Early-Stage Market Change and Effects of the Recovery Act Fuel Cell Program

Submitted to:

Lawrence Berkeley National Laboratory

Prepared by:

EnerSys Innovation, LLC

Under contract to:

Strategic Analysis, Inc.

Prepared for:

Office of Energy Efficiency and Renewable Energy, Department of Energy

January 2014

DOE Contract to LBNL: DE-AC02-05CH11231
LBNL Subcontract to Strategic Analysis, Inc.: No. 6995756

Acknowledgements

The U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), initiated this study as part of DOE's efforts to evaluate the impact of the DOE American Recovery and Reinvestment Act (ARRA) program related to fuel cell systems. Strategic Analysis, Inc. was awarded the contract through Lawrence Berkeley National Laboratory (LBNL) that included the evaluation team and authors of this study:

- William D. Ernst, Lead Author, EnerSys Innovation LLC

With co-authors:

- John H Reed, Innovologie, LLC
- Charles Stone, EON Consultants Ltd
- Douglas Wheeler, DJW Technology, LLC

This evaluation team developed the evaluation plan, collected data, conducted interviews with government officials and participants in the fuel cell markets, analyzed the data, and wrote the final report. Brian James, Project Manager, and Toni Marechaux of Strategic Analysis, Inc. also made programmatic and editorial contributions.

Ed Vine, Staff Scientist at LBNL, was the LBNL Project Manager for the evaluation. Jeff Dowd, EERE Office of Strategic Programs (OSP), was the DOE Project Manager for the evaluation. In addition, EERE's Fuel Cell Technologies Office (FCTO) and staff, under the leadership of Office Director Sunita Satyapal, provided assistance in understanding the DOE objectives and the FCTO and program background.

The authors would also like to thank the following reviewers.

Internal Reviewers:

- Yaw Agyeman, LBNL
- Sara Dillich, FCTO, DOE/EERE
- Jeff Dowd, OSP, DOE/EERE
- Sunita Satyapal, FCTO, DOE/EERE
- Ed Vine, LBNL

External reviewers:

- Ken Keating, Private Consultant
- Marianne Mintz, Argonne National Laboratory
- Rosalie Ruegg, TIA Consulting
- Steve Schiller, Schiller Consulting, Inc.
- Nicholas Vanderborgh, Gibbs Energy

Any errors in the report remain the sole responsibility of the authors.

Acronyms and Abbreviations

AC	alternating current
APU	auxiliary power unit
AMR	Annual Merit Review and Peer Evaluation for the DOE Fuel Cell Technologies Office
ARRA	American Recovery and Reinvestment Act
ARRA-FCP	American Recovery and Reinvestment Act Fuel Cell Program
BOP	balance-of-plant
BUP	backup power
BUP FC system	integrated package manufactured by OEM for end user to assure power in grid failure
CDP	composite data product
CERL	Construction Engineering Research Laboratory
CHP	combined heat and power
DC	direct current
DMFC	direct methanol fuel cell
DOE	U.S. Department of Energy
EERE	Office of the Energy Efficiency and Renewable Energy
EESA	Emergency Economic Stabilization Act
EPA	Environmental Protection Agency
EU	end user
FC	fuel cell
FCP	Fuel Cell Program
FCTO	Fuel Cell Technologies Office
FOA	funding opportunity announcement
FTE	full time equivalent
GDL	gas diffusion layer
H_2	hydrogen gas
HT-PEM	high temperature proton exchange membrane
ITA	Industrial Truck Association
ITC	Investment Tax Credit
kW	kilowatt
LBNL	Lawrence Berkeley National Laboratory
LH_2	liquid hydrogen
LPG	liquefied petroleum gas
LT-PEM	low temperature proton exchange membrane
MEA	membrane electrode assembly
MHE	material handling equipment
MHE FC system	integrated package manufactured by OEM for end user to replace MHE battery pack
MHE truck	material handling equipment vehicle
MTF	mean time to failure

NFCRC	National Fuel Cell Research Center
NG	natural gas
NGO	nongovernmental organization
NREL	National Renewable Energy Laboratory
OEM	original equipment manufacturer
OMB	Office of Management and Budget, Executive Office of the President
PEM	proton exchange membrane
PEMFC	proton exchange membrane fuel cell
R&D	research and development
RD&D	research, demonstration, and development
ROI	return on investment
SCV	supply chain vendor
SEC	Securities and Exchange Commission
SI	systems integrator
SOFC	solid oxide fuel cell
UNF	University of Northern Florida

Table of Contents

Tables

Figures

Executive Summary

On April 15, 2009, the U.S. Department of Energy (DOE) announced $41.9 million in funding for 12 fuel cell (FC) projects under the American Recovery and Reinvestment Act (ARRA). This effort, denoted in this document as the American Recovery and Reinvestment Act Fuel Cell Program (ARRA-FCP), was intended to accelerate FC system commercialization and deployment in materials handling equipment (MHE) and backup power (BUP) applications and to build a robust fuel cell manufacturing industry in the United States, with accompanying jobs in fuel cell manufacturing, installation, maintenance, and support service.

The ARRA-FCP directly supported the immediate deployment (installation and field operation) of 1,262 MHE and BUP FC systems. An additional 108 FC systems were in demonstrations for a total of 1,370 systems. Six deployment phase projects were initiated, four in MHE and two in BUP. Four demonstration phase projects were initiated along with two research and development (R&D) phase projects.[1]

This report presents the results of an early-stage market impact evaluation of the ARRA-FCP. The key impacts addressed in this evaluation are:

- Direct and indirect impacts of the program;
- Spillover impacts; and
- Follow-on impacts for future commercial growth of FC systems in MHE and BUP markets.

The evaluation method involved the collection and review of secondary data, in-depth interviews with key program staff, and in-depth interviews with a selection of ARRA-FCP awardees and non-awardees. Thirty-two interviews were completed with fuel cell original equipment manufacturers (OEMs); supply chain vendors (SCVs) that provide components, fuel, or maintenance services; end users (EUs) of FC-powered products; and systems integrators (SIs) that manufacture MHE trucks or provide BUP engineering services.

Using market and logic models, seven key metrics were identified: units sold; product value; incentives for product sales; OEM supplier revenues and cost of products sold; and SI, EU, and community acceptance. These seven metrics were used to identify measures which in turn were used as the basis for the development of interview guides and data collection activities. In addition, three periods of activity were covered in the evaluation: the pre ARRA-FCP period from 2004 to 2008, the ARRA-FCP period in 2009 and 2010, and the post ARRA-FCP period from 2011 to 2012 with some additional data from first quarter of 2013 where available.

The report is organized in three major analysis sections focused on: deployment of MHE systems, deployment of BUP systems, and demonstration and R&D projects. The main focus is the MHE and BUP FC systems deployments with short summaries of results for the demonstration and R&D projects.

Given the small population in this emerging industry, random selection of interviewees was not an option. Quasi-experimental designs using matching or other techniques were also precluded. There were only four FC system OEM awardees producing FC systems for MHE or BUP applications whose products were in the deployment phase. There were potentially three or four other OEMs that were developing similar FC systems whose systems were not yet at or near commercialization. Thus, it was not possible to construct a

[1] The categorization of projects into deployment, demonstration, and R&D was an invention of the authors and does not necessarily reflect the specific use of those terms by the FCTO. Demonstrations are defined as purchases of 10 or fewer units, and deployments are purchases of more than 10 units.

suitable comparison group or to use matching or other comparison techniques. It was possible to compare actual changes to the changes expected on the basis of the logic models that were developed.

The small sample sizes make it especially difficult to report specific comments or company data revealed in interviews, as such statements can be easily linked to the individual interviewee. For this reason, only publicly available information is clearly referenced and the data collected in interviews are presented anonymously.

ES-1.1 Materials Handling Equipment Deployments

In the pre ARRA-FCP period (2004-2008) working with leading FC system OEMs and SIs, first mover EUs were demonstrating the capabilities of FC-powered MHE. Tens of units of what were mostly prototype MHE FC systems were installed and evaluated by four firms at four sites. The MHE FC systems being delivered were an emerging technology and suffered some early reliability and other issues. These early demonstrations helped the OEMs, SIs, and EUs understand the advantages of MHE FC systems, to facilitate the introduction of hydrogen infrastructure, and to value the return on investment (ROI) for his technology. The lessons learned during this period helped to pave the way for the purchases that occurred during the ARRA-FCP period.

Interviews with awardees and non-awardees identified several key events that increased activity in the MHE FC systems market. These events included the 2008 DOE Funding Opportunity Announcement (FOA) and the subsequent ARRA-FCP awards, the 2005 Investment Tax Credit (ITC) of up to 30 percent or $3000/kilowatt (kW), the 2008 Emergency Economic Stabilization Act (EESA) that continued the ITC incentives, and the further expansion in 2009 of incentives to include cash grants in lieu of tax credits under ARRA Section 1603 and up to $200,000 for fueling Infrastructure (through 2010).[2] State governments offered additional incentives, all of which helped drive adoption of MHE FC systems.

In the ARRA-FCP period (2009-2010), awards were made to four firms that resulted in seven EUs deploying 504 MHE FC systems (Table ES-1).[3] Twelve EUs deployed an additional 673 units without direct ARRA-FCP funding, seven of which were first time EUs, and five of which took advantage of new tax incentives signed into law on February 17, 2009.[4] In 2010, sales of MHE FC systems increased with purchases by existing EUs and through orders from first time EUs. Of the total MHE FC systems deployed in 2009 and 2010, 57 percent did not receive ARRA-FCP funding. This overall acceleration of deployments was attributed in interviews to ARRA-FCP funding, tax incentives, or the combination of the two. A majority of EUs indicated that the availability of tax incentives was critical in their decision to buy MHE FC systems.

In the post ARRA-FCP period 36 EUs, 11 of which were first time EUs, deployed MHE FC systems. In 2011, 1,687 MHE FC systems were ordered, another 1,301 systems were sold in 2012, and 378 were sold as of the first quarter of 2013. The post ARRA-FCP unit sales were 6.7 times the sales made under ARRA-FCP funding. The total sales from 2004 thru the first quarter of 2013 was more than 4,920 units, 4,416 MHE units were sold without ARRA-FCP funding. More than 80 percent (4,543) were sold after 2008. EUs who had received ARRA-FCP awards purchased approximately 600 additional MHE units. From 2005 on, all of

[2] 1603 Program: Payments for Specified Energy Property in Lieu of Tax Credits. Available at time of press at http://www.treasury.gov/initiatives/recovery/Pages/1603.aspx

[3] Fourteen of these systems were removed in the first quarter of 2012.

[4] E. Delmont, J. Gangi, and S. Curtin, “The Business Case for Fuel Cells 2011”, Fuel Cells 2000, p. 4. Some of these purchases may have leased units through a capital firm and the capital firm likely received the tax incentive.

these units were eligible for the investment tax credit, and from 2009 on, all of these units were eligible for an expanded tax credit and the ARRA Section 1603 grants, if the application met the requirements.

Table ES-1 Total Sales of MHE and BUP FC Systems in the Pre, During, and Post ARRA-FCP periods

Time Period	MHE Sold/Leased	BUP Sold/Leased	Total
Pre ARRA-FCP	377	572	949
During ARRA-FCP (ARRA-FCP Units)	504	520	1,024
During ARRA-FCP (Non ARRA-FCP Units)	673	1,596	2,269
Post ARRA-FCP (ARRA-FCP Units)		214	214
Post ARRA-FCP through First Quarter, 2013	3,366	3,067	6,433
Grand Total	4,920	5,969	10,889

Note: BUP FC systems varied in power rating from 2 kW to 200 kW

In 2011, the MHE FC systems sold represented approximately 1.8 percent of the total MHE trucks—powered by all sources—sold in the United States. Also in 2011, sales, replications, and the number of first time purchasers peaked. It should be noted that while ARRA-FCP funding ended in 2010, the tax and grant incentives remained.

The key indicators of continuing market penetration, the number of firms making first purchases and the total number of units sold annually declined in 2012. Based on orders in the first quarter of 2013, it is unclear if the decline in 2012 will continue in 2013.

Figure ES-1 displays the overall timing of MHE unit sales and government funding incentives including the ITC, EESA, and ARRA-FCP for FC related commercialization activity.

ES-1.2 Backup Power Deployments

In the pre ARRA-FCP period, there were several OEMs running demonstration programs of BUP FC systems for cell tower power backup. By the start of the ARRA-FCP projects, ReliOn had sold more BUP FC systems than any other OEM in North America.

In the North American market, EUs appeared to be more comfortable with direct hydrogen BUP FC systems given the benefits of immediate start up, reduced maintenance (no reformer), simpler balance-of-plant (BOP) and total system onsite zero emissions. ReliOn and Altergy were the two OEMs in North America best positioned to deliver reliable direct hydrogen products to this market.

While only disparate data are available, 520 BUP FC systems sales can be partially attributed to ARRA-FCP funding during the ARRA-FCP period. These assumptions, made with limited confidence, also estimate an additional 214 ARRA-FCP funded BUP sales in the post ARRA-FCP period, as show in Table ES-1. More than double (1,596) the total ARRA-FCP supported sales (734) was sold during the ARRA-FCP period to existing and new EUs that did not have access to ARRA-FCP funding (Table ES-1). More than 3,000 BUP units were sold without ARRA-FCP funding in the post ARRA-FCP period.

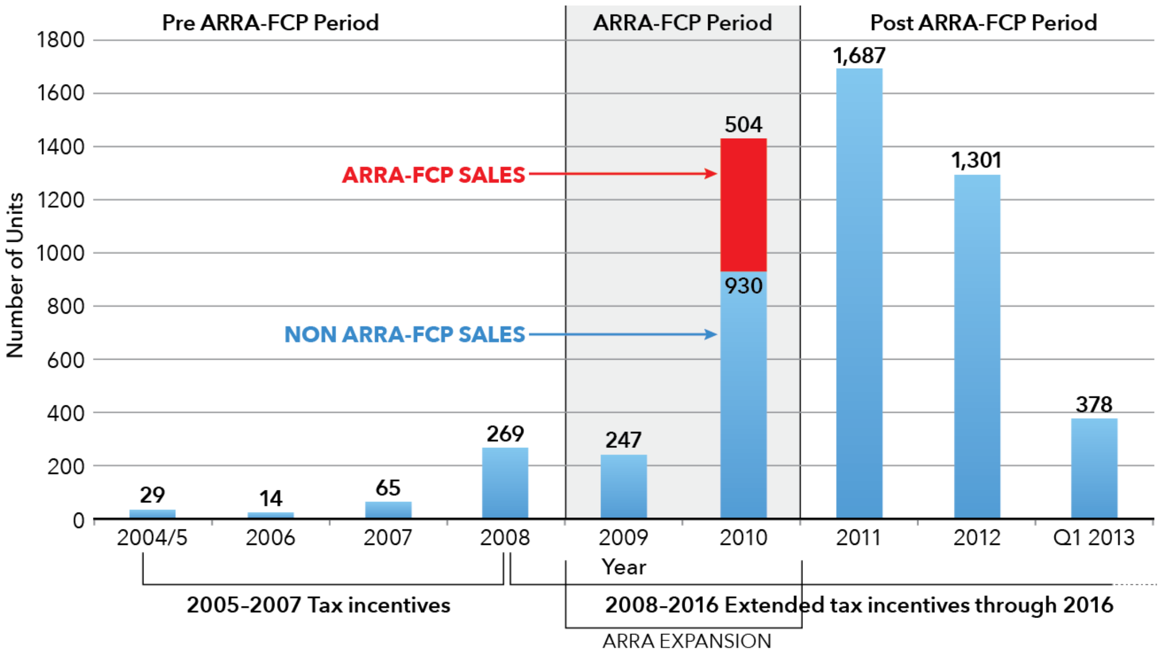


Figure ES-1 Incentives and the Timing of MHE Sales 2004 through First Quarter, 2013

Figure ES-2 displays the overall timing of BUP unit sales and government funding incentives including the ITC, EESA, and ARRA-FCP for FC related commercialization activity. This data were generated from Annual Merit Review and Peer Evaluation (AMR) reports.[5] Thetotal ARRA-FCP units in operation has been reported as 819 units rather than the 734 (520 plus 214) units but may have included retrofits and replacements.[6]

ES-1.3 Market Effects

MHE EUs and SIs reported that MHE FC systems provided increased operational efficiency and warehouse space, and reduced energy consumption with sustainability benefits. BUP EUs and SIs reported that BUP FC systems provided increased reliability, reduced maintenance, reduced fuel costs, and increased sustainability and instant power-on benefits relative to diesel generators.

There was agreement by all EUs interviewed that the funding and grants for the purchase of FC systems and hydrogen infrastructure was a strong contributor to their decision to purchase FC systems. As previously observed, funding took four forms: ARRA-FCP awards, tax incentives, ARRA 1603 Grants, and state and local funding sources. In locations where Class 1 MHE trucks operate 24/7, evidence from the National Renewable Energy Laboratory (NREL) and at least one awardee indicate that MHE FC systems might have been priced competitively with battery systems at the outset of ARRA-FCP funding. However, this was not true for sites that operated less frequently with one shift operation and fewer MHE units. Because the timing of the ARRA-FCP and the tax incentives and grants overlapped, it is not possible to

---

[5] The Annual Merit Review and Peer Evaluation (AMR) is an annual project review and peer evaluation. Information is available at time of press at http://www.hydrogen.energy.gov/annual_review.html

[6] J Kurtz et al, "Early Fuel Cell Market Deployments: ARRA and Combined Quarter 1, 2013 Composite Data Products-Deployment", May 09, 2013 J. Kurtz et al available at http://www.nrel.gov/hydrogen/cfm/pdfs/arra_deployment_cdps_q12013_4web.pdf

attribute specific increases in sales to one or the other incentive. However, one or the other or both influenced most sales. FC-powered MHE allowed the operators to perform more lifts per shift through avoidance of battery change outs and recharge time, while the more constant power output of the FC system allowed the MHE operators to maintain lift capability throughout a shift. Operational data from some facilities deploying MHE FC systems indicated that there was up to an 80 percent reduction in labor cost associated with the reduced downtime.

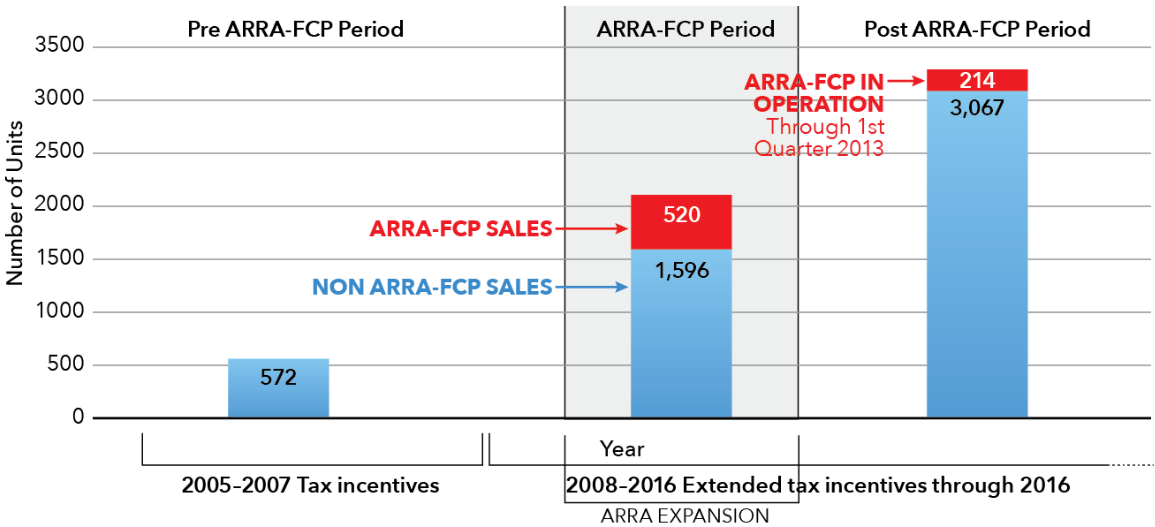


Figure ES-2 Additional ARRA-FCP Units in Operation **(2004 to first quarter of 2013)**

In the pre ARRA-FCP period, fueling infrastructure options were limited and costly. In that period, OEMs realized that fueling infrastructure was critical for the adoption of MHE and BUP FC systems and worked with vendors on fueling infrastructure issues. In the ARRA-FCP period, increased FC system sales encouraged fuel suppliers to appreciate the market potential and to thereby offer improved fueling infrastructure. The ARRA-FCP helped convince fuel suppliers that FC systems for MHE and BUP could be a significant market of the future that deserved their attention. Again, this infrastructure development was a result of the combination of the ARRA-FCP funding, tax incentives, and grants.

There was near unanimous agreement among those who were interviewed that the costs of fueling infrastructure and the cost of hydrogen and its delivery were high and needed to be reduced if MHE and BUP FC systems sales were to continue to grow.

Product value for FC systems included sustainability issues for some EUs, in particular the concern for emissions related to grid electricity generation. One end user reported a 19 percent reduction in kWh usage due to the deployment of FC systems. An effect of the large numbers of deployments, during and post ARRA-FCP, was to verify and solidify an understanding of the various benefits of FC systems in the hands of the EUs.

While thousands of FC systems were deployed during these timeframes, larger new manufacturing facilities by SCVs and OEMs were not constructed. While there were some new investments to reduce costs and increase reliability of FC systems, it is difficult to trace the cause solely to the ARRA-FCP because of the concurrent timing of the tax incentives and state funding activities.

Based on the interview data, deployment of MHE FC systems resulted in very few difficulties in siting hydrogen infrastructure as most of the facilities were in industrial areas where the use of volatile gases was common. The use of hydrogen with BUP FC systems was more complicated because some sites were in residential areas or rooftops in dense urban areas. OEMs offering BUP FC systems developed sophisticated briefings on hydrogen operational safety and used them beneficially with officials and regulators to facilitate siting. However, one engineering contractor for a large telecom did indicate that the siting process for BUP FC systems took almost twice the length of time as diesel generator systems, adding to the cost of siting.

Many ARRA-FCP awardees and non-awardees believed that more effort was needed on the development and implementation of state and federal level codes and standards for FC systems and that hydrogen would accelerate siting applications.

Evaluation data indicated that cost reduction for FC systems and related fueling infrastructure is needed to facilitate growth in sales. Profitability is a continuing struggle for the FC system OEMs. Early reliability issues with some deployments resulted in increased maintenance labor and replacement parts costs. The evaluation team was tasked to assess jobs created or retained as a result of ARRA-FCP. From ARRA-FCP awardee interviews, it was clear that a number of jobs were created and retained, especially for the FC system OEMs. While this study did not attempt a comprehensive count, the limited sample of interviews revealed 43 new direct jobs as a result of ARRA-FCP funding.

The overarching benefits of FC technology are yet to be realized even for industries such as MHE and BUP where more units have been evaluated by EUs than any other application. As in any growing industry, the timing and cost of financing new product development to reduce costs and increase reliability while developing plant capacity to deliver systems in volume is a continuing issue.

ES-1.4 Key Recommendations

The following are key recommendations drawn from a larger set of recommendations in the main report. The justification and data to support these recommendations are outlined in detail in Section 8.

ES-1.4.1 Information Dissemination

- Efforts should be made to collect and disseminate the value propositions of FC systems in achieving energy savings, operational cost savings, reductions in warehouse cost, and overall life cycle cost savings to potential EUs.
- Identify federal, state, and local government incentives and ways of combining them to reduce the first cost of FC MHE and BUP FC systems and fueling infrastructure.

ES-1.4.2 Supply Chain Development

- The DOE should consider increasing research, demonstration, and development (RD&D) support for the development of the supply chain for producing FC system components and reducing manufacturing costs.

- The DOE should consider increasing RD&D that supports cost reduction within the hydrogen fuel supply chain for equipment, hydrogen delivery, and hydrogen dispensing leading to a more cost-effective fuel infrastructure that reduces barriers to end user acceptance.

ES-1.4.3 Government Awards and Incentives

- Market incentives should be continued until technology and manufacturing development enables the product cost to stabilize and FCs are competitive with other technologies.
- State and local governments should be encouraged to continue to provide incentives for the deployment of FC systems and development of hydrogen infrastructure.

ES-1.4.4 Codes and Standards

- The DOE should continue to engage industry players and national codes and standards bodies to encourage more cohesive development and implementation of federal, state, and local codes and standards for installation of FC systems fueled by hydrogen to reduce the cost and increase the timeliness of permitting and installation approval processes.

ES-1.4.5 Sustainability

- The DOE should catalog the energy and non-energy benefits that can accrue to EUs and disseminate this information through tools and publications.

1 Background and Introduction

On April 15, 2009, the U.S. Department of Energy announced a $41.9 million program to fund 12 projects under the American Recovery and Reinvestment Act (ARRA). This program was a specific funding mechanism intended to accelerate fuel cell (FC) system commercialization and deployment and to build a robust fuel cell manufacturing industry in the United States, with accompanying jobs in fuel cell manufacturing, installation, maintenance, and support service. Built directly on the accomplishments of the Fuel Cell Technologies Office (FCTO) in the Office of the Energy Efficiency and Renewable Energy (EERE), and managed as a separate portfolio, it is denoted here as the American Recovery and Reinvestment Act Fuel Cell Program (ARRA-FCP).

This report presents the results of an evaluation of “early market” impacts of the ARRA-FCP. This program was specifically intended to accelerate FC systems deployment and commercialization for material handling equipment (MHE) and backup power (BUP) FC systems. The key issues to be addressed in this evaluation are:

- The direct and indirect impacts of the program;
- The spillover impacts; and
- The follow-on impacts for future commercial growth in MHE and BUP markets.

The key elements of the study were to:

- Assess the extent to which the investments from the ARRA-FCP accelerated FC systems deployment relative to the baseline (without ARRA-FCP funding);
- Determine if the projects produced quantifiable changes in the early stage acceptance of FC systems in the markets under study;
- Assess the extent to which the program facilitated volume purchases in key early market segments and/or resulted in additional subsequent purchases;
- Assess the rate of increase in the availability of low-cost FC systems and the number of companies using FC systems due to the ARRA-FCP relative to baseline;
- Assess any increase in capacity and leveraged activities throughout the supply chain (including numbers and profiles of end users, contractors to end users, systems

Study Terminology

1. **Direct impacts** are changes in such things as FC products sold, employment, and technology level for FC system OEMs, end users, and supply chain vendors who were directly funded awardees or beneficiaries of ARRA-FCP program funding compared to non-awardees.
2. **Indirect impacts** flow from direct impacts and include such things as upstream changes to technologies, the processes of component suppliers, the cost or quality of the FC systems, and changes to codes and standards as a result of trying to site products at prospective facilities.
3. **Spillover i**s the adoption of FC products or technology by either awardees or non-awardees as a result of the program who received no financial assistance from the ARRA-FCP program for their adoption.
4. **Replication** is the purchase of additional FC systems by end users at the original site or for use at other sites (a form of spillover).
5. **Emulation** is the uptake of the technology by other potential end users after seeing the ARRA-FCP awardees adopt the technology (a benefit of spillover).

integrators, original equipment manufacturers (OEMs) of FC systems, supply chain vendors, including sub-component and sub-system suppliers, hydrogen suppliers and providers of hydrogen infrastructure), due to the investments of the ARRA-FCP; and

- Determine if there has been any replication of FC market activities and projects among awardees and emulation among non-awardees and previous non-users of FC systems.

A key element of the study process was the development of an evaluation plan that included market models, logic models, metrics, measurements, research questions, and the identification of awardees and non-awardees to be interviewed. Upon the completion of the evaluation plan, the evaluation team developed in-depth interview guides, collected data from secondary sources, completed 32 in-depth interviews with grantee and non-grantee companies, analyzed the data, and produced this report.

1.1 ARRA-FCP

On May 27, 2008, DOE issued a Funding Opportunity Announcement (FOA) for the "Research, Development, and Demonstration of Fuel Cell Technologies for Automotive, Stationary and Portable Power Applications"[7] that included the demonstration of near commercial technology and support of market transformation activity for FC systems. Before the recipients of the FOA awards were announced in January 2009, the Federal Government announced the American Recovery and Reinvestment Act[8] of 2009 with major appropriations for projects that would create jobs. The Office of Management and Budget (OMB) released directives[9] in early 2009 to all government agencies indicating that job creation was to be a major consideration in all funding activities, and added job creation or retention as a criterion for award selection. In addition, projects were to be "shovel ready," that is, to be initiated immediately. OMB also emphasized optimizing economic activity in relation to the federal dollars obligated, meaning that the maximum number of units were to be fielded to provide the maximum economic impact.

Because of the need to immediately fund and initiate projects, and the lack of time to put forth a call for new proposals and evaluate them, the DOE FCTO reviewed the proposals in response to the FOA to see if they would be appropriate for ARRA-FCP funding. Three topic areas within the original FOA aligned directly with the ARRA-FCP objectives: Topic 5A - Portable Electronics Balance of Plant and Packaging, Topic 6 A&B - FC System Demonstrations, and Topic 7 A&B - Market Transformation Activities and Early Stage R&D.

In addition to satisfying the criteria set forth by OMB, DOE expected that ARRA-FCP funding would:

- Improve the potential of FC systems to provide clean power for MHE, stationary (BUP, combined heat and power (CHP)), and portable power applications;

---

7 The announcement may be viewed at https://gaia.lbl.gov/people/mwbeck/public/Fuel_Cell_Solicitation/DOE_Solicitations/Industry_Announcement_DE_PS36-08GO98009.pdf

8 American Recovery and Reinvestment Act of 2009, P.L. 111-5, February 17, 2009, (known as ARRA or Recovery Act).

9 Guidance from Peter Orszag, Director of OMB, dated April 3, 2009: "Long-term public benefits, optimizing economic and programmatic results. Also consistent with the President's March 20, 2009, Memorandum, departments and agencies should support projects that have, among other things and to the greatest extent, a demonstrated or potential ability to deliver programmatic results; optimize economic activity and the number of jobs created or saved in relation to the Federal dollars obligated; and achieve long-term public benefits by, for example, investing in technological advances in science and health to increase economic efficiency and improve quality of life; investing in transportation, environmental protection, and other infrastructure that will provide long-term economic benefits…"

- Reduce carbon emissions; and
- Broaden the clean energy technology portfolio for the United States of America.

DOE made awards for demonstration and R&D so that its project pipeline would remain full of promising technologies capable of being commercialized over time.[10]

1.2 ARRA-FCP Awards

The ARRA-FCP was a cost shared program and required that deployment and demonstration projects provide a minimum 50 percent cost share, while R&D projects required a minimum 20 percent cost share. Thus, beyond the funds invested by DOE, the industry awardees proposed investing an additional $54 million in cost-share funding, bringing the total investment to approximately $96 million. This program directly supported the immediate deployment (installation and field operation) of 1,262 FC systems in MHE and BUP applications. The awards for demonstration projects had an expectation for a much smaller number of FC systems being fielded and there was no expectation for fielding of R&D FC systems.

Table 1 provides a listing and breakdown of the projects and units planned to be fielded or installed by awardees, subcontractors, and partners. The evaluation team assigned each of the projects to one of three categories relating to the state of commercialization of the ARRA-FCP funding recipient's project: deployment (hundreds of units fielded), demonstration (ones to tens of units fielded), and R&D (no fielded units). Sixty-one percent of ARRA-FCP funding went to deployment projects, 28 percent to demonstration projects, and 11 percent to R&D projects. The awardees in the deployment phase installed all of their units, while several of the awardees in the demonstration and R&D phases did not field all of their units.

Six **deployment** projects were intended to accelerate the adoption of newly commercial products to set the stage for greater end user acceptance and commercial growth by placing 1,262 FC systems into the hands of end users. Awardee deployment projects received $26.9 million in awards. Four of the six projects were for MHE and two for BUP. There were nine different subcontractors associated with these projects. One awardee that provided FC systems to end user sites had five deployment partners who co-funded projects. A total of 1,262 FC systems were funded and installed for a total $64.4 million, with industry providing approximately $38.8 million (See Table 1). The Table 1 data regarding planned fielded units are based on published reports at the 2011 Annual Merit Review (AMR) by the project awardees. Subsequent accounting and redefinition of "unit" to include FC system refurbishments, replacements, and upgrades as additional units increased the total units from 1,262 units planned for deployment (2011 data) to 1,326 units actually deployed (first quarter 2013 data).[11]

Demonstration projects were to validate R&D and refine near commercial products by locating tens of units in controlled field tests. The four demonstration projects resulted in 107 FC systems[12] installed at end user sites and with consumers (portable power). The demonstration projects, an auxiliary power unit (APU) project, a portable power project, a CHP project, and a liquefied petroleum gas (LPG)-fueled BUP

[10] In this report, the authors use the terms "deployment projects", "demonstration projects", and "R&D projects" differently than the way the FCTO uses them.
[11] NREL FC Deployment CDP at: http://www.nrel.gov/hydrogen/cfm/pdfs/arra_deployment_cdps_q12013_4web.pdf.
[12] Delphi unit not installed before this report was completed.

Table 1 Awardees, Subcontractors, and Partners with Application and FC System Characteristics[13]

Awardee *Subcontractors* Deployment Partners	Application	DOE Funding (Millions)	Awardee Funding (Millions)	FC Type	System Fuel	Power Level	Planned/Fielded Units
Deployment Projects (MHE and BUP)							
MHE							
FedEx Freight East (Harrison, AR) *Air Product and Chemicals* *Plug Power, Inc.,*	MHE	$1.3	$1.6	PEM	LH_2	3 to 15kW	35
GENCO (Pittsburgh, PA) *Air Product and Chemicals* *Linde North America* *Plug Power, Inc.* Coca Cola Whole Foods Wegmans Kimberly Clark Sysco (Philadelphia)	MHE	$6.1	$6.1	PEM	H_2	3 to 15kW	357
Sysco of Houston (West Houston, TX) *Air Products and Chemicals* *Plug Power, Inc.*	MHE	$1.2	$2.1	PEM	LH_2	3 to 15kW	98
Nuvera FCs (Billerica, MA) *H.E.B. Grocery Co.*	MHE	$1.2	$2.2	PEM	NG	3 to 15kW	14
MHE Subtotal		$9.8	$12.0				504
BUP							
Sprint Communications (Reston, VA) *Air Products and Chemicals* *Black and Veatch Corp* *Burns and McDonnell Eng. Co* *Ericsson Services, Inc.* *ReliOn Inc.* *Altergy*	BUP	$7.3	$17.2	PEM	H_2	1 to 10kW	330 (Includes 70 retrofits)

[13] Information developed from DOE EERE 2011 and 2012 AMR reports. This is believed to be the accurate count.

Awardee *Subcontractors* Deployment Partners	Application	DOE Funding (Millions)	Awardee Funding (Millions)	FC Type	System Fuel	Power Level	Planned/Fielded Units
ReliOn Inc. (Spokane, WA) *Air Products and Chemicals* *AT&T* *PG&E*	BUP	$8.5	$9.6	PEM	H_2	1 to 5 kW	428
BUP Subtotal		$15.8	$26.8				758
Deployment Subtotal		**$25.6**	**$38.8**				**1262**
Demonstration							
MTI Micro FCs (Latham, NY)	Portable	$3.0	$3.3	DMFC	Methanol	1 W	75
Plug Power, Inc. (Latham, NY) *Sempra Energy* *National FC Research Center*	CHP	$3.4	$3.4	HT PEM	NG	6 kW	12
Plug Power, Inc. (Latham, NY) *Army Corp of Engineers CERL* *Warner Robins AFB* *Fort Irwin*	BUP	$2.7	$2.7	PEM	LPG/H_2	6 kW	20
Delphi Automotive (Troy, MI) *Electricore, Inc.* *PACCAR Inc.* *TDA Research Inc.*	APU	$2.4	$2.4	SOFC	Diesel	3 to 5 kW	1
Demonstration Subtotal		**$11.5**	**$11.8**				**108**
R&D							
University of N. Florida (Jacksonville)	Portable	$2.5	$0.6		H_2		N/A
JADOO (Folsom, CA) *Delphi Inc.* *NASCAR Media Group.* *City of Folsom, CA*	Portable	$2.2	$2.6	SOFC	LPG		N/A
R & D Subtotal		$**4.7**	$**3.2**				N/A
All Project Total		$**41.8**					1370
Awardee Contribution			$**53.7**				
Project totals		$**95.5**					

project, were funded for a total of $23.3 million, including industry matching funds. Eight subcontractors supported these projects.

Two **R&D** projects, both portable power projects, resulted in the development of FC components or laboratory quality prototype systems and were intended to advance FC technology toward a demonstration capability. No field installations were expected. These projects were funded for a total of $7.9 million including awardee funding contributions. Three subcontractors were associated with these projects.

1.3 Report Organization

This report is composed of seven sections.

Section 1 contains the background and introduction for the report. It provides a description of the ARRA-FCP, the objectives of the study, and key impact study terminology.

The following questions are answered in this section:

1. What were the key objectives and questions for this study?;
2. What was the ARRA-FCP?;
3. How many awards were made and to whom, at what levels of funding, and for what end objectives?; and
4. How is the report organized?

Section 2 addresses FC commercialization phases, markets, participants, and impact evaluation metrics. It provides the foundation for understanding the FC industry history and status, including descriptive market models and segments where active FC systems deployment and demonstration is underway, and the early market impact evaluation metrics.

The following questions are answered in Section 2:

1. What were the phases of FC products commercialization in MHE and BUP?;
2. Who were the players in the FC markets for MHE and BUP?;
3. How did the players relate to one another?; and
4. What were the potential points of intervention for a program such as ARRA-FCP?

Section 3 provides the study methodology. It presents an overview of how the evaluation was conducted and describes the sequence of steps taken in performing the study: secondary data collection, interviewee selection, how the interviews were conducted, how data were analyzed, and how data quality and attribution issues were handled.

The following questions are answered in this section:

1. What were the main activities that were conducted to produce this early market evaluation?;
2. What data were collected?;
3. How were the different kinds of data collected?;

4. How was it decided who to interview?;
5. How successful were the data collection efforts?; and
6. How were the data analyzed?

Section 4 includes the findings and analysis for the deployment phase projects in MHE. It describes the combined results from the analysis of secondary and primary data for the deployment phase for MHE FC systems**.** The secondary data were generated from government and FC industry stakeholders, quantitative data from public sources, and comparative crosschecks of quantitative data using NREL reports and other publicly available information. Quantitative data for the units demonstrated and sold are addressed in greater detail for the pre, during, and post ARRA-FCP periods, while the other metrics are addressed for the periods during and post ARRA-FCP. The primary data were obtained from interviews with supply chain vendors (SCVs), OEMs, systems integrators (SIs) and end users (EUs) for three related phases including: pre ARRA-FCP funding period, during the ARRA-FCP funding period, and the post ARRA-FCP funding period. The interviews also yielded answers to research questions such as technological impacts, benefits for the industry and participants, and many other areas identified in the interviewee guide. (See Appendix E.) The secondary data addressed the following questions:

1. How many MHE FC systems were fielded for deployment and demonstrations?;
2. How many units were fielded before, during, and after the ARRA-FCP funding period that were funded from sources other than the ARRA-FCP?;
3. How many firms purchased units for the first time and how many firms replicated their purchases at the same or other sites?;
4. What were the costs, comparative costs, return on investment, reliability, and other factors that influenced the purchase of FC systems?;
5. What direct or indirect market impacts did the ARRA-FCP have on units purchased?; and
6. Did the ARRA-FCP funding stimulate the market?

The primary data addressed the following questions:

1. How did the ARRA-FCP influence decision-making among the various players in the market?;
2. What direct or indirect market and technological impacts did the ARRA-FCP have?;
3. Which market participants benefited from the ARRA-FCP?;
4. How did the different players in the market benefit from the ARRA-FCP?;
5. To what extent did regulations and zoning requirements influence FC system deployment?; and
6. To what extent did the ARRA-FCP create or retain jobs?

Section 5 includes the findings and analysis for the deployment phase projects for backup power equipment. It parallels Section 4 (MHE market), albeit with less available data.

Some key differences related to the preceding questions include:

1. How did the role of systems integrators operate for BUP FC systems?;

2. What specific challenges were related to hydrogen fueling, fueling infrastructure, and FC system installation at end user sites?; and
3. What value can reformate-based BUP FC systems offer in telecommunication BUP applications?

Section 6 addresses demonstration and R&D phase projects. It contains a description and analysis of the demonstration and R&D projects and addresses questions like the following to the extent that data are available.

1. Did the demonstration and R&D projects achieve their stated objectives?;
2. What were the remaining key challenges for the technology to move to the next phase of commercialization?; and
3. What were the main lessons learned regarding project scope, execution, and commercial potential?

Section 7 describes the conclusions reached from the analyses of the primary and secondary data.

Section 8 provides recommendations for improvements in processes and procedures for maximum funding impact, in addition to some recommendations resulting from direct feedback from awardees and non-awardees made during the in-depth interview process. Secondary data were used to add value and where possible to quantify discussion of the primary (interview) data.

The following questions are addressed in Section 8:

1. Based on the analysis and conclusions, what recommendations are there from interviewees for the further development and commercial growth of FC technology in the markets under evaluation?;
2. What recommendations from interviewees are there for program emphasis?; and
3. What recommendations from interviewees are there for program policy changes??

2 Fuel Cell Markets, Participants, and Evaluation Metrics

To understand the market effects and impacts of the ARRA-FCP funding, it is necessary to identify the participants and the relationships among them in the target markets. What follows is a high level introduction to the markets tied to the commercialization phase.

2.1 Deployment Phase Projects

To understand the deployment phase for fuel cell systems, it is first necessary to identify the market participants and define the major relationships among them using market models.

2.1.1 Market Participants

Key market participants in the deployment phase are SCVs, OEMs, SIs, EUs, and financial services providers. A listing of awardees by their market role is found in Table 2.

Original equipment manufacturers are the FC system developers that design, develop, fabricate, and assemble FC systems and sell the systems to systems integrators, financial service providers, or end users. In some cases, the OEM also services and maintains the FC system. Examples of OEMs are: Plug Power, Nuvera, ReliOn, and Altergy.

Supply chain vendors manufacture components or supply materials or services to the FC system OEMs or EUs. There are three types of SCVs: mechanical or electrical component suppliers, fuel suppliers, and engineering service providers. Mechanical or electrical suppliers provide FC stacks or their sub components, such as membrane electrode assemblies (MEA) or plates, controls, and balance of plant components (pumps, blowers, heat exchangers, etc). Fuel suppliers provide hydrogen or other fuels along with storage, compression, and dispensing equipment. Engineering service providers are involved in site selection, facility construction, installation, and equipment maintenance or support, mostly applicable to the BUP market. Examples of SCVs include: mechanical suppliers (Ballard, 3M), fuel suppliers (Air Products, Linde), and engineering service providers (Ericsson, Black and Veatch).

Systems integrators receive the FC system from the OEM and install it into the final product. An example of a systems integrator is an MHE truck manufacturing firm that combines all necessary systems, including the FC system, into its MHE product and is responsible for its product warrantee. In some cases, the systems integrator and the end user may be the same entity. For example, a telecommunications company may be the systems integrator but uses an engineering service provider to install the BUP FC system at its telecommunications tower. Examples of systems integrators include: Raymond, Hyster, Ericsson, and AT&T. At present, there are no systems integrators that perform this function for MHE FC systems.

End users lease or purchase and then use the FC system in end products applicable to their businesses, for example, a company operating a distribution warehouse. An end user also could be the operator leasing space from or owning a communications tower. Examples include Wal-Mart, Sysco, AT&T, and PG&E.

Financial services providers may provide capital, business integration, or leasing services. For example, a financial services provider might raise capital and then purchase or lease MHE trucks, FCs, fueling equipment, and installation and maintenance services and in turn write a five-year lease contract for a turnkey system delivered to an end user such as a grocery company. An example is Somerset Capital.

Table 2 ARRA-FCP Participants by Award Type and Role

Deployment	Demonstration	Research and Development
OEMs		
Nuvera FCs (Billerica, MA)	Delphi Automotive (Troy, MI)	JADOO (Folsom, CA)
Plug Power, Inc.	MTI Micro FCs (Latham, NY)	University of N. Florida (Jacksonville)
ReliOn Inc. (Spokane, WA)	Plug Power, Inc. (Latham, NY)	
Altergy		
SCVs		
Air Product and Chemicals	Electricore, Inc.	
Black and Veatch Corp	TDA Research Inc.	
Burns and McDonnell Eng. Co		
Ericsson Services, Inc.		
Linde North America		
End users		
AT&T	Army Corp of Engineers CERL	City of Folsom, CA
Coca Cola	Fort Irwin	Delphi Inc.
FedEx Freight East (Harrison, AR)	National FC Research Center	NASCAR Media Group.
GENCO (Pittsburgh, PA)	PACCAR Inc.	City of Folsom, CA
H.E.B. Grocery Co.	Sempra Energy	
Kimberly Clark	Warner Robins AFB	
PG&E		
Sprint Communications (Reston, VA)		
Sysco		
Wegmans		
Whole Foods		

2.1.2 MHE Market Model

The MHE FC system power module contains all the FC system components (FC stack, balance-of-plant (BOP) including controls, small startup battery, and hydrogen storage) and a counterbalance in a single compact, rectangular metallic box, and is a one-for-one replacement for battery packs in an MHE truck. The weight distribution of the FC system plus counterbalance compared to batteries is such that the overall balance of the truck is not changed. The power modules are designed so that only minor modifications of the MHE truck, *i.e.,* wiring for a fuel gauge monitor, are needed. The on-board hydrogen storage is sized to allow full shift operation (8 hours). The on-board hydrogen tank can be refilled in a few minutes at the operator’s convenience. The term FC power pack is used here to explain and indicate the FC system specific to MHE use. Because different FC system configurations are used for different applications and this study addresses many applications, the general terminology of “FC system” will be used for all of the different systems.

Other often cited benefits of using FC-powered MHE include the release of floor space occupied by battery charging equipment and spare batteries, productivity increases from not having to replace the battery during operations, eliminating the need for multiple batteries per unit, and “green” branding and emissions benefits for the end users. Further, larger companies may benefit from reduced carbon emission taxes in states where such tax benefits are in place. Frequently cited disbenefits include perceptions of risk and safety associated with the use of hydrogen fuel, the space required for hydrogen infrastructure and dispensing and a safety margin around it, and capital write-offs for existing equipment when installing FC systems in extant facilities. The benefits and disbenefits are discussed in greater detail in Sections 4 and 5.

Figure 1 illustrates the MHE market. The MHE target market is comprised principally of end use customers in the warehousing, manufacturing, distribution, and storage industries that use various sizes and types of MHE trucks.

Bringing a new product to market requires resources for R&D, product development, manufacturing, and assembly including quality assurance, sales and marketing, and customer service. The model also identifies some of the financial sources essential to operating any business, such as investors, public stock offerings, profits from sales if they exist, and grants from federal, state, and local governments. The funds may be available to different players in the market at different stages of development and commercialization. Because of the potential for economic development, end users of products reaching the early market stage may find tax incentives available.

Financial services providers may act as business facilitators working with systems integrators, OEMs, and end users arranging for capital to purchase the equipment, secure investment tax credits, or secure ARRA Section 1603 grants. They may also create purchase or leasing arrangements with OEMs, systems integrators, and MHE manufacturers, establishing operations and maintenance contracts that result in the delivery of a turnkey system to the end user at a specified price. In some instances, Plug sold its MHE FC systems to Somerset Financial, who then became the lessor for many end users.

The end users, such as warehouse operators, evaluate the relative advantages of the various competitive alternatives from an operational, required infrastructure, and return on investment (ROI) standpoint and determine if it makes sense to purchase FC systems to replace the batteries in their existing MHE or purchase new MHE with the FC systems already installed in preference to traditional battery powered MHE. Some end users may purchase the MHE without FC systems or batteries installed and then separately purchase their preferred choice of power source. When sold as a complete unit, the cost of the battery or FC system is passed through to the end user. When the battery or FC system is sold separately, end users or their lease agents usually have direct contact with battery or FC system OEMs or their distributors

Because the FC system is powered, in the vast majority of cases, by an alternative fuel, hydrogen, there is a requirement for fuel supply, storage, and dispensing infrastructure that meets local zoning and code requirements. Fuel suppliers, such as Air Products, Air Liquide, and Linde, have partnered with FC system OEMs to develop and install the fueling infrastructure. A national contractor may provide leadership and oversight teaming with a local contractor to do the actual construction and to deal with permitting and zoning issues with local government officials.

