastructure, the roles of government, industry and the public in creating a viable hydrogen refueling infrastructure remain unresolved. The existence of an adequate refueling infrastructure and supporting government policies are likely to be the critical factors that determine when and where hydrogen FCVs are brought to market.

Estimates of the costs of 85-kW automotive fuel cell systems, produced in volumes of 20,000 units per year and 200,000 units per year in model year 2016 are shown in Table 1. The estimates are based on the published literature [1-3] and information provided in discussions with OEMs. By far the largest component of total cost in low volume, near future production will be the fuel cell stack. Hydrogen storage tanks will be the third largest component after the cost of the vehicle glider.

**TABLE 1.** Central Tendency Estimates of FCV Cost at 20K/yr Production Volume Extrapolated to 200K/yr Volume

| Cost in $ | 2016 (20K/yr) | 2016 (200K/yr) |
|---|---|---|
| Fuel cell stack (85 kW) | 24,000 | 15,150 |
| Hydrogen storage (5 kg) | 6,700 | 5,300 |
| Battery (35 kW,2 kWh) | 1,500 | 1,300 |
| Electric Motor/Inverter/Drive (110 kW peak, 60 kW continuous) | 3,600 | 3,150 |
| Gearbox | 400 | 350 |
| **Total Powertrain** | **36,200** | **25,250** |
| Electric HVAC/Regenerative Brakes (incremental) | 800 | 750 |
| Glider | 11,000 | 11,000 |
| **Total FCV cost** | **48,000** | **37,000** |

HVAC – heating, ventilation and air conditioning

High volume (200,000 units/year) cost estimates for 2016 and beyond 2020 are compared in Table 2. If high volumes could be achieved after 2020, fuel cell stack costs would still be in the neighborhood of $13,000 to $14,000, given today's technology. With significant advances in areas such as platinum loadings and membranes, fuel cell stack and balance of plant costs could be halved relative to high volume, 2016 costs (Table 1).

**TABLE 2.** Estimates of FCV Cost at 200K/yr Production Volume for 2016 and 2020+

| Cost in $ | 2016 (200K/yr) | 2020+ (200K/yr) without breakthrough | 2020+ (200K/yr) with technology breakthrough |
|---|---|---|---|
| Fuel cell stack (85 kW) | 15,150 | 13,650 | 7,575 |
| Hydrogen storage (5 kg) | 5,300 | 4,750 | 3,500 |
| Battery (35 kW,2 kWh) | 1,300 | 975 | 975 |
| Electric Motor/Inverter/Drive (110 kW peak, 60kW continuous) | 3,150 | 2,825 | 2,400 |
| Gearbox | 350 | 350 | 350 |
| **Total Powertrain** | **25,250** | **22,550** | **14,800** |
| Electric HVAC/Regenerative Brakes (incremental) | 750 | 650 | 650 |
| Glider (constant weight) | 11,000 | 11,000 | 11,000 |
| **Total FCV cost** | **37,000** | **33,200** | **26,300** |

The advances that are needed to achieve competitive costs for FCVs by 2020 are consistent with reasonably conservative estimates of scale economies, learning by doing and technological progress driven by R&D. Based on data provided by OEMs, it is estimated that a scale elasticity (percent change in cost with a 1% increase in production volume) of approximately -0.2 together with a progress ratio of approximately 0.95 (5% cost reduction for each doubling of production volume) and R&D driven technological progress of 5% to 8% per year would be sufficient to achieve the post 2020 high volume cost estimates (Table 2, "with breakthrough"). Estimates of the three parameters based on information provided by three different OEMs are shown in Figures 1-3.

