# SANDIA NATIONAL LABORATORIES
# FCTP MARKET TRANSFORMATION PROGRAM

QUARTERLY PROGRESS REPORT FOR JANUARY 2011–SEPTEMBER 30, 2011

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**RECIPIENT:** SANDIA NATIONAL LABORATORIES

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Sandia National Laboratories

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

# FCTP MARKET TRANSFORMATION PROGRAM

**COVERING PERIOD:** JANUARY 2011 THROUGH DECEMBER 31, 2011

**DATE OF REPORT:** JANUARY 30, 2012

**PRINCIPLE INVESTIGATOR:** JOSEPH W. PRATT (925-294-2133, JWPRATT@SANDIA.GOV)

**OTHER KEY NATIONAL LAB RESEARCHERS:** LENNIE KLEBANOFF, KARINA MUNOZ-RAMOS, ABBAS AKHIL, DITA CURGUS, BENJAMIN SCHENKMAN

## FY 2011 MILESTONES/DELIVERABLES

| Task | Planned | Status |
|---|---|---|
| **Task 1—Assessment of the Use of Stationary Fuel Cell Power at the Sandia Kauai Test Facility on the Pacific Missile Range Facility, Kauai, HI** | | |
| ***Subtask 1.1—Engage stakeholders at the KTF, PMRF, and the local utility to pave the way for project initiation*** | | Complete |
| ***Subtask 1.2—Write and submit proposal to the Navy for fuel cell support of the Navy Aegis Assure Program*** | | Not executed; decision by PMRF commander |
| ***Subtask 1.3—Write and submit final feasibility report*** | 9/30/2012 | In progress |
| **Task 2—Fuel Cell Mobile Lighting** | | |
| ***Subtask 2.1—Program management*** | | |
| Final project report | 9/30/2011 | 9/30/2012 |
| ***Subtask 2.2—Modification of original "alpha" prototype*** | | |
| Complete modifications to alpha unit | 8/1/2010 | Complete |
| Begin field test of upgraded alpha unit | 9/1/2010 | Complete |
| Complete alpha unit Caltrans field test | 9/30/2010 | 9/30/2012 |
| ***Subtask 2.3—Design, Construction, testing and field testing of a "show unit"*** | | |
| Complete design of show unit | 6/1/2010 | Complete |
| Complete construction of show unit | 8/1/2010 | Complete |
| Complete final testing of show unit | 9/1/2010 | Complete |
| Show unit at trade shows in 2011 | 9/1/2010 | Complete |

| Task | Planned | Status |
|---|---|---|
| ***Subtask 2.4—Design, construction, testing and field test of a "hybrid" fuel cell mobile light for field testing at SFO*** | | |
| Complete design of hybrid fuel cell mobile light | 7/1/2010 | Complete |
| Complete construction of a hybrid fuel cell mobile light system | 10/1/2010 | 4/1/2012 |
| Complete final testing of the hybrid system | 11/1/2010 | 6/1/2012 |
| Begin deployment of hybrid fuel cell mobile light at SFO | 12/1/2010 | 7/1/2012 |
| Complete field testing of the hybrid fuel cell mobile light at SFO | 9/30/2011 | 9/30/2012 |
| ***Subtask 2.5—Design, construction, testing and field test of a fuel cell mobile light for the kennedy space center*** | | |
| Complete design of the KSC unit | 7/1/2010 | Complete |
| Complete construction of the KSC unit | 9/1/2010 | Complete |
| Complete final testing of the KSC unit | 10/1/2010 | Complete |
| Begin deployment of KSC unit | 11/1/2010 | Complete |
| Complete field testing of KSC unit | 9/30/2011 | 9/30/2012 |
| ***Subtask 2.6—Design, construction, testing and field test of a fuel cell mobile light for the Boeing manufacturing plant and Paine field*** | | |
| Complete design of the Boeing unit | 8/1/2010 | Complete |
| Complete construction of the Boeing unit | 9/1/2010 | Complete |
| Complete final testing of the Boeing unit | 10/1/2010 | Complete |
| Begin deployment of Boeing unit | 11/1/2010 | Complete |
| Complete field testing of Boeing unit | 9/30/2011 | 9/30/2012 |
| ***Subtask 2.7—Construction and testing of a fuel cell mobile light for Disneyland*** | | |
| Complete design of the Disneyland Unit | 9/1/2010 | Not executed |
| Complete construction of the Disneyland unit | 10/1/2010 | Not executed |
| Complete final testing of the Disneyland unit | 11/1/2010 | Not executed |
| Begin deployment of Disneyland Unit | 12/1/2010 | Not executed |
| Complete field testing of Disneyland unit | 9/30/2011 | Not executed |
| **Task 3—Hydrogen ICE Bus Demonstration and Community Outreach** | 03/2011 | Complete |
| Final project report on bus use, GHG savings, energy savings, community response, employee response, possible employee survey, Joint with LLNL. | In progress | 9/30/2012 |