.

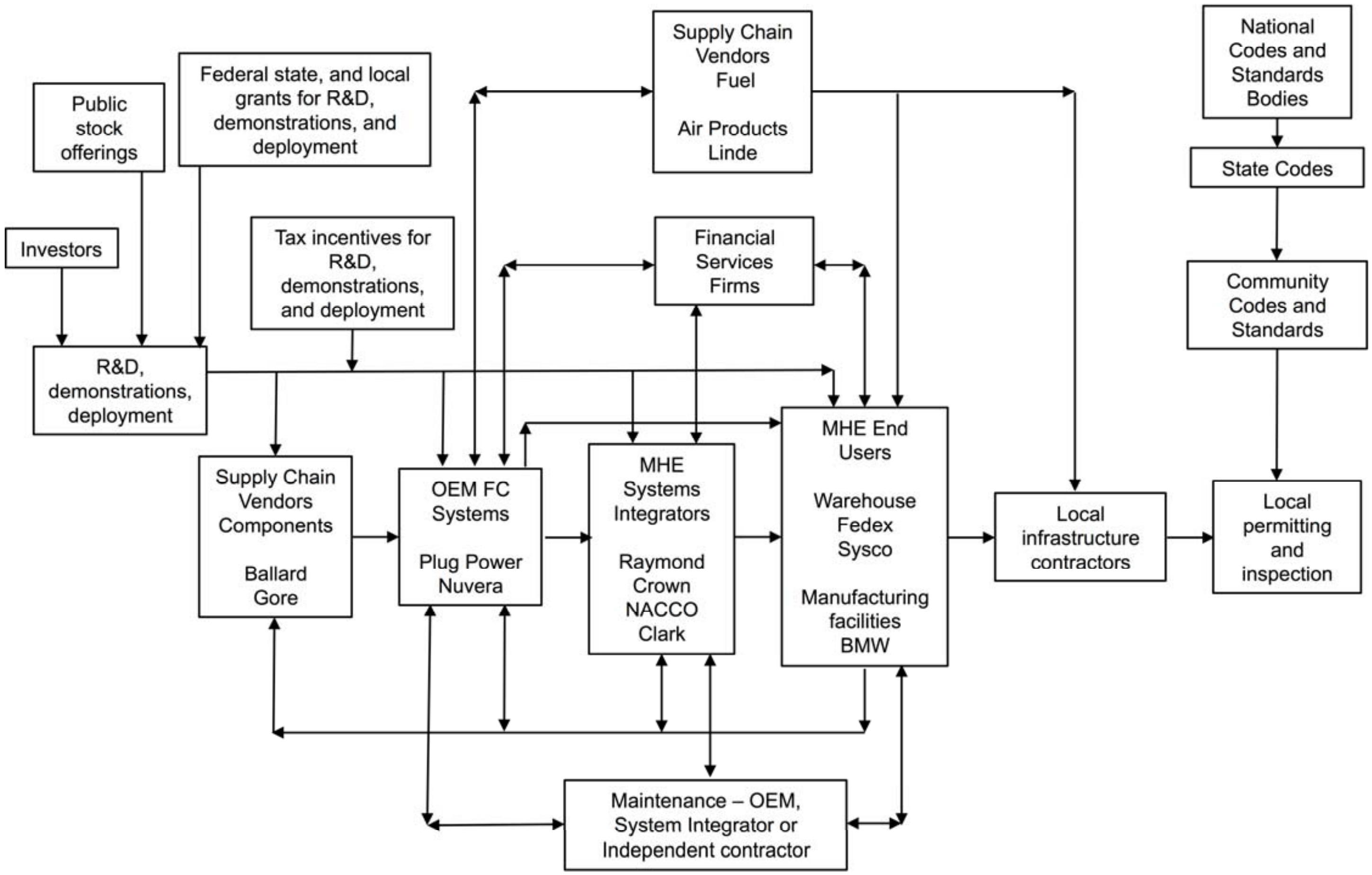


Figure 1 Market Model for MHE FC Systems

Maintenance may result in an additional player in the market depending on the situation. A systems integrator or their distributors might typically do the maintenance, because they have to do the maintenance on the MHE truck anyway. In early market situations, OEMs may provide maintenance services for the FC systems. In some cases, an independent contractor may perform FC system maintenance.

There are multiple feedback loops in this market. End users provide feedback to the systems integrators and to the OEMs either directly or through maintenance services. Systems integrators provide feedback to the OEMs; OEMs provide feedback to their SCVs about the need for revised designs and specification for components. These feedback loops drive change in the overall market that provide benefits to all key players.

2.1.3 BUP Market Model

Similar to the MHE application, the BUP market model involves the interaction of SCVs with OEMs to produce the FC systems and the necessary fuel and fueling infrastructure (see Figure 2). However, the value chain is more complicated at the system integration level with OEMs or end users performing the systems integrator’s role or collaborating to complete this function with the assistance of independent engineering service providers.

The market potential of FC-powered BUP systems is based on leveraging two key features of hydrogen fueled FC systems: nearly instant start-up from an off state and high reliability due to very few moving parts. The sub-systems elements are basically the same as those used in MHE (FC stack, BOP including controls, and H_2 supply) and a small battery that is required for start-up for the initial early seconds of operation in circumstances where the FC is not yet able to provide sufficient power. The ReliOn FC system has an additional feature that separates it from other FC systems, which allows for replacement of individual fuel cell stack elements (cell modules) without shutting down operation. Depending on the location, FC-powered BUP systems may also have an enclosure to “protect” the FC system from environmental factors such as extreme changes in ambient temperature. The lack of emissions and noise are also important benefits in dense urban areas.

Typical uses of BUP are powering telecommunication cell towers, remote control stations for utilities, emergency communication or response sites, and various military communication applications. Until recently, diesel generators in combination with large battery banks have been used to achieve the high levels of reliability and operational stability (up to 72 hours) to mitigate against natural disasters and other events that could result in significant downtime of grid electricity. Any end user application requiring uninterruptable power for a relatively short period of time from minutes to several days with onsite fuel storage and secure replacement is a candidate for a FC-powered BUP system. An advantage for FCs in the BUP market is that end users are less price sensitive because of the absolute requirement for near 100 percent reliability. When total capital costs, fueling costs, and maintenance issues for the diesel generators are taken into account, the diesel/battery BUP system is likely to be more costly and less reliable than the FC-powered BUP option for many uses.

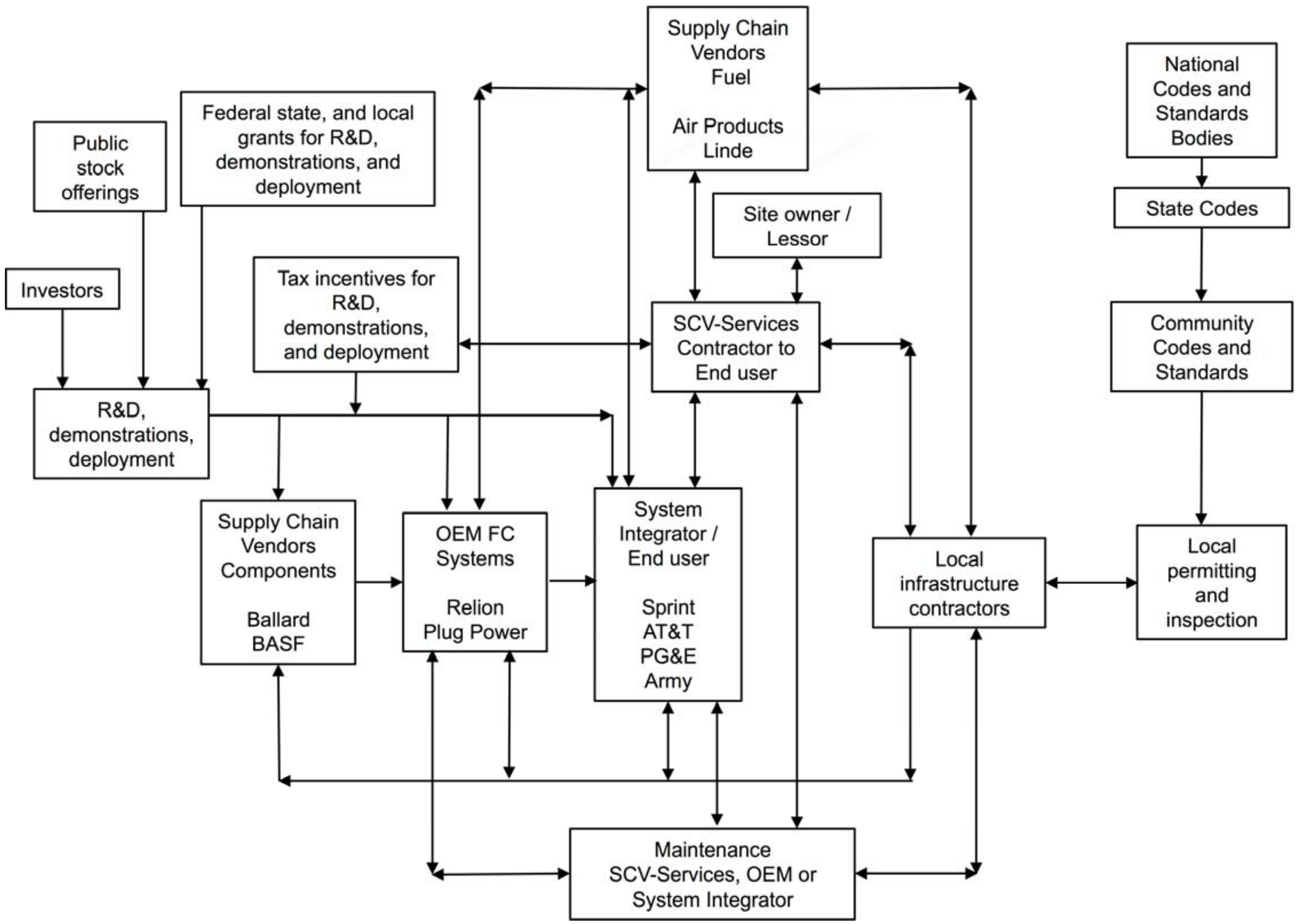


Figure 2 Market Model for FC BUP Systems

When FC systems were first introduced for use in BUP applications, the expected outage duration for which the FC system had to provide power was anything from minutes to a few hours per event with just a few events per month. The primary fuel was H_2 gas stored in “K bottles.” For units with power levels in the 1 to 5 kW range, about six K bottles of H_2 were required to sustain operations for 24 hours at half power. When operating time requirements increased to 72 hours or more, gaseous bottle storage became problematic because of the number of bottles required and space limitations. A more practical approach is to use larger pressurized H_2 tanks that are filled by using a medium pressure rated hose. With the improved storage, delivery time, and reliability for pressurized hydrogen, the operating time extends to three days.

Given the intermittent use of FC BUP systems where reliable grid electricity is available, it could be assumed that it would take years for these new technologies to fully demonstrate the required reliability. However, one FC system OEM with a history of selling FC-powered BUP systems since 2003, claims to have a proven reliability of 99.68 percent.

Given the similarity of the BUP market model to that of the market model for MHE, a detailed discussion of the market will not be revisited. However, there are two important differences between the MHE and the BUP models worthy of note. In the BUP market model, the end users and the systems integrators are often the same entities. For example, a telecommunications company may hire an engineering service provider to assemble the pieces, arrange for lease of space at a telecommunication site to address local siting and permitting issues, install, test, and operate the equipment. This arrangement tends to simplify decision-making with respect to initial and longer-term investments. However, this means that there is not a systems integrator promoting the product in the market, as might be the case with systems integrators in the MHE market and not all potential end users of the technology may be interested in doing the systems integration. In cases where the end user is not inclined to provide the integration, the end user would hire an engineering service provider to play that role. The FC system OEM and the fuel supplier may work together with the service contractor to provide turnkey packages.

The second key difference is the ownership of the transmission site. Typically, telecommunications operators piggyback on existing sites so that a single site may serve multiple communications entities. Sites may be owned directly by a telecommunications company, by end users such as an electric utility that has communication sites associated with its towers, by for profit companies that develop sites in order to lease them, and by governments who may lease space as well.

The implications of this are potentially substantial. With hydrogen as the fuel for BUP FC systems, fueling infrastructure and regulatory issues related to site location potentially present a significant challenge for end users. Space may not be available to support the hydrogen fuel and related infrastructure. There may be contractual issues between the firms and site operators that may make the introduction of an alternative fuel difficult. The owner of the site may be reluctant to seek permits for a new technology that might reopen local zoning and permitting issues. Finally, sites may have access infrastructure issues that make the delivery of hydrogen difficult.

2.2 Demonstration Phase Projects

The purpose of the field demonstration is to verify the real world operation of a product, ascertain and assess failure modes and causes, and address those failures through component improvements or product redesign. An additional purpose is to give the FC system OEM an opportunity to better understand the end user's requirements, and the end user a chance to understand the FC system's capabilities to meet those requirements. The number of units being demonstrated is generally a trade-off between the numbers needed to gain substantial experience and collect extensive data, the costs to the OEM of financial incentives, repair, and replacement, which are usually more frequent than in early market deployment, and responsibility for other potential losses.

Financial incentives may be provided to induce the end user to install and evaluate the product and risk disruption to the business and impacts resulting from possible safety shortfalls. Generally, the new product has been tested only in the laboratory to the extent it can be tested and, therefore, still needs field testing and evaluation in the hands of the intended market end users. The end user must be convinced that the OEM has an enviable track record, receive high recommendations for the product from expert sources, and receive the OEM's unshakeable commitment to not impede or damage the end user's business or employees. The incentives applied are very often financial in nature to cover special installation requirements or changes to the end user's facility.

The market model is a simpler version of the models shown in Figures 1 and 2. The OEM may take on some of the roles of systems integrators resulting in systems integrators being less involved. Because of the reduced number of end users, supply chain vendors provide lower quantities of components and the components may not differ greatly from those used in laboratory development systems. Supply chain vendors' involvement may increase if and when there is a need to modify components that they are supplying. If fuel supply capabilities are a part of the demonstration, then fuel supply vendors may play a greater role in demonstrations. Alternatively, the fuel supply chain vendors may provide an existing delivery system to meet the short-term need and deliver a more integrated fueling solution at a later date.

There were four different projects within the demonstration category: auxiliary power, portable power, LPG BUP, and CHP. Each of the OEM awardees was in a different stage of product development with respect to the number of units previously built and tested and the number of units to be fielded as part of the ARRA-FCP project and the technical/financial capability of the entity. Each of the OEMs pursuing these applications has a different back story, but each must pass through the wicket of subjecting its product to the rigors of a field demonstration in the hands of an end user before they can progress to the next phase of commercialization.

2.3 R&D Phase Projects

There were two projects in the R&D category. Both of them were in the very early stages of technology development for portable power applications. By their nature, R&D projects are generally confined to laboratory evaluations and do not require significant interactions with parties external to the research organization. The basic model is a simple one: obtain funding support, create an early stage prototype development plan, and perform laboratory development and experimentation until the performance of the prototype warrants a field demonstration. This model presumes that an assessment of the intended product's potential to meet end user ROI requirements has been determined, that there is a market of sufficient size, and that the intended product has other relative advantages that will allow it to enter and sustain itself in a market.

2.4 Metrics and Measures

Guided by the logic model (see Appendix B) and market models (see Figure 1 and Figure 2) developed at the beginning of the project that identified the participants and their interrelationships, a comprehensive list of metrics and related measures was developed.[14] The metrics and measures provide a basis for assessing "early market change." The metrics and measures defined what was to be measured and provided a basis for the development of the in-depth interview guides. The metrics and measures were used as appropriate for each industry type. This allowed the evaluation team to systematically address the important issues in each case. The metrics also provided a systematic framework for collecting and analyzing the data. Clearly, the metrics and measures had greatest relevance for the deployment projects and a much lesser relevance for the demonstration and R&D projects and as such were developed in accordance with the stated priorities for the study.

There are seven key metrics. Each of these seven metrics bears on the questions of market change. For each metric, there are a series of related measurements. The measures are designed to be as quantitative as possible, as follows:

1. **Units sold** are an indicator of whether the product is being accepted or rejected in the market and whether the market is developing. Basic measures are:
   - Number of units sold pre ARRA-FCP (from 2004 to the beginning of 2009 before the ARRA-FCP awards were imminent);
   - Number of units sold during ARRA-FCP (from beginning of 2009 through the end of 2010 when most of the funded units had been purchased and installed); and
   - Number of units sold post ARRA-FCP (from the beginning of 2011 and continuing for a number of years during which the impacts of the ARRA-FCP are still influential to the development of the MHE and BUP markets).

   Additional measures could include a change in the number of first time system purchasers or growth in repeat purchases, and were evaluated when appropriate.

2. **Product value** focuses on the relative advantages of the product from the standpoint of the end user. Basic measures are:
   - Capital cost of unit and supporting infrastructure
   - Energy and labor cost to operate unit
   - Energy cost to operate infrastructure
   - Labor cost to maintain infrastructure

   Additional measures could include (when appropriate) improvements in system performance and cost from the end user perspective; the ability to work with the supply base to enhance product capabilities and reduce cost; the ability to implement product updates and new products using a well managed product roadmap linked to a technology roadmap; and investment in improved designs and

[14] The market and logic models are discussed further in Appendices B and C.

manufacturing processes and equipment and their ability to increase product output, yield, and reliability while reducing cost.

3. **Incentives for product sales** indicate whether or not there were influencers other than ARRA-FCP that may have increased the attractiveness of the product and which may or may not exist in the future. Basic measures are:
   - Tax incentives (credits or grants)
   - Carbon credits or renewable energy credits for sustainability
   - Investment and other non-Federal incentives and credits

Other incentives could include(when appropriate) a positive ROI for end users in less than five years or attaining corporate societal objectives. All of these benefits might prove advantageous for hydrogen as a fuel.

4. **OEM supplier revenues** and costs are indicators that the OEM can successfully market the product and achieve sufficient return from sales to invest in R&D, product development, manufacturing scale-up and sales, and marketing efforts. Basic measures are:
   - Cost of components
   - OEM revenues
5. **Systems integrator acceptance** is an indicator that there will be entities who will offer the product to end users. Basic measures are:
   - Stable product design
   - Availability of components at stable or declining costs
   - Differentiated product with relative customer advantages
   - Customer demand
   - Market potential
6. **End user acceptance** addresses the willingness of the end user to adopt the product, encouraging other end users to follow suit. This metric has a wide range of potential measures.
   - Product characteristics, including the technical readiness and manufacturing readiness, reliability, safety, fueling infrastructure, and life
   - Training/learning requirements
   - Serviceability
   - Emissions
   - Installation
   - Operator requirements and responsibilities

- Organizational support, primarily the highest level of management awareness, and the highest level of decision-making support
- Organizational support when considering changes to plant operational structure, changes to employee responsibilities, changes to employee overtime, and changes in safety management

Additional measures could include (when appropriate) the entry into the market of end users that had not previously purchased a FC system or an OEM's response to maintenance issues and customer service needs.

7. **Community acceptance** focuses on whether or not the local communities in which these products are to be used will be accepting of the product and its required infrastructure.
   - Perceptions of safety by local officials—especially fire inspectors concerned with hydrogen safety
   - Changes in local inspection practices
   - Awareness of the general public
   - Opposition or support from local public, interest groups, and media
   - Applicable codes and standards

2.5 Development of Key Evaluation Objectives

There were six objectives of the evaluation. These were to assess:

1. **Accelerated deployment** assesses the extent to which the ARRA-FCP investments accelerated FC systems deployment in MHE and BUP applications relative to the baseline before ARRA-FCP funding.
2. **Improved acceptance** determines how the ARRA-FCP impacted quantifiable changes in the early stage acceptance of FC systems in the markets under study.
3. **Facilitated purchases** assess the extent to which the ARRA-FCP facilitated volume purchases in key early market segments or resulted in additional subsequent purchases.
4. **Increased availability** assesses the rate of increase in the availability of low-cost FC systems and the number of companies using FC systems due to the ARRA-FCP funding relative to baseline.
5. **Expanded capacity** assesses any increase in capacity and leveraged activities throughout the supply chain due to the investments of the ARRA-FCP. This included numbers of end users, end user contractors, systems integrators, OEMs of FC systems, SCV including subcomponent and subsystem suppliers, hydrogen suppliers, and providers of hydrogen infrastructure.
6. **Replication and emulation** determines if replication of market activities in ARRA-FCP awardee companies has occurred and if any emulation of market activities has occurred among non-awardees and previous non-users of FC systems.

Table 3 indicates with an x which of the 7 metrics will influence the six key objectives.

Table 3 Relationship between Key Metrics and Key Objectives

Objective	Units sold	Product value	Incentives for product sales	OEM, supplier revenue, costs	Systems integrator acceptance	End user acceptance	Community acceptance
Accelerated deployment	x	x	x	x	x	x	x
Improved acceptance	x	x		x	x	x	x
Facilitated purchases	x	x	x	x	x	x	
Increased availability	x	x		x	x		
Expanded capacity	x			x		x	
Replication, Emulation	x	x	x			x	

3 Study Methodology

This study was performed as a retrospective and contemporary analysis of the effects and impacts of the ARRA-FCP funding on early-stage markets for FC-powered systems deployed in MHE and BUP applications. The evaluation plan called for an awardee and non-awardee group design that would allow comparison of changes in ARRA-FCP participants' activities and behavior before, during, and after the occurrence of the ARRA-FCP projects and activities in the same period for a selection of non-awardees. The ability to fully carry out this design was limited by the small number of active entities in the markets under study.

In addition to the use of metrics and measures, this report includes two other organizing principles, the timing relative to the ARRA-FCP period and effects on four different market participants (end users, systems integrators, FC system OEMs, and supply chain vendors). The analysis extends over three time periods in order to document observed changes in FC product utilization in MHE and BUP due to the ARRA-FCP and other causes. The time periods are:

- Pre ARRA-FCP period from 2004 to the beginning of 2009 before the ARRA-FCP awards were imminent
- ARRA-FCP period from beginning of 2009 through the end of 2010 when most of the funded units had been purchased and installed
- Post ARRA-FCP period from the beginning of 2011 and continuing for a number of years during which the impacts of the ARRA-FCP are still influential to the development of the MHE and BUP markets

The primary data were mostly collected through interviews and are qualitative in nature. These data are objective but typically have a count of one with rich content. The secondary data were collected from a broad array of sources including reports, reviews, and extensive and detailed online searches of data related to the ARRA-FCP and the MHE and BUP FC markets. It is quantitative in nature, has counts of many but the meaning of units counted is narrow in scope. The secondary data permit a more quantitative analysis of the early stages of market commercialization in the pre, during, and post ARRA-FCP periods. The framework for this report is shown in Figure 3.

While the original intent of the study was to obtain quantitative data for all the metrics in the three time periods, this was only accomplished for the units sold. The analysis of the other metrics was based largely on anecdotal information that did not cover all the time periods. Further, it should be noted that not all metrics apply to each industry participant type. The three subsequent sections (starting with Section 4) are organized as MHE deployment projects, BUP deployment projects, and as both demonstration and R&D projects. The demonstration and R&D projects are not shown in the graphic because they did not involve deployment and instead are addressed through short summaries of project results rather than a metric based evaluation. The MHE and BUP deployments are organized around metrics and industry players. Each section begins with a discussion of units sold by period: pre ARRA-FCP, during ARRA-FCP, and post ARRA-FCP. This is followed by a section that discusses the effects on market participants with relevant metrics discussed by period as appropriate to the industry player.

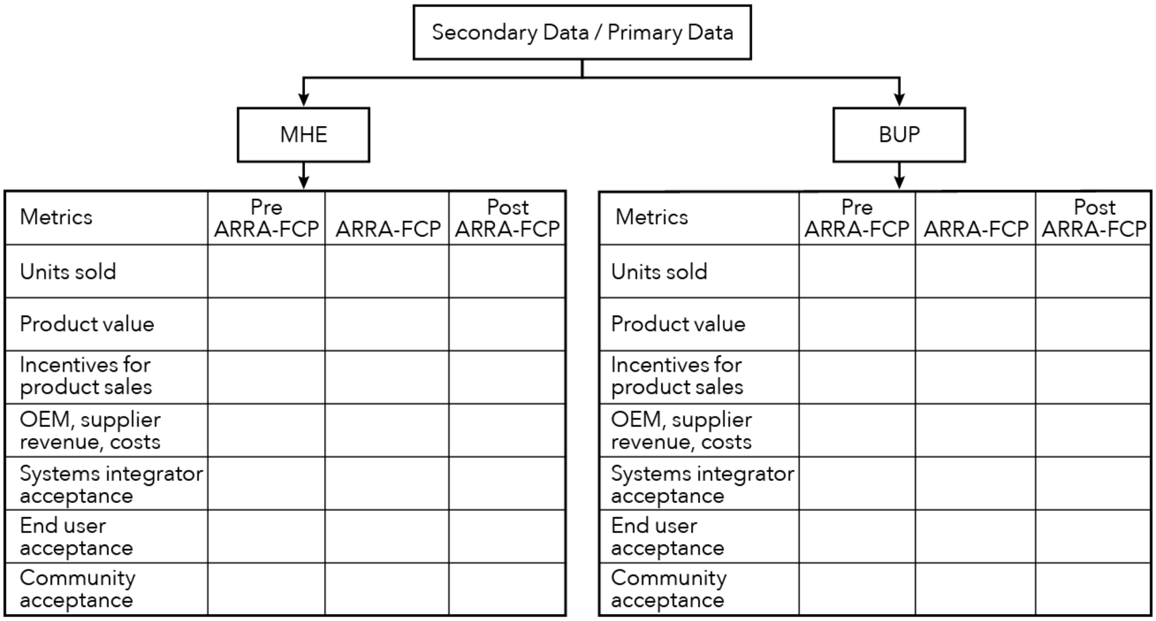


Figure 3 Framework for the Report

This evaluation was comprised of nine activities.

1. Conduct phased collection of secondary data.
2. Conduct in-depth interviews of selected key stakeholders including DOE personnel and other relevant government and nongovernmental (NGO) industry personnel involved with or knowledgeable about the ARRA-FCP projects.
3. Utilize data from the in-depth interviews and other sources to develop market models, logic models, metrics, measures, and research questions for in-depth interviews.
4. Establish a list of ARRA-FCP awardees and non-awardees to be approached for in-depth interviews. Complete as many interviews as possible within the budget and timing allocated.
5. Complete an evaluation plan for review and approval by a peer review team selected by Lawrence Berkeley National Laboratory (LBNL).
6. Collect primary data:
   a. Develop a master interview guide.
   b. Conduct in-depth interviews.
7. Evaluate any resultant limitations to interviewee selection and interview methodology.
8. Analyze the primary and secondary data.
9. Produce a final report:
   a. Produce a draft report for LBNL and peer review.
   b. Consider and respond to LBNL and peer review responses.
   c. Complete final report.

3.1 Conduct Phased Collection of Secondary Data

Secondary data were collected throughout the study. In the initial phases, secondary data were used to increase the team's understanding of FC markets and to provide background information to develop and conduct comprehensive interviews with program staff; to develop market models, logic models, metrics, and measures; to develop the evaluation plan; and to develop the interview guides. Later in the project, the scope of the secondary data collection was expanded to capture more detailed information on the number and type of FC systems that were deployed. Examples of the information and secondary data that were collected and reviewed included:

- Composite data products (CDPs) and other reports from NREL
- Articles and data from FC 2000 and FC Today reports
- Information from awardee and non-awardee company web sites and press releases
- News releases about awards and the implementation of the projects
- Security and Exchange Commission (SEC) filings through EDGAR (SEC data portal)
- Data from the Industrial Truck Association (ITA)
- Public presentations given at DOE annual merit reviews, FC seminars and energy expositions, and other public presentations
- Internet searches of publications and public information on relevant subject matter, including trade publications

The original award applications were unavailable to the team because DOE considers them to be proprietary. The team had access to the NREL CDP reports. Some awardees provided copies of their reports when they were interviewed. Many of these sources were revisited throughout the evaluation to collect data on changes that were occurring or to discover new sources of information.

3.2 Conduct In-depth Interviews of Selected Key Stakeholders, DOE Personnel, and Other Relevant Government and NGO Industry Personnel

Based on the background information, the team structured a series of comprehensive interview guides. The guides identified the range of topics to be discussed with selected key DOE program personnel and other relevant government contractor personnel and NGO industry personnel.

The interviews were conducted by telephone in a conversational style with follow-up questions asked as appropriate. These interviews took from one to two hours depending on the questions posed and the level of knowledge of the respondent. The guide served as a framework for conducting the interview and as a checklist to assure that all topics relevant to the respondents on the call were covered.

3.3 Utilize Collected Data to Develop Market Models, Logic Models, Metrics, Measures, and Research Questions

Using the background data gathered during activities described in Sections 3.1 and 3.2, market models were constructed for MHE and BUP applications. The market models also served as a basis for constructing logic models. While market models show the relationships among players, logic models represent the expected sequences of actions (see Appendix B) required of participants to move from ARRA-FCP funding to implementing and operating equipment in the field. Logic models have several uses. They can be used to compare the expected with what actually happens in the field. This comparison can reveal unnecessary actions, actions that should have been anticipated but were not, and situations where adjustments were made or need to have been made to produce a successful outcome. The logic model also provides a systematic basis for developing metrics, measures, and research questions so that key data are collected.

3.4 Establish the Number of Interviews to be Completed and Select Firms and Individuals to be Interviewed

Based on the available budget and some assumptions about the costs of completing interviews, it was determined that approximately 60 interviews could be completed. (See Appendix E for a list of candidate interview firms.) Firms to be interviewed included all prime contractors for ARRA-FCP deployment, demonstration, and R&D projects; other awardees; and non-awardees. Interviewees included relevant individuals among OEMs, SCVs, SIs, and EU industry types, both awardees and non-awardees.

Table 4 shows the distribution of completed interviews for awardees and non-awardees for the three commercialization phases and four participant types. There were 24 completed interviews for deployment, seven for demonstrations, and one for R&D. There were 26 awardees and six non-awardees. There were twelve OEM interviews, nine end user, seven supply chain vendor, and three systems integrator interviews.

Table 4 Interviews Completed by Awardee Type, Commercialization Phase, and Participant Type

	Demonstration			Deployment			Subtotal		Total
Type	Awardee	Non-awardee	Total	Awardee	Non-awardee	Total	Awardee	Non-awardee	
SCV[a]	1		1	4	2	6	5	2	7
OEM[b]	4	1	5	6	1	7	10	2	12
SI[c]				1	2	3	1	2	3
EU	1		1	8		8	9		9
R&D							1		1
Total	**6**	**1**	**7**	**19**	**5**	**24**	**26**	**6**	**32**

a Major component supply chain vendors are considered as subcontractors (*i.e.*, awardees).

b Counted as two interviews for Sprint deployments in their different roles as prime and subcontractor and two interviews for Plug Power demonstrations because they participated on two different contracts.

c Some BUP deployment end users also act as systems integrators, but are counted only as end users.

The following priorities were used to select the remaining entities to be interviewed.

- Entities receiving ARRA-FCP funding and contributing matching funding were given priority, with those receiving the greatest funding being given the highest priority.

- Deployment projects were given a higher priority than demonstration projects and R&D projects since it was anticipated that deployment projects would have more influence on the market and they were funded at a more substantial level to provide a larger number of products to end users.
- End users, systems integrators, and OEMs were given a higher priority than SCVs because it was anticipated that they might more significantly influence market growth.
- Non-awardees at the end user, systems integrator, OEM, and SCV level who were involved in the MHE and BUP markets were selected randomly as needed, to provide baseline and support data to related awardee interviews.

Table 5 shows the completion percentages by awardee status, commercial type, and project phase. The overall rate of completions is consistent with the evaluation priority of deployment, demonstrations, and R&D. Overall, OEM interviews had the highest completion percentage (86 percent) followed by systems integrators (60 percent) and supply chain vendors (58 percent). End user interviews had the lowest completion rate. For deployment awardees, the interview completion rate for OEMs and SIs was 100 percent but the completion rate for supply chain vendors was low.

Table 5 Interview Completion Percentage by Awardee Type, Commercialization Phase, and Participant Type

	Demonstration			Deployment			Subtotal		Total
Type	Awardee	Non-awardee	Total	Awardee	Non-awardee	Total	Awardee	Non-awardee	
SCV	100%		100%	17%	100%	55%	29%	100%	58%
OEM	100%	100%	100%	100%	67%	78%	100%	71%	86%
SI				100%	33%	60%	100%	33%	60%
EU	50%		50%	25%	38%	32%	29%	38%	33%
R&D							100%		50%

The completion percentage for end users was approximately 33 percent. End user response was adequate but not at the levels expected and in most cases did not benefit from the interviewers visibility within the FC industry because end users were in other industries. The low response rate was attributable to awardee and the awardees partners who declined to be interviewed. Equipment reliability issues that detracted from the overall FC systems implementation outcome may have made some awardees reticent to expose weaknesses in early market products for fear of unduly influencing financial support and adoption efforts.

The high level of participation of OEMs provided adequate information on the SI role and status thereby compensating for the lower SI participation level. Overall, the systems integrators' role in MHE was relatively standard across the industry and was more than adequately represented by those interviewed. For BUP, the somewhat diffuse role of systems integrators was covered in interviews with Ericsson (an engineering services provider to Sprint), the OEMs, and related end users. Overall, the few SIs who participated were important and adequate to understand the overall MHE and BUP markets for FC systems, along with the SIs' present and future role in the industry. The SIs provided similar responses in the interviews to similar questions and the later interviews just confirmed earlier results. Systems integrators did perform a role in qualifying their MHE trucks as capable of operating with a FC system early in the introduction phases of this technology.

While the overall number of completions is smaller than originally expected, it is unlikely that the lack of completions would have changed the major conclusions and recommendations of the study. There were few new pieces of data and information on the overall market that emerged after about the 20th interview. Secondary sources of information were used to fill some of the gaps.

3.5 Complete an Evaluation Plan for Review and Approval by Peer Review Team

The Evaluation Plan was completed on April 18, 2012, reviewed by the peer review team, modified, resubmitted to the peer review team, approved by the peer review team, and finalized before beginning the in-depth interviews of awardees and non-awardees. This report represents the work that was completed following the Evaluation Plan.

3.6 Collect Primary Data

In-depth interviews were conducted with end users, OEMs, systems integrators and others over the period from August 2012 to January 2013. There were two main tasks: developing interview guides and conducting the interviews.

3.6.1 Develop a Master Interview Guide and Interview Guides for Relevant Respondents

Nine interview guides, including guides for awardees, non-awardees, and non-users at the time of the ARRA-FCP projects were constructed. The guides were developed based on the metrics and measures identified in the previous tasks and then edited so that the topics were logically connected and that there was a flow so that more sensitive or more difficult questions appeared later in the guide. The questions in the guide were mostly open-ended although there were some sections that required specific quantitative answers. An example interview guide for the OEM awardees industry type is shown in Appendix F.

3.6.2 Conduct In-depth Interviews

The team deliberately chose to conduct in-depth interviews rather than survey because the interviews are particularly useful for gathering fact-rich data from small populations where the existing knowledge about the players and their activities is limited and where in-depth information about actions, perceptions, motivations, decisions, and reasons for decisions is needed.

As described in the evaluation plan, the in-depth interviews were to be conducted on site with a second interviewer connected by conference phone taking notes. However, because of resource constraints, the interviews were conduct by telephone. At each call, one member of the team conducted the interview and the second member took notes. During the session, the notetaker might ask for clarification or ask a follow-up question.

Following the interview, the notetaker produced a formal set of interview notes. The person who conducted the interview reviewed them, and then the notes were sent to the respondent for his or her review. A transcription service was used to produce the notes for the last few interviews. In most cases, requests for additional data or clarification of points made during the interview were included when the notes were sent to the respondent for review. Only in very few instances did any of the interviewees respond in writing to the request for numerical data related to product sales, costs and revenue, and new or retained jobs resulting from their participation in the ARRA-FC projects. A few respondents returned minor edits.

The evaluation plan called for the DOE FCTO to send an introductory letter or make a call informing candidate interviewees about the evaluation and asking for their cooperation. This was important for establishing the legitimacy of the interview. When this was not possible, the team deferred to other methods to establish contacts for an interview.

The evaluation team sent an introductory letter to the candidate interviewees. The letter introduced the team, explained the importance of the evaluation to DOE, provided a list of topics for the questions to be posed, asked the candidate interviewee for his or her cooperation, and explained that he or she would be contacted by e-mail or telephone to answer questions and schedule an interview. Within a day or two, a member of the team followed up on the communication to encourage participation, describe the interview procedure, and schedule a time and place for the interview. Respondents were told that the interview would be in-depth, not a survey, voluntary, and confidential. Information used in the report would be presented in a way that would shield respondents' identity.

The team member scheduling the interview sent an e-mail confirming the date and time of the interview and provided a list of 10 to 15 topics to be covered in the interview. Interviewees were encouraged to include others from their firms or organizations in the interview if they felt that would aid in providing detailed information based on the topics for discussion provided ahead of the interview.

Interviewees were encouraged to include colleagues when that made sense. When the interviewee agreed, the interview was recorded. Only one interviewee declined to have the interview recorded and the recording feature was disabled. The interviewees were told that they were under no obligation to respond to specific questions.

All of the interviews were quite cordial. Most respondents were very frank and open and provided clear narratives. A few interviewees placed certain information off limits. Attempts to collect quantitative information were not as productive as the team had expected. Most commonly, this was because respondents did not have the quantitative information at their fingertips or were uncertain about the information because it was held by someone else in their firms. Attempts to collect additional quantitative data by providing easy to complete blank tabular formats through written follow up were generally not successful.

3.7 Analyze the Primary and Secondary Data

The analyses of the primary and secondary data were initially done separately, and then evaluated collectively to fill in gaps in data, to find comparative data, and in some cases, to identify and resolve areas of inconsistency.

3.7.1 Primary Data

The analysis of the interview data was handled as follows. Each member of the evaluation team reviewed all of the notes. The person responsible for the interview was also responsible for completing a summary of the interview. Summaries contained two sections, a bulleted section of general findings and a bulleted section that identified findings related to specific metrics and measures. The general findings section identified larger picture contributions that were broader than the metrics and measures, or unrelated. The findings related to specific metrics and measures allowed the team to identify supportive and inconsistent data by application, industry type, individual entity, and metrics and measures across the various interviews. This facilitated the construction of a detailed outline. It also facilitated bringing the findings together in a coherent manner by grouping common themes across applications and respondents. The outcomes differed by application and by industry type. Using the summary points also allowed the members of the team to reach back to the relevant field notes to capture additional detail and nuance when writing the report.

3.7.2 Secondary Data

Quantitative data were collected from NREL CDPs, articles from FC 2000, presentations at the DOE's annual merit reviews, presentations from other conferences, extensive internet searches for press releases, SEC filings, and other sources. These data were meticulously reviewed and then organized to develop historical trends for demonstrations and deployments of MHE and BUP FC systems including the number of units shipped, replications, and emulations. Once the data were in tabular form, they were organized to provide high-level summaries for the pre ARRA-FCP period, the ARRA-FCP period, and the post ARRA-FCP period. These were then correlated with the primary data in order to interpret the trends.

3.8 Attribution

The key objective of the evaluation was the determination of early-stage market effects that are specifically attributable to the ARRA-FCP projects. With this in mind, the logic models, the metrics and measures, the interview guide, and the analysis of the FC system OEM market strategy were developed to assess the market effects of the ARRA-FCP projects.

A randomly controlled experiment was not possible because the awardees were selected for specific reasons rather than randomly assigned. Further, because the study was dealing in small populations sampling, except potentially for end users, random selection was not an option. Quasi-experimental designs using matching or other techniques were also precluded. There were only four FC system OEM awardees producing FC systems for MHE or BUP applications whose products were in the deployment phase. There were potentially three or four other OEMs that were developing similar FC systems whose systems were not yet at or near commercialization. Thus, it was not possible to construct a suitable comparison group or to use matching or other comparison techniques.

In addition to straight forward questions about what motivated the decision to invest in FC systems, the study focused on understanding the timelines of events of individual firms, namely, to determine if the decision was made pre, during, or post, ARRA-FCP. Further, the evaluators asked counterfactual questions in multiple ways within the interviews, such as, would your firm have purchased units or developed the technology in the absence of ARRA-FCP funding or tax incentives? When possible, these were triangulated with other types of questions, such as, would the units have met your ROI criterion without the tax incentive or, were there other reasons that contributed to the decision? With respect to the latter example, a firm might respond that they had a policy of promoting sustainability and they were willing in such cases to accept a lower ROI. Most of these responses were discussed with the interviewees in some detail. By integrating the information from the direct question, the timing question, the counterfactual response, the decision criteria, and the event data, it was possible to discern what drove the decision. For example, one of the ARRA-FCP awardee companies flatly stated that its decision to use MHE FC systems preceded the receipt of funding. However, this does not preclude the possibility that they were influenced by knowledge of the ARRA-FCP projects and upcoming funding. Participating in the FOA, as the aforementioned firm did, meant that ROI calculations would have been done and those calculations might have persuaded the firm that purchasing MHE or BUP FC systems made economic sense. The experience in calculating ROI for the FOA provided experience that may have transferred to other end users who would rely on the tax incentives.

There was comparative data between an awardee OEM and a non-awardee OEM that were similar with respect to product, market size, and commercialization phase in the MHE application to provide some hints as to what might have happened in the absence ARRA-FCP funding. The non-awardee did not receive ARRA-FC funding, and it wasn't until a later NREL award that the firm's sales began to grow. In the absence of the NREL funding, the non-awardee may not have been as aggressive in pursuing customers as the awardee. The total number of end users of FC systems for Class 1, 2, or 3 MHE was about 50, some of which had only evaluated one or two FC-powered MHE units for a few weeks several years prior to the ARRA-FCP funding. The situation with FC-powered BUP was similar, but the number of end users was smaller, probably fewer than ten. The limited number of end users precluded the more traditional methods of broadcast surveys.

3.9 Quality Control Procedures

Quality control was built into this study at all stages of the evaluation.

- The team developed a substantial evaluation plan that was reviewed by an external peer review team.
- The team used market and logic models to build a systematic understanding of the markets.
- The team generated metrics, measures, and research questions based on the market and logic models.
- Based on the metrics, measures, and research questions, the team developed interview guides for each industry type to be interviewed.
- Each member of the team reviewed the guides.
- The team aggressively sought interviews with all identified candidate participants. As many as ten to 12 attempts were made to contact each candidate respondent by telephone or e-mail. Respondents were only dropped from data collection activities when they declined to participate, or did not respond to the many attempts to secure their participation.
- All interviews were based on an interview guide.
- All respondents were asked if the interview could be recorded to ensure the accuracy of the data collected, and all but one responded in the affirmative.
- All interviewers took the online Human Subjects Committee training session provided through LBNL to ensure a common understanding of quality and consistency in the data collection.
- Field notes were produced and both the interviewer and the notetaker reviewed the notes.

- In most instances the notes were compared to the recordings.
- The field notes were sent to the respondent who had the opportunity to correct the notes.
- The interview notes were summarized and the findings organized by application, industry type, and general findings and metrics.
- An outline was developed and reviewed with LBNL to guide the analysis and writing of the draft report.

4 Findings and Analysis: Deployment Phase – Material Handling Equipment

The ARRA-FCP projects for MHE were intended to accelerate the commercialization and deployment of these FC systems and the related FC manufacturing, installation, maintenance, and support services. In pursuit of these objectives, close to $10 million of ARRA-FCP funds, matched by $12 million in awardee funding, were directed toward the commercialization of FC products in the MHE market.

The high-level objectives of the ARRA-FCP for MHE FC systems were to increase the number of units available to end users thereby increasing their understanding of the technology value and benefits and from there to encourage additional purchases of FC systems outside of ARRA-FCP funding. It was also anticipated that spillover benefits of the ARRA-FCP would include increased investor confidence and convince supply chain vendors of the growth potential and sustainability of the fuel cell markets in MHE and BUP.

MHE end user customers are principally involved in the warehousing, distribution, and storage industries. MHE is commonly divided into three classes. Figure 4 shows equipment typical of Class 1 (forklifts), Class 2 (lift jacks), and Class 3 (pallet Jacks).

Figure 4 Equipment Characteristics of MHE Classes

The onboard hydrogen storage is typically adequate for an eight-hour shift at full operational capacity. A significant benefit of FC systems is that the fuel tank can be refilled in a few minutes by the operator—typically once during each shift or when it is convenient, as compared to the hours required to fully recharge a lead acid battery.

To determine the success of ARRA-FCP funding in stimulating the early market and accelerating the commercialization of FC products, it is important to see a change in certain key metrics, such as units sold, product value (related to emulation and replication), and end user satisfaction.

The secondary and primary data presented here have been collected from a number of different sources and thus are disparate in nature. Analyzing these different pieces and then collecting the information in a set of summary charts reveals their significance in assessing the early market impact of the ARRA-FCP. For example, secondary data on maintenance mean time between forced outages were collected by the NREL as part of CDP report preparation that collects field data on FC systems operation. These data helped fill in some of the voids where interviewees declined or were unable to provide information.

4.1 Unit Sales of MHE Trucks

There are approximately 800,000 forklifts running on a variety of fuels in operation in the North America as of 2010 according to data from the Industrial Truck Association (ITA). Based on ITA data for 2010, the total factory sales for Class 1, 2, and 3 MHE trucks in North America was 92,326 units.[15] ITA data indicated that there were 1,000-1,500 MHE FC systems operating in the field in 2010. Thus, the introduction of approximately 1,000 FC-powered MHE trucks represented about a one percent market share of annual MHE truck sales and 0.125 percent of units in operation in North America. Although unit sales of MHE FC systems were just a small percentage (less than 1.5 percent) of total MHE truck sales in 2010, it is instructive in understanding the overall market for MHE FC systems to observe truck sales before, during, and after the ARRA-FCP funding period. Figure 5 shows that the total Class 1, 2, and 3 MHE truck sales in North America ranged between 57,000 and 109,000 units between 2004 and 2011.[16]

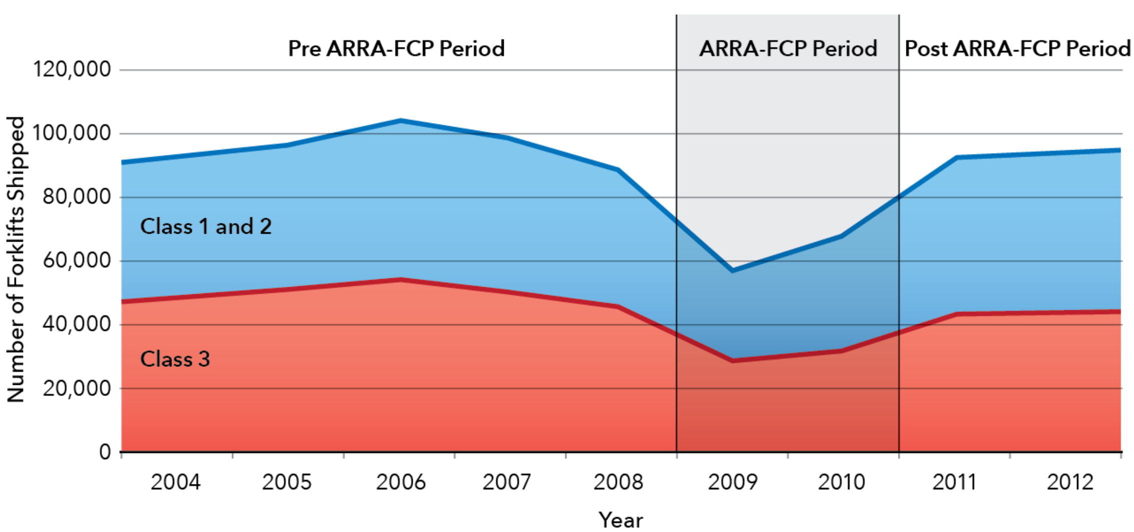


Figure 5 Combined Shipments of North American Classes 1, 2, and 3 MHE Trucks from 2004 to 2012

15 J. Rufener, "Presidents' Forum," Alliance of Industrial Truck Organizations, Palm Beach, Florida, 24 September 2011.

16 L.K. Rogers, "Top 20 lift truck suppliers, 2012," Modern Material Handling, August, 2012. The data for 2011 and 2012 are based on estimates using data from, J. Moran, "Alliance of Industrial Truck Organizations, President's Forum," Kyoto, October 2012.