California, Germany, Japan, South Korea and other countries intending to create markets for FCVs have developed plans for deploying hydrogen refueling infrastructure. At present, the hydrogen stations in operation are few and intended for demonstration purposes but their numbers are increasing. As the study was being completed in early 2013, the internet site H2Stations.org reported 18 stations operating in California, 30 in Germany, 29 in Japan and 12 in South Korea (as of August 2013, 24 stations were in operation in California: http://hydrogen.pnl.gov/cocoon/morf/hydrogen/article/707). In general, both planning and funding is being carried out cooperatively by automotive and energy industries, non-governmental organizations and governments. Coordinating station deployments and vehicle sales will be a major challenge. Every region is facing major uncertainties about how consumers will respond to hydrogen FCVs and limited fuel availability, the costs and availability of vehicles and hydrogen fuel, how the construction and operation of stations will be funded and what other supporting policies may be needed.

Together with the cost of FCVs, availability of hydrogen refueling stations is the OEMs' greatest concern at the present time and will strongly affect their plans for producing FCVs. Public and private statements by OEMs and independent evaluations of FCV technology all indicate that FCVs have met the performance benchmarks necessary for sales to the public to begin in 2015, if not sooner. Durability, energy efficiency, cold start, acceleration, refueling, packaging, and range goals have all been met.

OEMs are now focused on cost reduction and the deployment of an adequate refueling infrastructure. Midsize fuel cell passenger cars introduced in 2015-2017 could sell for $50,000 to $60,000, assuming manufacturers do not attempt to recoup full overhead costs. However, further technological progress will be necessary to reduce fuel cell system costs by another 50%, as is generally believed to be required for a sustainable FCV market. These goals could be achieved by