| Task | Planned | Status |
|---|---|---|
| **Task 5—Analysis of Use of PEM Fuel Cells On Board Commercial Aircraft** | 03/2011 | Complete |
| ***Subtask 5.1—Engineering analysis of deployment of 3 PEM fuel cells on board commercial aircraft for galley power, in-flight entertainment power and peaker power*** | | |
| Complete engineering systems analysis | 06/2010 | Complete |
| ***Subtask 5.2—Thermodynamic systems analysis of deploying three PEM fuel cells onboard commercial aircraft for galley power, in-flight entertainment power and peaker power*** | | |
| Complete thermodynamic-based analysis | 08/2010 | Complete |
| ***Subtask 5.3—Electrical grid analysis of the use of fuel cells for galley power, in-flight entertainment power and peaker power*** | | |
| Complete micro-grid analysis | 09/2010 | Complete |
| ***Subtask 5.4—Project final report*** | | |
| Final report integrating results of analyses | 09/2010 | Complete |

## TASK 1—ASSESSMENT OF THE USE OF STATIONARY FUEL CELL POWER AT THE SANDIA KAUAI TEST FACILITY ON THE PACIFIC MISSILE RANGE FACILITY, KAUAI, HI

This task describes the activities to be conducted at Sandia National Laboratories in FY 2012 in support of DOE's program for stationary fuel cell market transformation. Sandia operates the Kauai Test Facility (KTF), a missile test installation located on the greater Pacific Missile Range Facility (PMRF), Kauai, HI. There are two potential opportunities for placing a stationary fuel cell at this military facility. The first is at the KTF facility itself. The second opportunity is to place a fuel cell to provide power support for the upcoming Aegis missile test program, in which a shipboard defensive missile system will be tested at the PMRF by the Navy. The testing of this nominally shipboard-based system will require the establishment of significant new infrastructure at the PMRF. The KTF currently suffers from low-quality grid power at the site, which must often be supplemented by diesel generators. In addition to this installation at the military facility, there is the broader question of bringing fuel cell technology to the island of Kauai.

### ENGAGE STAKEHOLDERS AT THE KTF, PMRF, AND THE LOCAL UTILITY TO PAVE THE WAY FOR PROJECT INITIATION

As part of the project, we engaged stakeholders and third parties capable of providing or seeking funding for the project. We established a connection with the Sandia staff member in charge of the KTF (Steve Yesner). We also enlisted the support of Golden State Energy/Steam Power

Partners (Tom Damberger, Steve Petty), who have the world's deepest experience in installing stationary fuel cell systems from Fuel Cell Energy. Through our KTF Sandia contact, we communicated with the PMRF site commander. In addition, we established connections with the Ken Oscar and Bill Martin from Fluor Company, who have extensive experience with large alternative-energy installations. As time passed, we also brought into our team Joe Boivin from Hawaii Gas.

### WRITE AND SUBMIT PROPOSAL TO THE NAVY FOR FUEL CELL SUPPORT OF THE NAVY AEGIS ASSURE PROGRAM

The original idea was that once the fuel cell analysis indicated feasibility and local stakeholders were engaged, we would write and submit a proposal to the Navy for the installation of stationary fuel cell power at the KTF/PMRF. This proposal would have been led by Fluor. After much discussion with the local PMRF commander, it became clear that they would not entertain a proposal using fuel cells, due in part to an unsuccessful stationary fuel cell project ongoing on the PMRF site. Instead, interest turned to the non-military areas of Kauai.

The group investigated the feasibility of bringing liquid natural gas (LNG) to the island. The large stationary fuel cells require NG, and no land-based NG is available on Kauai. Research by Steam Power Partners (Damberger, Petty) and Hawaii Gas (Boivin) indicated that LNG could be brought to the island in cryogenic shipping containers, and that this method of LNG delivery was being conducted in Europe. Analysis indicated that the total cost for power (including LNG costs) derived from the fuel cell would be of order $0.30 /kW-hr, which is less than the current residential rate of ~ $0.40/kW-hr. Currently, Steam Power Partner is exploring interest of certain parties on Kauai for such a fuel cell system.