4.2 MHE FC Units Demonstrated and Sold in the Pre ARRA-FCP Period (2004 – 2008)

Prior to the development of FC systems for MHE, the market was dominated by lead-acid battery and propane powered systems. Table 6 shows the population of demonstrations and deployments of MHE FC systems in the pre ARRA-FCP period.[17,18] Nine of these were demonstration projects.[19] With one exception (ACE Hardware), the demonstrations occurred before 2008. In addition to the demonstrations, there were five larger scale deployment efforts, the most notable of which were the two deployments totaling 165 units to Central Grocers and deployments by Wal-Mart in Washington Court House, OH, and Smyrna, TN. The demonstrations and even the deployments served as a test bed for the equipment and began to acquaint end users with the potential of MHE FC systems. The success of these field trials and demonstrations helped to establish a basis for the ARRA-FCP MHE deployment projects.

The FC system OEMs—Cellex, Nuvera Fuel Cells Inc. (Nuvera), Plug Power Inc. (Plug Power), Oorja Protonics (Oorja), and Hydrogenics Corporation (Hydrogenics)—were the dominant FC system OEM companies participating in these demonstrations and deployments. Activities varied in scale but generally were demonstration conducted for the purpose of exhibiting the FC-powered MHE capabilities lasting between two weeks to several months for prospective end users, but did not represent commercial sales of FC-powered MHE, as compared to the larger deployments. There were cases, for example, where two units were delivered with no further units ordered.

Wal-Mart participated in a very early field trial conducted in 2002 by Cellex, a Canadian corporation purchased in 2007 by Plug Power, and by Plug Power itself. In a short two-week trial in mid-2005, Cellex and Wal-Mart, working with Crown Equipment Corporation, produced and evaluated four FC-powered Class 3 trucks at a Wal-Mart Ohio-based food distribution center.[20] Based on the success of the initial trial, Wal-Mart expanded to the evaluation of 69 Class 3 MHE FC systems from Cellex at two separate Wal-Mart distribution centers, 14 at one facility, and 55 at another facility during a two-year period in Ohio. The trials lasted for four months and the units logged over 18,500 hours of operation, which included 2,100 indoor hydrogen fueling events performed by MHE operators.[21] During the program over 100 employees from Wal-Mart and OKI Systems (a system support company) were trained to provide service and maintenance support. Data were collected on the operation of the FC systems and hydrogen fueling system to provide inputs for ROI analyses and assess product safety, reliability, and performance.

[17] Data for MHE FC system presented in this report reflect information collected from awardees and disparate sources with different definitions of sales and orders. The sequential steps in a typical procurement process (customer to supplier) include: purchase order or order, contract, internal sale, manufacture, delivery, installation, commissioning, and sale (money transfer). The timing for these steps varies in each situation and may be several months. The terminology used in typical public information releases is generally a mixture of orders, sales, deliveries, and installations without clear distinction. For the purpose of this study, all these categories are termed sales and attributed to a time period that is accurate within a few months.

[18] Within Table 6, only Plug Power received later ARRA-FCP funding.

[19] Within this report, a demonstration is defined as field operation of up to and including 10 FC systems at a site generally for a short period of time while deployment refers to more than 10 units.

[20] HighBeam Research, *Cellex Completes Fuel Cell Field Trials at Wal-Mart Subsidiary*, July 27, 2005. Available at time of press at http://www.highbeam.com/doc/1G1-134599241.html

[21] CellexPower, *Powering Business in Ohio with Cellex Fuel Cells*, February 7, 2013. Available at time of press at http://www1.eere.energy.gov/hydrogenandfuelcells/education/pdfs/cellex_report_odod.pdf

Table 6 Demonstration and Deployment Sales in the Pre ARRA-FCP Period

End User	OEM	2005	2006	2007	2008
Wal-Mart					
Missouri	Cellex	4			
Washington Court House, OH	Plug Power			55 Class 3 trial	
Grove City, OH	Plug Power		14 Class 2		
Central Grocers	Plug Power				220 Class 3
GM Canada	Hydrogenics	2 5,500 lb Hyster			
ISOLA Laminates	Hydrogenics			2 LiftOne 2 wk trial	
Leigh Fibers	Hydrogenics			2 LiftOne 2 wk trial	
Michelin	Hydrogenics			2 LiftOne 2 wk trial	
Ozburn-Hessey Logistics	Ballard	5 Class 3, pallet jack			
PBR	Hydrogenics			2 LiftOne 2 wk trial	
Ace Hardware, Sacramento CA	Plug Power				6
Nissan North America	Plug Power			9 3-4 week trial	
Smyrna, TN	Oorja				60 Class 3
Bridgestone-Firestone	Plug Power				23
Raymond Corp	Plug Power HydrogenicsNuvera			Prototype tests	

While the Wal-Mart trials were much more extensive than most, the progression of purchases exemplifies end users trying and experiencing the value of FC-powered MHE relative to their incumbent technology and continuing on to purchase larger fleets. It is a pattern that is replicated by other end users in later years, principally large firms with multiple facilities, as companies recognized the potential of this emerging market.

4.2.1 Overview of MHE Technology Development in the Pre ARRA-FCP Period (2004 – 2008)

At the time of these early demonstrations, the commercial use of FC technology in MHE was driven by the following end user identified limitations in the application of industrial lead acid battery technology:

- Reduced operational efficiency due to typical discharge times of four to eight hours and recharging plus cooling times in excess of eight hours;
- Large distribution centers deploying between 100 and 250 lift trucks, each of which required a dedicated charger and two to three spare batteries per MHE truck to minimize operational downtime; and
- Storage of spare batteries and charging units that occupied valuable warehouse space and required high voltage electrical infrastructure.

The MHE FC systems in the demonstrations operated without any safety incidents and were able to be refueled by the MHE truck operators in less than two minutes compared to a battery change out that can take six to 12 minutes, depending on the size of the battery and the design of the MHE truck. Wal-Mart's Executive Vice President of Logistics and Supply Chain, Rollin Ford, noted that the FC products provided operational benefits while also allowing Wal-Mart to further its environmental leadership.[22] The FC-powered MHE also ran longer than batteries while maintaining consistent power delivery. The rapid refilling of the hydrogen fuel tanks also provided greater overall productivity relative to batteries that have to be changed out, and typically take four to eight hours to be fully recharged.[23] This latter feature was beneficial to MHE operators who noted that the FC-powered MHE were able to maintain top speed and power at all times, thereby increasing operator productivity.

While the initial trials appeared to be very successful, there were issues with FC system durability, high initial capital costs, and deployment and cost challenges associated with hydrogen infrastructure and fueling costs. The U.S. Department of Defense supported a project by Ballard and Cellex (then owned by Plug Power) to reduce FC system capital cost and to further demonstrate capability of the cost reduced technology.

In early 2007, Bridgestone Firestone North American Tire LLC began a FC system trial with General Hydrogen, which was acquired that year by Plug Power, to evaluate the technology in its MHE fleet. Following the success of the trials, Bridgestone Firestone undertook to install FC systems in 23 forklifts in 2008 and this effort continued into the ARRA-FCP period when another 20 MHE FC systems were purchased as a "green initiative."[24]

During the pre ARRA-FCP demonstration period, MHE truck manufacturers and systems integrators, like Yale Materials Handling, Raymond, and Crown, began to take an increasing interest in FC technology. They participated in the demonstrations shown in Table 6, which led to their assessment of FC systems as a power source for many models of their commercial MHE applications. Raymond received a New York State

[22] Walmart, *Cellex Successfully Completes Hydrogen Fuel Cell Field Trials at Wal-Mart Distribution Center*, July 25, 2005. Available at time of press at http://news.walmart.com/news-archive/2005/07/27/cellex-successfully-completes-hydrogen-fuel-cell-field-trials-at-wal-mart-distribution-center

[23] Forklift Action, *Cellex Power Products to Trial Hydrogen Fuel Cells at Wal-Mart*, May 27, 2004. Available at time of press at http://www.forkliftaction.com/news/newsdisplay.aspx?nwid=1489

[24] Forklift Action, Bridgestone Firestone creates all-hydrogen fleet, April 10, 2008. Available at time of press at http://www.forkliftaction.com/news/newsdisplay.aspx?nwid=5486

grant in 2006 to help with the installation of hydrogen infrastructure into its green manufacturing site creating a laboratory to assist in its evaluation of FC systems and optimization of these power systems from the three main suppliers of FC systems with its MHE trucks The FC system OEMs had a productive relationship with MHE truck manufacturers that conducted much of the work to unite the FC system with the forklift. Plug Power and Nuvera collaborated with Crown Corporation and Raymond Corporation on various initiatives during the pre ARRA-FCP period to deliver FC-powered MHE to end users.

In 2008, Crown received funding from Ohio's Department of Development to develop testing and specification capabilities for MHE FC systems. The Ohio-supported Crown effort extended into the ARRA-FCP period, and by 2011 Crown had qualified close to 30 combinations of FC systems with its line of MHE trucks offering a broader selection to its customer base. Based on these development activities, Crown concluded that it is important to have each forklift and FC system combination qualified to ensure optimum performance, efficiency, and safety characteristics for the end user's specific operations. Further, it was concluded that FC-powered MHE was particularly advantageous when the end user ran a three-shift, high-duty cycle operation, with a fleet size of 15 units or more and planned to convert all existing or new MHE trucks to FC systems.[25]

In 2008, Plug Power formed alliances with Crown Equipment and Raymond Corporation for FC systems distribution in their MHE trucks and for further related product development activities.

The fuel suppliers Air Products and Linde are essential entities in driving growth in the FC-powered MHE market and in increasing end user confidence. During the pre ARRA-FCP funding, the small number of MHE FC systems sold meant that the demand for hydrogen was small and, as shown in Table 6, the geographical spread of end users was large and expensive to service. These conditions did not support significant investment by the fuel suppliers.

Plug Power's acquisition of Cellex and General Hydrogen as well as an exclusive FC stack supply agreement with Ballard Power Systems starting in 2008 positioned the company as the leading supplier of MHE FC systems in North America. As such Plug Power was in an excellent position to take advantage of the ARRA-FCP funding in early 2009 and facilitate the stated objectives of the program. While other OEMs did participate in the ARRA-FCP, more than 85 percent of the intended deployment of MHE FC systems was achieved through Plug Power.

During the pre ARRA-FCP period, the federal government promoted the development of FC technology and this was concurrent with an increase of the tax credit available under the Emergency Economic Stabilization Act of 2008 to $3,000 per kilowatt, or 30 percent of the unit price, whichever was less, and also extended the expiration date of the tax credit to 2016.[26]

While field trials continued to take place with a growing number of end users, the overall unit sales growth was slow. An important benefit of pre ARRA-FCP demonstration and deployment activity was increased understanding of the technology by MHE manufacturers and end users. The demonstrations accelerated the understanding of the end user requirements for a MHE FC system to OEMs and SCVs.

---

[25] Forklift Action, Crown builds 500th forklift designed for fuel cells, October 5, 2011. Available at time of press at http://www.forkliftaction.com/news/newsdisplay.aspx?nwid=10488

[26] Forklift Action, Fuel cells make progress in forklift world, December 18, 2008. Available at time of press at http://www.forkliftaction.com/news/newsdisplay.aspx?nwid=6557

4.3 MHE FC Units Demonstrated and Sold in the ARRA-FCP Period (2009 – 2010)

ARRA-FCP funding to accelerate FC commercialization in MHE applications was very timely and beneficial given the general downturn in the American economy that began in September of 2007, and the downturn's resultant negative impact to key players in the industry. The seriousness of the decline is evident in Figure 5, where shipments of MHE trucks had declined by more than 40 percent between 2006 and 2009. However, the magnitude and broad-based nature of the economic downturn and its impact on corporate spending, especially on technologies that remain to be fully proven and are more costly than incumbents, may have diluted the full potential effect of the ARRA-FCP funding during 2009 and 2010.

FC-powered MHE has advantages when deployed in greenfield facilities, where all the MHE is powered by FC systems and no expenditures or write-offs for batteries or battery charging infrastructure is required.[27] Historically, in times of economic downturn, firms invest in upgrading existing plant and defer new plant expenditures. Very few companies were willing to open new facilities during the peak of the recession which overlapped closely with the ARRA-FCP funding period. Some interviewees stated that work started as a result of ARRA-FCP funding may lead to the adoption of FC systems in MHE as the recovery from the recession progresses and companies start to invest in new warehousing and logistics facilities construction.

During the ARRA-FCP period, there were deployments with and without ARRA-FCP funding. These are discussed separately in the following sections.

4.3.1 Deployments with ARRA-FCP Funding

Table 7 depicts the sales of 504 (does not include seven temporary rental units) FC-powered MHE to the four ARRA-FCP awardees and seven end users. GENCO, a third party supply chain logistics firm, was responsible for supplying and managing the FC-powered MHE for five end user companies: Coca-Cola, Kimberly Clark, Wegmans, Whole Foods Market, and Sysco Philadelphia. As well, Sysco applied for and received ARRA-FCP funding for its Houston facility separately from the GENCO award. Sysco also received a $500,000 award from the State of Texas for a hydrogen fueling system at that facility. FedEx and HEB Grocery were the other two end users. These firms may have received tax incentives and other awards that were not identified by the research. There was a fifth award to Anheuser-Busch in Fort Collins, Colorado, but the firm rejected the award based on a cost benefit analysis that showed that the matching funds would be better spent on other efficiency opportunities with a higher payback.[28] These firms may have received tax incentives or other awards that were not identified by the research.

GENCO, Sysco, and FedEx used Plug Power FC systems while Nuvera, with HEB as its end user, used its own FC systems. FedEx converted existing battery units to FC-powered MHE. All three classes of FC-powered MHE were used in these deployments, although the systems that were supplied were at different stages of development with FC systems for some classes having more operational experience than others.

Seven of the eight ARRA-FCP participating end users made first purchases. The exception was Kimberly-Clark that had tested two units in 2007. The ARRA-FCP sales were reported in 2010 but the delivery dates for the FC-powered MHE were spread over 2010 and 2011.

---

27 In the context of this report, greenfield sites have not previously used MHE or BUP and brownfield sites are existing sites that have previously installed and used MHE or BUP FC systems.

28 Barloworld Handling. *OorjaPac Direct Methanol Fuel Cell Presentation*. Available at time of press at http://www.slideshare.net/leerts/new-oorja-presentation

Table 7 ARRA-FCP Funded MHE Deployment Sales in 2010 (ARRA-FCP Period)

Awardee	End User	First time acquisition?	FC System Sales & Type[a]		Notes
GENCO with Plug Power FC systems	Coca-Cola	Yes	40	Class 1	Reported for 2011
	Kimberly-Clark	No	25	Class 1	
	Wegmans	Yes	36	Class 2	Standup
			100	Class 3	50 Crown Pallet
	Whole Foods Market	Yes	45	Class 1	Stand up
			14	Class 2	
			2	Class 3	
	Sysco Philadelphia	Yes	25	Class 2	
			70	Class 3	
Sysco Houston		Yes	26	Class 3	
			72	Class 3	Does not include seven temporary rental units
FedEx		Yes	35	Class 1	Converted
Nuvera FC systems	H.E.B. Grocers	Yes	14	Class 2	

a Where different unit values were found in the literature, values from presentations presented at the 2012 Annual Merit Review (AMR) were used.

4.3.2 Deployments without ARRA-FCP Funding

Table 8 displays the fourteen organizations that purchased an additional 673 units of MHE during the ARRA-FCP period without ARRA-FCP funding. As such, 61 percent of the total units placed during the ARRA-FCP funding period were purchased without ARRA-FCP funds.

Wal-Mart replicated purchases in 2007 and 2008 (pre ARRA-FCP), respectively. The remaining 12 firms made first time acquisitions. While these sales did not have funding support from ARRA-FCP, they were eligible for federal tax incentives and, in some cases, state funding. There is no direct evidence that these firms were influenced by the ARRA-FCP funding, but they could not have helped but be influenced by the heavy marketing activity in the pre ARRA-FCP period that was driven in part by the tax incentives and the FOA. In addition, the DOE's issuance of the FOA helped to legitimize the technology.

Oorja Protonics was active during the ARRA-FCP period placing 230 Class 3 MHE FC systems with six firms. Oorja was the intended supplier for Anheuser-Busch and would have received ARRA-FCP funding if Anheuser-Busch had not rejected its award.

Table 8 MHE Deployments Financed through non ARRA-FCP Sources during ARRA-FCP Period

End User	First Time Acquisition?	2009	2010	OEM
Nestle Waters	Yes	32		Plug Power
Super Store Industries	Yes	75		Oorja
United National Foods Inc.	Yes		65	Plug Power
U.S. Food Service	Yes		40	Oorja
Wal-Mart Canada	No		95	Plug Power
Fedex	No		5	Plug Power
BMW Manufacturing	Yes		86	Plug Power
Defense Logistics Agency	Yes			
Warner Robins	Yes		20	Hydrogenics
Susquehanna	Yes	20	15	Nuvera/Plug Power
Susquehanna	Yes	20		Plug Power
East Penn Manufacturing	No	10		Nuvera
Nissan North America	Yes	60		Oorja
Ozburn-Hessey Logistics	Yes		20	Oorja
Sysco				
Canton, MI	Yes		45	Plug Power
Grand Rapids, MI	Yes	30		Plug Power
Testa Produce	Yes		20	Oorja
Martin-Brower	Yes		15	Oorja

4.3.2.1 Oorja Protonics—a Direct Methanol Fuel Cell System Solution for MHE

Oorja Protonics is the only OEM MHE FC System supplier still in operation in the post ARRA-FCP period and directly competes with Plug Power in a portion of Plug Powers' market. Discussion of their history and status is included to provide the basis for a comparative of a non ARRA-FCP funded company, Oorja, with an ARRA-FCP funded company, Plug Power.

Oorja Protonics received a small amount of DOE funding through a subcontract from NREL that was awarded in February of 2011 after the bulk of ARRA-FCP related MHE deployments were well established. This DOE funding to Oorja was not part of the ARRA-FCP activity. The effort with Oorja was initiated to help secure additional orders and engage new end users in the deployment of the company's direct methanol FC (DMFC) systems for application in Class 3 forklifts, the OorjaPac Model 3 DMFC system. The product had a power output of 1.5 kW and was fueled by a 12-liter methanol tank that provided 20 kWh of electrical output per tank providing up to 14 hours of grid independent operational time.[29] It should be noted that none of these end users had experience with hydrogen fueled FC systems so a direct comparison of the differing FC technology capabilities was not possible.

29 OorjaPac Model III datasheet.

The Oorja FC system offers end users an alternative option to capture the advantages of FC-powered MHE relative to battery systems. However, at present Oorja only has a product offering for Class 3 forklifts. The company expects to roll out Class 2 compatible FC systems sometime in 2013.

A challenge for Oorja is that it uses many different components both in the stack and in the BOP than those used in more conventional hydrogen-fueled FC systems. This limits leverage across applications and other supply chain concerns including cost issues that could limit adoption of the direct methanol-based technology in the broader MHE market. DMFCs are well known for the use of larger quantities of expensive platinum catalyst. Significant R&D will be required to reduce these quantities to the levels now more common in hydrogen-fueled FC systems.

Like the hydrogen-fueled FC system, the Oorja FC system only takes as few minutes to attach to the MHE, sitting on top of the battery pack of the Class 3 forklift. Even though the Oorja FC system does not provide primary power *per se*, it still fully qualifies for the federal tax break for FC system purchases. Until recently, Oorja has been the sole interface in all matters of sales, service, and maintenance directly with the end user having no formal relationship or involvement with the MHE manufacturers. More recently, Oorja has formed relationships with various MHE manufacturing distribution units, with these entities recommending the use of Oorja products to their customers in some cases.

Non ARRA-FCP funding from DOE through NREL allowed Oorja to deploy more products over a shorter period of time which resulted in more customer feedback, which in turn allowed Oorja to redesign its product to provide better reliability and fewer maintenance issues with related life cycle cost savings to the end user.

Use of the Oorja FC product involves fewer approvals since most facilities were already qualified to store and dispense flammable liquids on site. Methanol is not a well-known fuel for industrial use, but it does not have the same issues as hydrogen when it comes to community acceptance and fire marshal approval for use.

The challenge for Oorja and all FC system OEMs is whether they can bring down capital costs and offer reliable and low maintenance products over a period at least as long as the average three year lifetime of a lead acid battery. The relatively high initial cost of hydrogen infrastructure, which can be in excess of $1 million per site depending on the size of the fleet to be supported, and the cost of hydrogen fuel may end up with some end users favoring the use of Oorja's products. Oorja has published data that indicates that deployment of a 2,000 gallon UL-rated outdoor methanol storage facility would cost around $50,000 which they contrast to the cost of hydrogen fueling system at $1.5 million. For many end users the decision on what power system to use for their MHE will come down to a lifecycle cost analysis and ROI calculations with perhaps some premium applied to the FC systems relative to cost savings achieved through carbon credits and the deployment of a more environmentally friendly technology.

4.4 FC Units Deployed and Sold in Post ARRA-FCP Period (2011 – 2012 and beyond)

Table 9 depicts FC-powered MHE deployments in the period after ARRA-FCP. Twenty-one firms deployed MHE from 2011 through the first quarter of 2013. Ten of those were first time users. These data show that there were 1,687 units ordered in 2011, 1,301 in 2012, and 378 in the first quarter of 2013.

Table 9 Known MHE Deployment Sales after the ARRA-FCP Period

End User	First Time Acquisition?	Units in 2011	Units in 2012	Units in First Quarter, 2013
Associated Wholesale Grocers				
Kansas City	Yes	297		Plug
Pearl River LA	No		203	Plug
Ace Hardware (Wilmer, TX)	No			65
Baldor Specialty Foods	Yes		50 Oorja	
BMW Manufacturing	No		144 Plug	45 Plug
Central Grocers	No	11 Plug	3 Plug	
Coca Cola (San Leandro)	No	56 Plug		
CVS (Chemung, NY)	No		25 Plug[a]	
Defense Logistics Agency	No			
Fort Lewis	No	19 Plug[a]		
San Joaquin	No	20 Plug		
EARP Distribution	Yes	24 Oorja		
Golden State Foods	Yes	20 Oorja		
Kroger Co.	Yes	161 Plug	Number unknown	
Lowe's	Yes		161 Plug[a]	
Martin-Brower	No	NA Oorja		
Mercedes-Benz	No	Plug	72 Plug	123 Plug
Procter & Gamble	Yes	200 Plug	140	
Stihl Inc.	Yes	Plug	75 Plug[a]	
Sysco				
Riverside CA	No	80 Plug		25 Plug
Boston MA	No	160 Plug		10 Plug
Long Island NY	No	42 Plug		8 Plug
San Antonio TX	No	113 Plug		
Front Royal VA	No	102 Plug		
Houston TX	No	4 Plug		
Unified Grocers	No	200 Oorja		
Wal-Mart				
Cornwall ON	No	Plug	174	
Wash'n Court House OH	No	Plug	254	
Wakefern Food Corp	Yes	96 Plug		
WinCo Foods	Yes	82 Plug		102 Plug

a Plug Power lists these sales but timing and numbers have not been verified independently.

MHE FC system sales in the post ARRA-FCP period, funded entirely by end users, were 6.6 times the number of units funding by the ARRA-FCP. Slightly more than 16 percent of these sales were purchased by

Sysco, which had previously received ARRA-FCP funding and then purchased an additional 544 units at six sites in the post ARRA-FCP period.

The combined actual and planned sales for awardees and non-awardees of MHE FC systems, including before, during, and after ARRA-FCP from 2004 to the first quarter of 2013 was 4,920 units. The DOE data are reported through June 2012 while these data include the last half of 2012 and some units through the first quarter of 2013.

4.4.1 Examples of Effects of ARRA-FCP on End Users

The four most important metrics to the end user are product value, incentives for product purchase, acceptability, and community acceptance. Each of these metrics will be examined in the following subsections from the perspective of how the ARRA-FCP has influenced the end user. Then with this information as background the end user interview responses will be analyzed.

4.4.1.1 Product Value

Product value relates to the relative price of a product compared to other products and the value it provides in terms of productivity, reliability, and safety. The OEM generally determines the price based on the manufacturing cost, profit, and the price of competitive products.

With respect to the value of the product, two important benefits of replacing batteries with FC systems in MHE are fueling (or charging) cost and the cost of warehouse infrastructure. NREL reported operating cost was reduced by about 80 percent for refueling FC-powered MHE compared to battery powered MHE.[30] The annualized labor cost for battery charging is $6,000 compared to $1,100 per year for hydrogen fueling. Sysco Corporation, a company that has heavily invested in FC-powered MHE, reported that, "… the fuel cells should eliminate about 4,800 hours per year in battery recharging time" in their Houston facility that received ARRA-FCP funding.[31]

NREL also reported that when using FC-powered MHE, the cost of warehouse space dedicated to FC MHE refueling was only a quarter of that required for battery systems recharging. Coca-Cola recovered 2,000 square feet of facility space by removing the battery charging infrastructure from the warehouse during the ARRA-FCP period. Operation of FC-powered MHE in warehouse freezers is also identified as a benefit over battery powered MHE, although no quantitative benefit was identified.

Sustainability benefits are a growing component of financial performance.[32] One such benefit is carbon dioxide reduction achieved by reducing energy consumption and carbon footprint with high efficiency FC systems. Sysco reported a 19 percent reduction in kilowatt hour usage that translates into reduced carbon dioxide emissions.

As a Proctor and Gamble executive put it:

---

30 E. Delmont, J. Gangi, and S. Curtin, "The Business Case for Fuel Cells 2011," Fuel Cells, 2000.

31 Sysco Corporation, "Sysco 2010 Sustainability Report." Available at time of press at http://www.sysco.com/investor/onlinesustainabilityreport/index.html

32 S. Curtin, J. Gangi, and R. Skukowski, "The Business Case for Fuel Cells 2012", Fuel Cells, 2000; and K. Haanaes, M. Reeves, I. von Streng Velken, M. Audretsch, D. Kiron, and N. Kruschwitz, 2011 Sustainability and Innovation Global Executive Study and Research Project, MIT Sloan Management Review, 23 January 2012. Available at time of press at http://sloanreview.mit.edu/feature/sustainability-strategy.

> *Fuel cell forklifts can be a financially attractive proposition that increases productivity while helping us reach our sustainability vision. Our internal analysis shows that we cannot only achieve the sustainability benefits, but can also achieve an attractive rate of return on our investment at the same time. This is just another step on our environmental sustainability journey…*[33]

The product value for FC-powered MHE is obtained through operational efficiency increases, increased warehouse availability, and energy efficiency with increased sustainability benefits.

4.4.1.2 Incentives for Product Sales

The federal government subsidizes the purchase of FC systems under the ITC created under the federal Energy Policy Act of 2005. The Emergency Economic Stabilization Act of 2008 increased the incentive amount to 30 percent, or $3,000 per kW—whichever is lesser—and extended the credit through 2016. The American Recovery and Reinvestment Act of 2009 expanded these incentives.

- Hydrogen Fueling Facility Credit—Increased the hydrogen fueling credit cap from 30 percent or $30,000 to 30 percent or $200,000 through December 2010.
- ARRA Section 1603 Grants for Energy Property in Lieu of Tax Credits enacted as part of ARRA—Allows facilities with insufficient tax liability to apply for a grant instead of claiming the ITC or production tax credit through 2016. Only entities that pay taxes are eligible for a tax credit.
- Manufacturing Credit—Created a 30 percent credit for investment in properly used manufacturing facilities for FC components and other technologies through 2016.

Figure 6 displays the overall timing of MHE unit sales and government funding incentives including the ITC, the Emergency Economic Stabilization Act and ARRA for FC-related commercialization activity.

State incentives, such as development incentives for manufacturing facilities, increasing power generation efficiency, and reducing greenhouse gas emissions, complement the federal incentives for FC system purchases. State economic development programs also offer business grants, low interest loans, and tax incentives.

The following are examples of state incentives based on known MHE activities:[34]

- Texas (Sysco Houston). Texas has the Alternative Fueling Facilities Program that provides grants for 50 percent of costs, up to $500,000 to construct, reconstruct, or acquire a facility to store, compress, or dispense alternative fuels such as hydrogen.
- Pennsylvania (Sysco Philadelphia facilities operated by GENCO). The Pennsylvania Energy Development Authority provides grants up to $1,000,000 for alternative energy projects and research related to deployment projects or manufacturing. FCs are included.
- South Carolina (BMW Manufacturing). The Hydrogen and Fuel Cell Tax Exemption exempts from state sales tax devices, equipment, and machinery operated by hydrogen or FCs.

---

[33] S. Zenezini, Vice President, Procter & Gamble, "The Business Case for Fuel Cells 2012," p. 33.

[34] S. Curtin, J. Gangi, and R. Skukoski, "State of the States—Fuel Cells in America 2012," Fuel Cells 2000, September, 2012.

- Florida exempts the sale or use of hydrogen powered vehicles and related materials and hydrogen fueling stations from sales taxes, up to a maximum of $2 million in taxes per fiscal year in aggregate.

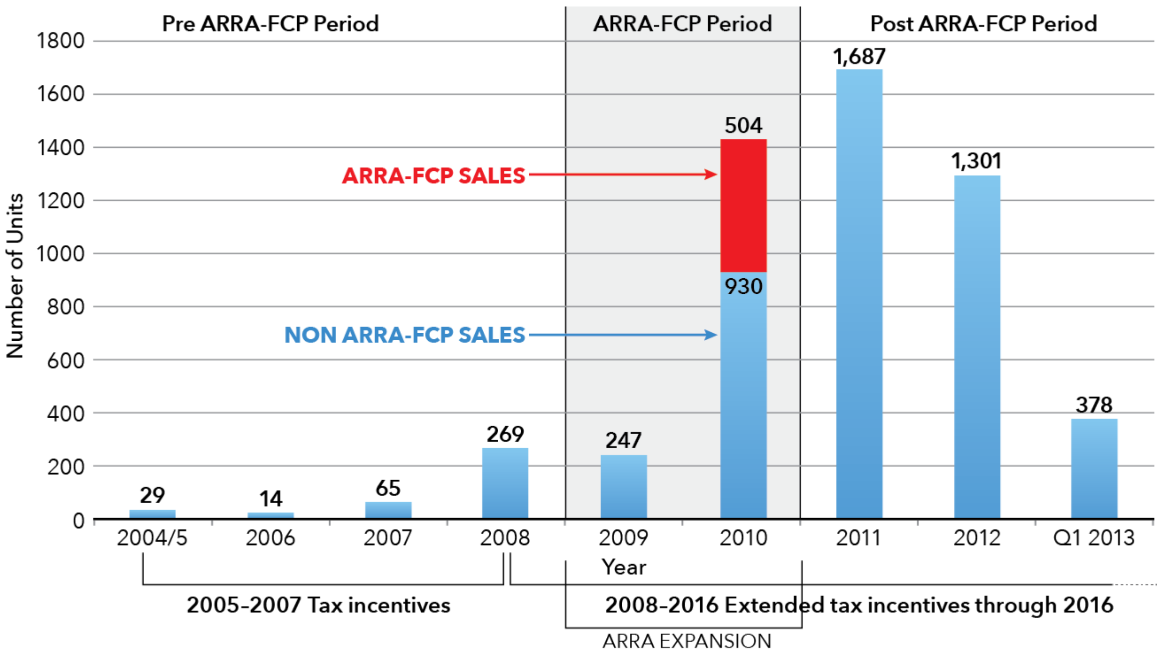


Figure 6 Incentives and Timing for MHE Sales

The combination of the federal and state incentives decreases the cost of ownership of FC systems by reducing the capital expenditures associated with the commercialization of FC systems and, in some cases, their related fueling infrastructure. These incentives increase the ROI (or shorten the pay-back period).

Ultimately to be sustainable and competitive, the manufacture and sale of FC systems must be able to survive in the market without such benefits and incentives.

4.4.1.3 Community Acceptance

An important issue for community acceptance of the technology is establishing a working understanding of FC systems and the hydrogen infrastructure with fire marshals and other permitting and regulatory officials. The DOE Hydrogen and Fuel Cells Program identifies streamlining and standardizing the permitting process as a high priority opportunity.[35] The DOE has active programs working to develop standards for hydrogen equipment, including FC systems. The DOE has established a web site that identifies model codes and standards to help local permitting officials deal with proposals for hydrogen fueling stations, FC systems use for telecommunication facilities, and other hydrogen projects. Many FC System OEMs, engineering service providers, and systems integrators have also established their own training and information seminars to facilitate understanding and acceptance from regulatory bodies. The

[35] S. Satyapal, "Hydrogen and Fuel Cells Program Overview," 2011 Annual Merit Review and Peer Evaluation Meeting, May 9, 2011.

primary observation from the evaluation is that permitting for hydrogen fueling does not appear to be a significant issue for MHE because warehouse facilities are found in industrial areas where there are facilities that use hydrogen and other volatile gases. When asked about siting a fueling facility, one respondent said that the local authorities were more concerned about placing shrubbery in front of the hydrogen storage container to make it less unsightly than about its risks.

4.4.1.4 End User Acceptance

Testimonials for companies purchasing FC-powered MHE without ARRA-FCP funding are reported by Delmont, et al.[36] The following are examples of testimonials from major companies.

> *Sustainability is a core component of our business at Coca-Cola, and we have a goal to be the beverage industry leader in energy conservation and climate protection. Converting to hydrogen fuel cell powered forklifts in our San Leandro facility represents one more step toward our commitment to reduce carbon emissions by 15 percent by 2020.*
> — Brian P. Kelly, Product Supply Leader, Coca-Cola Refreshments

> *Kimberly-Clark is constantly looking for innovative ways to minimize the impact of our operations on the environment. We are pleased to partner with GENCO ATC, Plug Power, and Air Products to help expand hydrogen fuel cell technology to our entire forklift fleet. This energy technology can reduce our carbon emissions by hundreds of metric tons per year, lower costs and drive efficiencies to power our operations.*
> — Rick Sather, Vice President of Customer Supply Chain at Kimberly-Clark

> *WinCo Foods appreciates the opportunity to utilize the GenDrive fuel cells (Plug Power) that will reduce our labor costs while powering our equipment in a more environmentally conscious way.*
> — Michael Read, WinCo Foods spokesman.

These testimonials and the sale of about 3,762 units since 2009 without funding support from ARRA-FCP is evidence of a high level of interest and acceptance among some end users.

4.4.1.5 Analysis of End User Responses

All end users reported that the ARRA-FCP funding contributed to their decision to purchase MHE FC systems for their warehouses and logistics facilities, which included both ARRA-FCP assisted purchases by some end users and purchases that were not part of the ARRA-FCP. At least two end users built greenfield facilities with the intent to operate only FC-powered MHE in these facilities. In such cases, the end users noted there were many additional advantages, the most significant of which was the decreased cost associated with having a single fueling solution and related infrastructure while maximizing the increased productivity benefits of FC-powered MHE. Such greenfield facilities did not have to bear the costs and complexity associated with operating both battery and FC-powered MHE. Plug Power has stated publically that greenfield facilities using their MHE FC systems can provide an internal rate of return with a payback of less than one year, a 15 percent increase in productivity and up to an 80 percent reduction in greenhouse gas emissions.[37]

[36] E. Delmont, J. Gangi, and S. Curtin, "The Business Case for Fuel Cells 2011", Fuel Cells 2000.
[37] J. Gangi, A Hussain, and J. Petrecky, "The Business Case for Fuel Cells 2012, Available at time of press at http://www.cleanenergystates.org/assets/Uploads/CESA-Business-Case-for-Fuel-Cells-Combined-Presentations-12.19.12.pdf

For the end user, the upfront high cost of hydrogen infrastructure is best amortized over a large fleet of FC-powered MHE FC systems and offset by corresponding reduced expenditure associated with battery storage and recharging infrastructure. One systems integrator noted that to warrant the use of installing infrastructure for the use of cryogenic hydrogen, a fleet of between 60 and 100 FC-powered MHE is required. To date, as noted by one fuel provider, the use of cryogenic hydrogen provides the least expensive per kilogram price for the fuel. However, fuel usage must be nearly continuous, *e.g*., round-the-clock operation, or the end user is losing fuel to boil-off. In some cases, the cost of hydrogen fuel was reported by end users as being comparable to the cost of electricity and even lower than electricity in states where the cost of electricity exceeded $0.10 per kWh.

Some end users were deploying battery and FC systems in the same facility. For those companies with a previous investment in battery systems, the combined use of both battery and FC-powered MHE at the same facility could be justified. The ROI advantages for end users of using FC-powered MHE, where they were operating both FC and battery technologies in the same location, were somewhat compromised due to the requirements of having both battery charging and hydrogen infrastructures in place to operate their combined fleet of MHE. It was noted that in some cases where the end user had already made a significant investment in providing the necessary infrastructure for batteries, especially in cases where automated battery change out equipment was installed or rapid battery chargers were available, the business case to introduce FC-powered MHE was more challenging.

The vast majority of end users experienced increased productivity from the use of FC systems. This was mostly related to very fast refilling of hydrogen tanks and constant power availability for lifting relative to longer downtime for battery change out and reduced power for lifting as the battery charge becomes depleted. As regards the environmental factors, the end user base had mixed perspectives. In some cases, the environmental friendliness, “green factor,” and sustainability benefits from using FC systems was cited by some end users as tipping the balance in favor of using these power systems relative to batteries. These firms generally had a strong corporate sustainability ethic. However, for other end users, the environmental benefits were deemed to be a negligible deciding factor in switching to FC-powered MHE.

Most end users reported concerns associated with maintenance issues, especially following the end of an initial one-year warranty period. The majority of issues resulted from software, balance-of-plant failures, and electrical problems, and in almost all cases the end users reported that the FC system OEM was responsive and quick to resolve problems as they arose to minimize downtime. Some end users were concerned about the high cost associated with parts replacement following the end of the warranty period. There were also instances at two or more end user sites where a full time maintenance person was hired to work to ensure the smooth operation of the FC-powered MHE fleet during the timeframe of the ARRA-FCP project. Also, one end user identified issues with FC systems start up in cold weather operation, but these were resolved through system improvement activities performed in conjunction with the OEM. In general, the nature of the maintenance issues was found to depend on which OEM’s FC system and which version of the system was being deployed. Of course, if part replacement becomes too frequent, the impact to lifecycle cost of the technology can quickly become a negative. Also, it must be noted that the FC systems supplied by one manufacturer failed to produce the rated peak power and had to be moved to a facility where the reduced power was more appropriate to the end user requirements.

It seems reasonable that the FC system reliability will continue to improve with feedback from end users and systems redesign combined with materials and component development by the supply chain vendors.

One end user indicated that if FC systems can be cost neutral with battery systems on an operating basis, then adoption rates would jump rapidly given advantages in productivity, increases in facility space (as there is no need for spare battery storage), and the stated environmental benefit of using FC technology.

Where possible, all end users took advantage of federal and state incentives and tax credits or grants. In combination, these incentives helped to reduce the higher capital costs associated with the FC systems and in some cases even helped offset some of the costs related to hydrogen infrastructure deployment. Some end users stated their belief that the lower overall carbon emissions for MHE FC systems provided a "greener" solution relative to incumbent technologies that was sufficient to justify the purchase of FC systems without tax incentives. However, the majority of end users believe that while the capital cost of FC systems remain high compared to incumbents, tax incentives or grants will continue to be an important driver in purchasing decisions for this technology. One end user had a requirement for an ROI of five years including FC system capital cost and hydrogen fueling infrastructure costs; this was only possible to achieve with a combination of ARRA-FCP funding, federal tax incentives, and state funding.

Several end users indicated that they thought the cost of capital (even though interest rates have been historically low) and the cost of installing hydrogen storage and fueling infrastructure for FC systems would stall market growth at the end of the ARRA-FCP, especially for new end user adoption. Indeed quantitative data presented later (see Figure 10 and Figure 11) indicate a decline in first time users in the post ARRA-FCP period. However, for end users who had already made investments in hydrogen infrastructure, continued conversion of battery power to FC systems would be the likely scenario to drive additional sales as long as federal tax and other state incentives remained in place. As shown later in Figure 11, there were many orders in place for FC systems in the post ARRA-FCP period from existing end users.

Attempts to obtain specific data on the cost of FC systems to end users was very challenging with most interviewees declining to provide this information because it was considered proprietary or company confidential data. However, relative cost data were obtained from secondary data sources. As such, it was difficult to analyze and comment on such factors as cost per unit variability dependent on volumes purchased, cost of unit per kilowatt dependent on usage in the various MHE Classes 1, 2, and 3 as well as cost of maintenance and service.

The end users specify which power systems they preferred when they purchase or lease new MHE, and in the case of existing owned MHE, the owner does the installation. By working with the FC system OEMs, all of the major systems integrators were able to provide the end users with FC-powered MHE. For the most part, the systems integrator performed the installation of the FC system into the MHE, although in some cases the end user completed the installation with assistance from the FC system OEM and systems integrator. For most Class 3 products the replacement of batteries was a straightforward process requiring less than an hour to achieve; for Class 1 and Class 2 MHE, the replacement was somewhat more challenging in some cases if the FC system was slightly larger than the battery it was replacing and some additional installation effort was required.

From a MHE operator's perspective, the end user experience in using FC-powered MHE was overwhelmingly positive. The MHE operators themselves were most often the greatest advocates for the use of the FC systems; for example, the one- to two-minute refilling of a hydrogen tank was deemed to be a huge positive benefit when compared with battery change out and slow battery charging. In many companies, the operators are not paid for battery change out, so FC-powered MHE allow the operators to move more product per shift, thereby increasing their personal income.

Community acceptance was a factor in the adoption of FC systems in certain geographical areas. Where community acceptance is an issue, the main issue appears to be lack of familiarity in the use of hydrogen as a fuel. This was highlighted to end users in extended regulatory approval processes driven by the absence of a single set of state or federal level codes and standards for the deployment of hydrogen infrastructure to power the installed FC systems. Often the main issues resulted at the municipal level with the local fire marshals having to be educated as to the safe use of hydrogen as a fuel within an industrial facility. While these issues resulted in some delays in deployment of the FC systems, they were mostly resolved through discussion involving the fuel suppliers, end users, and the fire departments. Hydrogen safety manuals and videos have been produced by fuel suppliers, FC systems OEMs, and by DOE and have gone a long way to facilitating the rapid understanding and acceptance of hydrogen use as a fuel. Also, the fact that many facilities have now operated for many thousands of hours with several thousands of units without any significant safety issues speaks volumes to the safe use of hydrogen in MHE.

For the sample of industry representatives interviewed, very few new jobs were reported to be created or retained at the current MHE FC systems production levels as a direct result of the ARRA-FCP funding at the end user facilities. Most often, FC systems were used to replace battery systems in MHE that already existed. In greenfield facilities where the complete operation was fitted with FC-powered MHE, most end users would likely have used battery powered MHE if the ARRA-FCP funding had not been available. In fact, it could be argued that the increased productivity of FC-powered MHE combined with reduced labor requirements associated with battery change out and recharging potentially would result in a smaller labor force or greater productivity than for the corresponding facility which used only battery powered MHE. Thus, there were few end user jobs created except for temporary jobs installing fueling systems.

The following is a collection of more general FC-powered MHE value propositions that end users recounted relative to battery powered MHE both during and post ARRA-FCP periods.

- Labor savings in refueling with hydrogen as compared to battery change out were estimated by one end user at approximately $100,000 per year for a 100-unit fleet (based on Class 3 type MHE).
- End users that operated with three shifts per day experienced the greatest productivity increase because they were able to maximize the value of reduced downtime from faster refueling and constant power availability.
- End users with large facilities could save up to 30,000 square feet of space by replacing battery storage (space for two to three batteries per MHE) with a FC charging infrastructure that is mostly external to the main facility.
- Operator acceptance and embracing of the new technology was a significant positive. MHE truck operators enjoy the experience of using FC-powered MHE as compared with battery systems as they can avoid the battery change out process and allow a higher throughput of work per shift.
- Some end users believed that the FC system could have up to a 10-year lifetime with appropriate maintenance once the technology has matured—far more than the two to three year predicted lifetime for lead-acid batteries. A 10-year life for a FC system is exceptional and has not, as yet,

been demonstrated in real operation in MHE for the types of FC systems used today in this application.

- Some users have seen fewer average repairs required for FC-powered MHE relative to battery systems while others have reported the MHE FC systems had greater maintenance issues.
- MHE FC-powered systems were able to perform well in cold environments (*e.g.*, freezer storage units).
- No safety issues have resulted from the use of hydrogen. Once the infrastructure was installed, all end users experienced good acceptance from employees, and operators readily adapted to refueling with hydrogen.
- FC-powered MHE were visible to corporate level managers and contributed to corporate strategy to increase use of sustainable energy sources and reduce carbon footprint.
- There was reduced energy demand during expensive peak hours for grid electricity.

4.4.2 Examples of Effects of ARRA-FCP on Systems Integrators

The metrics of importance to systems integrators are unit sales, systems integrator acceptance, and the product value (affordability, productivity, reliability, serviceability, and safety) of MHE FC systems. With this information as background, the systems integrator interview responses were analyzed.

4.4.2.1 Systems Integrator Acceptance

Systems integrators for MHE FC systems are the MHE manufacturers. In North America, Raymond is ranked number one, Crown is the third largest manufacturer of MHE trucks; and NACCO Industries, owner of Yale, is ranked number two.[38] Three of the largest manufacturers of MHE trucks have indicated their commitment to make FC technology available to their customers (end users) and have actively developed FC system compatibility options for their MHE.

Raymond reports there is “significant potential to improve warehouse productivity with fuel cell technology.”[39] Raymond’s assessment of FCs concludes that:

- Hydrogen fueled FC systems offer higher productivity simply because they can be rapidly refueled by the operators, eliminating the need to change, store, charge, and maintain batteries.
- FC systems produce constant voltage. There is no voltage drop towards the end of a shift like there is with batteries, so productivity does not decline.

As noted previously, Raymond works closely with major FC system OEMs to ensure that the MHE FC system was compatible with Raymond trucks in the future. Raymond’s intention is to provide its customers the widest range of options and be prepared to meet their FC system needs.

Crown reported in its 2012 Global Ecologic Report that it has “qualified more than 30 of its electric forklift models to operate with various [FC systems].”[40] Crown also reported they have built 500 FC-powered

---

38 L.K. Rogers, “Top 20 lift truck suppliers, 2012,” Modern Material Handling, August, 2012.

39 S. Medwin, “Applying Hydrogen Fuel Cells to Lift Trucks,” The Raymond Corporation, Greene, NY, July, 2009.

forklifts and reported they are working closely with FC system OEMs and Crown's customers (the end users) to qualify FC systems for greater use in MHE applications. Crown considers FC technology as part of its on-going sustainability program that focuses on sustainability beginning at the conceptual stage of design through the product's end of useful life. Crown maintains the FC option to ensure that they can meet customer demand as it arises.

NACCO Material handling Group (Yale) considers FC technology as part of its pathway to sustainable and greener technologies. The company reported that FC systems will help increase productivity and decrease operational expense while expanding the sustainability value of their products. Yale will provide MHE FC systems at customer request.