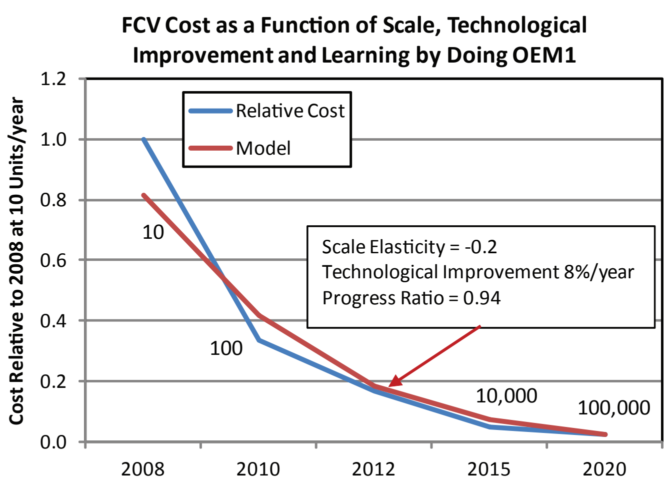


**FIGURE 1.** FCV Cost as a Function of Scale, Technological Improvement and Learning by Doing: OEM1.

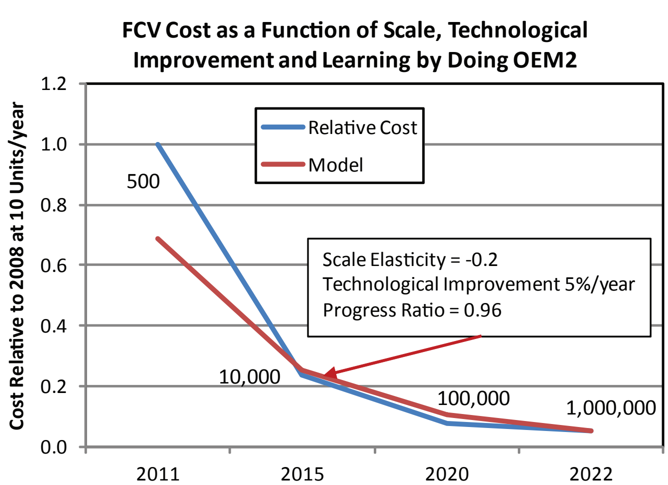


**FIGURE 2.** FCV Cost as a Function of Scale, Technological Improvement and Learning by Doing: OEM2.

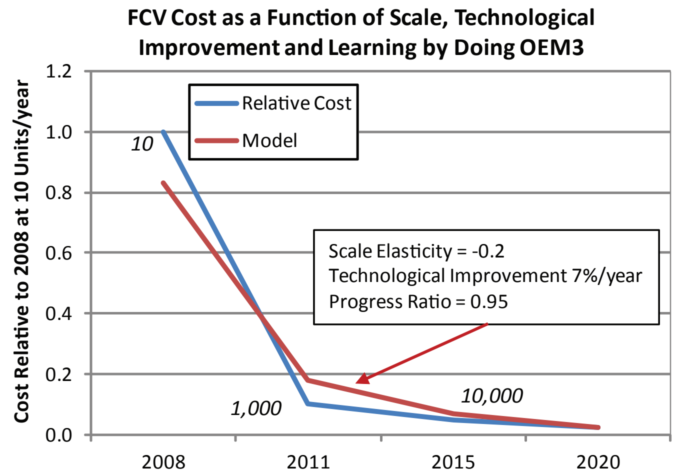


**FIGURE 3.** FCV Cost as a Function of Scale, Technological Improvement and Learning by Doing: OEM3.

2020-2025, assuming plausible scale economies, and rates of learning and technological progress.

## CONCLUSIONS AND FUTURE DIRECTIONS

- There is general agreement that the performance of FCVs with respect to durability, cold start, packaging, acceleration, refueling time and range has progressed to the point where vehicles that could be brought to market in 2015 will satisfy customer expectations.
- Fuel cell system cost and the lack of refueling infrastructure remain significant barriers to market success for FCVs. Costs have been dramatically reduced over the past decade, yet are still about twice what appears to be needed for sustainable market success.
- The U.S. (especially California), Germany, Japan and South Korea all have plans for the early deployment of hydrogen refueling infrastructure, yet the roles of government, industry and the public in creating a viable hydrogen refueling infrastructure remain unresolved.
- The existence of an adequate refueling infrastructure and supporting government policies are likely to be the critical factors that determine when and where hydrogen FCVs are brought to market.

It is recommended that this assessment be carried out bi-annually to provide updated information on progress towards commercialization and market success.

## FY 2013 PUBLICATIONS/PRESENTATIONS

**1.** Greene, D.L. and G. Duleep, 2013. "Status and Prospects of the Global Automotive Fuel Cell Industry and Plans for Deployment of Fuel Cell Vehicles and Hydrogen Refueling Infrastructure", ORNL/TM-2013/222, Oak Ridge National Laboratory, Oak Ridge, Tennessee, June.

**2.** Greene, D.L., C. Liu and S. Park, 2013. "Transition from Petro-Mobility to Electro-Mobility", in D. Stolten and V. Scherer, eds., *Transition to Renewable Energy Systems,* Wiley-VCH, Weinheim, Germany.

**3.** Greene, D.L., "The Transition from Petro-mobility to Electro-mobility", presented at the 3rd International Conference on Energy Process Engineering, Frankfurt, Germany, June 6, 2013.

**4.** Greene, D.L. and G. Duleep, "Worldwide Status of Hydrogen Fuel Cell Vehicle Technology and Prospects for Commercialization", presentation at the DOE Fuel Cell Technologies Annual Merit Review and Peer Evaluation Meeting, Arlington, VA, May 14, 2013.

**5.** Greene, D.L., "Transitions to Alternative Vehicles and Fuels", presentation to the Hydrogen Technical Advisory Committee, Washington, D.C., April 23, 2013.

## REFERENCES

**1.** McKinsey & Co. 2011. A Portfolio of Powertrains for Europe: A Fact-Based Analysis, sponsored in part by National Organisation Wasserstoff, Berlin, available on the internet at http://ec.europa.eu/research/fch/pdf/a_portfolio_of_power_trains_for_europe_a_fact_based__analysis.pdf.

**2.** (NRC) National Research Council. 2013. Transitions to Alternative Vehicles and Fuels, Appendix F, "Vehicles," National Academies Press, Washington, DC.

**3.** James, B.D., J.M. Moton and W.G. Colella. 2013. "Fuel Cell Transportation Cost Analysis," U.S. Department of Energy 2013 Annual Merit Review and Peer Evaluation Meeting for the Hydrogen and Fuel Cell Technologies Program, Arlington, Virginia, May 14.