### FINAL FEASIBILITY REPORT FOR PLACING STATIONARY FUEL CELL AT THE KTF/PMRF

We will submit a final report on the economic and technical feasibility of placing a stationary fuel cell at the KTF/PMRF. In addition, we will examine the net greenhouse and pollutant gases avoided by installation of the stationary fuel cell power.

**9/30/2012:** Final feasibility report for placing stationary fuel cell at the KTF/PMRF.

## TASK 2—FUEL CELL MOBILE LIGHTING

This report summarizes the activities conducted at Sandia National Laboratories, in collaboration with its project partners, with status update for Q2 of FY 2010-11 in support of DOE's program for fuel cell market transformation. In this project we originally targeted the construction of 5 Fuel Cell Mobile Lighting systems for field testing: one at San Francisco International Airport (SFO), and one for Paramount Pictures and in the work of Saunders Electric, Inc. A third unit was targeted for use at the Kennedy Space Center, Cape Canaveral, Florida. A fourth unit was planned for use at the Boeing Manufacturing Facility (and Paine Airfield) in Everett, Washington. A fifth unit was originally planned for use at Disneyland, but discussions with Disneyland did not lead to an agreement to deploy there.

## PROJECT MANAGEMENT

**Objective:** Manage the work and communications of the partners to allow successful project execution and reporting.

**Discussion:** In Q2-2011, the project has continued to be managed by Dr. Lennie Klebanoff of Sandia National Laboratory. Dr. Klebanoff helped has organized the team to accomplish the project tasks, keep the project on schedule and within budget, hold project meetings, lead demonstrations of the system, coordinate the field test activities, report to DOE, and write a final project report.

### *Milestone Status for Subtask 2.1*

**9/30/2011:** Final project report: Writing of the final report has been delayed as the units are only now being introduced into the field for testing.

## MODIFICATION OF ORIGINAL "ALPHA" PROTOTYPE FOR DEPLOYMENT WITH CALTRANS

**Objective:** Modify the existing alpha system prototype to allow its use in road construction work with Caltrans.

**Discussion:** This modification of the alpha took place in Q3-2010. However, we decided to use the modified alpha system in the entertainment realm. The upgrades included a better cabinetry and weatherproofing of the lights in standard Multiquip lamp housings. The unit now resides with Saunders Electric for use in entertainment industry events. The auxiliary power for the unit remains unchanged, as we decided to use the "beta" systems to evaluate the integrated electronic packages for the technology.

### *Milestones for Subtask 2.2*

**8/1/2010:** Complete modifications to alpha unit. Status: Complete.

**9/1/2010:** Field Test upgraded alpha unit with Saunders Electric. Status: Unit deployed in entertainment industry instead of at Saunders Electric.

**9/30/2011:** Complete alpha unit field test. Status: Unit just beginning field testing in Los Angeles.

## DESIGN, CONSTRUCTION, TESTING AND FIELD TEST OF A FUEL CELL MOBILE LIGHT OPTIMIZED FOR THE ENTERTAINMENT INDUSTRY

**Objective:** Design a fuel cell mobile light system that is optimally useful to the entertainment industry.

**Discussion:** Based on our early learning with the alpha system, we originally planned to design a near-commercial "alpha prime" version of fuel cell mobile light that still employs high-pressure hydrogen storage, but is modified in other ways for optimal performance for the film industry. The original plan was for Paramount and Saunders to provide the performance specifications regarding lighting level and control, auxiliary power requirements, weight, volume, and allowable noise for the system. We decided not to construct such an entertainment industry "alpha prime" system. Rather a "show unit" was constructed for Multiquip to demonstration at construction equipment shows to promote customer interest. This unit can eventually be used in the entertainment industry, but will not be upgraded with sound conditioning.

### *Milestones for Subtask 2.3*

**6/1/2010:** Complete design of show unit mobile light. Status: Constructed a "show" beta unit instead, which can eventually be used for field testing. Show unit design finished 6/1/2010.

**8/1/2010:** Complete construction of the show unit. Status: Show industry unit completed 9/1/2010.

**8/1/2010:** Complete construction of the show unit. Status: Show industry unit completed 9/1/2010.

**12/1/2010:** Show unit at trade shows. Status: "show unit" shown at the World of Concrete 2011, PowerGen 2010, and the National Association of Broadcasters Meeting 2011.