4.4.2.2 Analysis of Systems Integrator Responses

In the pre ARRA-FCP period, the systems integrators developed the required understanding of FC technology and the ability to incorporate the FC systems into their products. During the ARRA-FCP period, systems integrator attitude towards FC technology became more one of wait-and-see what the end user wants and be ready to accommodate that need. The business of these systems integrators is to sell MHE trucks, and as such they are agnostic to the technology that is used to power their trucks as long as it meets end user requirements. To protect market share, the systems integrators added FC-powered MHE to their product line. While they might discuss FC-powered MHE with an end user as an option, they were unlikely to press the issue of FC systems if the customer's requirements were unlikely to generate a favorable ROI.

From the perspective of the systems integrator, FC technology did not provide a significant increase in business. In the majority of cases, apart from greenfield deployments of FC-powered MHE, trucks that were already owned by the end user were converted from batteries to FC systems. In many cases, the systems integrator worked with the end user and the FC system OEM to certify that the MHE was fit and safe for use after the FC system had been installed. In some cases, experienced end users would go directly to the FC system OEM, and they would jointly complete the retrofit.

From a systems integrator perspective, end users purchased new MHE trucks based on need and the choice of power system was incidental to the purchase. In most instances, except for greenfield facilities, the choice of power system did not drive purchases of the MHE truck. Given that systems integrators make the vast majority of their profits from the sale of the MHE truck and not the power system, the impact to their bottom line, to date, from FC systems has been negligible.

Some systems integrators had hopes of making additional revenues through service and maintenance contracts, but this did not really materialize. Some major MHE manufacturers noted that the use of FC systems by their end users accounted for between one and two percent of the total sales of all MHE trucks in a given year during the ARRA-FCP.

Some systems integrators developed a sufficiently high level of knowledge and understanding of FC technology that they were really able to assist end users in evaluating the business case for using FC systems compared to other power systems, especially in cases where greenfield facilities were being

[40] 2012 Crown ecologic report. Available at time of press at http://www.crown.com/usa/about/ecologic_report_sf18494_us.pdf

planned. MHE manufacturers observed that where upper management had adopted a clean energy policy, clean energy tipped the balance towards FC systems for many end users when making a purchase decision.

If FC-powered MHE reaches its full potential of increased productivity with enhanced reliability at a cost competitive to battery technology, then as the technology gains greater market share there could be a net reduction in the number of MHE units required to operate MHE at a given facility. This is not necessarily a positive outcome for systems integrators.

The federal and state level incentives were of negligible direct benefit to the MHE equipment manufacturers because they were restricted to the cost of the FC system and not the full cost of the MHE truck. Federal tax credits for FC system capital expenditures either went to end users or to the FC system OEMs, if the systems were leased. Changing from battery to FC systems did not change the overall MHE total sales. One MHE manufacturer mused that if federal tax credits could be extended to cover the full cost of the MHE, and not just the FC system, then MHE manufacturers in general would likely benefit in increased sales.

While it was expected that systems integrators would have benefitted more directly from the ARRA-FCP, most of them claimed that their revenue was not positively impacted by the increased sale of FC systems used to power MHE. When completely new FC-powered MHE were purchased, it was likely that the end user would have purchased battery powered MHE anyway in the absence of the FC system alternative.

Anticipated revenues from maintenance and service contracts did not materialize for the systems integrators, with the FC system OEM ultimately taking control of service and maintenance for the FC system. Maintenance was a negative for some systems integrators, and they abandoned maintenance efforts and returned the responsibility to the FC system OEM. In some instances, Plug Power had their maintenance people located at end user facilities to address the maintenance issues. By virtue of providing funding and support in the deployment of large FC-powered MHE fleets, the ARRA-FCP demonstrated that there were only minimal financial risks, at this stage of commercialization, for the systems integrators.

The community acceptance issues for deployment of MHE FC systems were similar to those noted by end users during interviews. Systems integrators did not directly experience issues resulting from regulatory acceptance of hydrogen infrastructure installation and hydrogen use. One systems integrator noted that the true community impact of FC-powered MHE has not likely been realized to date given the relatively low market penetration of the technology.

4.4.3 Examples of Effects of ARRA-FCP on FC System OEMs

The four metrics of greatest importance to the FC system OEMs are unit sales, OEM and supplier revenue and other costs, external sales incentives (*i.e*., federal or state funding), and end user acceptance. These are discussed in the following sections.

4.4.3.1 Cost of Ownership

An important factor that influences unit sales is the cost of ownership. For the ARRA-FCP period, NREL reported on a comprehensive analysis of the MHE performance, cost, and calculations of the total cost of ownership for FC or battery powered MHE units for Classes 1, 2 and 3. NREL identified the FC system capital cost for Classes 1 and 2 MHE at $33,000 or approximately $3,000 per kW and $15,000 for a Class 3

MHE system.[41] Although reported as the cost of the FC system, the values are most likely the price paid by the end user or systems integrator.

The cost of ownership analysis was based on information provided by end users. In the NREL analysis, the "total cost represents the annualized cost of ownership of Classes 1, 2, and 3 MHE on a net present value basis, accounting for capital, operating, and maintenance costs of forklifts, FC systems, and infrastructure (labor costs for maintenance and for charging or fueling are included, but labor costs of forklift material handling operations are excluded)."

The analyses included the federal tax credit for FC, $3,000 per kW or 30 percent of the purchase price whichever was less, but did not include any state or utility incentives. The analysis did not identify tax credits or incentives for battery powered forklifts.

NREL provided non-intensive and intensive cost of ownership cases. The intensive case assumes three-shift operation while the non-intensive case assumes a single shift A comparison of the costs of FC MHE and battery MHE are reproduced in Table 10. As reported by NREL, the total cost of ownership favors the FC-powered over the battery powered MHE. A comparison of the data for the non-intensive case suggests the federal tax credit has an important impact on the total cost of ownership. For the intensive case, operating three shifts per day and 350 days per year, the benefits of the FC system were sufficiently high that, even with elimination of the federal tax, the FC-powered MHE would still have an advantage in the market.

Table 10 Calculated Total Cost of Ownership

Class	Fuel Cell	Battery
	Non-Intensive Case	
1, 2	$17,800	$19,700
3	$11,700	$12,400
	Intensive Case	
1, 2	$21,000	$27,000
3	$11,600	$14,800

The NREL analysis was built on several assumptions, most importantly a 10-year life for the FC system. For Class 1 and 2 forklifts, the continuous power rating selected for the Plug Power GenDrive 1000 series is 10 kW. It could not be determined whether or not the NREL's $33,000 price for the FC system represents the initial cost of the FC system and a subsequent replacement or refurbishment of the FC stack necessary to achieve the 10-year life, in which case the total cost of ownership calculated by NREL is undervalued because the assumed lifetime is outside the current range of consistently demonstrated FC system lifetimes from actual operation in MHE. A five-year life for a FC system would be exceptional based on available data and certainly competitive with batteries. Even with a replacement of the FC stack or the MEAs after five years, the total cost of ownership is optimistic based on the average lifetime of FC systems deployed in MHE at end user facilities during the ARRA-FCP period.

[41] Kurtz, K. Wipke, S. Sprik, T. Ramsden, C. Ainscouogh, and G. Saur, "ARRA MHE Composite Data Products for Data through 2011 Q4", NREL/PR-5600-55308, April 4, 2012.

Battelle reported the cost of FC systems for MHE applications at the 2012 Fuel Cell Seminar by manufacturing volume. The costs of FC systems for MHE applications by manufacturing volume are tallied in Table 11 which highlights the results of that analysis for a 10 kW (Classes 1 and 2 MHE) FC system.[42]

Table 11 10 kW MHE PEMFC System Cost Summary

Description	100 units	1000 units	10,000 units
Total stack manufacturing cost	$4,357	$3,974	$3,203
Stack manufacturing capital cost	$2,825	$283	$74
Balance of Plant	$27,272	$21,079	$17,856
System assembly, test, and conditioning	$279	$267	$266
Total System Cost, before markup	$34,733	$25,603	$21,099
Total system cost with 50% sales markup	$52,100	$38,405	$32,099

Source: K. Mahadevan, *et al.*

The components that comprise the BOP are estimated to cost four to five times that of the FC stack. The system assembly costs are very small compared with the stack capital cost and the BOP costs. The study did not identify the maturity level of the manufacturing and only referenced the Boothroyd Dewhurst design for manufacturing assembly tool for calculating manufacturing costs of BOP components. The costs used for the BOP and their data are given in Figure 7. The total system cost was $52,100 for 100 units and $32,099 for 10,000 units. This analysis demonstrates that 100 10 kW units can be manufactured at $34,733 compared to $21,099 for production of 10,000 units. Stack costs represent 21 percent of the total cost for the 10 kW FC system manufactured at a rate of 100 units per year, which is a low rate of initial production. The benefit of full-scale production at 10,000 units per year reduces the stack cost to 15 or 16 percent of the total FC system cost with most of the cost reduction a result of capital costs of the production facility spread over a greater number of units and potential cost reduction through automation.

It is not clear why the analysis requires such an expensive battery, approximately $6,000 for the 10,000 unit production case. Based on the high-level system design presented, the battery provides power during rapid transients where the response of the FC system is insufficient. The battery cost in the system design reported by Mahadevan, *et al*., is greater than the cost of the battery in the NREL comparison of battery MHE to FC-powered MHE for Class 1 and 2 forklifts. DOE funded both studies, and the total cost of the FC system is consistent between the two studies. However, further discussion of the BOP cost is necessary.

Based on these cost analysis data, it is clear that there is more significant cost reduction potential to increase unit sales in the BOP components than in the FC stack. This could be achieved through system simplification efforts as are apparent in Plug's GenDrive 3000 products for Class 3 MHE or by working more closely with BOP manufacturers to help them understand more clearly the FC system requirements and allow them to reduce costs and increase reliability as they become more convinced of further growth in the industry.

[42] K. Mahadevan, F. Eubanks, V. Contini, J. Smith, G. Stout, and M. Jansen, "Manufacturing Cost Analysis of Fuel Cells for Forklift Applications," 2012 Fuel Cell Seminar and Energy Exposition, Uncasville, CT November 6, 2012.

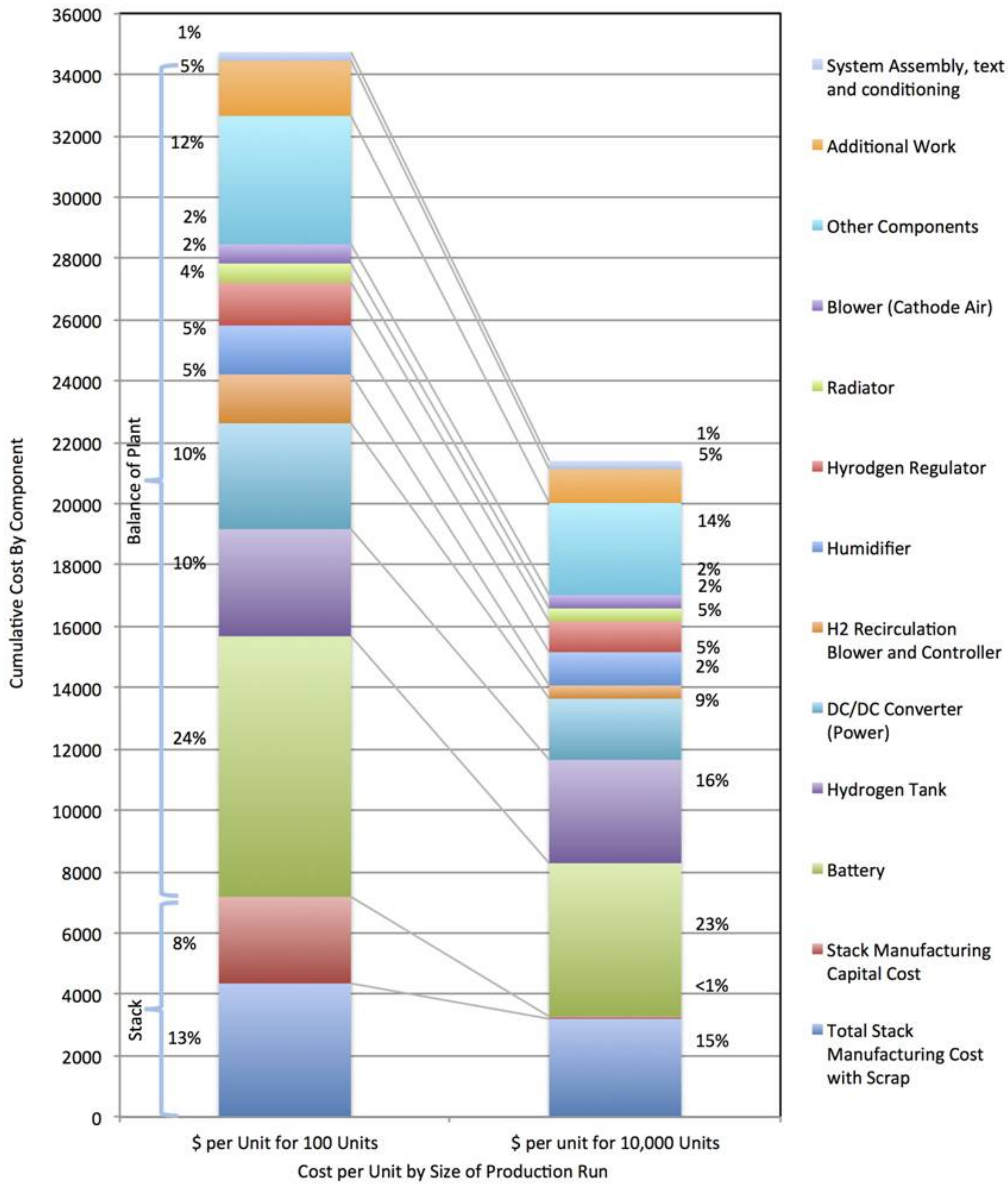


Figure 7 FC Stack and Balance of Plant Costs

SOURCE: Adapted from K. Mahadevan, F. Eubanks, V. Contini, J. Smith, G. Stout, and M. Jansen, "Manufacturing Cost Analysis of Fuel Cells for Forklift Applications," 2012 Fuel Cell Seminar and Energy Exposition, Uncasville CT.November 6, 2012.

4.4.3.2 OEM and Supplier Revenue/Costs (Profitability)

The secondary data provide limited but informative insights into the financial status of the OEMs. The focus is on Plug Power who is the only OEM recipient of ARRA-FCP funding and one of only two suppliers of FC systems for MHE trucks. The other supplier, Oorja Protonics, is described in Section 4.3.2.1, but because they are not a public company like Plug Power, there is little publicly available financial information. Plug Power, the OEM leader in MHE FC system sales, reported revenues for 2012 to be readjusted downward to $30 million from $35 million in product and service revenue to $26 million from $30 million in total revenue. These reductions were caused in part by the cost of retrofitting fielded units that had developed isolated product quality issues identified at customer sites. By the third quarter of 2012, the majority of units shipped were based on a simplified architecture featuring 30 percent fewer components designed to reduce manufacturing costs and improve quality. Plug Power's 2012 third quarter total revenue was $4.8 million while the total cost of revenue for that period was $11.7 million.[43] Plug Power also reported a reduction in staff of 22 full time employees that would result in a $4 million annual savings.[44] While Plug Power has increased its sales of FC systems for the MHE market, they have not yet turned the corner to profitability.

4.4.3.3 Analysis of FC System OEM Responses

The ARRA-FCP announcement was a very important event for the FC system OEMs because it came at a critical time when the product had increased its reliability where there was good traction and acceptance by many of the first mover end users, but the relatively high cost of FC systems combined with the barriers associated with hydrogen use, hydrogen infrastructure costs, and production ramp up, limited production volume growth. The ARRA-FCP, combined with other federal and state incentives, lowered the barriers to purchases by end users and allowed a greater number of units to be deployed over a shorter period of time that otherwise would have been possible.

One effect of the ARRA-FCP is that Plug Power became by far the most successful company in securing orders for FC systems both stimulated directly by ARRA-FCP funding and through follow-on indirect sales to ARRA-FCP awardees and non-awardees. As noted in Section 4.2, Plug had some pre ARRA-FCP success with Wal-Mart and Central Grocers and then additional successes during the ARRA-FCP period with Sysco and BMW. By the end of the ARRA-FCP period, Plug Power's top five customers were Sysco (600 units deployed at seven sites), Associated Wholesale Grocers (500 units at two sites), Wal-Mart (500 units at three sites), BMW Manufacturing with more than 400 units (at a single site) that has fully converted to FC-powered MHE, and Central Grocers with over 230 units operational at a single location.[45] New customers secured after ARRA-FCP funding ended include Lowe's Home Improvement that acquired more than 160 MHE FC systems for its facility in Atlanta; Stihl, Inc. that deployed 72 MHE FC systems at its site in Virginia; and Mercedes-Benz that purchased 72 MHE FC systems for their MHE fleet in Alabama.

During the ARRA-FCP period, Plug Power amassed a market share of over 85 percent, making the company by far the dominant supplier of MHE FC systems in North America.[46] This situation is potentially a double-edged sword as regards future growth of the business. While this market leadership position means that

---

43 Plug Power, Inc., Form 10-Q for 2012. Available at time of press at http://www.sec.gov/Archives/edgar/data/1093691/000100329712000474/es10q-ppwer.htm

44 Plug Power, Inc., Form 10-K for 2012. Available at time of press at http://www.sec.gov/Archives/edgar/data/1093691/000100329713000101/esplugpower10k1.htm

45 Alternative Energy eMagazine. *New Customers and Repeat Orders Signal Positive Developments in Fuel Cell Material Handling Markets*, January 15, 2013. Available at time of press at http://www.altenergymag.com/news/2013/01/15/new-customers-and-repeat-orders-signal-positive-developments-in-fuel-cell-material-handling-marke/27809

46 Plug Power. *At a glance*. Available at time of press at http://www.plugpower.com/News/Media.aspx

end users approach Plug Power first when they need quotes for FC systems, interviewees indicated that in the future larger end users will require multiple quotes to place large orders and to drive competitive pricing. If battery technology becomes the only competitive bid option, as opposed to bids by other FC system OEMs, end users that have already invested in the infrastructure to support the use of batteries, may find it difficult to make the ROI calculations work in favor of purchasing FC systems, especially when the costs of fueling infrastructure are included. This competitive situation is made even more difficult by advances in battery technology that reduce change out times with automated battery changing equipment, and decreased recharge times with increased reliability that allows end users to store fewer spare batteries. Further, it allows the battery companies the option to price their products very aggressively to keep the FC system OEMs from growing their market share.

The ARRA-FCP activities with Plug Power also resulted in a significant level of positive global publicity that may have facilitated business opportunities for the company in Europe. Europe's market for MHE is 50 percent larger than the North American market, but to date has lacked the stimulus effect of coordinated government support.[47] To expand its business beyond North America, Plug Power formed HyPulsion, a joint venture company with Axane (an Air Liquide subsidiary) to sell and market FC systems for MHE in Europe. Already the joint venture has a business opportunity with IKEA International Group to convert its operations in southern France to GenDrive FC-powered products in 2013.[48]

Nuvera had some challenges with the development of its higher power density FC systems for use in Class 1 and 2 forklifts but the company expects that these issues will be resolved in 2013 allowing an additional 42 units to be deployed without ARRA-FCP funding in addition to 14 units that were deployed under the ARRA-FCP.

A clear effect of the ARRA-FCP was that it allowed the FC system OEMs to get more units into the hands of a larger number of end users over a short timeframe, something that would not have been possible in the absence of the ARRA-FCP funding. This surge of product sales in the ARRA-FCP period resulted in a significant increase in FC system orders funded by industry players in the form of follow-on orders from existing customers and new orders from end users that had not participated in the ARRA-FCP but became aware of the successes at ARRA-FCP sites. It also motivated the supply chain vendors especially the fuel providers to take a stronger supporting position in a way that had not been previously seen in this market—another key effect of the ARRA-FCP.

In the early stages of the FC systems deployment during the ARRA-FCP funding period, especially for the Class 2 MHE from one FC system OEM, maintenance issues were problematic for some end users. This was especially true following the end of the warranty period. Overall, the strong business relationships between the FC system OEMs and the end users ensured a responsive fix to the problems and a rapid learning curve that helped the FC system OEMs to drive root cause analysis and redesign, thereby ensuring that failures were resolved and reoccurrences minimized. Interestingly, particularly for Class 3 MHE, very

[47] Fuel Cell Today, *Selling Fuel Cells Globally: Materials Handling Equipment*, January 2, 2013. Available at time of press at http://www.fuelcelltoday.com/analysis/analyst-views/2013/13-01-02-selling-fuel-cells-globally-mhe

[48] Forklift Action, *Major Brands Sign up for Fuel Cells*, May 16, 2012. Available at time of press at http://www.forkliftaction.com/news/newsdisplay.aspx?nwid=11474

few maintenance issues were noted for the FC stack itself with most of the problems resulting from software, electrical, and BOP issues.[49]

To help drive cost reduction and system simplification, which hopefully would contribute to improved reliability and lower maintenance costs, Plug Power introduced its new GenDrive Series 3000 FC system based on a novel stack design by Ballard Power Systems in late 2011. This product design was driven by end user requirements for lower operating costs, operational performance enhancement, and MHE operator productivity in applications where order picking is the primary activity. The FC system power output is matched to meet the specific needs of the application so the end user is not paying for more power than is required. The product is air-cooled as opposed to water cooled and has no external humidification unit or air blower, eliminating some of the costly balance-of-plant components and increasing product reliability. The GenDrive Series 3000 FC system is also more effective in providing constant power at lower temperatures to allow greater productivity in freezer applications. The GenDrive Series 3000 FC system is well matched for Class 3 applications, but it is not clear the air-cooled FC system, as currently designed, is capable of satisfying the higher power requirements of Class 1 and 2 forklifts.

For one FC system OEM, the total number of ARRA-FCP funded sales was not significant relative to the balance of their other business activities during the period of the ARRA-FCP and as such had little effect on their overall revenue. For Plug Power, a NASDAQ-listed company, the total revenue related to the sale of FC systems is a matter of public record. For fiscal year 2011, Plug Power received orders for $46.1 million from MHE customers resulting in 2,503 GenDrive system orders, accounting for a five-fold increase over the 543 units ordered in 2010.

The availability of ARRA-FCP funding and the spillover effect of product sales funded by end users without ARRA-FCP support was an economic boost to FC system OEMs who had, in some cases, challenges attracting other sources of financial investment.

Some delays in product deployment did occur because of the lack of familiarity with hydrogen and hydrogen-fueled products. However, this was quite variable and often dependent on the facility zoning requirements and the individual municipality, city, and state regulations. On a high point, as noted by one FC system OEM, the deployment of FC-powered MHE for Mercedes-Benz at its Alabama site was achieved in a record three months from order to fully commissioned and functional equipment, including the installation of a new hydrogen fueling station.

4.4.4 Examples of Effects of ARRA-FCP on Supply Chain Vendors

The metric of greatest importance to the supply chain vendors is unit sales (with an aligned dependency on sales incentives and end user acceptance).

4.4.4.1 Analysis of Supply Chain Vendor Responses

The component supply chain vendors interviewed as part of this evaluation provided two of the most expensive FC systems components: membrane electrode assembly and the stack subsystem. The team also interviewed two key hydrogen fuel suppliers and providers of fueling infrastructure. Overall, the ARRA-FCP for MHE did not significantly effect the supply base as the ability to meet the demands for their

[49] Sysco Houston Progress Report, *Fuel Cell-Powered Lift Truck Sysco Houston Fleet Deployment*, January 9, 2013. Available at time of press at http://www.hydrogen.energy.gov/pdfs/progress12/xii_5_kliever_2012.pdf

products was well within the existing capacity and labor force allocation of these companies. However, it was proposed by one interviewee that the accelerated ordering of components driven by the activities of the ARRA-FCP allowed the company to retain employees that may otherwise have had to be reallocated.

For the MEA suppliers, there was not a significant increase in business as a result of the ARRA-FCP activities in MHE. The main FC system OEM, Plug Power, had a mutually exclusive agreement with Ballard to buy its stacks and for Ballard to sell its stacks only to Plug Power for MHE in the North American market. It was not clear from the interview with Ballard if the company was still making its own MEAs. If Ballard did make the MEAs for its MHE stacks, it is unclear if they were manufactured from purchased membrane and catalyst using gas diffusion layers (GDL) from Ballard Materials Products,[50] or if Ballard purchased catalyst-coated membranes from a supplier like W. L. Gore & Associates and made the MEAs using Ballard GDL. The company certainly has the expertise and equipment to execute any of these options. The air-cooled stack technology that Ballard developed for the Plug Power GenDrive 3000 line of products is most likely to involve a catalyst coated membrane material. However, these products have only been available since the end of 2011, and it is unlikely that the demand for such materials has been significant to date. The DOE had partly funded, with non ARRA-FCP funds, the development of the FC stack technology for the GenDrive 3000 product.

Ballard indicated that the ARRA-FCP allowed it to dedicate more manufacturing capacity to its MHE products line, especially given that it was unable to participate in the ARRA-FCP deployment programs for BUP. As a key supply chain participant, Ballard was fortunate to have received DOE funding to help optimize its GDL material for use in later generation stack products as a means to drive cost reduction. In general, Ballard remains committed to continuous cost reduction and design improvements to ensure that its FC stack products remains at the forefront of technology and in line with customer requirements to continue to grow its business. The hydrogen fuel and fueling infrastructure providers played a very significant role as a key supply chain vendor and enabler for FC-powered MHE deployment. Without a cost-effective, safe, and reliable source of fuel and the means by which it can be dispensed by the MHE operators, the ARRA-FCP projects could not have been successfully executed. The fuel providers were very proactive in supporting the efforts of the FC systems OEMs and MHE manufacturers to ensure that end users were provided with a complete solution in the implementation of FC-powered MHE in their facilities.

Air Products and Chemicals Inc., a pioneer in the provision of hydrogen fuel and fueling infrastructure to enable deployment of FC systems, was heavily involved in the ARRA-FCP projects. The company played an active support role in many ARRA-FCP projects providing safety training and education in the use of hydrogen and the efficient delivery of the fuel through infrastructure that was appropriate to the size of the fleet of FC MHE being deployed by the end user. This effort was undertaken even though the effect on sales for fuel providers was relatively insignificant compared to their overall business activities with hydrogen. A fleet of 25 to 50 FC-powered MHE, depending on classification and number of shifts, would use around 100 kg of hydrogen per day. However, Air Products can produce 5 million kg per day. So even with 50 facilities operating FC systems on an average demand cycle, the combined usage would be around 0.1 percent of capacity. However, while hydrogen sales are a very small percentage of their overall business, the fuel providers noted that ARRA-FCP funding definitely produced a major increase in fuel sales

[50] On January 31, 2013, Ballard Material Products was sold to ALY Holdings LLC. In partnership with the division's senior management, through AvCarb LLC, a new company formed as a result of the transaction.

for FC applications in MHE. One of the fuel providers expected to see further growth in sales following the end of the ARRA-FCP.

Linde North America provided three indoor hydrogen dispenser stations to allow Coca-Cola Bottling Company Consolidated to deploy its FC-powered MHE under an ARRA-FCP funded program. The FC systems were used in Class 1 sit-down counterbalanced forklifts, replacing propane-powered systems.

Before they can sell hydrogen fuel for FC systems, OEMs must sell their products and end users must embrace them. One fuel provider interviewed believes that the FC-powered MHE market in North America is the only significant growth market for hydrogen fuel sales over the next two to three years.

Through the activities of the ARRA-FCP, the fuel providers interviewed stated that they learned how to better deliver their services and contributed to some end user decisions to deploy larger FC-powered MHE fleets through a better understanding of how to manage and amortize the cost of hydrogen fuel and the related fuel infrastructure. As noted by one end user, the fuel providers were able to help move their company towards cryogenic hydrogen that reduces the cost of infrastructure and overall fuel costs.

Where state level incentives were available to support the installation of fueling infrastructure, the economics of deploying FC systems became more acceptable to some end users, with one end user noting that the availability of such funding was a critical deciding factor in their adoption of FC-powered MHE.

The actions in safety training and hydrogen education and broad participation of fuel providers in the deployment process of FC systems and related fueling infrastructure increased end user acceptance for this new technology. Initially, surety of continuous hydrogen supply was a concern as noted by some end users. With the possibility of facility shutdown through hydrogen shortages or interrupted delivery being a concern relative to the near certainty of grid electricity supply, the commitment of the fuel suppliers ensured that supply was continuous and lost productivity due to availability of hydrogen was not an issue.

The community acceptance of hydrogen was either transparent given the relatively remote location of some facilities, or where facilities were more centrally located, the education of local fire marshals ensured that concerns were addressed.

4.5 Overview of MHE FC Systems Market 2004-2013

In Figure 8, the numbers of firms having demonstrations (10 or fewer units) and deployments of MHE FC systems by year, based on date of the sales or purchase order, are displayed.[51] Sales orders are developed from customer purchase orders, which then set in motion the manufacture of the product to be sold and delivered to the customer at a later time. Demonstrations are defined as purchases or implementations, for the purpose of this evaluation, that are ten or fewer units. Deployments are more than ten units. There were eight demonstrations in the pre ARRA-FCP period (about 40 percent of the total number of demonstrations and deployments) and just two demonstrations in the periods that followed. By the end of the pre ARRA-FCP period, the market appeared to be settled enough that FC system OEMs and end users had little interest in demonstrations.

[51] There are some discrepancies in the annual totals between these tables and the corresponding graphics. The data in the graphics are based on orders and the year the order was placed while the counts of units in the preceding tables are more closely associated with commissioning. In many cases it was impossible to make an accurate determination of the year in which an order occurred or the units were delivered or commissioned. However, the overall totals are consistent.

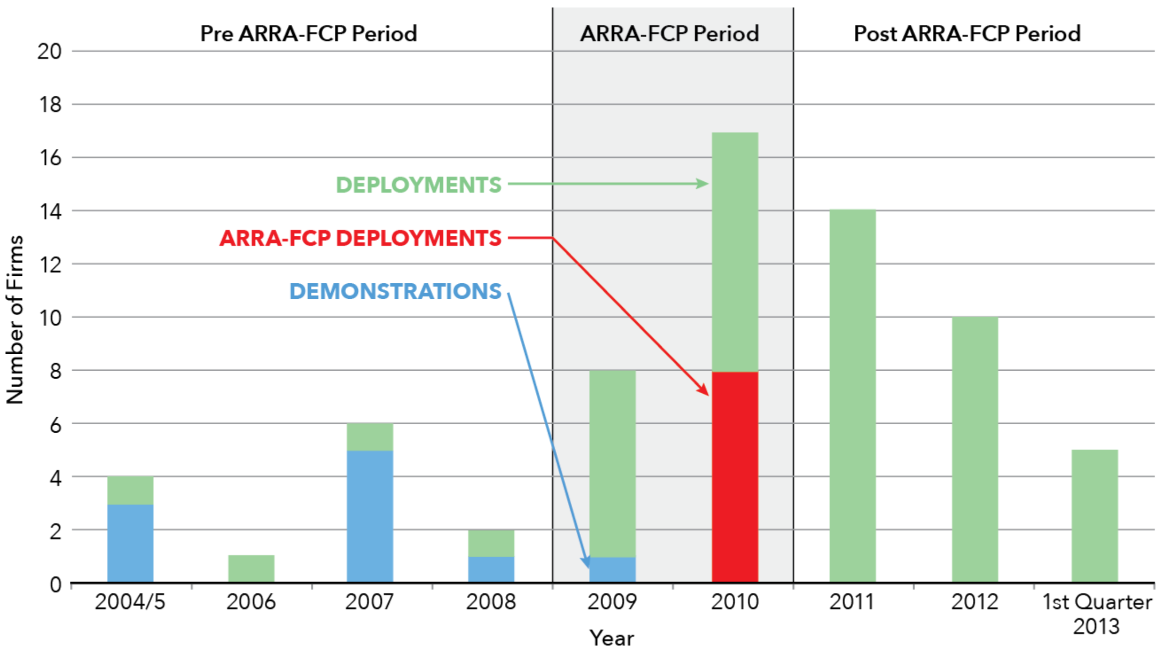


Figure 8 Demonstration and Deployment FC System Orders With and Without ARRA-FCP Funding

Figure 9 depicts the overall orders for MHE FC systems from 2004 through the first quarter of 2013. The orders are divided into FC systems sold by Plug Power without ARRA-FCP funding, ARRA-FCP funded FC systems, and all other systems in North America sold by OEMs other than Plug Power.

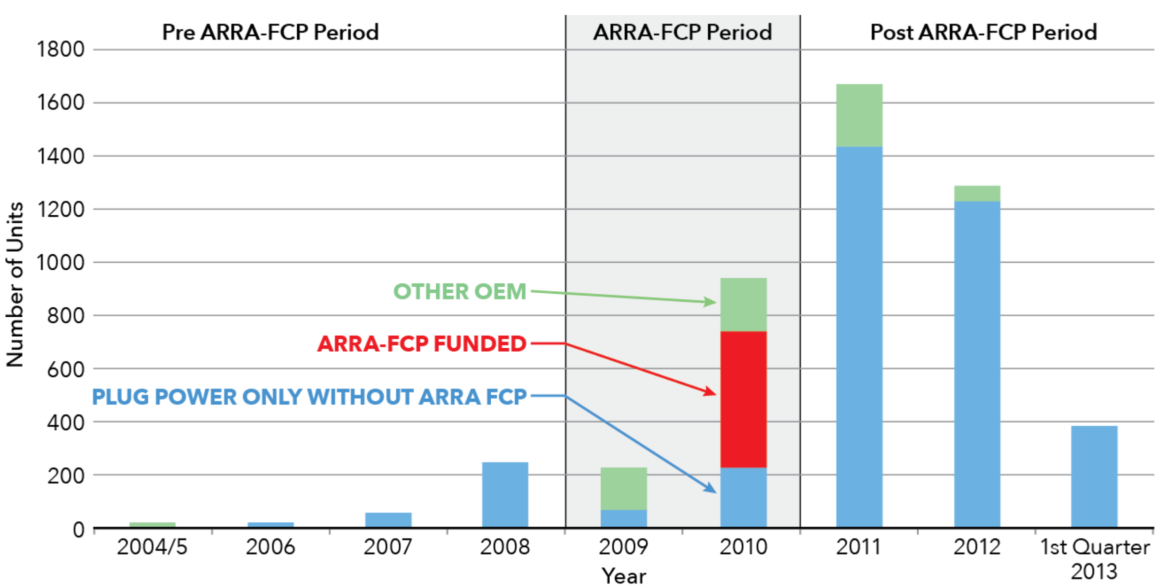


Figure 9 Orders for MHE FC systems 2004 to 2013

The number of FC MHE orders ranged from a handful in 2004 to 2006 to 63 and 269 MHE FC systems in 2007 and 2008 respectively with the total pre ARRA-FCP sales reaching over 375 units. The pre ARRA-FCP sales were followed by an increase in sales for 2009 to 2010 period to 1,172 units with 668 sales generated by non ARRA-FCP funding. ARRA-FCP funded units accounted for 43 percent of the 1,172 units in the 2009-2010 period. Thus, the non ARRA-FCP sales in the ARRA period almost doubled the sales in the pre ARRA-FCP period. The post ARRA-FCP sales followed with orders of 1,687 units in 2011 and then a decline in orders to about 1,301 units in 2012 and 378 in the first quarter of 2013.

Our evaluation of the secondary data demonstrates an increase associated with the ARRA-FCP funding and an increase of units purchased without ARRA-FCP support in the 2009-2010 ARRA-FCP period.

Another perspective on the orders for MHE FC systems is to compare them to the number of Class 1, 2 and 3 MHE systems sold in a given year regardless of the power system, as shown in Table 12. The percentage of MHE FC systems sold was well under one percent until 2010 when the uptick in MHE FC system sales as well as the reduced level of overall truck sales, raised the percentage of MHE FC systems in the market to 1.35 percent. In 2011, MHE FC systems were 1.8 percent of total orders when the total units sold increased alongside the overall U.S. economic recovery. Orders declined as a percentage of total sales in 2012. A decrease in units sold in 2012 is observed in Figure 9.

Table 12 FC Systems (Class 1, 2, and 3) Sales as a Percentage of MHE Truck Sales

	2004/5	2006	2007	2008	2009	2010	2011	2012
MHE Truck Sales[a] (Class 1, 2, 3)	94,002	104,756	98,875	89,077	57,044	68,396	93,019	95,251
FC System Orders	29	14	65	269	247	930	1,687	1,301
Percent of all MHE Truck Sales	0.03	0.01	0.06	0.30	0.43	1.35	1.80	1.36

a Sales in the Americas. Some Canadian company purchases not included.

Figure 10 displays the number of firms making first purchases and replications. The number of firms making first purchases peaked in 2010 at 14 dropping to 7 and 5 in 2011 and 2012, respectively, while replications peaked at 11 in 2011 and then dropped to 6 and 7 in 2012 and the first quarter of 2013, respectively

Figure 11 displays the number of units that were first purchases (purchases by a company who had not previously purchased units) and replications (units installed by a company at an existing or another site belonging to the company. While some of the ARRA-FCP awardees did place additional orders in 2011 without ARRA-FCP funding, others did not. As noted earlier, Sysco purchased an additional 536 units adding to the 210 units purchased with ARRA-FCP funds for a total of 746 units. There were approximately 2,100 first purchases by firms in the 2010 to 2012 period compared to about 1,080 replications in the same period.

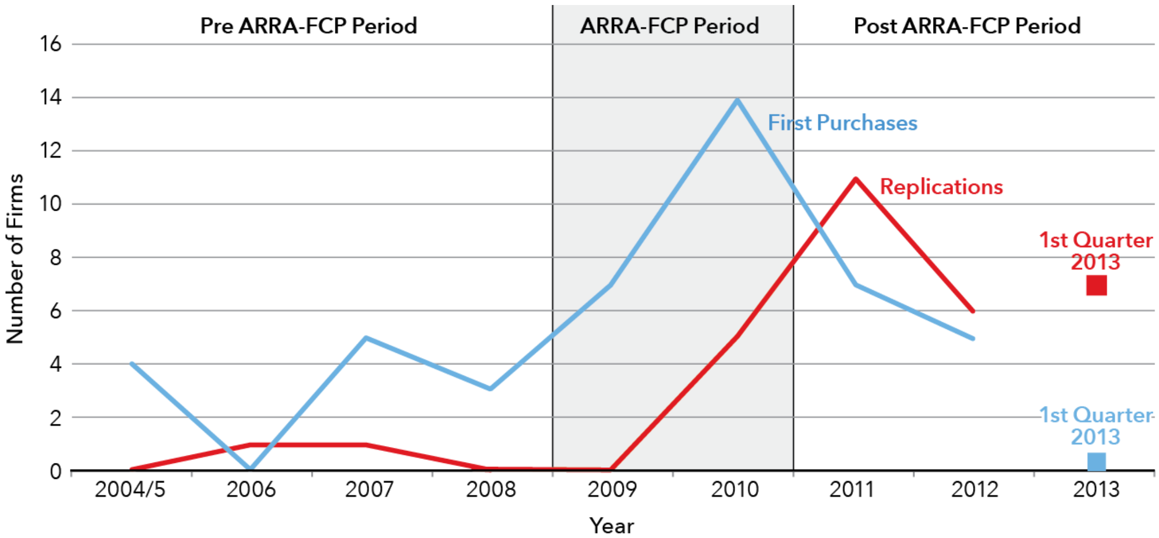


Figure 10 Number of Firms Making First Purchases and Replications

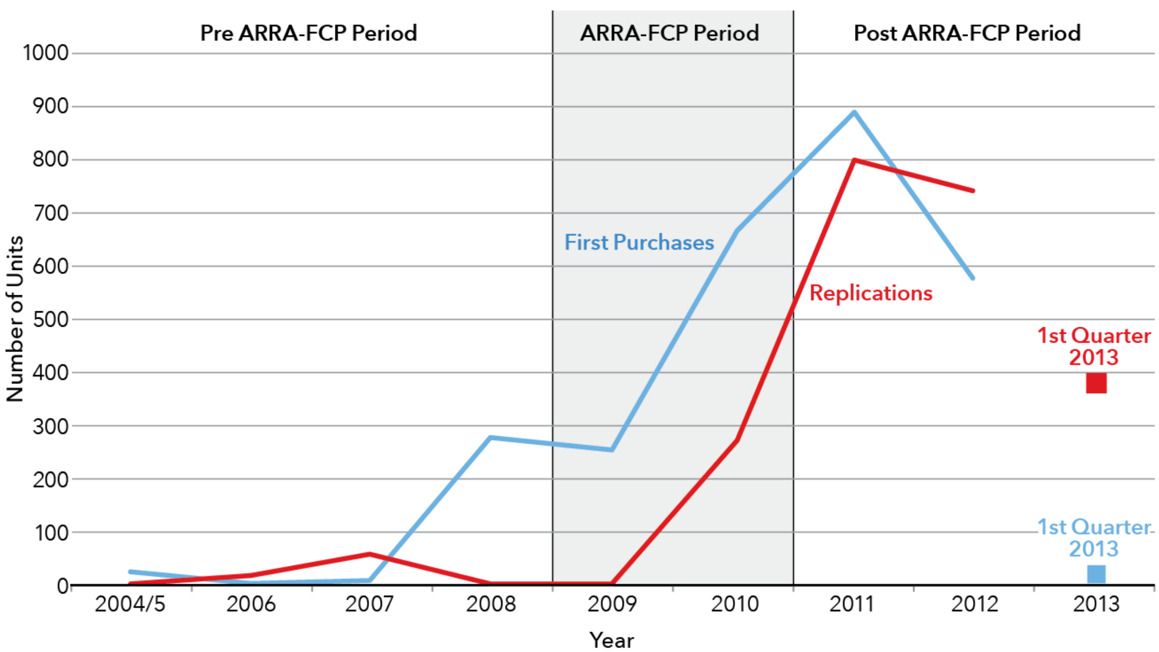


Figure 11 First Purchases and Replications in the Period after ARRA-FCP Based On FC System Orders

4.6 Market Assessment and Market Effects Revealed in Unit Sales Data

Figure 12 provides a comparison of the MHE FC systems sold by all ARRA-FCP funding recipients (dominated by Plug Power) and by non ARRA-FCP funding recipients (dominated by Oorja). These curves are typical of the S-curves of early stage adoption of a new technology. Such curves show an accelerating rate of change over time. According to Rogers, the takeoff or tipping point where the product becomes a real commercial product is around 10 to 15 percent market share.[52] The curve for Oorja is much flatter in the pre ARRA-FCP period as its DMFC technology was developed several years later than the technology developed and acquired by Plug Power.

The data show increases for both firms in 2011 immediately following the ARRA-FCP period although Oorja takes a dip in 2012. The rate of increase from 2010 to 2011 for Plug Power was more than 20 times that of Oorja, a significant measure of the effect of ARRA-FCP funding, even though they had been at similar sales in the prior year. This difference occurred even though Oorja did receive some government funding assistance, namely, the receipt of a 2011 NREL award for the sale of 75 units and higher usage projections for Class 3 units by the ITA.[53] Oorja had already developed its product for Class 3 MHE trucks and was ready to deploy these units to end users, most of whom had already evaluated the products in demonstration trials.

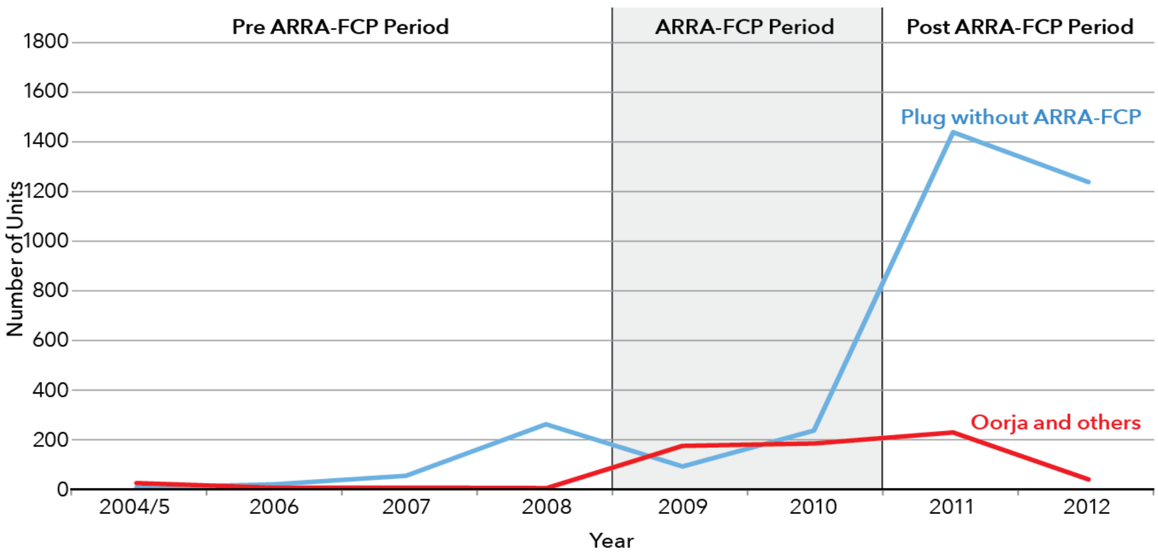


Figure 12 Effect of ARRA-FCP Funding on Acceleration of Deployment of MHE FC System Orders

Oorja produces DMFC-based MHE FC systems for Class 3 MHE trucks but does not currently produce systems for Class 1 and 2 MHE trucks. Figure 5 indicates that the potential for sales of Class 3 MHE for North America is about half the MHE market. Oorja is growing in stature and market presence in selling its product for Class 3 MHE. Plug Power and Oorja are subject to the same economic conditions and are pursuing the same MHE market with a different product offering and strategy but with similar end user markets and the same selling points, except that Oorja is restricted so far to end user of Class 3 MHE trucks. However, given the nature of a liquid (methanol) versus a gaseous fuel (hydrogen), Oorja has the advantage of lower fueling infrastructure cost and a much simpler fuel supply system.

Plug Power is three years ahead of Oorja in sales experience and has technology that has somewhat broader applications than the Class 3 MHE that Oorja currently sells and services. Plug Power had a larger

52 E. Rogers, *Diffusion of Innovations*, Free Press, New York, 2003.
53 J. Moran, “Alliance of Industrial Truck Organizations, President’s Forum,” Kyoto, October, 2012.

customer base with end users that purchase larger and more varied classification of MHE trucks. Plug was in the market much earlier and had established the value of its products through many demonstration programs with end users and had already sold quite a substantial number of units, relative to Oorja, before the start of the ARRA-FCP. These are most likely the contributing factors accounting for the larger absolute number of FC systems sold in 2010 by Plug Power.

The sales of MHE FC systems are still in the range of one percent of MHE truck sales. If either of the companies, Plug Power and Oorja, should falter in the near term, it could have a significant dampening effect on the further commercial growth of MHE FC systems.Less than 33 percent of the Industrial Truck Association (ITA) membership believes that Class 1 FC-powered forklifts will penetrate the market to any extent by 2017. Between 33 and 66 percent of members answered that Class 2 FC-powered forklifts will increase market penetration by 18 percent. Based on the overall market size, this would represent 5,000 to 10,000 Class 2 MHE FC systems. Combined sales have already achieved 5,000 units in 2012, and the 2017 prediction appears conservative. The Class 3 MHE FC systems are predicted to have the greatest market penetration with 33 to 66 percent of the survey participants identifying a 24 percent market penetration. The ITA survey predicts remarkable growth for Class 2 and Class 3 FC-powered MHE.

4.7 European Activities in FC systems for MHE during ARRA-FCP

The market for MHE in Europe is 56 percent larger than in the U.S., according to the World Industry Truck Statistics. However, to date, the FC industry has lacked the coordinated government support that has been evidenced by such efforts as the ARRA-FCP to increase and accelerate the number of MHE FC systems deployed to end users. There is also no comparable tax incentive in Europe related to purchases of MHE with FC systems as exists in the United States.

The issue of hydrogen fueling and infrastructure cost also exists in Europe as an impediment to end user adoption of FC systems. A UK-based company, ITM Power, has initiated a number of trials in the UK with MHE end users, to demonstrate their electrolyser products as a cost effective and efficient means to overcome hydrogen infrastructure and delivery challenges.[54] ITM is working in conjunction with Infintium Fuel Cell,[55] a new FC systems OEM, to provide coordinated offerings of FC systems and hydrogen infrastructure and supply.

The application of FC technology by the MHE FC system OEMs, such as Plug Power, into the European market is further challenged by differences in the mix of MHE Classes 1 and 3 operated by end users, voltage and duty cycle difference, use of battery technologies other than lead-acid and the packaging of the batteries into the MHE. The FC systems OEMs must also meet differing regulatory requirements, codes, and standards as well as end user operational requirements. Despite these challenges and strengthened by its market activities in the U.S., Plug Power has begun developing its MHE FC systems for Europe through a joint venture wiith Air Liquide and HyPulsion. In May 2012, the joint venture signed a deal to retrofit the entire warehouse operation at an IKEA site in southern France with hydrogen-powered MHE FC systems.

[54] ITM Power, *Fuel Cells Materials Handling On-site Hydrogen Production*. Available at time of press at http://www.h2fc-fair.com/hm13/images/ppt/08mo/1030.pdf

[55] Infintium Fuel Cells Systems, Inc. *Infinitium is committed to the innovative implementation of hydrogen fuel cells in battery operated forklifts*. Available at time of press at http://ifcsglobal.com

5 Findings and Analysis: Deployment Phase – Backup Power

For the purpose of this analysis, BUP refers to low temperature proton exchange membrane fuel cell (PEMFC) systems with a power rating of less than 25 kW (typically in the 2 to 5 kW range) and operating on hydrogen or reformate fuels to provide instantaneous power in the event of grid power interruptions. Although, all of the ARRA-FCP-funded BUP deployments of FC systems were operated on hydrogen, it is important that an analysis of ARRA-FCP markets also include reformate technology. The only difference in the operation of these systems is that the hydrogen system will have a battery to provide power for a few tens of seconds during power switch to the FC system, while a methanol system will require several minutes for the reformer to heat up and produce a sufficient quantity of hydrogen to provide quality power, and an LPG fueled unit will take even longer—about three hours. Hybrid systems using hydrogen and LPG fuel were funded in the ARRA-FCP as one of the demonstration projects. In this case, hydrogen fuel for the FC system provided all the required power while the LPG reformer heated up. Solid oxide fuel cells (SOFC), molten carbonate fuel cells, phosphoric acid, and alkaline fuel cells were not part of the ARRA-FCP deployment program, but SOFC was one of the ARRA-FCP demonstration projects.

The ARRA-FCP projects for BUP were intended to accelerate the commercialization and deployment of these FC systems and the related FC manufacturing, installation, maintenance, and support services. In pursuit of these objectives, close to $19 million of ARRA-FCP funds, matched by almost $27 million in awardee funding, were directed towards the commercialization of FC systems in the BUP market.

The ARRA-FCP projects for BUP deployment had a series of specific high level goals to:

- Increase the number of FC systems available to end users, mostly in the telecommunications market for cell tower site BUP;
- Expand end user experience of FC technology while validating performance;
- Generate more volume for the supply chain while stimulating development of lower cost next generation products; and
- Increase private equity confidence in the market's potential for growth and profitability.

BUP applications in the ARRA-FCP are readily separated into two categories. First, BUP for telecommunications, where FC systems are targeted to replace battery systems or in some cases diesel generators, or a combination thereof, as emergency power when the power grid is interrupted. The first application is a commercial application, and is especially important for cell towers. The second application is backing up the grid at mission critical facilities that require continuous power for operating controls, computer networks, and/or databases. This application has only been dealt with briefly as part of one of the demonstration projects, with the BUP deployment focused on the telecommunications application.

The deployment of FC systems in telecommunication BUP applications had been shown to be viable with both direct hydrogen and, in some applications where instant start-up is not a prime requirement, reformer-based fueling of FC systems.

For reasons that were not apparent from our evaluation, but perhaps because of the maturity of the technology, ARRA-FCP projects were focused on OEMs that produced hydrogen-fueled FC systems. One participant, ReliOn, headquartered in Spokane Washington, has been in business since 1995 and has been deploying commercial products since 2003. Another important OEM participant was Altergy Systems headquartered in Folsom, California.

Prior to the ARRA-FCP, many companies in North America were producing and selling BUP FC systems into the market in the form of demonstration field trials, demonstration projects, and commercial deployments. In addition to ReliOn and Altergy, Plug Power, Ballard Power Systems, and Hydrogenics manufactured, marketed, and sold products based mostly on a simplified direct-hydrogen system. Sprint was one of the very early adopters in North America of FC systems for BUP, installing close to 250 units, without any government assistance, to help them understand this new technology.[56] The units were sourced predominantly from Plug Power and ReliOn. From its initial commercial activities in 2003 to the fourth quarter of 2008, ReliOn stated publically that it had deployed more than 1.7 MW of BUP products primarily to customers in North America. In the third quarter of 2009, Altergy reported that it had sold more than 330 BUP FC systems to Metro PCS, none of which were part of the ARRA-FCP.[57] Recent changes in regulations in the United States that require BUP systems to provide a 72-hour runtime per cell tower site have increased the value proposition of FC technology relative to batteries which are limited to a four-hour backup runtime, unless they are stacked in series, or supported by diesel generators—which can be expensive and occupies a lot of often valuable real estate. The 72-hour runtime capability brings FCs in line with what the telecommunication service providers can achieve with their noisy and polluting diesel generators, assuming the power requirements for BUP warrant the use of such systems. In larger cities, cell towers are more often located in areas of high population and high real estate costs. These factors favor the use of FC technology given the low noise and zero or near zero emissions combined with a low profile footprint. Zoning, code, and fire officials are becoming more comfortable with hydrogen as a fuel and given that city cell towers are often located on high rise building roof tops, the use of a volatile gas as fuel, when compared to a nonvolatile liquid fuel like diesel, is more acceptable from an overall safety perspective.

Given the demand in this market for instant power when there is a grid failure, with 99.9999 percent reliability, plus the huge cost of even minutes of cell tower downtime, both in dollars and in end user reputation, the direct hydrogen solution seems preferable to a reformer based system, which has a much longer start up time and requires some form of hybridized power system to meet the instant power requirement.[58]

IdaTech pioneered the development of reformer based systems for BUP. In January 2011, IdaTech announced that it had sold more than 445 BUP FC systems during 2009 and 350 units during 2010, none of which were funded by ARRA-FCP.[59] The company has sold many BUP products outside of North America to telecommunications companies in South Africa, Mexico, and Indonesia where extended runtimes to back up less reliable electric grids are a market requirement. There are similar large markets for telecommunications back up in places such as India, China, and India. Efforts to use direct hydrogen fuel cells as backup power failed in India because of the lack of infrastructure for hydrogen fuel production and

---

56 K. Fitchard, *The Greening of Xohm*, September 15, 2008. Available at time of press at http://connectedplanetonline.com/wimax/news/telecom_greening_xohm/index2.html

57 ReliOn, *ReliOn E-1100v Fuel Cell Product Offers Footprint Space Savings*, February 28, 2012. Available at time of press at http://www.relion-inc.com/news.asp#41

58 M. Billingham, *Backup Power Systems*, June 5, 2012. Available at time of press at http://goo.gl/zs5RU

59 IdaTech, "IdaTech plc Public and Trading Update," January 2011. Available at time of press at http://www.idatech.com/uploadDocs/IdaTech%20plc_2010%20Trade%20Update_Jan2011.pdf

delivery. Methanol reformate-based FC systems appear to have technological advantages in these situations. IdaTech worked closely with Ballard Power to develop such systems. In July of 2012, Ballard Power Systems acquired IdaTech's FC product lines for BUP applications, along with distributor and customer relationships and a nonexclusive license to related intellectual property. Ballard intends to pursue BUP FC commercialization in Southeast Asia, the Caribbean, Latin America, and South Africa. [60]

Somewhat dissimilar to the current MHE market, telecommunication BUP products have more commercial growth traction and a higher value proposition outside of the United States. As such, growth in this market should be less impacted by the significant financial crises that have impacted the United States and more recently, Europe. The major growth markets for telecommunications BUP are in faster growing and developing markets such as India, China, Latin America, and Africa.

With the exception of IdaTech and Ballard Power Systems, most of the North American FC system OEMs have focused their marketing efforts in their own markets.

5.1 BUP Units Demonstrated and Sold in the Pre ARRA-FCP Period

In 2012 the DOE FCTP reported 649 BUP FC systems in field operation up to that time.[61] The companies developing and fielding BUP FC systems are identified in Table 13.

Table 13 Companies Supplying BUP FC Systems for Telecommunications (2004-2012)

Company	Number	Power	Fuel	Locations
Altergy Systems	5	30 kW	hydrogen	California, Florida, South Africa, India
Hydrogenics	2 2 25	30 kW 200 kW Not available	hydrogen hydrogen Not available	North America
IdaTech	3	5 kW	hydrocarbon	Europe, India, Indonesia, Australia
Nuvera	5	5 kW	hydrogen	North America
Plug Power	NA	5 kW	hydrogen	North America,
ReliOn	NA	500 W 17.5 kW	hydrogen	North America, Indonesia, other unspecified countries
Ballard Power Systems	NA	1-5 kW	hydrogen and reformate	Caribbean, South Africa, China, Latin America

ReliOn, Plug Power, IdaTech, Hydrogenics, Ballard Power Systems, and Nuvera were the North American companies that had fielded BUP FC systems prior to ARRA-FCP, starting back as early as the late 1990s. The U.S. Army Corp of Engineers through their Construction Engineering Research Laboratory (CERL) managed several projects prior to 2005 evaluating residential power as prime power and BUP.

[60] Ballard, *Commercializing Fuel Cells Systems in South Africa*, November 6, 2012. Available at time of press at www.fuelcellseminar.com/media/51071/b2b23-1.pdf

[61] J. Kurtz, K. Wipke, S. Sprik, T. Ramsden, C. Ainscough, and G. Saur, "Spring 2012 Composite Data Products—Backup Power," NREL/PR-5600-55311, April 3, 2012.

Hydrogenics manufactured BUP FC systems prior to ARRA-FCP and reported sales of 25 units in 2004. Hydrogenics reported a large order of 500 units in 2006; however, no announcement of delivery was made and the customer could not be identified.

Plug Power developed the GenCore FC system for telecommunications BUP that operated on hydrogen fuel. Sales, shipments, or installations of the GenCore units over the time period 2005 through 2009 are reported in Table 14.

The announced sales are reported as a separate category because in the early days of developing FC-powered BUP, many of the announced sales did not come to fruition.

Table 14 Pre ARRA-FCP BUP FC System Shipments by Plug Power

Year	GenCore Sales Announced	GenCore (shipped or installed)
2008	109	
2007		208
2006		94
2005		95

The failure to finalize the sales may be a result of Plug Power's misinterpretation of the market drivers for this application. Whereas ReliOn focused on providing a more expensive "plug and play" FC system that could be maintained with low-level personnel, Plug Power provided a more complex FC system that was aimed at lower initial capital cost. The telecommunications industry was accepting of a plug-and-play unit that could be maintained but shied away from the more complex Plug Power offering—valuing perceived reliability more than low initial capital cost. Further, technical advances in onsite hydrogen storage subsequent to Plug Power's involvement were also favorable to ReliOn.

The ReliOn systems had an average lower heating value electrical efficiency of approximately 30 percent. This direct hydrogen electrical efficiency is similar to the requirement by DOE in the FOA solicitation. In an early study, 23 percent of the ReliOn BUP FC systems demonstrated reliability at or greater than 99 percent where the reliability is measured as the percent of successful, on demand, instant startups of the FC system.[62] However, only 54 percent of the ReliOn system demonstrations achieved 99 percent availability where availability is measured as the percent of FC units ready to be used in a backup power mode. The data for this study are shown in Figure 13.

Plug Power withdrew from the stationary BUP market in 2010 and licensed the intellectual property of the GenCore BUP unit, and also the GenSys stationary power unit, to IdaTech. Plug Power completed this transition during the ARRA-FCP, while the company was an awardee, to demonstrate a hybrid hydrogen-LPG version utilizing both the GenCore and GenSys systems technology.

[62] D. Wheeler, "Stationary Fuel Cell Demonstrations," submitted to National Renewable Energy Laboratory, 2009.

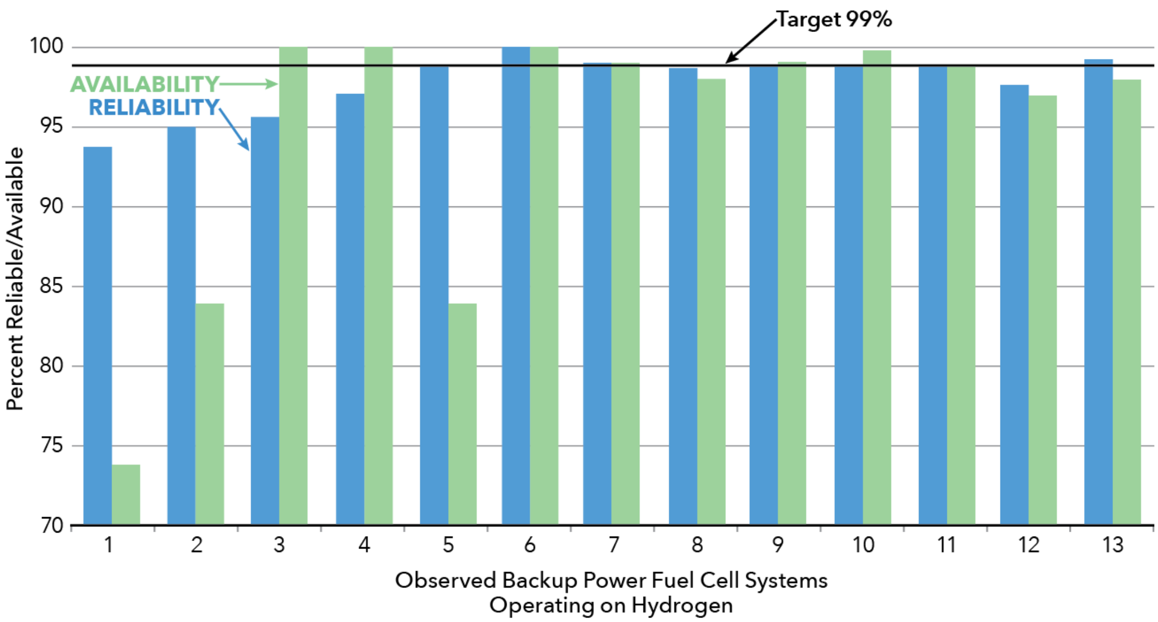


Figure 13 Pre ARRA-FCP ReliOn Reliability and Availability Data, CERL FC Program

5.2 BUP Units Demonstrated and Sold during the ARRA-FCP Period

The deployment of FC systems for BUP during the ARRA-FCP period greatly increased the sales volume for the industry and expanded the customer base. NREL reported that 649 BUP units were deployed by 2012 both with and without ARRA-FCP funds. However, a portion of the units procured without ARRA-FCP funding was purchased through a different program at NREL that was the beneficiary of separate ARRA funding for laboratory-based awards.

As shown in Figure 14, the DOE reports nearly twice as many purchases of FC-powered BUP (1,300 units) without funding during the ARRA-FCP funding period than with funding (730).[63] The purchases without ARRA-FCP funding were facilitated because of tax credits and grants that were available to end users. Thus, the rapid growth cannot be totally attributed to ARRA-FCP funding. Because of involvement in the grant process and the associated investment calculations, ARRA-FCP funding may have influenced end users to consider FC systems for BUP that resulted in additional purchases. The data in Figure 14 were published in June 2012 and as such may contain post ARRA-FCP data.

Altergy Systems was an indirect recipient of ARRA-FCP funding for BUP in their sales of at least 330 units during the ARRA-FCP period; Altergy sold 38 units to Sprint using ARRA-FCP funds. Increases in overall sales of BUP units from 2009 to 2010 are shown in Figure 15. Overall, FC-powered BUP sales increased by 25 percent to a 2010 total of 1,221 and the ARRA-FCP FC-powered BUP sales were 42 percent of the 2010 total.

[63] P. Devlin, “Market Transformation & American Recovery and Reinvestment Act,” 2012 Annual Merit Review and Peer Evaluation Meeting, May 14, 2012.

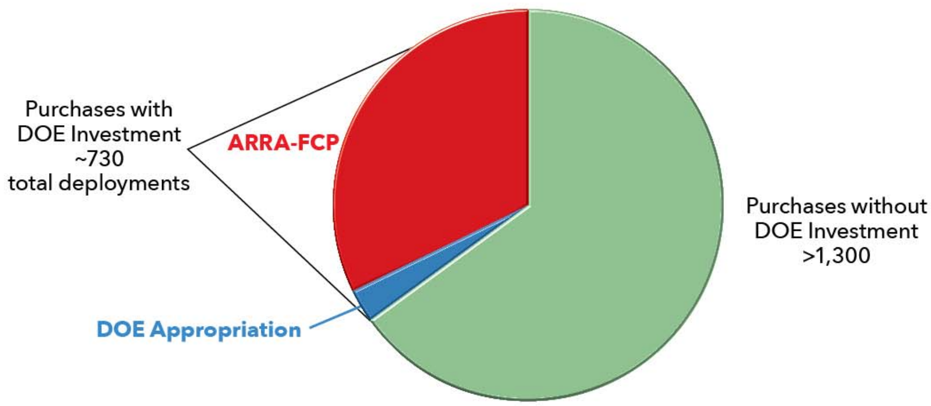


Figure 14 Effect of ARRA-FCP on Purchases of BUP FC Systems during the ARRA-FCP Period

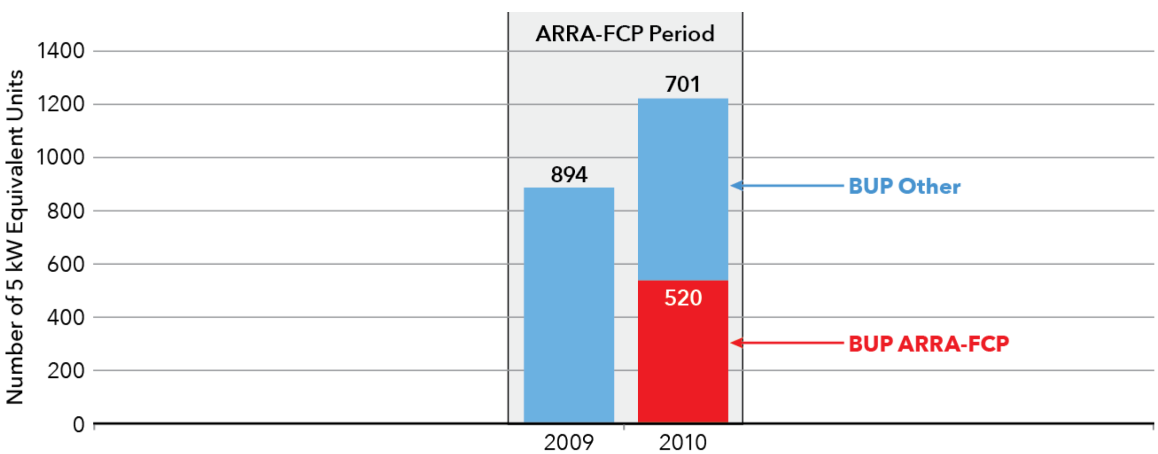


Figure 15 Sales of ARRA-FCP and Non ARRA-FCP BUP FC Systems during the ARRA-FCP Period

SOURCE: D. Greene, K. Duleep, and G. Upreti, "Status and Outlook for the U.S. Non-Automotive Fuel Cell Industry: Impacts of Government Policies and Assessment of Future Opportunities", Oak Ridge National Laboratory, ORNL/TM-2011/101, May 2011.

5.3 BUP Units Demonstrated and Sold in the Post ARRA-FCP Period

FC systems for BUP applications ordered, sold, delivered, or commissioned continued to grow after ARRA-FCP in 2012 as shown in Table 15. Altergy announced they planned to deploy 22 MW of BUP FC systems in California working with MetroPCS. Altergy also initiated a program in India to conduct a demonstration prior to deployment of additional FC-powered BUP. The company activities in India could lead to the Altergy products being manufactured in India. Altergy announced in August of 2012 the sale of 1,000 7.5 kW FC systems to an unnamed wireless telecommunications carrier.

Table 15 Growth in Sales of BUP FC Systems in the Post ARRA-FCP Period

Sales	Number of units	Power	Notes
North America - MetroPCS	1,528	10 kW	
North America - MetroPCS	537	15 kW	
India	1	2.5 kW	Trial
India	1	5 kW	Trial
North America	1,000	7.5 kW	

In 2011, CERL placed an order to evaluate 19 BUP FC systems from at least four manufacturers (ReliOn Inc., Altergy Systems, IdaTech, and Hydrogenics). In this five-year demonstration program, bottled hydrogen was used at all but one site. The FC systems supply electricity to critical electric loads whenever there is a local electrical grid failure. In 2012, Hydrogenics announced a contract to supply BUP FC systems to CommScope, Inc. but did not provide details of the transaction.

The total FC-powered BUP units entering the market is shown in Figure 16 and is derived from many disparate data sources as indicated earlier. These units entering the market are the sum of all data derived from known ordered, sold, delivered, or commissioned transactions. Although every precaution has been taken to prevent double counting, these data can only be considered as a reasonable estimate of overall market growth. At this time, these data are not at a level where quantitative values can be given at high confidence level for the direct and indirect effects along with replications and emulation to be assumed as resulting from the ARRA-FCP.

The data from Figure 16 are an indication that the market for FC-powered BUP is growing at a substantial rate. How much of this can be directly attributed to ARRA-FCP is not known with certainty. The spike in 2011, which is similar to the spike for MHE, is a significant acceleration from what was happening prior to ARRA-FCP funding. Verification of this effect will have to await the availability of more public information from the companies involved. For one BUP FC system OEM, ReliOn, had the ARRA-FCP funding not been available, the company may not have been in the financial position to take full benefit from the increased end user demand for FC systems and participate as fully in the follow-on market growth after the ARRA-FCP funding period.

5.4 Examples of Effects on FC Market Participants in ARRA-FCP and Post ARRA-FCP Periods

As with the MHE analysis in Section 4, the team interviewed a range of BUP FC market participants some of whom (*i.e.*, supply chain vendors such as Air Products and Linde) supported the deployment of MHE FC systems, as well as BUP FC systems, to address the key objectives of this evaluation.

Because the BUP market is smaller and there are no public companies at the FC system OEM level, there was greater difficulty in obtaining detailed sales data. As such, data were not publically available and had to be sourced from the OEMs themselves. However, the respondents were cooperative without violating their companies' confidential or competitive policies and provided what information they could, offering keen insights into the value and challenges of the ARRA-FCP projects and into the status of FC systems in the deployment phase of early market penetration. As a reminder, demonstration and R&D phase project insights for the stationary, portable, and auxiliary power respondents are addressed in Section 6.

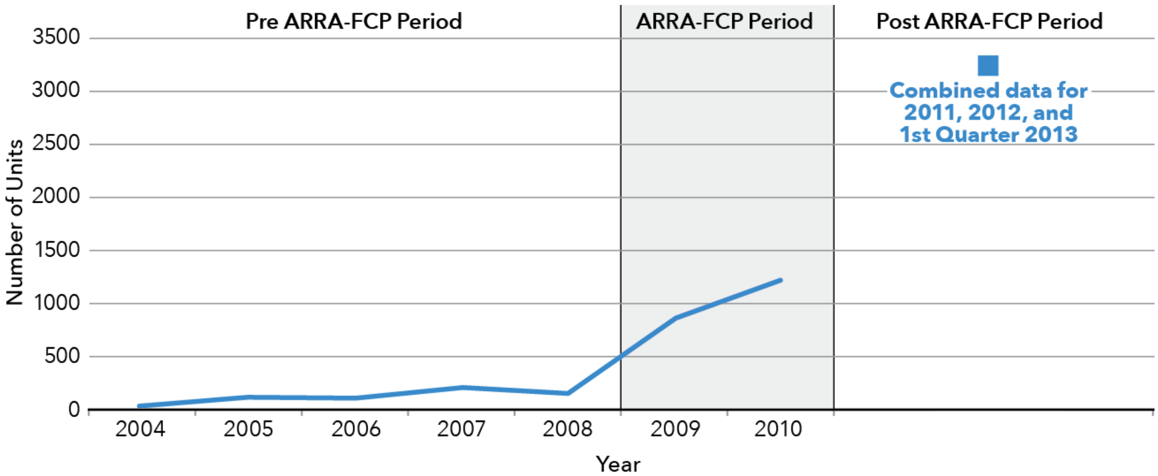


Figure 16 Estimated Annual Sales for BUP FC Systems Entering the Market

5.4.1 Examples of Effects of ARRA-FCP on End Users

The four metrics of greatest importance to the end users are product value, incentives for product purchase, acceptability, and community acceptance. Each of these metrics will be examined from the perspective of how the ARRA-FCP has influenced the end user. With this information as background, the end user interview responses will be analyzed.

5.4.1.1 Product Value

Reliable uninterrupted service and sufficient power to meet a 72-hour runtime, with low noise and zero emissions are the primary values delivered to the customer by FC-powered BUP. As an on-site BUP for telecommunication cell towers to offset the risk of grid failures, one of the great advantages delivered by FC-powered BUP is extended operating time compared to standalone battery BUP systems. Seventy-two hours of continuous operation is a critical discriminator for FC-powered BUP when compared to battery systems.

Diesel generators are the baseline for 72-hour BUP operation. These systems have an initial cost advantage over FC systems; however, maintenance costs for diesel generators are 7 times the maintenance cost for FC systems. ReliOn compared and analyzed hydrogen-fueled BUP systems with diesel generator BUP systems.[64] The cost comparison is given in Table 16.

The equipment cost for the FC system is higher than the cost of the diesel generator. However, after the tax credit or ARRA Section 1603 grant and the permitting costs, the FC systems have similar or lower first cost than diesel generators. Note, however, ReliOn does not provide an explanation for the fact that the power rating of the diesel generator is five times that of the FC system. The annual maintenance and fuel costs are considerably less for the FC system when compared to the diesel generator. A big difference is the need to overhaul the diesel generator after approximately 800 hours of operation. The lifecycle costs definitely favor the FC systems. There may be a problem with ReliOn's analysis in that they have utilized a

[64] ReliOn, *Backup Power for Telecommunication Applications—Comparing Fuel Cells to Diesel Generators*, June, 2011. Available at time of press at http://www.relion-inc.com/pdf/ReliOn_BackupPowerComparison_0611.pdf

10-year lifetime, and it is not clear that a FC system will remain functional for 10 years even when the application requires operation for only 10 percent or less of the 10 year timeframe.

Table 16 Comparison of BUP FC System Cost to Diesel Generator BUP Cost

	10 kW system in enclosure with fuel storage	**Diesel generator 50 kW with automatic transfer switch and fuel storage**	**10 kW system indoor rack mount with external storage**
Capital cost			
Equipment cost	$50,000	$30,000	$45,000
Federal incentives	-$15,000	0	-$15,000
State incentives	Varies	0	Varies
Permitting/installation	$13,500	$18,000	$13,500
Total first cost	$48,500	$48,000	$45,000
Operational cost			
Annual maintenance and fuel	$700	$5,000	$700
Lifecycle cost after 10 years	$55,500	$98,000	$52,000
Cost comparison after five years	$52,000	$73,000	$48,500
Cost comparison after 1 year	$49,200	$53,000	$45,700

Carbon dioxide reduction and sustainability are concomitant benefits of hydrogen fueled FC-powered BUP. Industry has an emerging need to fulfill sustainability requirements.

> *With the installation of this fuel cell system [from Altergy], Time Warner Cable's superior service reliability will now be even better. In addition, to providing our customers with the highest quality services, this reserve power system will help us reach the State of California's goals for improving air quality, secure our energy future by reducing greenhouse gas emissions, and cut our petroleum dependency.*
> — Jon Tennies of Time Warner Cable

Sprint and Motorola both stated the benefits of sustainability and reducing greenhouse gases:

> *Sprint gets it—this alternative source of energy for mobile communications will not only help stimulate the nation's economy and rebuild America, but also help lead to a greener cleaner environment.*
> — Bob Azzi, Senior Vice President of Network, Sprint

> *This HFC [hydrogen fuel cell] deployment is the tip of the iceberg for us. The recent DOE grant is helping us to double the number of hydrogen fuel cells deployed across the U.S., as we continue to examine opportunities to green our network. We are making great progress in pursuing environmentally sound alternative energy solutions to power our network.*
> — Sarabeth Patch, Sprint Environmental Sustainability Communications Manager

Motorola has deployed more than 100 fuel cells to provide backup power to a public safety communications network:

> *. . . fuel cell technology offers a no carbon, low acoustic alternative to match the needs for TETRA[65] base stations in challenging locations. They are proven in critical power backup situations and can run for extended periods limited only by the supply of the hydrogen, and the only emission is water. . . . Loss of power should never be an issue to professionals working in mission critical or emergency environments, and Motorola has continued to invest in environmentally friendly backup power systems for TETRA. We are delighted that the SINE rollout has been such a success, and we look forward to rolling out further hydrogen powered fuel cells in critical locations across Northern Europe.*
> — Jens Kristiansen, Vice President and General Manager, TETRA Global Products and Solutions, Motorola

As noted, product value is a matter of cost and value produced. The product value for FC systems in the BUP market results from competitive costs, operational efficiency, reduced maintenance, reduced fuel costs, and increased sustainability benefits.

5.4.1.2 Incentives for Product Sales

In addition to ARRA-FCP funding, tax incentives play a role in product sales. These incentives were in place before, during, and after the ARRA-FCP funding period. David Greene, *et al,* in the ORNL analysis of the impact of federal incentives (*i.e.*, ITC) on the sales of FC systems predicted that removal of policy support in 2010 would likely cause a collapse of the BUP FC market.[66] As it turned out, the tax policies were continued. As shown in Figure 17, in the predicted removal of the federal incentives in 2016 would have an immediate negative impact on sales; however, the market would likely re-establish itself to continue its growth within two years, assuming the FC system OEMs survive the downturn during that period.

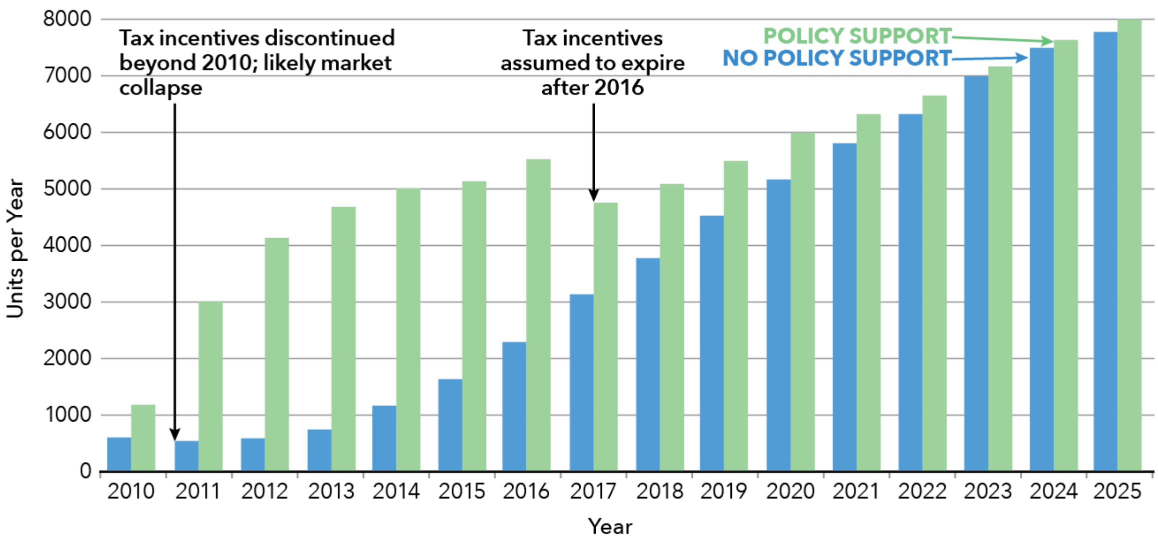


Figure 17 Projected Sales of BUP FC Systems (5kW) With and Without Policy Support for ITC

65 Tetra stands for Terrestrial Trunked Radio. It is a mobile radio and two-way transceiver designed for public safety use.

66 D. Greene, K. Duleep, and G. Upreti, "Status and Outlook for the U.S. Non-Automotive Fuel Cell Industry," Oak Ridge National Laboratory, ORNL/TM-2011/101, May 2011.

Figure 18 displays the overall timing of BUP unit sales and government funding incentives including the ITC, EESA, and ARRA-FCP for FC related commercialization activity. These data were generated from AMR reports. Other reports indicate the total ARRA-FCP units in operation as 819 units rather than the 734 units but may have included retrofits and replacements.[67]

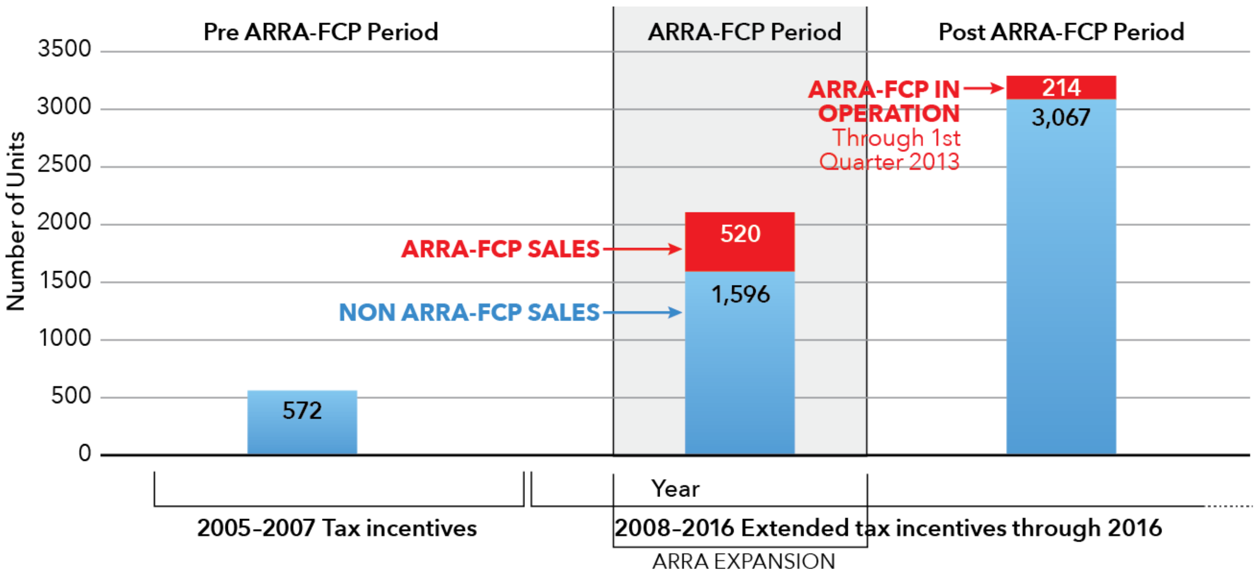


Figure 18 Additional ARRA-FCP Units in Operation **(2004 to first quarter of 2013)**

5.4.1.3 Community Acceptance

There has been concern about community acceptance of hydrogen-based FC systems at telecommunications sites. Much of this has been driven by perceptions of public acceptance of hydrogen and concerns about local permitting.

In many geographical locations, the total length of time from initial planning to operation of direct hydrogen BUP FC systems is sometimes as much as 10 months, significantly longer than to deploy diesel generators, making FC systems more expensive overall to deploy. Securing end user acceptance does not ensure that a FC system will be purchased and installed. In many cases, the owner of the site is not the telecommunications service provider who leases or rents the site from an owner or another commercial entity. The approval of these parties is a requirement before the FC system can be purchased and sited.

Initially, it was expected that one out of every three selected sites would encounter significant issues such that deployment efforts would be abandoned. In practice, according to one engineering service provider, close to two out of every three sites were deemed unacceptable.

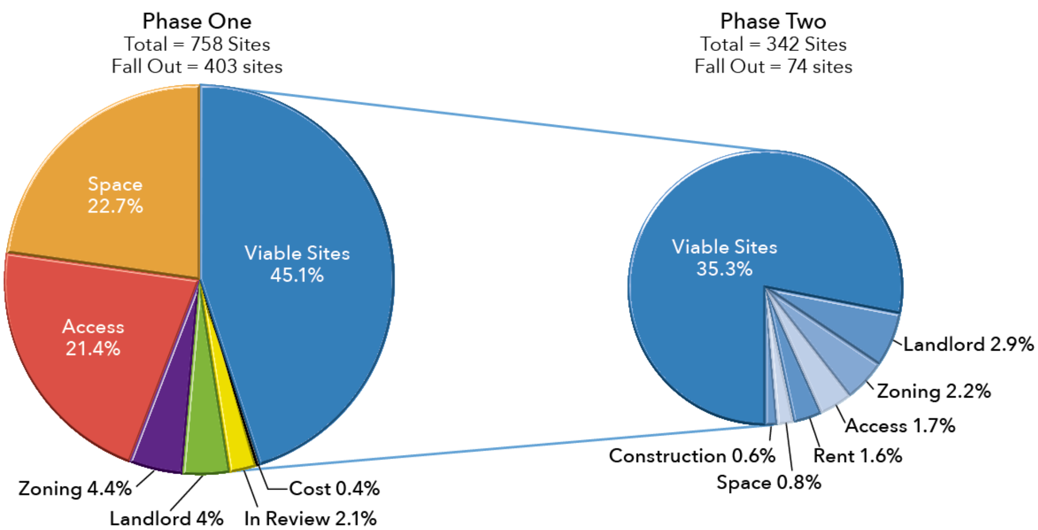
[67] J. Kurtz, S. Sprik, C. Ainscough, G. Saur, M. Post, and M. Peters, "Early Fuel Cell Market Deployments: ARRA and Combined Quarter 1, 2013 Composite Data Products- Deployment", May 09, 2013. Available at time of press at http://www.nrel.gov/hydrogen/cfm/pdfs/arra_deployment_cdps_q12013_4web.pdf

Sprint approached the siting of BUP FC systems as a three step process. The first phase was a site investigation to evaluate the challenges with siting including leasing and permitting. The second phase was site design for the BUP FC system placement and operation with all documentation prepared for the landlord or tower owner approvals. Phase three involved taking the lease for construction through to final siting and operation of the FC system.

The goal of the three-step process was to save cost and to quickly identify sites that are potentially viable and then proceed to a more in-depth assessment and deployment. There are a number of issues that can make siting slow, costly, or not feasible: access to the site may be difficult for fueling or other purposes, there may be insufficient space to locate the fuel cells or the fueling infrastructure, site landlords may be reluctant or unwilling to allow the equipment, it may be difficult to obtain permits, and the site may impose excessive costs.

Figure 19 presents the results of Sprint's screening of 758 sites. Forty-five percent of the sites remained after the first phase screening and 35 percent after the second phase.[68] After both screenings, 23.5 percent of dropouts were due to space issues, 23.1 percent were due to access issues, landlord issues accounted for 6.9 percent, zoning was 6.6 percent, rent was 1.6 percent, and cost or construction issues were 1.2 percent.

What these data imply is that zoning issues were responsible for the inability to site systems at only 6.6 percent of 758 sites. More prominent reasons for sites being dropped were space and access issues each accounting for 23 percent of sites. Landlord issues accounted for about seven percent of sites being dropped. Space and access issues are not necessarily independent of permitting and zoning issues. For instance, buildings and equipment may have to have certain setbacks from the boundaries of the site. These are not issues dealing with risks associated with the equipment.



[68] The percentages for the second phase were calculated from a prior year report, but they should be very close to the actual. K. Kenny, "Use of 72-hour Hydrogen PEM Fuel Cell Systems to Support Emergency Communications," presentation at the 2013 Annual Merit Review and Peer Evaluation Meeting, May 15 2013.

Figure 19 Reasons for Excluding a Site from Deployment after a Two-phase Evaluation

On the basis of these data, concerns about community acceptance, if zoning issues are defined as a measure of acceptance, seem to be primarily a problem of perception. As a result of the ARRA-FCP and non ARRA-FCP deployments, there have been advances in educating first responders, regulators, and the general community as to the safe use and environmental advantages of hydrogen as a fuel. The BUP FC system OEMs reported developing detailed briefings and using them to good effect with community officials and with officials of major cities on both coasts. The analysis suggests local officials can be accepting of hydrogen-fueled FC systems when given appropriate information.

5.4.1.4 End User Acceptance

Nearly twice as many purchases of FC-powered BUP systems were made without ARRA-FCP funding during the ARRA-FCP period, *i.e.*, greater than 1,300 purchases without ARRA-FCP funding compared to approximately 730 total ARRA-FCP supported units deployed. (See Figure 14.) The 1,300 purchases without ARRA-FCP funding were eligible for a tax credit or grant from the federal government and state incentives, and it is anticipated the purchasers benefited from these incentives. Sprint and Motorola's acceptance of FC-powered BUP was expressed by their words and actions.

5.4.1.5 Analysis of End User Responses

Prior to the ARRA-FCP, many telecommunication companies indicated they had run small field trials and demonstration programs to better understand FC technology in their application. Given the high reliability requirements identified earlier, the end user base in the telecommunications market is very reluctant to embrace new technology until it is proven. More than one respondent stated that telecommunication providers are a very conservative group. While batteries and diesel generators have well known issues of short operating times for batteries and high maintenance issues respectively, all of the end users wanted demonstration of reliability and stability of the fuel cell systems prior to committing to accepting fuel cells as a replacement for batteries and diesel generators. The ARRA-FCP provided financial incentives for the demonstration of fuel cell reliability and stability. Competing with fuel cell technology is the continued evolution of battery technology.

The ARRA-FCP projects in BUP have provided some of the necessary investment to help ensure that enough key end users have the experience of FC technology to understand and evaluate the economics and business risks associated with a broader scale commercial adoption of the technology. The ARRA-FCP has allowed end users the opportunity to evaluate a larger number of FC systems, from various manufacturers, at a cost point and with a supporting infrastructure that minimizes the barriers to potential acceptance for new technology adoption.

From a sale of products perspective, the objective of the ARRA-FCP was to put into service some 539 FC systems in BUP applications. A significant number were deployed through Sprint Nextel. The ARRA-FCP actually exceeded this objective with the deployment and upgrading of more than 750 units at end user facilities by April 2012. The ARRA-FCP activities provided confidence and encouragement in FC systems at a time when over 1,300 industry funded FC systems for BUP were being deployed. In the timeframe of this study, Sprint had deployed 183 of the 260 planned units and had commissioned 25 out of 70 units that were to be retrofitted. Other units included new units sold or existing units upgraded for AT&T Mobility and T-Mobile, and with PG&E for some of its cell site customers, as well as FC systems sold to various U.S. government departments.

For end users, the reliability of the FC systems is more important than the cost of the system for large telecommunications providers who have tens of millions of customers. FC systems for BUP applications must be reliable and perform in an exacting and wholly predictable manner. Additional attributes that were important to customers and highlighted by end users were sustainability, low carbon footprint, and zero emissions when hydrogen gas is used as the fuel. Some end users found advantages of FC systems for BUP applications related to significantly increased efficiency and minimal maintenance relative to diesel generators. BUP FC systems were readily scalable to different power outputs while providing a smaller physical footprint relative to battery and diesel generator combinations and providing excellent start up reliability and a quiet operation. The ability of end users to swap nonfunctional fuel cell modules in the ReliOn FC systems with replacement units without interrupting product functionality *(i.e*., plug and play) is a significant capability to ensure rapid and simple maintenance operations.

When questioned regarding incentives, a majority of end users expressed a belief that the ARRA Section 1603 federal renewable energy grant should be continued beyond 2016 for FC systems. They felt this program would provide a greater stimulus for the adoption of FC systems across nationwide telecommunication service providers as compared to the value offered by the federal tax credit or various state level programs. The main benefit of ARRA Section 1603 is the extension of the ITC to 2016 and the introduction of grants for organizations with no tax liability.

Most of the end users acted as their own systems integrators to ensure that the FC systems were housed appropriately to the site requirements and desired functionality and serviceability based on climate issues and other factors critical to the safe operation of the FC systems. The FC system OEMs or their agents performed any required maintenance. Depending on the failure mode, the simplicity of the ReliOn FC system design often made it possible for an end user service technician to perform the required maintenance with some instructions from the FC system OEM via telephone. Some of the FC systems were fitted with automated self-detection alarms that issued a warning by cell phone directly to the FC system OEM or a designated service company to initiate an immediate response, especially those failures that related to a low fuel situation or an impending FC system breakdown.

5.4.2 Examples of Effects of ARRA-FCP on Systems Integrators

The metrics of importance to MHE systems integrators are unit sales, systems integrator acceptance, and the product value. Information for BUP is limited because there are no public BUP companies, but a limited analysis was performed.

5.4.2.1 Systems Integrator Acceptance

FC-powered BUP systems are often installed by engineering service providers such as Ericsson, as well as end users such as AT&T and PG&E. No specific information was available from AT&T, PG&E, or other end users. It is likely the role of systems integrator was performed by the FC system OEM or the end user or a combination of the two entities. No specific information on acceptance was available from any systems integrator.

5.4.2.2 Analysis of Systems Integrator Responses

For the BUP market value chain, the role of systems integrator, that is the entity that places the FC system into an environmental box to manage temperature control and air conditioning as would be required to ensure optimum performance of the FC systems is most often performed by the end user or the end user and FC system OEM working together. Sprint took the approach of outsourcing this function, including site selection, regulatory approval, hydrogen infrastructure, refueling logistics, and service and maintenance activities to Ericsson.

The engagement Sprint had with Ericsson was highly functional in that several of the key Ericsson employees working on the FC systems' integration, service, and maintenance were former longtime employees of Sprint and had detailed understanding of the telecommunications industry. Ericsson managed and operated all of Sprint cell tower sites, not just those operating FC systems. Basically, Ericsson managed all the activities from site selection to on-going operations of the FC systems through the end of their scheduled lifetime.

At the time of the interview in January 2013, Sprint had secured all the planned 260 BUP sites, under the ARRA-FCP, for new FC systems deployment or system upgrading. All but 15 sites remained to be commissioned, and completion dates for these installations were scheduled for the end of March 2013.

In general, the FC systems installed or upgraded through the ARRA-FCP projects have performed efficiently and with excellent reliability over the 1.5-to-2-year period of operation for the earliest deployed units in telecommunications cell tower BUP. One of the potential failures of greatest concern, noted by one end user, was a low fuel alarm for a FC system located in a remote geography that generally would require two to four days to be refueled. With the new 72-hour requirement, this can be a challenge for the larger power systems. From time to time, as noted by an engineering service company, some contract challenges were encountered with hydrogen fuel suppliers that gave rise to a lower than desired level of comfort with regard to the surety of fuel supply. However, these issues were being effectively addressed through detailed negotiations.

The service engineering company also developed an effective training plan for service technicians. Where there was a critical mass of FC systems operating in a given location or state, these technicians can have permanent roles, moving from site to site performing regular service functions or emergency maintenance operations as needed. Where the sites were more separated geographically, the technician's work is generally done through contractors, but the same training is used to ensure optimum functioning of the FC systems. The service engineering approach worked on the basis of a five-year lifetime warranty for the BUP FC systems that they installed. This covers the DOE requirement that the FC systems be evaluated over this timeframe based on an assumed average outage of tens of hours on an annual basis, absent natural disasters.

One engineering service provider expressed a belief that the use of hydrogen as a fuel would be positively impacted as regards consumer acceptance if there were more general public education about the safety of hydrogen and its positive local environmental impacts. Improved consumer acceptance, in turn, could go a long way toward faster permitting and regulatory acceptance of BUP FC systems at cell tower sites, especially those located in highly populated areas.

Overall, from a full-time equivalent (FTE) perspective, one engineering service provider had about two FTEs dedicated to activities with their specific end users and the BUP FC system deployments and upgrading, which included some short term subcontractors for specialty work at the sites.

5.4.3 Examples of Effects of ARRA-FCP on FC System OEMs

The metrics of greatest importance to the BUP FC system OEMs are unit sales and OEM and supplier revenue and costs (*i.e.*, profitability). The end user interview responses were analyzed with this information as background.

5.4.3.1 OEM and Supplier Revenue and Costs

Financial data are unavailable for the major suppliers of BUP FC systems, ReliOn and Altergy. These entities are not public companies and have no requirement to publish such data and have a strong desire to avoid making this sensitive information available to competitors. However, given that these companies continue to seek investments to operate and grow their business, it could be assumed that profits from FC system sales are not yet sufficient to fund on-going business activities.

Cummins Inc. made a strategic investment in ReliOn as announced in January 2013. As part of the strategic investment, Cummins will provide engineering and manufacturing expertise to accelerate ReliOn's commercialization of FC systems for BUP. In April of 2011, ReliOn secured an additional $6 million in equity financing with existing investors, which was used to continue commercial growth in the U.S. and to expand international marketing and sales activities.

Altergy Systems was the recipient of an investment by a battery maker, EnerSys Inc., in 2009; however, details regarding the investment and commitment by EnerSys Inc. to Altergy were not identified. Clean Energy Investments and South Africa's PGM Development Fund investments in Altergy Systems will also helped provide the company with market information on base station telecommunications in South Africa for Altergy's BUP FC systems. The investment by PGM in Altergy secured the transfer of Altergy's technology to Clean Energy. Clean Energy plans to manufacture FC systems in South Africa for the sub-Saharan market. Altergy's continued need for investments to expand its market base indicates the on-going revenues alone are not sufficient to maintain Altergy's growth.

Hydrogenics has announced sales of BUP FC systems during the period 2004 to 2012, but details have not been forthcoming. In 2012, Hydrogenics announced it had achieved over $100 million in sales for its overall FC power business.

5.4.3.2 Analysis of BUP FC System OEM Responses

The majority of BUP FC systems delivered under the ARRA-FCP came from ReliOn, with Altergy Systems delivering 38 FC systems to Sprint. Both entities were very strong in their belief that the ARRA-FCP had positively influenced end user acceptance of FC systems and their willingness to adopt the technology in greater numbers. The ARRA-FCP also allowed the FC system OEMs to capture a greater level of interaction with the highest level decision makers within the target companies. The total dollar value of purchases, given the increased number of units sold to a single end user, pushed the purchasing decision to executive-level employees who then wanted to understand more about the technology and its benefits. The ARRA-

FCP also allowed end users to deploy a critical mass of units, sufficient to assess for themselves the value propositions of FC technology as an alternative BUP solution for telecommunications.

ARRA-FCP funding helped to accelerate product sales but it did not lead to any significant improvements in product design and manufacturing processes. These elements were somewhat fixed as the FC systems had already shown promise from earlier field trials and sales to end users. However, the ARRA-FCP did facilitate some design improvements to the FC systems as a result of end user feedback and some maintenance issues that required resolution.

In operational terms, the ARRA-FCP also allowed an increase in hydrogen fueling infrastructure activity and an increased capability to deliver hydrogen to a disparate collection of some 650 sites spread across the United States. The ARRA-FCP incentivized the fuel providers and distributors to get more involved, increase focus, and reduce pricing by increasing the overall size of the business to something of reasonable commercial value. The ARRA-FCP objective of deploying such a large number of units and the overall increased activity through ARRA-FCP related sales, follow-on sales, and indirect sales all added up to make it reasonable for the fuel providers to offer more efficient and cost-effective hydrogen delivery methods. In many instances, the fuel providers were able to move from costly bottled hydrogen systems and banks of T-size cylinders to a more bulk hydrogen delivery system. One FC system OEM noted, “An indirect outcome of the ARRA-FCP, specifically the independently funded bulk refueling capability, has resulted in an expanded market for our company’s products outside the ARRA-FCP activities.”

Drops or lost calls due to power outages are a major concern for telecommunication companies in retaining their customers. One FC system OEM stated that some of their BUP FC systems had demonstrated 12,000 to 15,000 hours of durability at end user sites without any refurbishment to MEAs in the stack subsystems. Overall, failure rates of less than one percent were noted as an average across all the sites where the company had deployed products. While this is an excellent level of performance for a new technology, it still falls short of the 99.9999 percent reliability target of most telecommunication service providers. However, one FC system OEM noted that its calculated reliability for deployed products had reached 99.63 percent. This reliability is a very significant improvement over the 88.4 percent reliability of diesel generators that do not have battery back-up.

One FC system OEM developed a two-day training program for customers that covered product use, hydrogen use and safety, and codes and standards that are key to obtaining optimum performance from their products. Another FC system OEM focused on working with its preferred fuel supplier to provide end users and community groups with seminars on the safety of hydrogen and its use as a fuel.

One FC system OEM demonstrated that regulatory approval for roof top siting of hydrogen BUP FC systems can be achieved, a consideration for the deployment of FC systems in highly populated urban areas. Some localities are quite comfortable with hydrogen fuel use on rooftops of buildings, even in preference to liquid fuels like diesel. This preference was not just from a noise and pollution perspective, but also because any leaks of hydrogen gas rapidly and harmlessly dissipate into the atmosphere while liquid fuels, especially nonvolatile fuels like diesel, tend to spread fast across a horizontal surface during a spill and create a greater potential fire hazard. One FC system manufacturer noted that after training, “[The company] had no issues getting permits for ground and roof top facilities in New York and San Francisco.”

An interesting extension of product value that was proposed by one FC system OEM based on the high confidence in the durability of its systems, is that some end users would install larger BUP FC systems and use the electricity from the FC system to offset high costs of peak power grid electricity without compromise to the emergency BUP capability requirements of the systems. This would reduce the payback period for the initial capital investment and improve the overall ROI analysis to help drive the initial purchasing decision.

The FC system OEMs of hydrogen-fueled BUP systems declared the ARRA-FCP a great success and felt strongly that the stimulus to product sales and the related exposure of end users to the technology advantages over incumbents would likely lead to a continued growth in sales following the end of the ARRA-FCP funding.

While FC system OEMs did not benefit directly from tax incentives, all FC system OEMs expressed support for the federal tax credit incentive for FC system capital equipment purchases as a stimulus for end users as they calculate the value of various technology options for BUP solutions. One FC system OEM stated that the federal ARRA grant and tax credit can offset the $45,000 to $50,000 capital cost of a 10 kW FC system by between $13,500 and $15,000 depending on where the system is installed and whether it is an indoor or outdoor facility. State tax incentives are also available across the various states, with the best incentives offered by California and New Jersey. As FC commercialization continues to grow, one FC system OEM expressed a desire to see incentive programs increase in value to more closely approximate those provided to other renewable energy systems.

FC system OEMs were reluctant to speak directly to revenue data resulting from their participation in the ARRA-FCP. However, both companies acknowledged that revenues increased and in some cases substantially with direct and in some cases, indirect, sales resulting from ARRA-FCP activities.

The accessibility to efficient hydrogen fuel delivery, especially for some of the more remote sites, also posed some problems. Toward the end of 2012, there was a significant improvement in the fuel availability and the refueling situation as most sites moved from T-cylinder replacement, a cumbersome and costly process, to a bulk refueling process where the cylinders are refilled and re-pressurized from higher capacity fueling tanks. The FC system OEMs are working directly with the fuel providers to improve the end user experience and to increase confidence level for surety of hydrogen supply in all situations. These improvements address higher capacity installation requirements for fuel allowing facilities to operate for longer outages, thereby addressing the requirement for up to 72 hours of BUP capability. The availability of bulk hydrogen fuel was a critical driver in reducing operating costs and thereby increasing end user acceptance of FC systems as a solution to telecommunications BUP needs. Other technologies for providing reliable hydrogen such as onsite reforming have been evaluated but have failed to find much application given the high initial capital cost and the relatively small quantities of hydrogen required by the average site.

The cost share nature of the ARRA-FCP, with more than 50 percent coming from the industry partners, plus the large numbers of units involved, ensured that there was significant financial and hence business involvement by industry partners in making sure that the program was successful. This level of end user commitment was greater than what existed with FC system OEMs prior to the start of the ARRA-FCP and was a very positive effect from the program.

For FC system OEMs that sold less than 100 units as a result of the ARRA-FCP, there was insufficient additional revenue to warrant hiring new staff. FC system OEMs who sold in excess of 100 units were able to retain employees that may otherwise have had to be reassigned or let go and were even able to hire new employees.

FC maintenance costs were calculated by the FC system OEMs to be substantially lower, by a factor of five or six, as compared to the corresponding maintenance costs for diesel generators. For FC systems, maintenance was scheduled approximately once per year based on the relative simplicity of the systems and the lack of moving parts. By comparison, major components of the diesel generators required maintenance on a quarterly basis.

5.4.4 Examples of Effects of ARRA-FCP on Supply Chain Vendors

The metrics of greatest importance to the supply chain vendors are unit sales (heavily dependent on sales incentives, end user acceptance) that were examined earlier. As such, this section focuses on the analysis of the supply chain vendor interview responses.

5.4.4.1 Analysis of Supply Chain Vendor Responses

The supply chain vendors interviewed as part of this evaluation covered the MEA and the stack subsystem of the FC system. The team also interviewed two key hydrogen fuel suppliers and providers of fueling infrastructure. The feedback from the supply chain vendors of materials and components was that there was no significant impact to their overall business from the ARRA-FCP. The main FC system OEM who benefited from the ARRA-FCP for BUP systems had a very competitive policy of outsourcing all major materials and components for the stack and the limited BOP components used in their FC systems. In many instances, these were based on competitive bidding processes with the company managing to qualify a number of materials and components from different supplier chain vendors to help drive competitive pricing.

The potential downside to this sound business strategy is that no particular supplier would experience exclusive access to the increased product volume and therefore would experience limited positive impact to the bottom line. However, as stated during interviews, when the FC system sales grow, this competitive bidding process and flexibility to use various supplier components without impact to FC system performance will result in value to all players across the supply chain, further driving cost reduction, materials improvements, and component design, all of which will reduce cost and increase product reliability for end users.

The hydrogen fuel and fueling infrastructure providers played a significant role in increasing end user acceptance and surety of fuel supply. Air Products was the major player in the deployment of BUP FC systems during the ARRA-FCP. Cost of hydrogen fuel and fuel infrastructure delivery was reduced as a function of the introduction of bulk fuel sales as opposed to the laborious and costly refilling or replacement of banks of standard T or K-size cylinders. The fuel providers became increasingly more proactive through the duration of the ARRA-FCP projects in supporting the efforts of the FC system OEMs to ensure that end users were provided with a reliable and cost-effective solution in the implementation of BUP FC systems at often disparate geographical cell tower sites.

It should be noted that while hydrogen fuel cost remains relatively high, the fuel is consumed at almost twice the efficiency of power conversion as diesel. From 2009 to 2011, diesel prices have risen almost 58 percent, whereas hydrogen fuel prices have only risen 30 percent during the same timeframe.[69]

ARRA-FCP has gone a long way to convince the fuel suppliers that there is a growth business opportunity in FC systems. The relatively large number of FC system sales, during and post ARRA-FCP, not funded by the ARRA-FCP also speaks volumes for end user acceptance of the technology, which provides additional comfort to fuel providers that they are supporting a growing business.

Where state incentives were available to support the installation of fueling infrastructure, this made the economics of deploying FC systems more acceptable to some end users. Overall, the increase in sales of FC systems, through programs like the ARRA-FCP, increased the interaction between engineering service providers and FC OEMs with the regulatory and permitting bodies. All of the engineering service providers and OEMs interviewed indicated that the ARRA-FCP increased understanding of hydrogen safety issues and the use of hydrogen as a fuel.

Community acceptance of hydrogen was a real issue at a relatively small number of proposed locations and remains an issue of educating the public and key decision makers among first responders regarding the safety and properties of hydrogen gas. Funding from DOE was specifically directed to enhance hydrogen safety during the execution of the ARRA-FCP, but clearly more needs to be done. There has been no safety issue related to the use of hydrogen reported at the BUP sites where FC systems have been deployed through the ARRA-FCP.

5.5 European Activities in FC systems for BUP during ARRA-FCP

In addition to the many product value advantages of BUP FC systems relative to battery and diesel generator systems described in Sections 4 and 5, in Europe, the ability of the FC systems to allow low maintenance and remote control capability are highly valued by end users.[70] There are many companies that already offer BUP FC systems in Europe, such as P-21 Gmbh, ReliOn, Axane, and Hydrogenics.

Through its distribution partner Dantherm, Ballard Power Systems is supplying its ElectraGen BUP FC system products to telecommunication end users in Europe. The ElectraGen products are sold as units that can be operated on hydrogen fuel or on methanol reformate. The BUP FC systems are available in modular units of either 2.5 or 5 kW. As of the end of 2012, Ballard had sold over 2,200 ElectraGen systems (approximately 9 MW of power capacity) globally, including in Europe.[71]

In 2011, ReliOn formed a partnership with HOPPECKE, a leading manufacturer of industrial batteries, charging equipment, and energy systems to supply BUP FC product under the HOPPECKE name throughout Europe, the Middle East, and Africa.[72] ReliOn started to ship its E-1100v BUP FC systems into the European market for telecommunications backup power applications at the end of 2011. To more successfully

---

69 ReliOn. *Backup Power for Telecommunication Applications: Comparing fuel cells to diesel generators*, June 2011. Available at time of press at www.relion-inc.com/pdf/ReliOn_BackupPowerComparison_0611.pdf

70 Roads2HyCom. *Case Study: Back-up/Remote Power for Telecom*. Available at time of press at http://www.ika.rwth-aachen.de/r2h/index.php/Case_Study:_Back-up/Remote_Power_for_Telecom

71 Ballard. *Telecom Backup Power.* Available at time of press at http://www.ballard.com/fuel-cell-applications/backup-power.aspx

72 ReliOn. *HOPPECKE Batterien GmbH & Co. KG adds ReliOn Fuel Cell Products*, March 9, 2011. Available at time of press at http://www.relion-inc.com/news.asp#32

penetrate markets like Europe, ReliOn entered into a partnership with Hy9, a Massachusetts based designer and manufacturer of palladium alloy membrane hydrogen purifiers and on-site hydrogen generation systems, to develop a reformer based system so that its BUP FC systems can be operated on fuels other than direct hydrogen.[73]

[73] Hy9. *ReliOn and Hy9 Announce Collaboration Agreement on a Fuel Processor for Fuel Cell Products*. Available at time of press at http://www.hy9.com/uploads/ReliOn%20and%20Hy9%20Announce%20Collaboration%20Agreement.pdf

6 Demonstration and R&D Phase Projects

In addition to the major deployment phase projects in MHE and BUP, the ARRA-FCP also funded four smaller cost-shared demonstration projects in APU, portable power, CHP, and BUP for military applications. Delphi Automotive was funded in part to complete the development of a SOFC-based auxiliary power unit for demonstration in a standard long distance delivery truck. MTI Micro fuel cells received support for the manufacturing process development of a portable power product based on DMFC technology for portable electronic applications as a battery replacement. Plug Power co-funded a program to demonstrate a natural gas reformate CHP based on high temperature PEMFC technology. Finally, Plug Power was funded in part to demonstrate low temperature PEMFC systems, fueled by reformate from LPG, for mission critical BUP applications at military bases. Further, the ARRA-FCP co-funded two smaller R&D projects in portable power.

Typically, the general objective of demonstration phase projects is to advance product technology or design to the point where the product is ready for initial field trial and subsequent validation by performing field trials of up to tens of units in controlled tests in preparation for deployment phase evaluation. Results from those field trials were intended to help assess customer requirements in greater detail, improve their product design, and eliminate shortfalls. Typically, the general objective for R&D phase projects is to advance laboratory level technology and assess its viability for further product development and demonstration.

The projects and their progress as a result of ARRA-FCP funding are each described in more detail as follows.

6.1 Auxiliary Power Demonstration Phase Project

This project was funded with $2.4 million from the ARRA-FCP and $2.4 million of cost share by Delphi. The stated objective of the project was to develop, design, and demonstrate a 3-to-5 kW SOFC APU system for heavy duty commercial Class 8 trucks to supply hotel power and heating using diesel fuels.[74] The unit made use of Delphi's SOFC system as the core power plant to demonstrate the market potential for driver-based APU requirements inside a commercial truck.

The market drivers for the development of a SOFC APU were to avoid the high cost of diesel combustion and the related emissions resulting from truck driver mandatory stops where engines are often left idling for lengthy periods of time to provide refrigeration or heat or air conditioning while the driver rests or sleeps in the truck cab. Statistics indicate that these stops result in the annual consumption of close to one billion gallons of diesel fuel and emit 11 million tons of carbon dioxide, 180,000 tons of nitrogen oxide, and 5,000 tons of particulates. Many local jurisdictions in the U.S. now have programs aimed at getting drivers to shut off the truck when parked in order to improve air quality. The SOFC APU is targeted to reduce idling fuel consumption by 85 percent, reduce emissions to below Environmental Protection Agency (EPA) standards, and reduce noise to below 60 decibels.

As part of their program Delphi committed to demonstrate the operation of one unit in an actual truck operating in over-the-road conditions. Similar products are currently being developed using both DMFC

[74] K. Vaughn. "Jadoo Power Fuel Cell Demonstration," Presentation at the 2011 Annual Merit Review Proceedings. Available at time of press at http://www.hydrogen.energy.gov/pdfs/review11/h2ra005_vaughn_2011_o.pdf

and SOFC in Europe. The European companies appear to have a head start in the development of the SOFC APUs with Topsoe Fuel Cell and AVL Gmbh reporting the development of prototypes.

Delphi identified the product value of the SOFC APUs (as yet undemonstrated on an actual truck), as follows:

- High quality, reliable power: 110 volts AC or 12 volts DC
- High fuel efficiency: 40 to 50 percent higher than current generating set APUs
- Low noise: less than 60 decibels at three meters
- Ultra-clean: near zero emissions
- Meets Tier 4 emissions standards for non-road diesel engines
- Less than 8 g per kWh carbon monoxide emissions
- Less than 0.2 g per kWh non-methane hydrocarbons and nitrogen oxide emissions
- On-board reforming capability

The SOFC APU technology is not ready for demonstration and must await successful completion of the internal evaluation phase. However, any sale of a SOFC APU would be eligible for federal incentives should they meet these criteria.

In devising the project, Delphi identified the key system level challenges as:

- Cost and weight
- Manufacturability and vibration robustness
- Durability and reliability
- Packaging

During phase 1 of the project, Delphi worked with its truck partner PACCAR to establish application specifications and commercial level requirements for the SOFC APU system. Phase 2 activities focused on system design verification and system testing on the bench and in an actual truck. In phase 3, the SOFC APU system was to be tested in a customer-owned Class 8 truck under realistic operating conditions.

At the time of the interview in 2012, Delphi had achieved most of the technical goals of the project but had not accomplished over-the-road testing.

The main technical reason that the FC system was not fleet tested in the third quarter of 2011 was a previously known functionality issue with the desulfurizing unit mostly observed during repeated thermal cycles. Delphi believes that this issue can be resolved or circumvented to allow the planned customer truck testing to be conducted at a later date.

The ARRA-FCP funding was instrumental in continuing the development that would have been significantly curtailed without the funding.

6.2 Backup Power Demonstration Phase Project

The Plug Power BUP project was funded with $2.7 million from the ARRA-FCP and $2.7 million cost share from Plug Power. The stated objective of the project was to demonstrate an improvement in the reliability and efficiency of mission critical BUP utilizing Plug Power's low-temperature GenSys LT system fueled by a hybrid hydrogen-hydrocarbon reformate FC BUP.[75] The GenSys LT system has been demonstrated to deliver effective BUP over a temperature range of -5°C to 40°C at altitudes of up to 1,000 meters in remote locations.

The project plan was developed to accomplish the following key objectives:

- Perform a cost analysis and commercialization study based on the GenSys LT product line.
- Conduct site planning and applications engineering.
- Conduct site specific engineering development.
- Build GenSys LT FC systems and perform factory testing.
- Make field deployments.
- Conduct field operations and related management services.

The ARRA-FCP contract goals were to install and operate 10 hybrid hydrogen LPG FC systems at each of two different military installations, Ft. Irwin Engineering Building and Warner Robins Air Force Base Air Logistics Center. This system was designed to operate for 72 hours in mission critical or emergency environments specifically for the military. The unit was to have rapid start up capability because the hydrogen used in the equivalent of a GenCore front end unit would allow the LPG-fueled GenSys LT continuous power unit to start up and come to temperature and operate on a hydrocarbon LPG fuel to attain the 72-hour desired operational capability. Ida Tech was enlisted as a subcontractor to assist in the field testing.

The Warner Robins site was commissioned and operated for over 18 months with system life projections of 3,000 to 16,000 hours and a lower heating value electrical efficiency in the mid 20s. The Warner Robins site was hampered by permitting problems.

The testing identified the need for design improvements to address control, BOP, and operating problems.

In the pre ARRA-FCP period, the CERL programs operated prior to 2005 were the backbone for the evaluation of hydrocarbon fueled stationary power for BUP and continuous power applications. Plug Power supplied 65 of these FC systems, IdaTech supplied three FC systems, and Nuvera one FC system for the CERL study. The units also operated as stationary power systems providing an alternative to grid power.

Electrical efficiency data (lower heating value) for these FC systems is shown in Table 17. This identifies a reduction in PEMFC electrical efficiency for the LPG FC system compared to natural gas FC systems.[76] For the Plug Power FC systems operating on natural gas, the average electrical efficiency is 24.3 percent while

[75] D. Rohr, "Accelerating Acceptance of Fuel Cell Backup Power Systems," Presentation at the 2011 Annual Merit Review Proceedings. Available at time of press at http://www.hydrogen.energy.gov/pdfs/review11/h2ra007_rohr_2011_o.pdf

[76] D. Wheeler, "Stationary Fuel Cell Demonstrations," submitted to National Renewable Energy Laboratory, 2009.

the LPG fueled system was 21.4 percent. The average efficiency for the Nuvera FC systems operating on natural gas was 24.2 percent. These natural gas and LPG efficiencies are inferior to grid efficiencies.

Table 17 Pre ARRA-FCP Electrical Efficiency by OEM in CERL Program

PEMFC OEM	Fuel	Electrical Efficiency (%)
Plug Power	LPG	21.4
Plug Power	Natural Gas	24.3
Nuvera	Natural Gas	24.2
IdaTech	Natural Gas	22.0
IdaTech	LPG	21.5
Grid Efficiency [a]	Coal	28 - 33

[a] B. Fesmire, "Energy Efficiency in the Power Grid," ABB Inc., July 9, 2007.

In addition to the CERL FC program, three other projects prior to ARRA-FCP were of significance: the Cooperative Research Network program, the U.S. Navy FC Demonstration Program, and the Long Island Power Authority FC demonstration program. These sales data are provided in Table 18.

Table 18 BUP and Stationary Power Deployments Prior to ARRA-FCP

Fuel cell program/company	Number of PEMFC units
CERL	6
Cooperative Research Network	11
U.S. Navy	20
Long Island Power Authority (with partial DOE funding)	137
Total	**237**

Sales of hydrocarbon fueled stationary systems continued through the ARRA-FCP funding period and IdaTech was the U.S. leader in those sales. The IdaTech sales data are given in Table 19.

Table 19 Non ARRA-FCP Sales of BUP FC Systems during ARRA-FCP Funding Period

Company	Number of units	Year
IdaTech	445	2009
IdaTech	350	2010

During the ARRA-FCP period, Plug Power decided to abandon their efforts on stationary FC systems (both high and low temperature) and focus their business development activities on MHE FC systems only. Plug licensed the intellectual property for its stationary power products, GenCore and GenSys, to IdaTech PLC on a nonexclusive basis. Plug Power sold inventory, equipment, and certain other assets related to its stationary power business unit as part of the licensing agreement with IdaTech.

In 2012, IdaTech sold its BUP assets to Ballard Power Systems including the IdaTech manufacturing facilities in Mexico. The purchase of the assets was made through the transfer of $7.7 million in Ballard shares to Investec, IdaTech's principal funder. The acquisition of IdaTech's BUP assets and a nonexclusive intellectual property license to these assets by Ballard is indicative of the funding and revenue generating difficulties faced by many of FC system OEMs and related subsystem manufacturing companies.

Multinational telecommunications company CommScope estimated that by 2013, wired and wireless operators worldwide would be spending over $10 billion on the generation of power for their networks.[77] CommScope says an estimated 1.8 billion liters of diesel are used each year to fuel wireless networks in India. With the development of an economic fuel infrastructure, for hydrogen or methanol, FC systems for BUP applications will be viable in Asia, noted CommScope.

The FC system OEM supplier revenue from hydrocarbon-based, low temperature FC stationary power systems was built on federal and state funding of demonstration programs for Plug Power and IdaTech. IdaTech had additional revenue from foreign sales before, during, and after ARRA-FCP. These sales revenues were insufficient to offset the operating expenses of these companies. As indicated before, Plug Power operated at a loss during this period and ended up exiting the stationary power business.

6.3 Combined Heat and Power Demonstration Phase Project

The Plug Power high temperature PEMFC for the CHP applications project was funded with $3.4 million from the ARRA-FCP and $3.4 million from Plug Power.[78] The stated objective of the project was to demonstrate the durability and economic value of the Plug Power GenSys Blue 5 kW high temperature CHP PEMFC system. The GenSys Blue is a natural gas fueled product that has demonstrated good beginning of life performance but needs to be redesigned to reduce cost and increase durability to meet the end user requirements of CHP applications. The National Fuel Cell Research Center (NFCRC) was part of the project and tasked with performing modeling analyses of the FC system to help with design improvements and also functioned as an external testing facility of the GenSys Blue 5 kW units.

Ahead of the project, Plug Power had already demonstrated an alpha system that proved out the key elements of technical feasibility for the design. In the high temperature PEMFC system, the CHP efficiency can exceed 85 percent. The stack technology makes use of a phosphoric acid functionalized membrane based on polybenzimidazole, which allows the FC system to operate at up to 180°C and produce both high quality heat at 160 to 180°C and electricity.

The major deliverables for the project were as follows.

- Perform durability and reliability tests of the GenSys Blue 5 kW system.
- Build and text six GenSys Blue 5 kW units under standard CHP protocols.
- Install four GenSys Blue 5 kW units in real world residential and light industrial end user locations.

[77] Fuel Cell Today, "The Fuel Cell Industry Review 2012," Johnson Matthey PLC.
[78] M. Vine, "Why Plug Power Could Double," Seeking Alpha, March, 2012. Available at time of press at http://seekingalpha.com/account/portfolio

Since testing of the Six GenSys Blue 5 kW units began in January 2010, the units have logged over 30,000 hours of stack operation, producing 50 MWh of electricity and 417 MWh of heat, averaging over 30 percent electrical efficiency and over 85 percent thermal efficiency. Stack durability has been increased on average from 1,500 hours to 3,800 hours during the lifetime of the project. These improvements were attributed to plate and MEA advances. As with previous experience in FC system demonstrations, more than 50 percent of the failures related to the BOP components and the electrical controls as opposed to the stack and its components.

Three of the GenSys Blue 5 kW units continue to be operated at NFCRC in Irvine, California and one unit is being tested at a Taco Bell facility.

Plug Power made a business decision to abandon this technology line and did not complete the deliverables. ClearEdge Power has since joined the activities and is reviewing the test data and testing articles available to them through NFCRC. It is believed that the test data are a valuable contribution to ClearEdge with respect to understanding how these systems are functioning relative to design intent.

A stationary, high-temperature PEMFC operating in a continuous power mode providing both power and heat at a high combined efficiency was demonstrated in the laboratory as part of the ARRA-FCP project. Plug Power's ARRA-FCP contract targets were to deploy 12 GenSys Blue, natural gas, CHP FC systems. Six were commissioned in Plug Power labs producing over 31,000 run hours at CHP efficiency of up to 90 percent and electrical efficiency of up to 32 percent. Three were operated at the NFCRC at UC Irvine. Problems with MEA availability for the Plug stack configuration curtailed further field testing of additional Plug units and instead Plug engaged ClearEdge participation with some of their systems. The testing did identify weaknesses and required corrections in both the system and stack design of the GenSys Blue product. In the post ARRA-FCP period, Plug has focused on MHE applications.

The ARRA-FCP provided critical funding to Plug Power that allowed the high temperature system technology to be evaluated.

ClearEdge is a manufacturer of high temperature stationary PEMFC systems and shipped its first FC systems in 2009. ClearEdge has established two very large sales agreements that would require delivery of over 10,000 of ClearEdge's base 5 kW stationary power plants, as shown in Table 20.

Table 20 Unit Sales of High Temperature PEMFC Systems

Manufacturer	Units Sold	Period
Plug Power	14	2009-2010[a]
ClearEdge Power	800[b]	2009-2010
	100	2011 Commercial
	38	2011 DOE
	1700 (8.5MW)[c]	2012
	10,000[c]	

a In 2010, Plug Power discontinued high temperature PEMFC activities.
b Announced sale to LS Industries; no shipping or installation data available.
c Announcement as part of 50 MW agreement with Gűssing Renewable Energy, no delivery or installation data available. The 50 MW announcement implies that 10,000 5 kW base units were sold.

However, no follow-up information on deliveries or installations of the large orders was available. For the Gűssing Renewable Energy sale, it was identified that 1,700 units would be delivered as part of a multi-phase effort. No information was available regarding performance warrantees for the ClearEdge FC systems.

The product value for stationary FC systems is built on their high reliability, high availability, and high efficiency production of quality heat and electricity for commercial usage. Stationary FC systems provide electrical power for critical loads where power interruptions are costly while having low operating cost and low lifecycle costs.

Stationary FC systems operating on hydrocarbon fuels have lower operating costs than hydrogen-powered stationary systems as shown in the Koyama reference.[79] However, while the initial cost for a FC system operating on hydrocarbons is greater than a FC system operating on hydrogen, Figure 20 demonstrates that the cumulative cost after two years favors the FC system operating on hydrocarbon fuel.

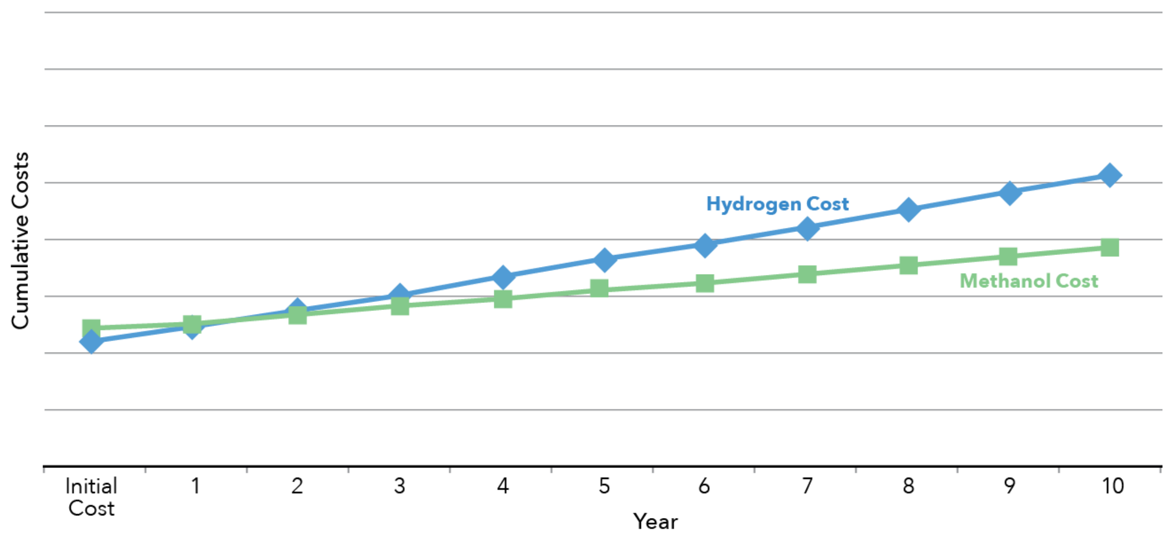


Figure 20 Cumulative Cost for FC Systems Operating on Hydrocarbon Fuel and Hydrogen

Carbon dioxide reductions and reductions of harmful emissions like NOx and SOx are sustainability benefits for the FC systems operating on natural gas or other hydrocarbons when compared to electricity from the grid that is generated by coal power plants (41 percent of U.S. facilities) or natural gas fired power plants (efficiency issues relative to FC systems). ClearEdge reports their 40 kW ClearEdge FC system installed at the Lafayette Hotel will eliminate 100 tons of greenhouse gas emissions each year. The average payback period is 6 to 8 years for a ClearEdge 5 kW baseline system costing $56,000 before taxes, installation costs, and rebates.

High temperature PEMFC developer ClearEdge Power successfully sold Oregon Business Energy Tax Credits to raise $5.9 million in cash.[80] This investment served as the basis for developing new and stronger equity investments and commercializing the high temperature FC technology. ClearEdge completed a $73.5

[79] H. Koyama, "IdaTech briefing for HTAP," October, 2010.
[80] R. O'Neill, "Purchasing Oregon Business Energy Tax Credits," Moss Adams, LLP.

million funding round in 2012. While the private firm does not report revenue, ClearEdge did report a 400 percent increase in revenue year-to-year for the second quarter of 2012.[81] ClearEdge continues to operate on investment funds and while revenues have grown, they do not have sufficient funds to cover all of their expenditures.

6.4 Portable Power Demonstration Phase Project

The MTI Micro Fuel Cell DFMC portable power project was funded with $3 million from the ARRA-FCP and $3.3 million of cost share from MTI. The stated objective of the project was to reduce the manufacturing cost of their portable power unit for consumer based electronic devices and demonstrate 75 units in the field under actual operating conditions.[82] This FC system was configured in a compact 1 W package using a DMFC operating as a battery charger. This charger has been proposed to increase the operational life of cell phones and other hand-held electronics when grid power is not available. The design objectives for the DMFC system were low-cost, high volume manufacturing processes and ease of assembly for a unit that could perform across the temperature and humidity range required of consumer electronics.

MTI Micro Fuel Cells identifies the advantages of the DMFC battery chargers as:

- Grid-free electrical power with no AC adapter required
- Charge on-the-go
- Generating electricity anywhere at any time
- Small cartridge—energy of 17 AA batteries in the footprint of 4 AA batteries

MTI was able to verify product operation in the field and obtained feedback from the users that provided a basis for modifications to develop a more commercially viable unit.

Under the ARRA-FCP project, MTI Micro Fuel Cells developed a working prototype with improved manufacturability and field-tested 75 units.

MTI met its commitment to deploy 75 units in field trials. The manufacturing processes for both the DMFC system and the replaceable methanol cartridge were evaluated and deemed to be acceptable for scale-up. The project was organized into three main phases of activities.

During Phase 1 of the project, many of the components were redesigned so that they could be manufactured in a smaller number of processing steps using existing high-volume manufacturing processes. The system simplification processes succeeded in eliminating an entire subassembly along with all the associated costs and potential reliability issues. Machined plastic parts were replaced by injection molded parts, sheet metal parts were stamped as opposed to machined, and use of adhesives and bridging components were eliminated by creating “lock and key” interfacing components.

The major objective of Phase 2 was to produce tools that would result in high yields for redesigned components. This required iterations of tools development and parts evaluation followed by redesign of the tools to improve tolerances and yields of acceptable parts. Comprehensive subsystem testing was performed to ensure that optimum functionality had been achieved before unification and full system

---

[81] C. Williams, “ClearEdge Lands the Big One: $73.5 Million,” Sustainable Business Oregon, August 2011.

[82] C. Carlstrom, "Commercialization of 1 Watt Consumer Electronics Power Pack," Presentation at the 2012 Annual Merit Review and Peer Evaluation, May 2011.

testing for performance and durability. Parametric testing of system level functionality was also performed at this stage to ensure that the design was capable of meeting design specifications during startup and shutdown and across the temperature and humidity profile regardless of the orientation of the device.

In Phase 3, evaluation kits, each containing the full 1 W DMFC charger and two filled methanol cartridges, along with multi-connectors so the device could be tested with all major cell phone designs, were sent to 75 users. The field testing group included 33 individuals, 21 military groups, 17 electronic consumer product OEMs, and four government agencies. Feedback was generally positive and highlighted some key areas of end user acceptance:

- An iPhone was successfully charged 10 times from 25 percent to full power on one fuel cartridge;
- The cell phone charging rate was similar to electrical outlets;
- Form factor was very user friendly;
- Charging could not be achieved in a confined space due to some fuel off-gassing and restricted access to air and was identified as a minor annoyance; and
- Some military users hailed the device as a potential candidate after further development for soldier tactical energy requirements.

Users identified the greatest advantages of the device as the freedom from wired charging and the convenience of power always being available as long as a methanol cartridge was at hand. User suggestions for improvements to the device, such as moving from a dual to a single switch to initiate charging, were incorporated into an early design change.

Unfortunately, following the end of the ARRA-FCP project, MTI was unable to obtain sufficient investments to allow them to continue the development. This forced MTI to suspend most operations and lay off employees. The ARRA-FCP provided an opportunity to improve the manufacturability and commercial viability of the MTI unit and increase its visibility to potential investors.

6.5 Portable Power R&D Phase Project

The University of Northern Florida (UNF) DMFC Portable Power for Mobile Computing Project was funded with $2.5 million from the ARRA-FCP and $0.6 million from the UNF. The stated objective of the project was to develop a DMFC portable power system for laptop computers making use of a novel passive water recycling technology licensed from PolyFuel, Inc.[83]

The major milestone required that a 20-W DMFC system be built and tested. As of mid-2011, system components had been selected and built into a functioning assembly for in-situ testing. The intent was to test the system for specific power, energy density, operating lifetime, and potential manufactured cost and to devise appropriate BOP components for overall systems integration.

To achieve the stated performance targets, UNF performed rigorous testing of all BOP components and the integrated subsystems. Through these testing protocols, UNF was able to transition the design into a

[83] J. Fletcher, "Advanced Direct Methanol Fuel Cell for Mobile Computing," Presentation at the 2012 Annual Merit Review and Peer Evaluation, May 2011.

packaged 20-W DMFC power supply that was then subjected to a series of tests to produce the functionality data.

Beyond the single packaged prototype, no more units have been built. A manufacturing assessment of the prototype conducted by Johnson Matthey indicated no obvious show stoppers to the commercial production of the unit. However, given the financial collapse of PolyFuel and the dependence on their membrane material to achieve the desired passive water recycling, it is unclear what alternative materials could be used to render the design functional. The PolyFuel membrane material has not as yet been proven to be effective over standard commercial membranes in any commercially available FC product. While UNF has adsorbed several former PolyFuel employees and has secured a license to the membrane technology, significant work still remains to be done to demonstrate the commercial viability of the 20 W prototype.

UNF has also questioned the viability of the intended market given the growing dominance of tablet computers combined with the ever increasing capability of battery technologies and the growing dominance of tablets over laptops.

UNF indicated the potential product values of their DMFC system as follows:

- Methanol fuel (as opposed to gaseous hydrogen);
- Grid-free electrical power with no AC adapter required;
- Charge on-the-go; and
- Generation of electricity anywhere at any time, as long as fuel is available.

UNF believes the device is ready for prototype demonstration. The UNF stated it was pursuing additional R&D funds to complete the prototype phase of their program. There was no indication that other manufacturers of similar devices are progressing to demonstration phases with qualified end users with the intent of product deployment.

The ARRA-FCP funding was critical to the continued development (as yet unsuccessful) of the novel membrane based passive water recycling technology that is part of this DMFC power system.

7 Summary and Conclusions

7.1 ARRA-FCP Funding for MHE and BUP Fuel Cell Systems

There was agreement among all interviewed end users that the ARRA-FCP funding was a strong contributor to their decision to purchase FC systems for their MHE for use in their warehouses/logistics facilities and for their BUP units for telecommunications and mission critical facilities. The funding stimulated both direct, unsubsidized purchases by end users and indirect purchases by other end users that were not part of the ARRA-FCP, but who had heard and read about the value propositions of using FC systems in MHE applications, based on the activities of the ARRA-FCP. This was similarly true of BUP FC systems purchased for telecommunication cell towers, especially given the smaller number of market participants at the end user level.

7.1.1 Effects on Sales from the ARRA-FCP

In the pre ARRA-FCP period (2002-2008), the OEMs demonstrated the capabilities of MHE FC systems. The FC system OEMs successfully worked with systems integrators to integrate FC systems into MHE trucks. The OEMs and systems integrators worked together to market MHE FC systems to distributors and wholesalers and worked successfully to deploy MHE FC systems with four firms at four sites. The products being delivered were early commercial prototypes and were still subject to reliability and other issues. During the latter part of this period, products were heavily marketed to distributors and wholesalers, particularly in food and beverage industries.

There were several key events that set the stage for the increase in market activity: the DOE Funding Opportunity Announcement (FOA), the ARRA-FCP awards, the establishment of the ARRA Section 1603 30 percent tax and grant incentives, ARRA section 1123 incentives of up to $200,000 for fueling (through 2010), various incentives offered by state governments, and active participation of systems integrators in incorporating the MHE FC systems into their MHE trucks. At the close of the pre ARRA-FCP period, the market for MHE FC systems was primed for growth.

The FOA that led to the ARRA-FCP awards and the strong marketing effort by the OEMs in the pre ARRA-FCP period were key to helping end users understand the advantages of MHE FC systems and determine how to calculate ROI, and they paved the way for the purchases that occurred during the ARRA-FCP period. In 2009, ARRA-FCP funding was awarded to four firms and seven end users resulting in 504 units being placed in active use at end user facilities. In 2009 and 2010, 12 end users, seven of which were first time users, deployed an additional 673 units without ARRA-FCP funding with some taking advantage of the tax and grant incentives. A slightly higher percentage (60 percent of total sales) of non ARRA-FCP than ARRA-FCP units were deployed in 2009 and 2010. This acceleration of deployments was made possible because of the ARRA-FCP, the ARRA Section 1603 tax and grant incentives or the combination of the two providing an acceptable ROI to end users. Without the tax incentives, it is unlikely that the non ARRA-FCP fleet purchases of FC systems would have been greater than those that were ARRA-FCP funded.

In the post ARRA-FCP period (2011 and 2012), 36 end user firms deployed MHE FC systems. Of those firms, 12 were first time users. There were 1,687 units sold in 2011, 1,301 in 2012 and 378 (partial data) were sold as of the first quarter of 2013. All of these units were eligible for the ARRA Section 1603 tax and grant incentives.

In 2010 there were increased sales, replications by existing users, and an increase in the number of new first time purchasers. Sales, replications, and the number of first time purchasers peaked in 2011, the first year following the ARRA-FCP period. Although the ARRA-FCP funding stream had ceased, the tax incentives remained. All three indicators of continuing market penetration declined in 2012. According to inputs from stakeholder interviews, a number of factors may have accounted for this relative decline in sales from 2011. There was a backlog of orders already processed in 2011. Some of the orders in 2011 may have occurred because of new spending by firms given the general US economic recovery. Because of the heavy marketing push, there may have been some acceleration of orders in 2011 that might otherwise have occurred in out years. The question for 2013 and beyond is whether orders and the number of firms making orders will increase in the out years.

Based on disparate data with limited confidence levels, during the ARRA-FCP period, 520 ARRA funded BUP FC systems were sold with an additional 214 ARRA funded BUP sales in the post ARRA-FCP period (see Table 21). More than double (1,596) the total ARRA supported sales (734) was sold during the ARRA-FCP period to existing and new EUs that did not have access to ARRA-FCP funding. More than 3,000 BUP units were sold without ARRA funding in the post ARRA period.[84]

In the interviews, FC systems OEMs and end users reported that positive experiences and outcomes from the ARRA-FCP contributed to the growth in product sales following the end of the program and contributed to replication and first purchases of FC systems. End users also made it clear that the availability of federal tax credits, grants and state-level incentives that offset some of the capital cost of the FC systems and hydrogen infrastructure were strong contributing factors to the final purchasing decisions. Table 21 summarizes the number of MHE and BUP purchases or leases by period and identifies the number of ARRA-FCP units.

Table 21 Total Sales of MHE and BUP FC Systems in the Pre, During, and Post ARRA-FCP Periods

	MHE Sold/Leased	BUP Sold/Leased	Total
Pre ARRA-FCP	377	572	949
During ARRA-FCP (ARRA Units)	504	520	1,024
During ARRA-FCP (Non ARRA Units)	673	1,596	2,269
Post ARRA-FCP through First Quarter, 2013	3,366	3,067	6,433
Grand Total	**4,920**	**5,755**	**10,675**

a BUP FC systems varied in power rating from 2 kW to 200 kW

Interviews with FC system OEMs indicate that very little money was spent on improvements to manufacturing processes as a result of ARRA-FCP funding. The FC system OEMs were unable to take full advantage of the manufacturing credit that created a 30 percent credit for investment in qualifying manufacturing facilities for FC components and other technologies. For the most part, the production of FC systems was managed through the careful use of labor and using existing equipment and processes. In the first quarter of 2013, for example, Plug Power, in collaboration with its suppliers, announced that it

84 P. Devlin, "Market Transformation & American Recovery and Reinvestment Act," Presentation at the 2012 Annual Merit Review and Peer Evaluation, May 2012.

had reduced its average manufacturing cost by 30 percent using its own funding. Finally, the quantity and predictability of sales made it difficult for upstream supply chain vendors to make significant contributions to cost reduction, either through investment in new materials and component development or in reduced component costs. However, one supply chain vendor did report that the increased sales due to ARRA-FCP funding and non ARRA-FCP sales made possible improvements to its process and changes to its product.

In summary, the data collected during the evaluation support the success of the ARRA-FCP in helping to spur early market commercial growth of FC systems in MHE and BUP for telecommunications cell tower sites. The data also support the conclusion that replication and first purchases of FC systems sales are attributable, in part, to the activities related to the FOA and the subsequent ARRA-FCP. In the case of the MHE application, there was sufficient effect from ARRA-FCP and the ARRA Section 1603 tax and grant incentive to accelerate FC commercialization. At the same time, the volumes are not yet sufficient or consistent enough to predict future growth or create a sustainable market share for FC systems in either MHE or BUP.

7.1.2 The Value Proposition

One of the market effects is that ARRA-FCP generated experience with the equipment that helped MHE truck manufacturers and end users understand, first hand, the value propositions for the technology and to appreciate the challenges and benefits associated with using hydrogen as a fuel. Interviewees reported that factors favoring the use of FC systems in MHE relate to increases in operational efficiency, increased warehouse space, and reduced energy consumption with sustainability benefits. Similarly, factors favoring the use of BUP FC systems are operational reliability and efficiency, reduced maintenance, reduced fuel costs, and increased sustainability benefits relative to diesel generators.

7.1.3 Tax Incentives and Grants

The 30 percent federal tax credit and ARRA Section 1603 grants, as well as additional state and local tax incentives (including direct tax incentives such as contributions towards the installation of fueling infrastructure equipment), changed the offset cost to the end user, making their investment decision easier and, in many cases, an essential factor in the purchase of FC systems, especially during and after the ARRA-FCP. The majority of end users, existing and new, made it clear that the availability of grants and tax incentives was a factor in their decision to purchase FC systems post ARRA-FCP. In conjunction with ARRA-FCP funding, the addition of incentives for energy property in lieu of tax credits that allow facilities with insufficient tax liability to apply for a grant (ARRA Section 1603) instead of claiming the investment or production tax credit, expanded FC system funding opportunities and encouraged financiers to participate. Without the ARRA awards, the grants, or tax incentives or some combination of them, it is unlikely that more than a few firms with multi-shift operations with numerous MHE would have selected the FC MHE.

While the vast majority of interviewees recommended that the federal tax credit for FC system purchases be extended beyond 2016 to help secure smooth and continued growth in sales, the total cost of ownership data for MHE FC systems indicates, for the intensive case (where MHE is operated three shifts per day and 350 days per year), that elimination of the federal tax credit would still favor the use of FC-powered MHE. However, the basis for this analysis appears to assume a 10-year lifetime for the FC system, which is an aggressive assumption based on the current information available on FC system durability from end user sites. There was widespread agreement among respondents that the current designs of FC stacks in FC systems have a three to five year life and then need to be replaced or refurbished. The data on which the assumption was based came from the FC system OEMs and there was an insufficient level of detail to allow for a reasonable independent analysis and confirmation of the basis for the assumed 10-year lifetime.

7.1.4 OEM Challenges

With the exception of the GenDrive 3000 air-cooled product line from Plug Power, most data sources indicate that the largest cost both in initial capital expenses for FC systems and in maintenance costs are related to BOP components. It is unclear from the evaluation data how FC system OEMs will reduce these costs. Even with continued stack price reductions, the stack is not at a high enough percentage of total FC system cost to have a truly significant impact in the short term. The three keys to cost reduction for BOP components are increasing market growth and resulting production volume, simplification of overall designs, and development of robust components that fulfill the durability and life requirements for a FC system.

Profitability is a continuing struggle for the FC system OEMs. For example, Plug Power, which has more than 85 percent of the market, faces a number of challenges. Reliability issues with some of the early deliveries have consumed some of the potential profits. If the failures can be engineered out of new product generations, then profitability may be improved in the near future. Financing new product development is another challenge. Developing plant capacity to deliver product in volume is yet another challenge.

None of the publicly listed FC system OEMs or their related FC stack SCVs have, to date, produced a net annual profit from the sale of FC-related products. For the private companies who are not required to disclose such financial details, it is also very likely that they are taking a net loss from the sale of FC systems. This situation, especially in light of limited investor interest in the FC market, makes it very challenging for FC system OEMs to meet rapid growth in demand and to significantly reduce product costs.

While new battery technologies are being developed by cash rich enterprises or by startups readily accessible through acquisition by these entities, the FC system OEMs remain relatively starved of investment dollars and unable, so far, to “cross the chasm” to commercial success and profitability. The ARRA-FCP and tax incentives have provided some of the investment to help ensure that enough key end users have experience with the technology to at least understand for themselves the benefits and to evaluate the economics and business risks associated with a broader scale commercial adoption of the technology. Significant challenges remain before these FC systems will be sustainable in the MHE and BUP markets.

7.1.5 Fueling Costs

A major market effect of the ARRA-FCP resulted from the partnerships between the FC system OEMs and suppliers of hydrogen. These partnerships resulted in the evolution of fuel delivery systems from temporary systems (*i.e.*, K bottles) used in early BUP applications to more permanent and economically viable solutions for adopters of FC systems, such as liquid hydrogen or tube trailers for MHE and larger pressurized hydrogen storage tanks for BUP. The ARRA-FCP helped convince fuel suppliers that FC-powered MHE and BUP could be a market in the future that deserved their attention. There was also near unanimous agreement that the costs of fueling infrastructure and the cost of hydrogen and its delivery must be reduced if the FC-powered MHE market is to become sustainable. The ability of the fuel supply companies to provide surety of fuel supply and competitive fuel and fueling infrastructure costs are essential to the commercial growth of these FC systems in these markets.

The ARRA-FCP and non ARRA-FCP funded deployments demonstrated that fuel suppliers like Air Products and Linde are essential to driving growth in the FC-powered MHE and BUP markets and in increasing end user confidence.

The deployments also made clear the need for fueling solutions with lower capital costs for sites with fewer units and one or two shifts. There are many options to reduce the cost of fueling: reduce the cost of liquid hydrogen infrastructure, do on-site fuel conversion, or use on-board fuel conversion to continuously charge an MHE battery (*i.e.*, Oorja Protonic DMFC technology). The cost savings achievable from these alternatives are significantly related to scale. With large facilities operating continuously and using a high percentage of FC-powered MHE, reducing the cost of liquid hydrogen infrastructure could be quite viable. Either of the fuel conversion options would be appropriate for smaller scale operations. One comparison suggested that $1.5 million of capital investment for a liquid hydrogen refueling system could be displaced by a $50,000 reformer system. Making an informed choice about fuel options and technological advancements would be well served with more market intelligence about the number of MHE FC systems at sites and facility operating hours.

7.1.6 Maintenance

The ARRA-FCP funding had an effect on both end users and OEMs. Maintenance cost is a significant component of the ROI analysis used by the end users in making the decision to purchase FC systems. The larger fleet sizes and greater management visibility facilitated by the size and scope of ARRA-FCP funding greatly reduced the per unit maintenance cost of MHE and BUP FC systems. This was accomplished both by internal maintenance personnel and by outside contractors. However, initially in almost all cases, for both MHE and BUP FC system deployments, it was the FC system OEMs that performed any required maintenance and servicing. Without the increased revenue from the ARRA-FCP funded and influenced sales, the OEMs would have been unable to address initial reliability issues that required additional maintenance manpower, support, and parts supply.

7.1.7 Jobs

While an uncounted number of jobs were added or retained as a result of the ARRA-FCP, especially for the FC system OEMs, more than 43 new jobs were directly linked to the ARRA-FCP based on the interviewed sample of companies. An economic analysis of impacts was not completed, and the indirect job impacts were not assessed. It is unclear how many of these new jobs are still in place following the end of the ARRA-FCP. It should also be noted that implementation of MHE FC systems improved productivity, and the improvements may have resulted in workforce reductions or movement into other existing jobs. For example, it could reduce the need for battery technicians or for the overall number of MHE trucks and operators at a facility.

7.1.8 Siting and Community Acceptance

Much discussion and concern has surrounded the actual and perceived risks and safety associated with hydrogen fuelled FC systems. The siting of MHE FC systems appeared to raise few risk and safety issues largely because they are used in industrial areas where hydrogen and other volatile gases are already being used. The risks and safety of hydrogen appeared to be of more concern for BUP because of the location of towers in small plots or atop buildings in urban locations. However, local acceptance may be less of a problem than it is sometimes perceived to be. The Sprint data presented earlier suggests that 46 percent of the attrition rate in siting is due to site access issues and the availability of space within the perimeter of the site. Only 6.6 percent of sites were passed over due to zoning and permitting issues. Sitings of ARRA-FCP and non ARRA-FCP projects provided substantial experience to understand what is required to implement FC back-up. A contractor observed that it takes much longer (twice as long) to site BUP FC systems compared to a diesel generator. It is unclear if the additional time that is needed results from misperceptions, lack of familiarity, lack of packaging of components, technical complexity, or greater scrutiny by various parties.

Work still remains to be done to ensure that the siting and installation of FC systems and the related fueling infrastructure can be achieved in a timely and cost effective manner. The data from the interviews suggest that there are perhaps more effective ways to educate local officials that would help to accelerate acceptance and siting and reduce overall costs. The FC system OEMs reported that they were working closely with national standards bodies.

The DOE Fuel Cell and Hydrogen Technologies Program identifies streamlining and standardizing the permitting process as a high priority opportunity.[85] The DOE has active programs working to develop standards for hydrogen equipment, including fuel cells. The DOE has established a website that identifies model codes and standards to help local permitting officials deal with proposals for hydrogen fueling stations, FC systems used for telecommunication facilities, and other hydrogen projects.

Local codes vary from locale to locale. Many locales have codes that are several generations old, have been heavily modified, and are not likely to be updated rapidly. Those wishing to site FC systems at telecommunication sites can leverage the newer codes that include hydrogen usage as a fuel to buttress their cases even though they have not been locally adopted. During the ARRA-FCP period and in the post ARRA-FCP period, the significant increases in FC system purchases influenced directly and indirectly by ARRA-FCP have had a positive effect on the issues associated with FC systems deployment and hydrogen usage, and the related improvements in siting and community acceptance.

7.2 ARRA-FCP Funding for MHE FC System Applications

7.2.1 Productivity

End users reported productivity increases and that equipment operators were universally reported to be pleased with the new equipment from an operational, ease of refueling, and work efficiency perspective. FC-powered MHE allowed the operators to perform more lifts per shift because of reduced battery change out and recharge time. Further, because hydrogen refueling was so rapid, operators could refuel (opportunity refueling) at their convenience when time allowed. Operational data from FC-powered MHE facilities indicate that there was up to an 80 percent reduction in labor cost associated with the increased efficiency and reduced downtime, thereby increasing the personal income of operators and contributing

[85] S. Satyapal, “Hydrogen and Fuel Cells Program Overview,” Presentation at the Annual Merit Review and Peer Evaluation, May 2011.

to operator acceptance of the technology; but beyond that, there was no measurable influence on the productivity improvements experienced by end users.

7.2.2 Floor Space

Interviewees reported a reduced need for space for battery equipment and battery support equipment management, and some data suggested that the cost of warehouse space to support MHE was reduced four fold due to liberated real estate formerly used for spare batteries and battery charging equipment. There was indication from some of the end users that the additional available space was partially consumed by a maintenance facility for the FC systems. It is expected that as commercialization continues and the product matures, such space requirements will continue to be reduced. Once again, firms making ARRA-FCP and non ARRA-FCP purchases were able to experience this first hand; however, the projects themselves did not contribute to this value proposition as it was inherent outcome of the different operating characteristics of FC systems and batteries.

7.2.3 Competitiveness with Battery Options

For end users that did not want to completely convert from battery powered MHE to FC-powered MHE, especially those entities that operate only one or two eight-hour shifts per day, the cost of installing a second infrastructure for hydrogen was a barrier to acceptance. The DMFC technology offered by Oorja Protonics, which operates as an onboard battery charger for in Class 3 MHE, allowed entities to avoid the cost and complexity of installing a hydrogen infrastructure, while retaining the previously stated advantages of a FC system fueled by pure methanol. Class 3 MHE applications are about half of the potential market. With the significantly lower capital costs for fueling infrastructure, the market potential for a DMFC product may be significant if these products can perform reliably over the required lifetime demanded by end users.

For end users who had already made investments in the hydrogen infrastructure, but still operated a mix of battery- and FC-powered MHE, the decision to continue conversion of battery power to FC systems will drive additional sales. This assumes positive experiences with the initial deployment from an operational and ROI perspective, as was the case with many end users who continued to deploy FC-powered MHE following the end of the ARRA-FCP. As noted by one end user who operated facilities in close proximity to other users of hydrogen, cooperative agreements to share a hydrogen facility can offset costs.

In cases where the end user had already made a significant investment in infrastructure for batteries, especially in cases where automated battery change out equipment was installed and rapid battery chargers were available, the business case to introduce FC-powered MHE was more challenging.

Battery technology is improving with increased power densities, new internal battery chemistries and structures, more rapid charging, and increased overall stability and reliability, thereby narrowing the gap with respect to productivity and the need for end users to store spare batteries. The potentially competitive technology advances to FC systems are lithium-ion batteries and quick charging capability for existing battery technologies. Quick charging increases the kW load and increases operating costs at peak hours, thereby reducing ROI because of higher electric costs. Moreover, improving battery technology does not reduce a carbon footprint or reduce the negative sustainability impacts of battery charging relative to on-site use of hydrogen as a fuel. Thus, FC systems retain some advantages. This became clear to firms making ARRA-FCP and non ARRA-FCP purchases.

7.2.4 System Challenges

The majority of FC-powered MHE systems resulted with a switch from battery to FC systems in existing fork-lift trucks. This was a trivial process performed by the end user, the systems integrator, the FC system OEM, or a combination thereof. At green field facilities, the end user could choose between battery or FC systems, the result being that the ARRA-FCP generated no new net sales of MHE trucks to the systems integrators. The competitive environment limited the ability of systems integrators to charge a premium for FC-powered MHE. At the end of the ARRA-FCP period, systems integrators were not involved in the maintenance of the MHE FC systems at a significant level, so anticipated additional revenue from such activities in the logic model was not realized.

7.2.5 Sustainability and Environment

Most end users cited environmental benefits including reduction in emissions and increased sustainability. The emission benefits primarily accrue from the reduced use of grid electricity and the reduction in carbon emissions from generating electricity that is used to charge the batteries and the line losses associated with the delivery of that electricity. One end user reported a 19 percent reduction in kWh usage due to the deployment of FC systems. For some end users, sustainability is increasingly important in the measurement of ROI and how these entities meet challenging regulatory requirements and corporate social responsibility commitments. The importance of emission reductions may increase in significance with cap and trade systems such as now exist in New England (Regional Greenhouse Gas Initiative and California or a carbon tax. The tradeoff of the costs and environmental impact with the production and the delivery of hydrogen were not investigated. However, 40 percent of grid electricity in the U.S. is still generated from coal combustion, while the dominant commercial process for producing hydrogen is based on natural gas steam reforming.

Ultimately, the decision to adopt FC-powered MHE equipment comes down to the ROI calculations with sustainability as a secondary factor. None of the respondents reported adopting FC-powered MHE solely for sustainability reasons, but larger firms sensitive to the issues of the environment reported that sustainability was a factor and tipped the decision when the return between technologies was closely competitive. The experience with the FC technology helped to reinforce sustainability as part of the values for all purchasers, while the sustainability value of using FC systems can be enhanced by increases in overall system efficiencies. This was not something that was addressed as an objective of the ARRA-FCP projects in MHE and BUP.

7.3 ARRA-FCP Funding for BUP FC System Applications

7.3.1 Telecommunications

The market potential of BUP FC systems is based on leveraging two key features of hydrogen-fuelled FC systems: nearly instant start up from cold temperatures and high reliability due to very few moving parts. Lower or zero local emissions and much lower noise compared to diesel generators are also seen by end users as strong value propositions for FC systems, especially in dense urban areas. Lower operating and maintenance costs are expected to be of increasing importance favoring FC system use as the liquid/gas fuel price ratio becomes ever more favorable to gas.

The new legislative requirement to have 72 hours of BUP to minimize the impacts of natural disasters and other events causing significant downtime of grid electricity favors the use of FC systems over diesel generators in combination with large battery banks. The latter hybrid BUP solutions are likely to be more costly and less reliable for many end users. For certain application areas, these hybrid systems are too noisy and too polluting, especially for deployment in certain states and in almost all densely populated urban areas. In the future, this will likely make it more challenging for diesel generator systems to achieve regulatory approval in these application areas. The requirement for 72 hours of BUP also means that many sites implemented larger pressurized H_2 storage tanks that are filled using a medium pressure rated hose. With the improved storage, delivery time, and reliability for pressurized hydrogen, operating costs were reduced. This technique, developed as a result of the ARRA-FCP, was a major improvement over the bulky K bottles used in the past.

As a result of both the ARRA-FCP and non ARRA-FCP FC system installations for BUP and the firms' efforts working with local authorities, interviewees suggest that officials involved in governing jurisdictions are becoming comfortable with hydrogen fuel storage on the roofs of buildings and are developing a preference for hydrogen over liquid hydrocarbon fuels. This preference is due to the fact that hydrogen gas will rapidly and harmlessly dissipate into the atmosphere—while liquid fuel, especially nonvolatile fuel such as diesel, tends to spread fast across a horizontal surface during a spill and create a potential fire hazard.

7.4 Demonstration Projects

The demonstration phase projects were intended to advance product development from the R&D phase to the deployment phase by demonstrating up to tens of units in field trials. Through ARRA-FCP funding, all but one of the four demonstration projects did complete field trials and performance data were generated to assess the state of commercialization. The four ARRA-FCP demonstration projects had technology in differing stages of development, with varying potential for progress to product deployment even given success in the field trials. Three of these projects had complex and challenging technology end user requirements, and for various reasons, none resulted in direct benefits to the awardee OEMs in accelerating FC system commercialization and deployment.

For two of the projects, overall economic conditions and a refocusing of corporate objectives prevented further development by Plug Power and the technology was transferred to other parties who could continue the technology development and commercialization. LT PEM technology used by Plug Power in its reformate-based BUP project (and that of IdaTech, also an OEM) was acquired by Ballard Power Systems, who is continuing the commercialization process. HT PEM technology, used by Plug Power in its reformate-based CHP project, is continuing to be commercialized by ClearEdge Power, who worked with Plug during the field trials.

In the third project that used a miniature DMFC portable power unit for cell phones, encouraging test results were obtained but the OEM was not financially able to continue the development. While the ARRA-FCP investment did not advance the technology and commercialization technology for these three awardees, the knowledge gained is being utilized in the FC industry by other OEMs.

The fourth project, by Delphi, is an SOFC used as auxiliary power for heavy duty commercial Class 8 trucks to supply hotel power and heating using diesel fuels auxiliary power for hotel use in the long haul truck industry. The OEM is continuing development and still preparing for a field trial, but the date is unknown at this time.

Had the ARRA-FCP not provided funding, these technologies may not have been fully evaluated and the knowledge of their potential benefits and commercialization potential would have been delayed or remained unknown.

7.5 Revisiting the Basic Objectives of the Study

In a broad summary to the conclusions for the overall evaluation, it is instructive to provide specific responses to the six key objectives outlined in the introduction:

1. Accelerated deployment—Assessing the extent to which the investments from the ARRA-FCP accelerated FC systems deployment relative to the baseline before ARRA-FCP funding.

Market activity prior to the ARRA-FCP period resulted in a number of demonstrations and several deployments ranging in size from 25 to 55 units. The establishment of the ARRA Section 1603 tax and grant incentive, FCTO Funding Opportunity Announcement, the subsequent ARRA-FCP funding, and the substantial development work and marketing activities of the OEMs laid the ground work with potential customers for the accelerated deployment of FC systems in both MHE and BUP markets.

MHE FC systems, as a proportion of the total MHE market, went from less than a third of a percent annually in 2008 and before to 1.4 percent in 2010 during the ARRA-FCP period and to 1.8 percent in 2011 in the post ARRA-FCP period and then saw a decline to 1.3 percent in 2012. The increases in 2009 and 2010 were due to the market preparation work in the pre ARRA-FCP period, ARRA-FCP, and the ARRA Section 1603 tax and grant incentives. Without the latter incentives, it is likely that deployments, if any, would have been limited to the larger sites with three shifts, where MHE FC systems offer their greatest benefits. Based on statements from FC system OEMs and end users, both ARRA-FCP funding and non ARRA-FCP sources of funding/grants accelerated FC system deployment. It is not known whether the decline in orders in 2012 when tax and grant incentives were still available was temporary, will continue, or will be reversed, but it does suggest that there were other market factors at work that were modulating sales, such as the desire and capability of end users to continue to replace battery powered MHE and to invest in new greenfield facilities. A comparison of the experience of Oorja, which did not receive ARRA-FCP funding with that of Plug Power, suggests that receiving the awards did aid Plug Power in its marketing and increased sales over the ARRA-FCP and post ARRA-FCP periods. Although BUP FC system sales increased significantly for ReliOn, it is likely, but not as clear, that this can be directly attributed to the ARRA-FCP funding. However, the ability of ReliOn to retain key employees necessary to execute and support FC system sales and the role of the ARRA-FCP funding in supporting this employee retention is clear from the interviews.

2. Improved acceptance—Determining if the projects produced quantifiable changes in the early stage acceptance of FC systems in the markets under study.

End user awareness of FC system benefits relative to incumbent technologies was demonstrated by end users in a number of applications across both the MHE and BUP markets. Improvements in acceptance of the use of hydrogen as a fuel and in achieving timely permitting for FC systems and the related hydrogen infrastructure installation also improved. Systems integrators took on independent or joint development activities with FC system OEMs to ensure that their product lines of MHE were compatible with a simple and rapid engineering change to move from battery to FC system power. This primed the pump for sales during and after the ARRA-FCP funding period.

3. Facilitated purchases—Assessing the extent to which the program facilitated volume purchases in key early market segments and or resulted in additional subsequent purchases.

The data from this early stage market evaluation indicated that 4,920 MHE FC systems are planned or in active use at end user facilities as of the first quarter of 2013. In 2010 and in 2011, there were over 668 additional MHE FC system sales that were funded outside the ARRA-FCP, exceeding the ARRA-FCP direct sales by over 75 percent. This trend continued in 2012, when post ARRA-FCP sales of MHE FC systems were 1,301 units, bringing the total number of FC-powered MHE sales made since 2009, not funded through the ARRA-FCP, to over 4,034 units. FC system purchasers in this category were end users awardees from ARRA-FCP projects buying additional product as well as end users that had not previously purchased FC systems for this application.

BUP FC systems experienced close to a two-fold increase in sales during the ARRA-FCP funding period over ARRA-FCP funded units with 1,598 units purchased outside of ARRA-FCP funding. Existing and new end users made purchases of BUP FC systems outside of the ARRA-FCP projects, during and following the end of the ARRA-FCP projects.

4. Increased availability—Assessing the rate of increase in the availability of low-cost FC systems and the number of companies using FC systems due to the ARRA-FCP relative to baseline.

Assessing the rate of increase due to ARRA-FCP is difficult due to the confounding influences of the market preparation, the ARRA-FCP funding, and the tax incentives. It should be pointed out these three factors were all part of the general strategy of the OEMs to get product into the market. It is clear from the number of new customers that Plug Power has been able to sign-up in new purchase agreements and repeat orders for FC-powered MHE after ARRA-FCP that more companies are adopting FC technology and that the positive experience of MHE FC system deployments made under the ARRA-FCP projects was a contributing factor in these purchasing decisions. For BUP, both of the major direct hydrogen FC system OEMs noted that the quantity of units deployed and the high profile of the deployments secured involvement of executive-level decision makers at the telecommunication service providers. Given the highly competitive nature of this business, it was not long before new end users were placing orders for BUP FC systems, expanding the number of companies using these products.

5. Expanded capacity—Assessing any increase in capacity and leveraged activities throughout the supply chain due to the investments of the ARRA-FCP. This included numbers of end users, end user contractors, systems integrators, FC system OEMs, supply chain vendors including subcomponent and subsystem suppliers, hydrogen suppliers, and providers of hydrogen infrastructure.

The increase in capacity and leveraged activities for companies was very much dependent on where the entity was positioned along the supply chain. FC system OEMs and end users were the most active and impacted entities, with the majority of ARRA-FCP investments effecting these groups. Systems integrators saw minimal change to their regular business activities of selling MHE as most end users dealt directly with the FC system OEM. The most impacted supply chain vendors were the fuel suppliers given their critical role to supply the necessary infrastructure and hydrogen to safely and reliably ensure that the end user always had the fuel to operate their FC systems. For BUP, the engineering service provider that facilitates and implements site selection, permitting construction and operation and maintenance of FC systems and related fueling for telecommunication cell tower sites also saw a significant upturn in FC related business as a result of the ARRA-FCP investment. For the most part, material and component supply chain vendors were able to manage any increased demand for product within their existing business operations making minimal or temporary adjustments.

6. Replication and Emulation—Determining if any replication of market activities in awardee companies has occurred, and if any emulation of market activities has occurred among non-awardees and previous non-users of FC systems. The qualitative and quantitative data (see Sections 4 and 5) show that both replication and emulation for MHE and BUP occurred following the ARRA-FCP

In order for a new technology to penetrate a market at least three conditions must be met: first adopters must continue to adopt the technology (purchase it) after initially trying it, the value propositions for the technology must be demonstrated and verified, and the information about this must spread and be accepted by other potential adopters in the market. There are several examples of replication, the first condition. Sysco has now purchased FC MHE for use at several sites as had Wal-Mart and others. There are several firms that have now made purchases for multiple sites exceeding 500 units per firm. Emulation is more difficult to trace because a firm has to learn about a technology and its benefits and either be influenced by direct contact with a firm that has already adopted the technology or observe that a competitor has adopted the technology and investigate it. It is very clear that the OEMs were very active in promoting the technology to firms in the food and beverage industry. However this study was not able to measure the emulation effect.

7.6 Methodological Lessons Learned

Although the participation rate for FC industry interviewees was 85 percent, the overall participation rate was not as high as hoped. The relatively low completion rate for awardee and non-awardee interviews was just half of what was planned even with extraordinary efforts. This required that the team implement a more thorough sourcing and evaluation of secondary data than initially anticipated. The secondary data also helped elevate the overall level and quality of the quantitative data above what could be obtained from the in-depth interviews. The joint evaluation and cross correlation of primary and secondary data significantly improved the evaluation of early market impacts of the ARRA-FCP.

The use of in-depth interviews rather than surveys with awardees and non-awardees was particularly useful for gathering fact rich data from interviewees where the existing public knowledge about the players and their activities was limited. This approach also helped the team to gather more detailed information about actions, perceptions, motivations, decisions, and reasons for decisions as they related to ascertaining early market impacts of ARRA-FCP and individual projects.

8 Recommendations

The foundation for the recommendations is the inputs from the 32 interviews and reflect the contributions of the end users, OEMs, systems integrators, and suppliers, both ARRA-FCP awardees and non-awardees. The secondary data support the contributions from the interviewees (primary data) and provide an added level of confidence in their robustness. Care was taken to ensure that the recommendations were based on the data collected and analyzed during the evaluation and were not influenced by opinions or perspectives of the evaluation team. To facilitate the reader's ability to review the supporting information used by the authors to structure the recommendations, each of the recommendations contains references to sections of the report that supports them. The primary and secondary recommendations are listed from highest to lowest priority based on the strength and degree of reinforcement of data that underpins each recommendation. Recommendations specific to DOE are so noted, and the recommendations have also been characterized by topic area.

8.1 Primary Recommendations

8.1.1 Business Development – Increased Unit Sales

Recommendation: Identify and promote federal, state, and local government incentives for applications of MHE and BUP FC systems and identify ways of combining the incentives to reduce the first cost of FC systems and the cost of the fueling infrastructure.

The need for and the benefits of combined federal, state, and local funding are described in Sections 4.2.1, 4.3.1, 4.4.1.2, 4.4.1.5, 5.4.1.5, 5.4.3.2, 5.4.4.1. In Section 4.4.1.5, it is pointed out that, "Where possible, all end users took advantage of federal and state incentives and tax credits or grants. In combination, these incentives helped to reduce the higher capital costs associated with the FC systems and in some cases even helped offset some of the costs related to hydrogen infrastructure deployment."

Recommendation: Efforts should be made to collect and disseminate the value propositions of FC systems in achieving energy savings, operational cost savings, reductions in warehouse cost, and overall life cycle cost savings to potential end users.

Examples of such benefits reported by end users are found in Sections 4.4.1.1, 4.4.1.4, 4.4.1.5, and 5.4.4.1. The savings benefits of using MHE FC systems from Oorja Protonics, a non-awardee of ARRA-FCP, and a recipient of DOE funding through NREL, are highlighted in Section 4.3.2.1.

There are clear benefits from the use of FC systems in MHE and BUP applications. The penetration of these technologies will increase when users understand and can identify the benefits and disbenefits of these technologies and have easy-to-use tools that will help them quantify the benefits. The data from the ARRA-FCP projects and other projects need to be organized into easy-to-understand case studies and fact sheets, and integrated into simple and easy-to-use tools that allow potential end users to calculate benefits for their own cases.

8.1.2 Supply Chain Development

Recommendation: The DOE should consider increasing RD&D support for the development of the supply chain for producing FC system components and reducing manufacturing costs.

Issues with supply chain costs are identified throughout the report. Based on the Battelle study, BOP costs are four to five times the cost of the BUP FC stack indicating a potential opportunity for significant cost reduction (see Fig. 6). Plug Power and Warner Robins, and an end user, called out the need for BOP design improvements. Oorja Protonics noted that BOP supply chain cost could limit the adaptation of their technology. Another party stated (see Section 5.4.4.1) the importance of developing a strong supply chain: "… [A] competitive bidding process and flexibility to use various supplier components without impact to FC system performance will result in value to all players across the supply chain, further driving cost reduction, materials improvements and component design all of which will reduce cost and increase product reliability for end users."

It is clear that cost reduction is essential to the development of FC systems for MHE and BUP. The data make clear that at least some of the reductions have to occur in BOP components. Cost reductions can accrue through simpler designs, more robust components, and more universal parts and materials. DOE can assist by helping to identify opportunities, prioritize them, and provide RD&D support.

Recommendation: The DOE should fund and promote technologies and organizational arrangements that support cost reduction within the hydrogen supply chain for equipment, hydrogen delivery, and hydrogen dispensing leading to a more cost-effective fuel infrastructure that reduces barriers to end user acceptance.

The challenge of high costs associated with the hydrogen infrastructure favors operators of large multi-shift fleets of MHE FC systems. Approximately fifty appeals were made for the development of a low cost hydrogen infrastructure from interviewees and references from secondary data sources documented in this report. One end user said that it was only possible to achieve a five-year ROI with a combination of ARRA-FCP funding, federal tax incentives, and state funding. As noted in the report, "Several end users indicated that they thought the cost of capital (even though interest rates have been historically low) and the cost of installing hydrogen storage and fueling infrastructure for FC systems would stall market growth at the end of the ARRA-FCP, especially for new end user adoption." (see Section 4.4.1.5). IdaTech's "efforts to use direct hydrogen fuel cells as backup power failed in India because of the lack of infrastructure for hydrogen fuel production and delivery" (see Section 5.0). The report also states that, "With the development of an economic fuel infrastructure, for hydrogen or methanol, FC systems for BUP applications will be viable in Asia, noted CommScope" (see Section 6.2).

Hydrogen fueling infrastructure is an area of significant cost and potentially a barrier to further market penetration of FC systems in MHE and BUP. There are options, such as simpler infrastructure, greater standardization of fueling infrastructure, and the use of reformers either at the facility level or directly with the FC system. The diffusion of these technologies would be well served by segmentation studies focusing on the fueling requirements for various size firms and differing types of applications within the MHE and BUP markets with the goal to identify an optimized set of fueling options that would serve broad segments of the market. DOE can assist follow-on efforts by helping to identify opportunities, prioritize them, and provide RD&D support of candidate technologies.

8.1.3 Government Awards and Incentives

Recommendation: Market incentives should be continued until technology and manufacturing development enables the product cost to stabilize and FCs are competitive with other technologies.

ReliOn (see Section 5.4.1.1) identifies "The equipment cost for the [BUP] FC system is greater than the cost of the diesel generator. However, after the tax credit or 1603 ARRA Program grant…, the [BUP] FC systems have similar or lower first cost than a diesel generator." A majority of end users stated there should be an extension of the 1603 ARRA grant beyond 2016. For MHE FC projects reported in Section 4.4.1.5, one end user stated they could not achieve an ROI of five years including FC system capital cost and hydrogen fueling infrastructure costs; this was only possible with a combination of ARRA-FCP funding, federal tax incentives, and state funding.

It is clear that there are segments of these markets where deployment will not occur or will not occur rapidly until the cost of the capital equipment and infrastructure decline. It is also clear that incentives continue to be needed to assist these technologies until their market share reaches 10 to 15 percent penetration and/or until the unit costs and their operation stabilize and are competitive with other technologies. Specifically, the incentives that need to be continued are: the tax credit and 1603 grant incentives associated with acquisition of FC systems, fueling incentives for building the hydrogen infrastructure that was originally a part of ARRA, and the 30 percent Manufacturing Credit to be used for manufacturing facilities for FC components and other technologies.

Recommendation: State and local governments should be encouraged to continue to provide incentives for the deployment of FC systems and development of hydrogen infrastructure.

An important input for the OEMs developing FC systems is that "The ARRA-FCP, combined with other federal and state incentives, lowered the barriers to purchases by end users and allowed a greater number of units to be deployed over a shorter period of time that otherwise would have been possible" (see Section 4.4.3.3). In the case of end users and OEMs, the combined benefits of ARRA-FCP funding, federal incentives, and state incentives were essential to overcome the high capital cost of FC systems and the large investments often needed in hydrogen infrastructure (see Section 4.4.1.5). Beneficial state incentives are identified in Section 4.4.1.2.

State and local governments can play a vital role in promoting FC systems and fueling infrastructure. Furthermore, by providing incentives for deployment of FC systems and fueling infrastructure, state and local governments can promote economic development by attracting new and retain existing FC firms and related companies.

8.1.4 Codes and Standards

Recommendation: The DOE should continue to engage industry players and national codes and standards bodies to encourage more cohesive development and implementation of federal, state, and local codes and standards for installation of FC systems fueled by hydrogen to reduce the cost and increase the timeliness of permitting and installation approval processes.

From Section 4.4.1.3, community acceptance of the technology was facilitated by establishing a working understanding of FC systems and the hydrogen infrastructure with fire marshals and other permitting and regulatory officials. As cited in Section 4.4.1.5, the important issue for end users is the, "…extended regulatory approval processes driven by the absence of a single set of state or federal level codes and standards for the deployment of hydrogen infrastructure to power the installed FC systems." BUP FC systems deployments were hindered by the lack of national codes and standards as noted, "In practice, according to one engineering service provider, close to two out of every three sites were deemed unacceptable based on the long and expensive process required to secure regulatory approvals and other issues related to access and appropriateness of the proposed site for FC system deployment."

With the safety record of the FC systems that have been installed and efforts to develop codes and standards, concern by officials and issues surrounding the use of hydrogen FC systems may be receding. Even so, in many areas of the country, new standards are not in place, and public officials do not understand either the risks or existing safety standards for hydrogen use as a fuel. There is a continuing need for education at all levels of government among regulators and the implementation of standards so as to facilitate siting.

8.1.5 Technology Advancement

Recommendation: The DOE should investigate the potential for development of smaller scale and cost-effective steam methane reforming systems for on-site use to reduce life cycle cost and increase end user acceptance related to the use of hydrogen as a fuel, for deployments of MHE FC systems.

The need for less expensive fueling systems is repeated often by interviewees in this study. This is especially true for small firms that have single shift operations and relatively few MHE for whom the capital cost of liquid hydrogen fueling system might be unapproachable. This, or the development of some other small scale hydrogen production systems, could potentially make hydrogen MHE cost effective. DOE can facilitate this approach by identifying and prioritizing development opportunities and providing RD&D support.

8.1.6 Sustainability

Recommendation: The DOE should catalog the benefits that can accrue to end users from carbon offsets and reduction of the carbon footprint, including tax relief both at the federal and state level.

Sustainability benefits are a growing component of financial performance for many end users. Sustainability was identified as a benefit from carbon dioxide reduction achieved by reducing energy consumption and carbon footprint with the use of FC systems, relative to grid electricity used to recharge batteries. "Sysco reported a 19 percent reduction in kilowatt hour usage that translates into reduced carbon dioxide emissions" (see Section 4.4.1.1). Kimberly Clark reports "This energy technology can reduce our carbon emissions by hundreds of metric tons per year, lower costs, and drive efficiencies to power our operations" (see Section 4.4.1.4). Some end users stated their belief that the lower overall carbon emissions for MHE FC systems provided a 'greener' solution relative to incumbent technologies that was sufficient to justify the purchase of FC systems without tax incentives (see Section 4.4.1.5).

The early adopters have for the most part been sophisticated end users with a broad understanding of the energy and non-energy benefits from the use of FC systems. As the market penetration of FC systems in MHE and BUP proceeds, there will be an increasing need to explain the benefits of these technologies to end users, especially the environmental benefits (*e.g.*, carbon reductions), and to help them capture those benefits. End users will need explanations and tools that help them identify, quantify, and reap the benefits.

8.2 Secondary Recommendations

8.2.1 Analyses to Support Business Development Activities

Recommendation: The DOE should support industry players at all levels to develop tools and provide data that allow end users to better assess the economic and other value propositions of using FC systems for MHE and BUP applications.

For many end users, the decision on what power system to use for their MHE will come down to a lifecycle cost analysis and ROI calculations with perhaps some premium applied to the FC systems relative to cost saving achieved through carbon credits and the deployment of a more environmentally-friendly technology identified in Section 4.4.3.1. The FC system analyses produced by NREL that support end user acceptance reported in Section 4.4.3.1 should continue. Support for RD&D should be provided for economic case studies of FC systems installations in MHE and BUP applications.

Recommendation: The DOE should strive to reduce the divergence between solicitation objectives and business objectives of industrial proposers that occurs over the time between proposal submittal and award.

As indicated by one OEM who was involved in multiple proposals addressing the FOA, companies submitting proposals must go forward with their development plans and accomplish their business objectives while awaiting an uncertain award. The time between proposal and award should be minimized and a means should be found to negotiate an updated statement of work based on advances in technology or change in business direction or adjustments in government needs. The simplest approach would be to shorten the time between proposal submittal and contract awards but that is often not possible. Instead, considering all the nuances of the need for fair and open competition, the government should establish the regulations and processes that govern the updating of the statement of work and objectives for projects that have aged while awaiting awards. One major player in particular indicated that the ability to renegotiate the statement of work would have provided considerable benefit to both the commercialization objectives of the company and the government.

8.2.2 Alternative Business Concepts

Recommendation: The DOE should encourage key stakeholders to establish a network of national contractors capable of providing leadership and oversight that can team with local contractors to perform the installation of the FC system and related fueling infrastructure including dealing with permitting and zoning issues with local government officials.

In Section 5.4.2.2, the time to get a permit and the total length of time from initial planning to FC system operation were reported to be significantly longer than to deploy diesel generators, making FC systems more expensive overall to deploy in these applications. The report describes how a service engineering company developed an effective training plan for service technicians and facilitated efficient installation and operation of BUP FC systems. DOE could facilitate the formation of such a network by sponsoring an educational workshop for potential contractors.

8.2.3 Manufacturing Advancements

Recommendation: The DOE should encourage and provide incentives for FC system OEMs to invest in more automated and high volume manufacturing processes to accelerate cost reduction and improve product reliability, but only after the MHE and BUP markets have established a firm market share that exceeds 10 percent.

The benefits of DOE funding of manufacturing processes is reported in Section 5.4.4.1. Ballard, as a key supply chain participant, was fortunate to have received DOE funding to help optimize its Ballard Material Products manufacturing for the production of electrode material (GDL) for use in later generation stack products as a means to drive cost reduction. The DOE should continue to support its manufacturing RD&D programs for FC components and products used in MHE and BUP applications.

Recommendation: The DOE should support efforts that encourage producers of key BOP components for FC systems to design more robust and cost-effective devices that will drive cost reduction while enhancing end user acceptance.

Design for manufacturing was identified as part of the Battelle analysis in Section 4.4.3.1. The ARRA-FCP did facilitate some design improvements to the FC systems as a result of end user feedback and some maintenance issues that required resolution as reported in Section 5.4.3.2. The DOE should continue to support its manufacturing RD&D programs for FC components and systems in MHE and BUP applications.

Appendix A In-depth Interviews of Selected Key Stakeholders

The team conducted interviews with the following selected key DOE program personnel and other relevant government contractor personnel and NGO industry personnel.

- Jim Alkire, DOE Project Officer,
  DOE Golden Field Office
- Sara Dillich, Supervisory Physical Scientist R&D
  DOE Fuel Cell Technologies Office
- Jennifer Kurtz, Senior Engineer
  National Renewable Energy Laboratory
- Sunita Satyapal, Office Director
  DOE Fuel Cell Technologies Office
- Jennifer Gangi, Senior Engineer
  Fuel Cell 2000
- Reg Tyler, DOE Project Officer
  DOE Golden Field Office

Appendix B Logic Model for Early-stage Market Impact Assessment

The logic model is a two dimensional depiction of interrelated actions with a sequence of activities in one dimension and identification of resources, activities, outputs of the activities, outcomes or responses of the target audiences to the program outputs, or responses of the target audiences to their own earlier activities or the activities of other stakeholder audiences in the other dimension. A logic model should not be confused with a mathematical model. Outcomes may be immediate or longer-term. A logic model lays out the sequences of actions describing how target audiences, in this case, supply chain vendors, OEMs, systems integrators, and end users, are expected to respond to an intervention in a market. In this study, the intervention was the ARRA-FCP funding, used as part of the overall effort to achieve the goals of DOE, which broadly, are to improve the potential for fuel cells to provide high efficiency power for stationary, MHE, and portable power applications, reduce emissions, and accelerate the adoption of fuel cell systems in the market, thereby broadening the fuel cell technology portfolio. For implementers and evaluators, the value of logic modeling is to identify the logical paths whereby a program is to reach its goals. Doing so assists in telling the story of the program; provides a credible explanation for how the market intervention is to work; provides a set of hypothesized outcomes that can be checked against what is happening in the market place to identify gaps; and provides a systematic basis for developing evaluation questions, identifying performance metrics and measures, and tracking changes to the program. The team has used the logic model to develop key metrics and their related measures that probe the factors critical to determining the impacts of the ARRA-FCP funding.

The basic elements of a logic model are:

- Resources: Specific resources consisted of the funding allocated to the 12 projects comprising the ARRA-FCP that totaled approximately $96 million including industry cost share.
- Activities: The specific process by which resources were applied was to utilize ARRA-FCP budget line items allocated to the DOE to finance the grants for the selected, unfunded winners of a previously announced solicitation that was consistent with the ARRA-FCP objectives. A further activity was the program management oversight of the projects for the R&D, demonstration, deployment, and evaluation of fuel cell systems and their supporting infrastructure for defined end user applications.
- Outputs: The result of this activity was the award of grants (cost shared) to perform the R&D, demonstration, and deployment activities under the oversight of ARRA-FCP project management.
- Outcomes: The beneficial outcomes from these grants accrued to a disparate group of fuel cell industry beneficiaries to improve the potential for fuel cells to provide high efficiency power for stationary, MHE, and portable applications; reduce emissions; and accelerate the adoption of fuel cell systems in the market. Beneficiaries include: supply chain vendors who provide their products and services to OEMs; the OEMs who are able to introduce more of their products into the market; systems integrators and end users who could operate, observe, and evaluate products in the field; and governmental officials who could demonstrate progress to the general public toward meeting energy efficiency and environmental goals.
- Timing: The projected logic model outcomes would be spread over different time scales with some being immediate and others stretching over multiple rounds of product and market advances.
- External factors: External factors are factors outside of the program that may influence the outcomes. Examples are improvements to the economy that might result in substantial new

investment in equipment. Other examples are state and local tax incentives or utility incentives that may influence equipment choices.

The logic model specifically applicable to this study is limited to what is occurring with awardees and their subcontractors and non-awardee audiences in the outcome space. The DOE has a large number of programs, including research and development, demonstration projects, and deployment activities. Given that the ARRA-FCP funds were primarily directed to the deployment and demonstration of fuel cell technology, this logic model is focused on these specific activities. R&D activities are not addressed in this model because they are less directly related to early market change.

Demonstration activities are designed to validate and refine near commercial products, including but not limited to, pilot and field trials that are completed prior to a product being fully commercial. An example of a demonstration project might be the replacement of batteries with fuel cell power modules in a limited number of stationary backup power units operating on hydrocarbon fuels to test the concept, identify issues, and refine the design of the fuel cell systems to improve their performance. Deployment involves the placement of many units of a product into everyday operation with the expectation that it will meet the requirement of the application and the end user. This is not to say that the OEM and systems integrator may not receive valuable feedback about how to improve the design of a product at the deployment stage.

Figure 21 shows a very high-level conceptual logic model.

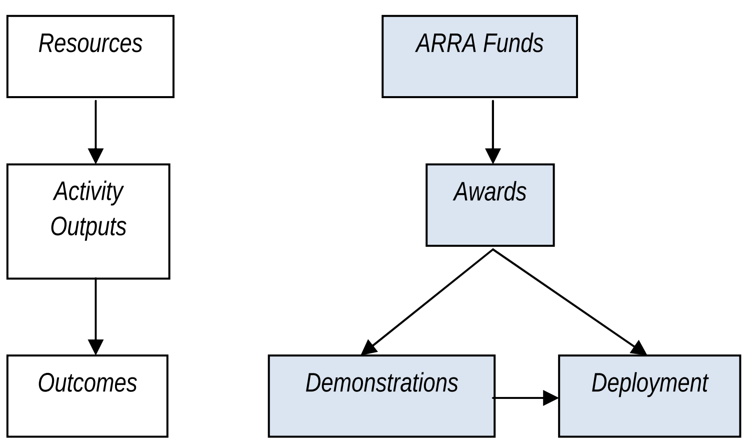


Figure 21 High Level Logic Model Schematic

In this model, demonstration activities precede deployment. Key industry types have been identified under each of these activities. Under the ARRA-FCP demonstration activities, the key industry types are supply chain vendors, OEMs, systems integrators, and end users. Under deployment activities the key players are the OEMs, supply chain vendors, systems integrators, end users, and local communities. As well, communities—including fire marshals, building inspectors, and neighbors—play a role in approving site installation and changes.

B.1 Logic for Demonstration Projects

In this elaboration as shown in Figure 22, manufacturers are developing, testing, and demonstrating their product. In this logic, the OEM identifies and evaluates potential markets. For example, the OEM decides to target the backup power market. The OEM may market the benefits of the equipment to systems integrators and end users. The ultimate goal of the OEM is to recruit systems integrators and end users to purchase, pilot test, and assess the equipment. The OEMs also seek to push systems integrators to adopt the technology for use in their equipment and to acquaint end users with the equipment so that they generate market pull. A grant application and an award may offset many of the costs associated with the demonstration, increasing chances of the demonstration proceeding. If OEM and end user agree, demonstrations are implemented, the performance of the products are assessed and analyzed by all parties, required changes to the products are identified, and a near commercial product may result.

At the demonstration stage, systems integrators or OEMs become aware or increases their understanding of the product and its related technology. The systems integrators assess the potential of the technology for themselves in terms of a viable product and their ability to sell that product to end users. The systems integrator examines the product based on its advantages and disadvantages relative to an existing product, compatibility with existing systems and manufacturing capability, complexity, and the ability to try and observe the benefits of the technology. Based on this, the systems integrator may decide to collaborate with the OEM and end user to assess the product and its related technology.

Finally, the OEMs may approach end users, making them aware or increasing their interest in the technology and its related products. Much like the systems integrator, the end user assesses the potential of the new product’s relative advantages over an existing product. The end user examines the potential effects on costs, operations, difficulty of implementation, and the potential for implementing the product within existing operations. With the advantage of the grant, the end user may agree to participate in the demonstration.

A key point is that the advantages to the systems integrators and the end users are not necessarily the same or equal in value. Thus, it may be easier to recruit end users than systems integrators to participate.

The key outcome of the demonstration activity for the OEM is a near commercial product and perhaps even a systems integrator who is prepared to build and sell systems based on the product. In addition, the OEM may have established the value of the technology for both systems integrator and end user participants.

B.2 Logic for Deployment Projects

Figure 23 and Figure 24 detail a similar logic model for deployment. The deployment logic assumes a commercially viable product in the market place. Again the OEM is likely to be the key proponent of this process. The OEM becomes aware of the ARRA-FCP funding and views the funding, amongst other advantages, as an opportunity to lower the capital costs and installation of new equipment. The OEM’s long term interest is to develop the market for the product by placing as many units as possible in the hands of systems integrators and end users so they can use the product and observe and understand the benefits. The stakes for the end user are much higher because this entity is now committing to system changes that will require capital investment, retraining of personnel, new safety requirements, numerous changes to overall operations, and the inherent risks associated with integrating new technologies into the work place.

In the deployment logic, the OEM recruits and collaborates with end users or systems integrators to apply for funding. Upon receipt of the grant, the OEM, end user, or systems integrator must implement the project, which requires collaboration amongst systems integrators, fuel suppliers, end users, and others to produce and implement product deployments.

In addition, the OEM may begin to promote the benefits of the technology to other systems integrators and end users, resulting in new adoptions of the technology and its related products. If there are increased sales and adoptions, the OEM may seek capital to hire more staff, expanding plants and operations to meet demand. Further, the OEM will place more orders for components from supply chain vendors, thereby increasing volumes and reducing costs while stimulating competition among supply chain vendors to compete for this growing market. A secondary impact will likely be the development of new and improved components and enhanced functionality while further reducing costs.

In the deployment phase, the role of fuel suppliers becomes more critical than in the demonstration phase where ad hoc systems may have been used. Fuel suppliers may need to modify their operations to meet the needs of the new customers. Further, they may observe the potential of the market and assess the size and requirements for the market. This may lead to improved standardization of infrastructure delivery requirements and changes to pricing to serve the market. Further, fuel suppliers may begin to think in terms of turnkey delivery systems, and they may begin to establish linkages with systems integrators to develop these markets. Ultimately, the outcome for fuel suppliers may be an expanding long-term market for their products and services.

At the deployment stage, systems integrators must assess the value of the product especially with respect to its long term potential. They must agree to participate in the grant proposal, have a finalized commercial product design, and deliver equipment.

At the deployment stage, there are a number of outcomes for end users. They must become project, product, and technology aware. They must assess product value. They must commit to the technology and agree to participate in the ARRA-FCP. In addition, they must set aside capital, design alterations to their facilities, obtain construction permits, hire new or re-train existing employees, and have the facility changes constructed. Training is required and there may be changes to internal operations, especially for adoption of new codes and standards that will be needed. When these conditions are met, operations with the new products can begin.

At this point, the focus of the OEM, the systems integrator, and the end user may shift to the performance of the systems and analysis of the benefits. The resulting analysis may lead to a series of steps for the OEM or systems integrator, including confirmation that a commercial product line be established, assessments about managing maintenance and sales, the need for product design revisions, capital investment requirements to support expanded sales or product line development, provision of ancillary services and products, and achieving additional sales.

For the end user the analysis will confirm the wisdom of the investment. The analysis will lead to decisions about making additional purchases for the existing site and for replicating purchases throughout the end user's organization. There will be feedback to the systems integrators and the OEM. And perhaps, most importantly, other firms may observe and decide to emulate the action of the end user, further increasing product sales for the OEM.

The logic model includes one additional stakeholder, the local community. The community plays a role in the permitting and inspection of the facilities. Some attention may be required to assist the community to understand the technology or to modify local codes or inspection procedures. Although hydrogen is commonly used in industrial settings, this fact may not be widely understood within the local community. Further education about the safe use and benefits of hydrogen will be needed.

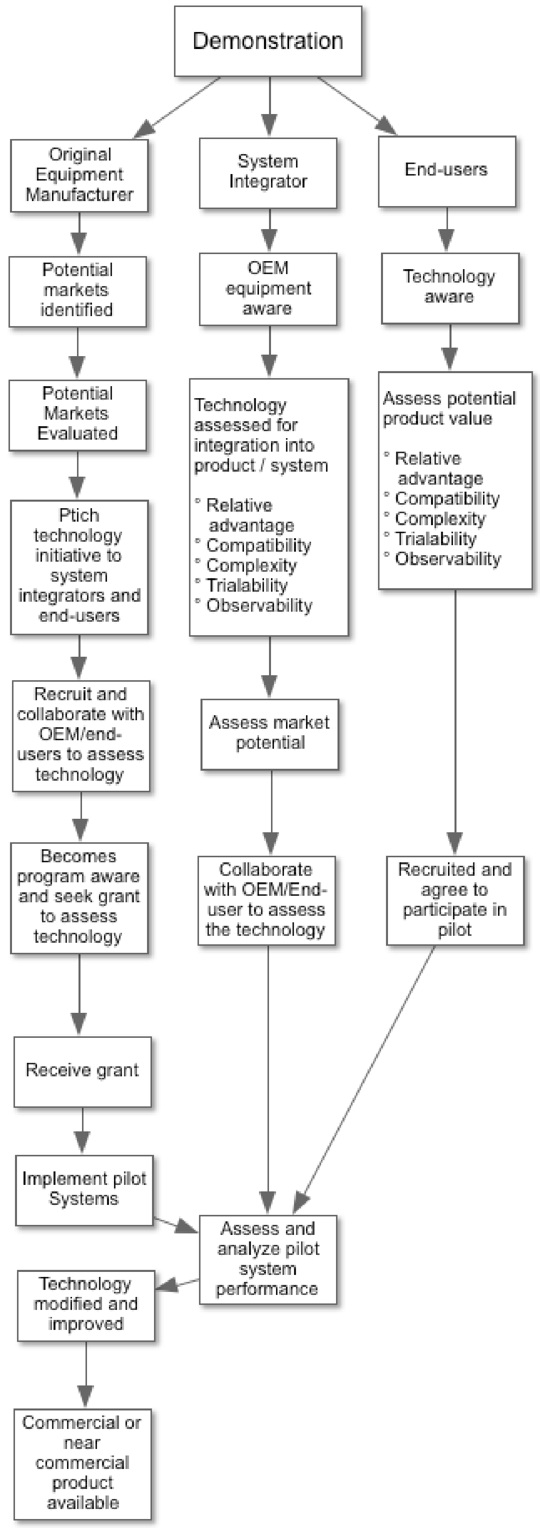


Figure 22 Logic Model for Demonstration Projects

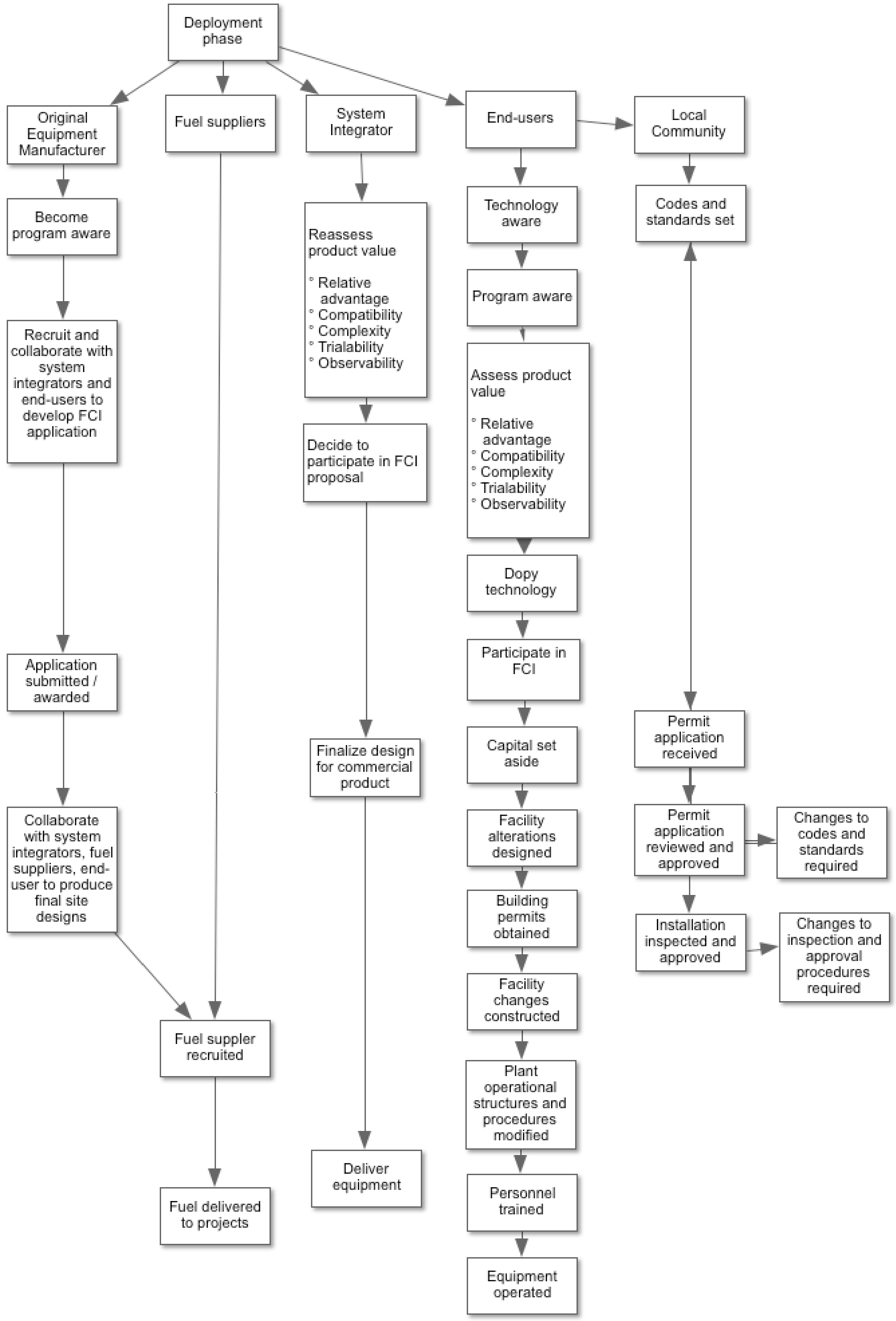


Figure 23 Logic Model for Deployment Phase Projects

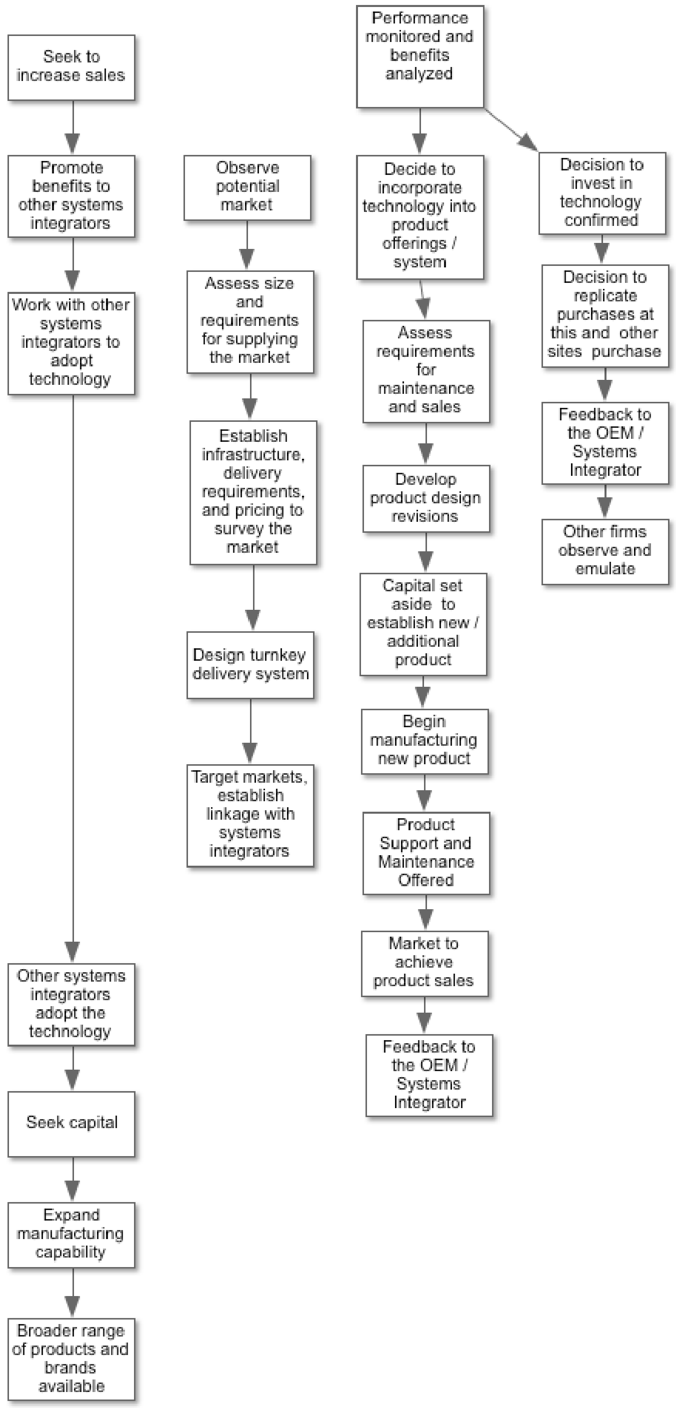


Figure 24 Logic Model for Deployment Phase Projects (Continued)

Appendix C Initial Market Models

To systematically determine the evaluation requirements, the team developed a market model to identify the main industry types and the relationships among these entities. Based on this, the team then constructed a logic model to describe how the grants are expected to produce outcomes for the identified market industry types. In turn, the outcomes are used to identify the metrics and, as well, the measures associated with the metrics. These form the basis for the design of the interview guides. The market models also assist in guiding the analysis by indicating relationships and expected outcomes.

The following terms to describe the different fuel cell industry types are consistently used throughout this plan:

- The **Supply Chain Vendor** manufactures materials or components for the fuel cell system OEM or end user. Specifically, there are two types of supply chain vendor: fuel suppliers and related fuel cell mechanical or electrical components manufacturers. Examples of supply chain vendors would be hydrogen producers, membrane electrode assembly manufacturers, fuel cell stack manufacturers, installation and maintenance service providers, and manufacturers of balance-of-plant components. For the sake of simplicity, “component” is used in the sample questions to mean the product or service provided by the supply chain vendor.
- The **Original Equipment Manufacturer** is the fuel cell system developer that manufactures the fuel cell system and sells it to the systems integrator or end user.
- The **Systems Integrator** is the company that receives the fuel cell system from the OEM and integrates the latter into the final device. An example of a systems integrator is a forklift truck manufacturer that installs the fuel cell system in the forklift truck. In some cases, the systems integrator and the end user may be the same entity—*i.e.*, a telecommunications company may install a backup power fuel cell system at its telecommunications tower.
- The **End User** represents the industry segment that uses the fuel cell product—for example, a company operating a warehouse or high volume manufacturing facility that uses and benefits from forklift trucks powered by fuel cell systems.

C.1 Market Models

Two market models have been constructed one for the case with separate systems integrators and end users (materials handling equipment or MHE) and another in which the systems integrators and the end users are the same entity (backup power or BUP).

C.1.1 The Market Model for Materials Handling Equipment

For MHE, the current market is the sale of compact integrated fuel cell power modules containing the fuel cell stack, balance of plan, and hydrogen storage that have the same dimensions as the battery packs they replace. The end user customers are principally the warehousing, distribution, and storage industry that use these products in MHE (divided into Classes 1, 2, and 3, which denote separate forklift sizes and functions). The onboard hydrogen storage is typically adequate for an eight-hour shift at full operational capacity. The fuel tank can be refilled in a few minutes by the operator, typically once during each shift or when it is convenient. The specific design of a forklift product optimized for fuel cell system use is the end goal for fully commercial production by the OEMs. Some systems integrators have made progress in this area.

Based on ITA data for 2010, the total factory sales for Class 1, 2, and 3 forklifts in North America was 92,326 units.[86] The current status is that there are between 1,000 to 1,500 fuel cell units operating in the field. Thus, 2010 fuel cell system battery replacements of approximately 1,000 units represent a market share of about 1 percent.

For materials handling equipment, fuel cell systems can offer increased value in terms of productivity for certain end-product operating cycles, but based on secondary data analysis, fuel cell systems still lack the market penetration and broad acceptance to encourage the majority of end users to take the risk for a large fleet deployment. End user concerns on fueling infrastructure and safety, especially in the case where the fuel is hydrogen, have been identified as important issues. These same issues plague OEMs or systems integrators resulting in a reluctance to design a product specific for fuel cells.

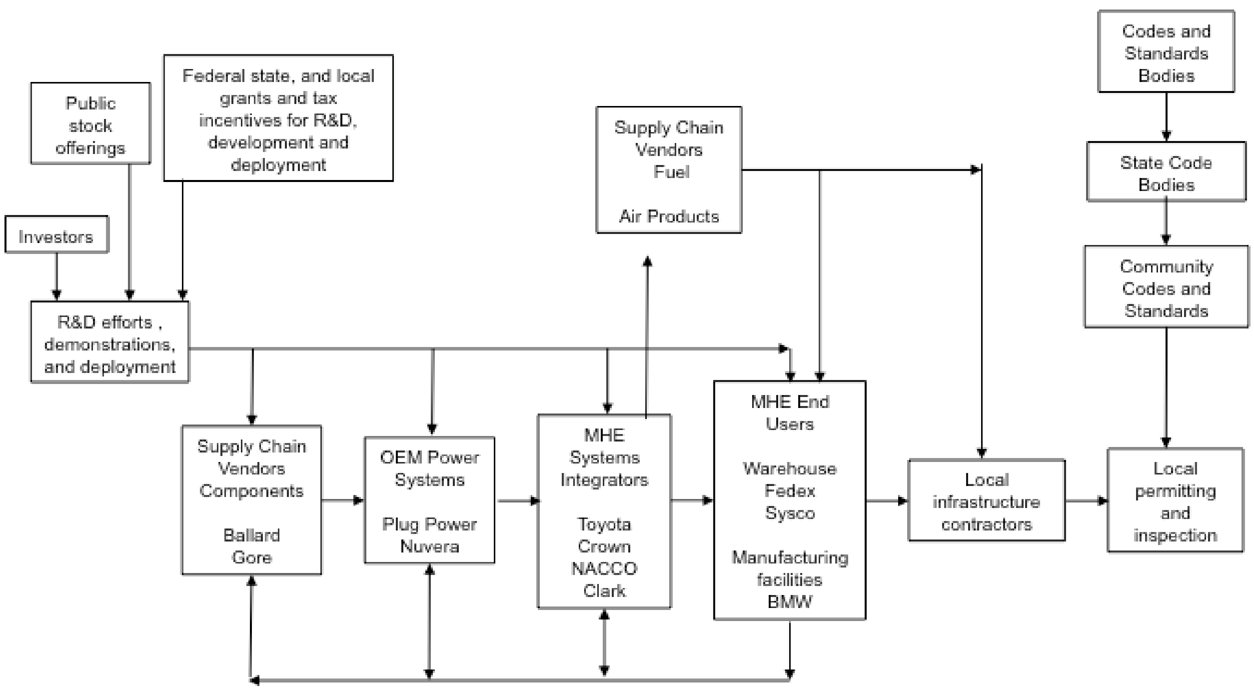


Figure 25 Market Model for Material Handling Equipment

In this model, as shown in Figure 25, the key players are supply chain component vendors, OEMs providing power systems, MHE systems integrators, and MHE end users such as warehouse operators and manufacturing facilities. Supply chain vendors, including Ballard and W.L. Gore & Associates, supply components such as stacks and membrane electrode assemblies to OEMs. Plug Power and Nuvera are OEMs that assemble them into compact fuel cell systems.

Systems integrators who sell material handling equipment such as Toyota Material Handling USA Inc., Crown Equipment Corporation, or Clark Material Handling Company must be convinced that the fuel cell

86 J. Rufener, "Presidents' Forum," Alliance of Industrial Truck Organizations, Palm Beach, Florida, September 24, 2011.

product can be easily integrated into equipment that they produce—Class 1, 2, or 3 forklifts, for example—and that end users such as warehouse operators, will see the relative advantages of the product and purchase fuel cell based battery replacement modules or fuel cell powered forklifts in preference to traditional (battery-powered) forklifts. Because the product uses an alternative fuel, hydrogen, there is a need for specific fuel supply arrangements, infrastructure, and satisfaction of regulatory requirements. Specific installation procedures are required for the fueling facility, which, in turn, requires a local contractor and permits from local government officials.

In the case of demonstrations and deployments, the OEMs are the entities producing the fuel cell power systems for delivery to end users or systems integrators. Given the existence of fuel cell forklift product orders from end users, the systems integrators are then responsible to produce and deliver such fuel cell-based forklifts (Class 1, 2, or 3). The systems integrators are likely to want confirmation that there is sufficient interest among the end users to warrant the investment needed to enter the fuel cell market. Thus, there is a valid commercial feedback loop from the end users to OEMs and systems integrators. The feedback may include desired changes to the product as well as future orders for more equipment. There is also feedback from the OEMs to the supply chain vendors with respect to technical issues as well as new orders. As interest increases among end users and as end users translate that interest into purchases from systems integrators, the OEMs place orders with the supply chain vendors.

The market model also identifies financial resources. These resources include funds from investors, public stock offerings, and grants and tax incentives from federal, state, and local governments. Grants from the Fuel Cell Technologies Program may be targeted to different industry types at different stages of the commercialization cycle.

C.1.2 The Backup Power Market Model

Similar to the MHE application, the backup power market model, as shown in Figure 26, involves the interaction of supply chain vendors with OEMs to produce the fuel cell systems. However, the value chain is more complicated at the systems integration level with either OEM or end users performing the systems integrator role or collaborating to complete this function with the assistance of independent engineering contractors. With hydrogen as the fuel for backup power systems, fueling infrastructure and regulatory issues related to site location present a significant challenge for end users.

The market success of fuel cell backup power is based on leveraging two key features of fuel cell systems: nearly instant start up from cold temperatures and high reliability due to very few moving parts. The lack of emissions and noise is also a strong feature in dense urban areas.

A typical application would be a telecommunications cell tower, a remote control station for a public utility, an emergency communication or response site, or various military communication applications. In essence, any end user applications requiring uninterruptable power for a relatively short period of time from minutes to several days with onsite fuel storage and secure replacement is a candidate for a fuel cell backup power system. An advantage for fuel cell backup power is that end users are less concerned about price because of the absolute requirement for 100 percent availability and reliability.

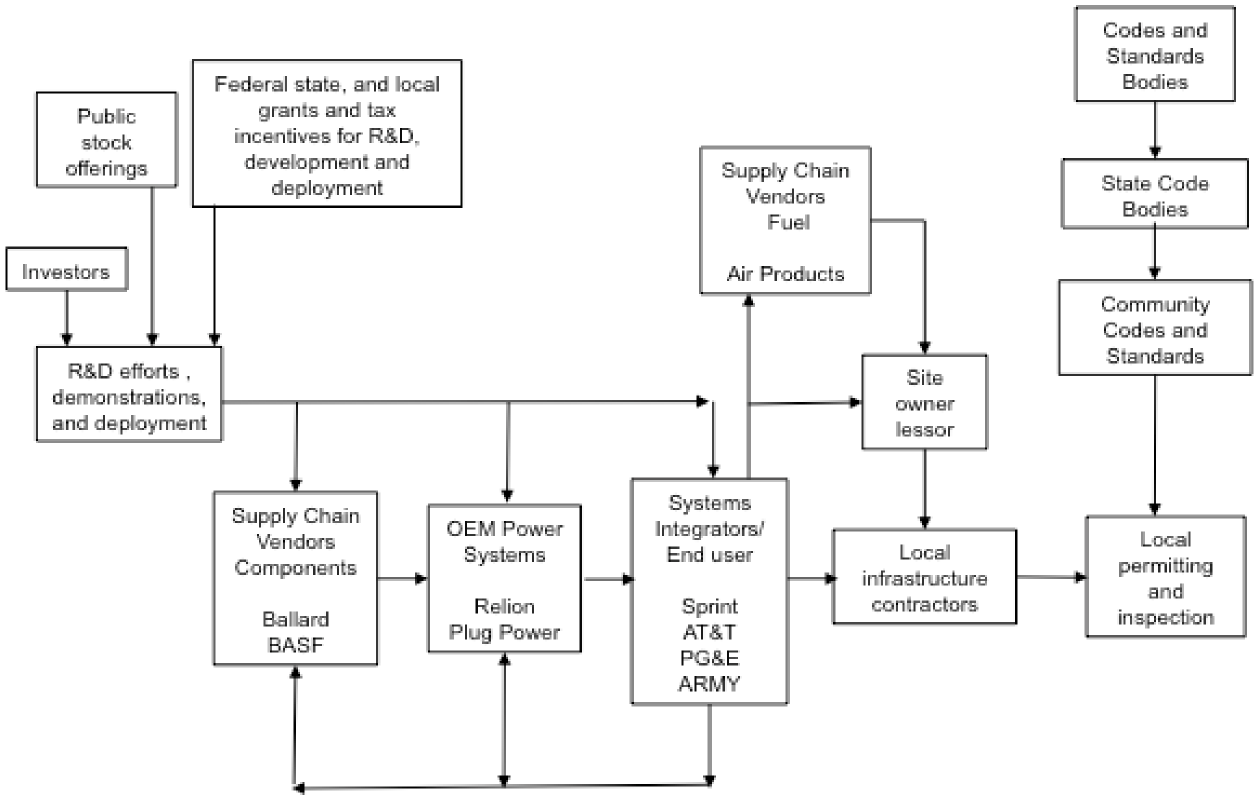


Figure 26 Market Model for Backup Power

When fuel cell backup power was first introduced, the expected outage duration for which the fuel cell had to provide power was anything from minutes to a few hours. The primary fuel was H_2 gas stored in "K bottles" holding about 50 liters. For units with power levels in the 1 to 5 kW range about six K bottles of H_2 were required to sustain operations for 24 hours at half power. When operating time increases to 72 hours or more, gaseous bottle storage is difficult. A more practical approach is to use a liquid H_2 supply. With the improved storage, delivery time, and reliability for liquid hydrogen, the operating time extends to three days.

Given the limited time use of fuel cell backup power systems where reliable grid electricity is available, it can take years for these new technologies to demonstrate the required reliability. This can be a severe limitation in the timing required to achieve end user acceptance.

Given the similarity of the backup power market model to that of the market model for material handling equipment, a detailed discussion of the market will not be revisited. However, there are two important differences between the MHE and the backup power model worthy of note. In the backup power market model, the end users and the systems integrator often tend to be the same entities. For example, Sprint and AT&T provide their own systems integration. That tends to simplify decision-making with respect to initial and longer-term investments. However, it does mean that there is not a systems integrator promoting the product in the market and not all potential end users of the technology may be interested in doing the systems integration. A response might be that the OEM and the fuel supplier work together to provide turnkey packages.

The second key difference is that there is potentially another industry type in the market, the owner of the transmission site. Typically, telecommunications operators piggyback on existing sites so that the same site may serve multiple entities one of which may own the site and the rest that may lease space. Sites may be independently owned as well. The implications of this are potentially substantial. Space may not be available to support the hydrogen fuel and related infrastructure. There may be contractual issues between the firms and site operators that may make the introduction of an alternative fuel difficult. And the owner of the site may be reluctant to seek permits for a new technology that could reopen local zoning and permitting issues. These potential issues were analyzed during the evaluation.

Appendix D Metrics and Measurements

Guided by the logic model, the team developed a comprehensive list of metrics and related measures that drove the development of in-depth interview questions. This list formed the basis of the data collection and the measurement data were then analyzed in the assessment of "early market change."

Each of these metrics bears on the issue of market change. For each metric, there are a series of related measurements. The measures are designed to be as quantitative as possible.

Units sold are an indicator of whether the product is being accepted or rejected in the market and whether the market is developing. Basic measures are:

1. Number of units sold pre ARRA-FCP
2. Number of units sold during ARRA-FCP
3. Number of units sold post ARRA-FCP

Additional measures may include a change in the number first time system purchasers or growth in repeat purchases.

Product value focuses on the relative advantages of the product from the standpoint of the end user. Basic measures are:

1. Capital cost of unit and supporting infrastructure
2. Energy and labor cost to operate unit
3. Energy cost to operate infrastructure
4. Labor cost to maintain infrastructure

Additional measures may include improvements in system performance and cost from the end user perspective; the ability to work with the supply base to enhance product capabilities and reduce cost; the ability to implement product updates and new products using a well-managed product roadmap linked to a technology roadmap; and investment in improved designs and manufacturing processes and equipment and their ability to increase product output, yield, and reliability while reducing cost.

Incentives for product sales indicate whether or not there were other influencers that may have increased the attractiveness of the product and which may or may not exist in the future. Basic measures are:

1. Tax incentives
2. Carbon credits or renewable energy credits for sustainability
3. Investment and other non-Federal incentives and credits

Other incentives may include a positive ROI for end users in less than five years or attaining corporate societal objectives. All of these benefits might prove advantageous for hydrogen as a fuel.

OEM supplier revenues and costs are indicators that the OEM can successfully market the product and achieve sufficient return from sales to invest in R&D, product development, manufacturing scale-up, and sales and marketing efforts. Basic measures are:

1. Cost of components

2. OEM revenues

Systems integrator acceptance is an indicator that that there will be entities who will offer the product to end users. Basic measures are:

1. Stable product design
2. Availability of components at stable or declining costs
3. Differentiated product with relative customer advantages
4. Customer demand
5. Market potential

End user acceptance addresses the willingness of the end user to adopt the product, encouraging other end users to follow suit. This metric has a wide range of potential measures:

1. Product characteristics including the technical readiness and manufacturing readiness, reliability, safety, fueling infrastructure, and life
2. Training/learning requirements
3. Serviceability
4. Emissions
5. Installation
6. Operator requirements and responsibilities
7. Organizational support, primarily the highest level of management awareness and the highest level of decision making support
8. Organizational support when considering changes to plant operational structure, changes to employee responsibilities, changes to employee overtime, and changes in safety management

Additional measures may include the entry into the market of end users that had not previously purchased a fuel cell system or an OEM's response to maintenance issues and customer service needs.

Community acceptance focuses on whether or not local communities in which these products are to be used will be accepting of the product and its required infrastructure. Basic measures are:

1. Perceptions of safety by local officials, especially fire inspectors concerned with hydrogen safety
2. Changes in local inspection practices
3. Awareness of the general public
4. Opposition or support from local public, interest groups, and media
5. Applicable codes and standards

The metrics and measurements are represented graphically in Figure 27.

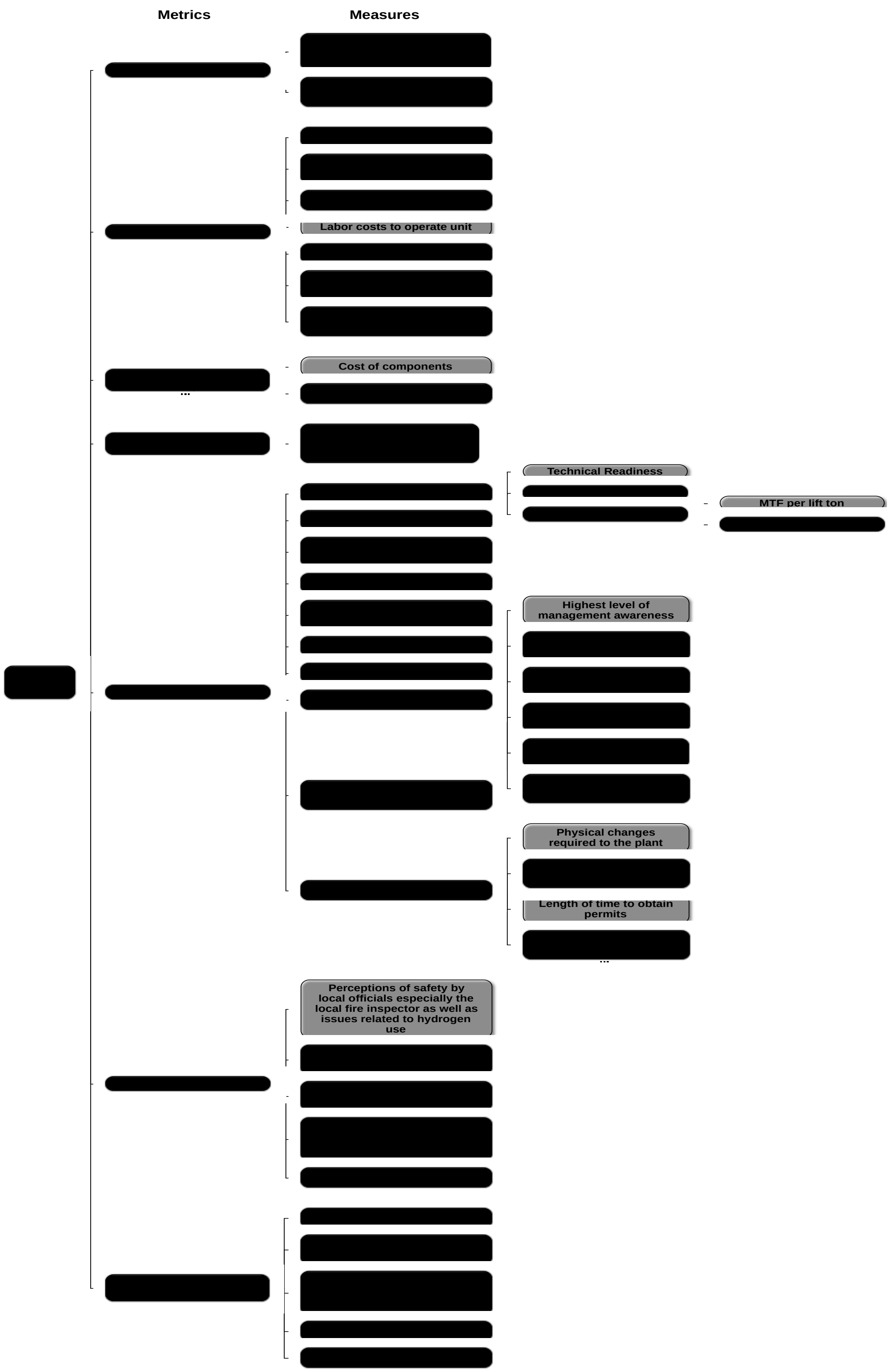


Figure 27 Chart of Metrics and Measures

Appendix E Candidate Interviews

The following is a listing of the concerns interviewed as part of the study.

Awardees are in underlined, subcontractors are normal text, and deployment partners are in italics. For clarity, each interviewee is also denoted as an end user (EU), supply chain vendor (SCV), original equipment manufacturer (OEM), system integrator (SI), or research and development (R&D) concern.

E.1.1. Deployment Phase

<u>FedEx Freight East (Harrison, AR) (EU)</u>

- Air Products and Chemicals (SCV)
- Plug Power (OEM)

<u>GENCO (EU)</u>

- Linde North America (SCV)
    - *Sysco Philadelphia(EU)*
    - *Kimberly Clark Corp(EU)*
    - *Wegmans (EU)*
    - *Whole Foods Market (EU)*
    - *Coca Cola (EU)*

<u>Nuvera Fuel Cells (OEM)</u>

- H. E. Butt Grocery (EU)
- Air Gas Southwest (SCV)

<u>ReliOn Inc. (OEM)</u>

- Ericsson Services, Inc. (SCV)
- AT&T Inc. (SI, EU)
- PG&E Corporation (SI, EU)

<u>Sprint Communications (EU)</u>

- Black and Veatch Corp (SCV)
- Burns & McDonald Engineering (SCV)
- Altergy Systems (OEM)

<u>Sysco of Houston (EU)</u>

- Big D Construction (SCV)

The non-awardee interviews for the deployment phase were as follows.

3M Corporate (SCV)
Air Gas Merchant Gases (SCV)
Clark Material Handling Co. (SI)
Crown Equipment Corp (SI)
Hydrogenics (OEM)
Lift One (SI)
The Kroger Company (EU)
Oorja Protonics (OEM)
The Raymond Corp (SI)
Toyota Industrial Equipment (SI)

Wal-Mart Corp (EU)
Whole Foods Market Inc. (EU)
WL Gore & Associates (SCV)
Yale Material Handling (SI)

E.1.2. Demonstration Phase

<u>Delphi Automotive (OEM)</u>
    TDA Research (SCV)
    PACCAR, Inc. (SI)
    Electricore, Inc. (SI)
<u>MTI Micro Fuel Cells (OEM)</u>
    National Fuel Cell Research Center (R&D)
<u>Plug Power, Inc. (CHP) (OEM)</u>
    Sempra Energy (SI, EU)
<u>Plug Power, Inc. (OEM)</u>
    CERL (EU)
    Fort Irwin (EU)

The non-awardee interviews for the demonstration phase were as follows.

ClearEdge (OEM)
IdaTech (OEM)

E.1.2. R&D Phase

<u>Jadoo Power (R&D)</u>
<u>University of North Florida (R&D)</u>

Appendix F OEM Participant Interview Guide for the ARRA-FCP Awardee

This interview is intended for use with the DOE ARRA-FCP Market Evaluation.
Full Name:
Title:
Start Time:
End Time:
Interviewer names:
File name of the recording:
Location of the recording:

Personnel Background

1. What is your title?
2. What are your current responsibilities?
3. How were you involved with the application to the DOE Fuel Cell Technologies Program that resulted in the ARRA-FCP funding?

Company Background

4. Company name, location, facilities that do work with fuel cell companies
5. Principle business and how it relates to fuel cell products
6. Sales, revenue, employees
7. What percentage of company revenue is derived from your business in fuel cells?
8. How long has your company been doing business in the fuel cell area?
9. What type of products or services does your company provide to the fuel cell market?
10. What is your company's perspective on fuel cells as a growth market?
11. How did your company first become involved in the fuel cell market?
12. Did your company develop new commercial products to address the fuel cell market or were you able to adapt existing products to service the fuel cell applications?

Project History

13. How long has your firm been involved in the development of fuel cells for material handling or backup equipment?
14. Could you give me a brief history of the development of the fuel cell project(s) that resulted in the ARRA-FCP proposal? (*If more than one, provide details for each.*)
    a. When did the efforts that resulted in the ARRA-FCP grant start?
    b. Did the program start with your firm or was your firm recruited to participate by another firm? If the project was started by another firm, how and why was your firm recruited?
    c. Why did your firm undertake the program? *Interviewer: Do not read the following; use these ideas to probe the respondent. Keep probing until the respondent is unable to mention more reasons.*
        i. Potentially large market where the technology is superior to the alternatives?

ii. Opportunity to further refine the technology?
iii. Opportunity to gain legitimacy for the product?
iv. Opportunity to validate the benefits of the product?
v. Opportunity to showcase the technology in the systems integrator and end user communities?
vi. Opportunity to increase the penetration of the product in the market?
vii. Opportunity to engage market leaders who want to be leaders?
viii. Provide users a product that is cost competitive?
ix. Lower the cost or risk to partners?
x. Increase production volume to move further down the cost/volume curve?
xi. Participation essential to keep company going?
xii. The company needed additional funding to develop its product(s)?
xiii. ARRA-FCP funding was seen as an endorsement of the firm's technology and product(s)?
xiv. Other?

d. Of the motivations you just mentioned for pursuing this project, which do you consider to be the most important or to which would you assign the highest priority?
e. What were your firm's initial goals? Have they changed?
f. When did the planning start? (Month, Year)
g. How many systems integrators and/or end user partners did you attempt to engage with this/these projects?
h. How did you recruit these partners?
i. Was it easier to engage end users than systems integrators or vice versa?
j. Why do you think these partners engaged?
k. If there were some good candidate firms with which you were unable to partner, why do you think they did not engage?
l. When did implementation start? (Month, Year)
m. What other opportunities for funding was the firm pursuing, assuming that ARRA-FCP funding may not have been successful?
n. Was ARRA-FCP funding incremental to other funding efforts? If yes, what other funding sources? Was it essential to the planned execution of the project?

Organization Impact

15. How many people at your firm were/are involved with the project?
16. What were/are the responsibilities of these individuals?
17. How was the program organized/structured within your firm?
18. Once the project got underway how were the responsibilities among the systems integrators, the OEMs, the end users, and the supply chain vendors (fuel, component, service providers) divided?
19. Were there other types of firms that played key roles that facilitated the projects or provided engineering and construction services? What roles did those firms play?

Prior Fuel Cell History

20. How long has your firm been targeting fuel cells for use in material handling or backup power? (*Get an approximate date.*)
21. Had your firm received prior funding through DOE that allowed your firm to develop the technology to this point? Can you briefly describe the yearly and total funding amounts?
22. Prior to submitting the application that resulted in ARRA-FCP funding, had you sponsored/ participated in any demonstration or pilot programs or implemented any fuel cell material handling or backup power projects?
    a. If so, can you briefly describe the size (capital and/or units involved) and scope of those projects?
    b. The results from those projects?
    c. Any influence those projects had on the decision to pursue the ARRA-FCP funding?

Market Estimates

23. Just prior to the application to DOE, what was your best estimate of the total size of the market for material handling or backup power? In the U.S.? Worldwide?
24. In the ***absence*** of the ARRA-FCP funding, what is your ***best estimate*** of the number of fuel cell MHE or backup units that your firm would have sold in 2009, 2010, 2011, 2012, and 2013?
25. In 2009, 2010, 2011, and 2012, how many units did your firm sell as a direct result of the ARRA-FCP project?
26. Including units sold during the ARRA-FCP project period, how many total units did your firm sell in 2009, 2010, 2011, 2012, and 2013?
27. As a result of the ARRA-FCP funding, end users may have ordered more units than they would have otherwise. How many additional units do you believe end users sold as a result of ARRA-FCP funding in 2009, 2010, 2011, and 2012?
28. Are you aware of end users who purchased additional units as a result their experience with the units that the received ARRA-FCP funding? If yes, how many customers and how many units?
29. End users that did not receive direct ARRA-FCP funding may have been influenced to purchase units that they would not otherwise have purchased or purchased units at a later time because your firm was able to further develop and promote its products as a result of ARRA-FCP funding. How many such customers and how many units would they have ordered or purchased in 2010, 2011, 2012, and 2013?

Manufacturing Inputs

30. At the time the application was approved for ARRA-FCP funding, what was the status of the fuel cell stack and power system being incorporated into material handling or backup power systems? What was the:
    a. Estimated lifetime of the fuel cell?
    b. Estimated mean time to failure?
    c. Existing systems integrator, end user, and supply chain vendor relationships?

d. Estimated time to 10 percent reduction in voltage?
e. Person hours to produce a fuel cell?
f. Maximum number of fuel cells that could be produced in an eight-hour shift?
g. Cost to manufacture?
h. Selling price?
i. As a result of the ARRA-FCP funding, has the performance and cost of the technology changed for items a through h? If so, what were the changes?
j. Were there changes for other reasons?

	At the beginning of ARRA-FCP funding	Changes that resulted from funding	Changes that occurred for other reasons
Estimated lifetime of the fuel cell?			
Estimated mean time to failure?			
Existing SI, end user, and SCV relationships?			
Estimated time to 10 percent reduction in voltage?			
Person hours to produce a fuel cell?			
Maximum number of fuel cells that could be produced in an eight-hour shift?			
Cost to manufacture?			
Selling price?			

31. As a result of the ARRA-FCP project how did the manufacturing process change?

a. As a result of feedback from the ARRA-FCP project, what technology, design, materials selection, BOP simplification, functionality, manufacturing, operational capability, operational strategy changes, etc., were made to the product?
b. Following ARRA-FCP funding, were there any supply chain issues that limited execution of the program? If so, how were these resolved?
c. As a result of the ARRA-FCP project, were you able to drive down material, subsystem, and production costs? If so, what contribution did these efforts make each as a percentage to the overall product cost reduction during the project?
d. As a result of increased production to meet ARRA-FCP goals, were any of the manufacturing processes changed? If so, what were the drivers for process changes, and what specific changes were instituted?
e. Did the ARRA-FCP change any requirements for quality control? If so, what were the impacts of such changes to product design, manufacturing and product costs, etc.?
f. As a result of the ARRA-FCP, was additional training of existing staff required? Which additional skills were required, how was training accomplished, and at what cost?

g. Were the manufacturing facilities altered (capital expenditures) to meet the needs of the ARRA-FCP project? Did additional product demand as a result of the ARRA-FCP project, require facility changes to meet increased volume demand? If so, how was this addressed?
h. What were the impacts of the ARRA-FCP on manufacturing personnel and supply chain vendor employment?
i. Which supply chain vendors did you work with in carrying out this project? What was their role in executing the project during and after the ARRA-FCP award?

32. Are you able to supply the names of a few representative supply chain vendors that participated in your project that we could interview? Who are the main contact persons and the best means to contact them?
33. Did you work with a systems integrator?
    a. If working with a systems integrator, what was the most difficult engineering issue to resolve to meet the systems integrator and end user needs?
    b. How did solving these issues through the ARRA-FCP project lead to a mature product?

34. Did you work with an end user?
    a. If working with an end user, what problems did you address and how did you resolve them?
    b. How did the ARRA-FCP funding influence the process?

Jobs

35. How many new jobs/positions (FTEs) were added because of ARRA-FCP funding?
36. How many employees (FTEs) would have been laid off or let go or were likely to have been laid off or let go without the funding?
37. How many employees were shifted to different jobs not related to the projects as a result of ARRA-FCP funding?

	2009	2010	2011	2012
New jobs/positions (FTEs) that were added because of ARRA-FCP funding				
Employees (FTEs) that would have been laid off or let go or were likely to have been laid off or let go without the funding				To date
Employees shifted to different jobs not related to the projects				To date
New jobs/positions that were added that have since been eliminated?				

38. How many of the new jobs or positions that were added have since been eliminated?

End User Decision-making Process

39. For the end users, were the projects initiated at the corporate level or were they initiated by champions at a regional or site level or at different levels depending on the end user?

40. Was there sign-off at the corporate level or the local level?
41. Were any of these projects follow-on projects to demonstrations or purchases at other sites? Please explain.
42. What product attributes and functionalities were most attractive to the end users? Did ARRA-FCP funding make these attributes or functionalities more attractive by encouraging participation? How did the ARRA-FCP funding contribute to funding decisions to purchase equipment?

ARRA-FCP Project Implementation

43. Who designed the ARRA-FCP installations?
44. Describe any design issues or site issues that impeded end user acceptance?
45. Who supervised the installations?
46. Was finding companies to do the installation a barrier to selling product and gaining end user acceptance?
47. Was it difficult to find companies to provide onsite fuel supply capability? If so, how was fuel cell supply capability addressed?
48. Who designed and delivered the fuel supply capability?
49. Please describe the overall installation process including the fuel supply capability?
50. Were there delays in the installation of the equipment? If so, what caused the delays? How were the delays resolved?
51. What is the current status of the project?

Local Permitting Issues

52. Were there community acceptance and/or regulatory issues that made siting difficult or provided challenges?
53. What special efforts, if any, were required to provide information to local officials to secure permitting for site location? How was regulatory “education” managed? Who was responsible for this process? Did this slow product sales/placement? If so, what if anything was done to overcome this obstacle?
54. Were the installations covered by existing local codes? If not, did local codes have to be changed or was there fallback to statewide codes?
55. Were there any problems in obtaining construction permits?
56. Were local inspectors able to handle the process or were third party inspectors used?
57. Did the use of hydrogen cause officials to more closely review and/or inspect the installations?
58. Can you supply contact information for parties involved in these issues?
59. How did this impact product acceptance and future product purchasing?

Training

60. What training was required to operate and maintain the new equipment? What was the key content of the training? Was the training primarily safety training? What entities paid for and arranged for this training?
61. What role did you as an OEM play in developing the training?

62. Who was trained? Facility engineers? Operators? General facility employees?
63. How long did the training take? Did the training reduce interest in the product? Did it reduce or slow sales?
64. What challenges were encountered in completing the training?
65. Has the training been incorporated into general facility training requirements?
66. Was the content of the training adequate? If not, what were the deficiencies? Was further training/retraining required? With groups?

End User Facility Operation

67. Were the new products rolled out a few units at a time or did the transfer occur all at once? Were the fuel cell products operated in conjunction with conventional technology (battery) equipment?
68. During the first eight weeks of operation, what operational issues arose, if any? Please explain. How were these issues resolved?
69. After the first eight weeks of operation, were there operational issues that arose? What were they, and how were they handled?
70. What was the response of the operators to the new equipment?
71. What was the response of other employees to the new equipment?

Equipment Operation and Maintenance

72. How is the operation of the equipment being monitored? What data are being collected? Who is collecting that data? How is the data stored? How is the data used, and how does it influence end users with regard to future product purchases?
73. Can you supply data for the following?
    a. Daily hours of operation?
    b. What failure modes are being observed and with what frequency?
    c. Mean time to failure?
    d. Amount of hydrogen used?
    e. Productivity efficiency relative to incumbent technology products?
    f. Operator acceptance?
    g. Reliability factors relative to incumbent technology?
    h. Capital Expense Payback period relative to incumbent technology?
    i. Hydrogen refilling times for MHE products?
    j. Role of automated battery changing equipment and its impact on acceptance and value proposition of fuel cell technology products?
    k. Installation costs
74. From your perspective, what are the key lessons learned from the installation and operation of this equipment?

Other Incentives

75. Other than the ARRA-FCP funding, did you receive any incentives for the project? Federal, state, other? Please explain. How did these incentives add value beyond ARRA-FCP funding to product sales and product acceptance?
76. How did ARRA-FCP funding impact the ability to secure these incentives?
77. As a result of ARRA-FCP funding were you able to gain more funding from private sources? How much funding did you receive relative to the ARRA-FCP funding? Did it impact the execution and delivery of the project? Did it allow you to make additional changes to the product? If so, what changes?
78. Do you know if end user customers that participated in ARRA-FCP funding obtained grants, tax incentives, or other incentives from state and local government entities? Which firms and what types of incentives? How did securing of such incentives influence purchase decisions?
79. Does your firm provide information about or use tax incentives, grants, or other types of funding obtained from state and local government entities as a sales tool? Could you please briefly describe the use of such incentives in the pursuit of product sales?
80. What percentage of product sales do you estimate would have been lost if local, state, and federal level incentives had not been available?