## DESIGN, CONSTRUCTION, TESTING, AND FIELD TEST OF A "HYBRID" FUEL CELL MOBILE LIGHT FOR FIELD TESTING AT SFO

**Objective:** Assess the use of metal hydride technology in the fuel-cell mobile light product.

**Discussion:** An alternative method to high-pressure storage of hydrogen is to employ a metal hydride "bed" as the storage medium. One advantage of using a metal hydride system is a greater volumetric storage density, thereby allowing more hydrogen to be stored in a given space, which increases mobile light duration. Another advantage is that a metal hydride allows a lower overall system pressure, thereby increasing safety. These advantages are offset by the higher cost of metal hydride tanks (at least currently), and managing the thermal issues that arise because the metal hydride bed material must be heated to release its hydrogen and heat must be removed from the tanks when they are refueled. We felt it important for Multiquip to gain some experience with the metal hydride technology so that when the metal hydride storage becomes more affordable in the years ahead and can be used in production units, personnel are familiar with the technology.

Sandia designed the hybrid fuel cell mobile light in the summer of 2011, in collaboration with Multiquip and Altergy Systems. The parts for the unit were ordered in the fall of 2011, and all components have been received by Multiquip in Boise, Idaho. Construction of the unit will

commence in April 2012, with expected completion in May of 2012. After construction, the unit will be tested at Sandia in Livermore, California, and then transferred to SFO for field testing.

### *Milestones for Subtask 2.4*

**7/1/2010:** Complete design of hybrid fuel cell mobile light. Status: Completed 8/31/2011.

**10/1/2010:** Complete construction of a hybrid system. Status: Planned for 4/1/2012.

**11/1/2010:** Complete final testing of the hybrid mobile light. Status: Planned for 6/15/2012.

**12/1/2010:** Begin field test of the hybrid unit at SFO. Status: Planned for 7/1/2012.

**9/30/2010:** Complete field test of the hybrid unit at SFO. Status: Planned for 10/1/2012.

## DESIGN, CONSTRUCTION, TESTING, AND FIELD TESTING OF A FUEL CELL MOBILE LIGHT FOR THE KENNEDY SPACE CENTER

**Objective:** Build and field test one fuel cell mobile light for use at the Kennedy Space Center.

**Discussion:** One of the beta fuel cell mobile lights was targeted for use at the Kennedy Space Center (KSC), in collaboration with NASA. The purpose of the deployment is to gather system duration information in a hot, humid, and salty air environment. This information will allow Multiquip to gather much-needed endurance information prior to fuel cell mobile light commercialization.

The unit was designed, constructed, and deployed at the Kennedy Space Center in August 2011. It is noteworthy that for the final Space Shuttle launch in July 2011, the upgraded alpha unit was deployed in the International Press area.

### *Milestones for Subtask 2.5*

**7/1/2010:** Complete design of the KSC unit. Status: Completed 5/1/2011.

**9/1/2010:** Complete construction of KSC unit. Status: Completed 7/1/2011.

**10/1/2010:** Complete final testing of the KSC unit. Status: Completed 7/15/2011.

**11/1/2010:** Begin deployment of KSC unit. Status: Deployment commenced 8/1/2011.

**9/30/2011:** Complete field testing of the KSC unit. Status: To be completed 9/30/2012.

### DESIGN, CONSTRUCTION, TESTING AND FIELD TESTING OF A FUEL CELL MOBILE LIGHT FOR BOEING MANUFACTURING AND PAINE FIELD USE

**Objective:** Build one fuel cell mobile light for use in the Boeing Manufacturing Plant and for their Paine Field Operations in Everett, Washington.

**Discussion:** The purpose of the deployment is to gather duration information in a cold and rainy environment, in manufacturing and Air Field operations. This information will allow Multiquip to gather much needed endurance information prior to commercialization.

The unit was designed by 6/1/2011, constructed by 7/15/2011, tested, and shipped to Boeing by 8/15/2011. The unit was introduced to Boeing staff on 8/30/2011. The unit has not yet been deployed because Boeing is undergoing a thorough safety review of the system. The Boeing unit was sent to the Aberdeen Proving Ground on November 16, 2011 to support a DOE-related fuel cell event. The current plan is to return the unit to Boise Idaho, have the lighting upgraded with a new generation of plasma lighting that is becoming available, and return to Boeing for eventual use.

#### *Milestones for Subtask 2.6*

**8/1/2010:** Complete design of the Boeing unit. Status: Completed 6/1/2011.

**9/1/2010:** Complete construction of the Boeing unit. Status: Completed 7/15/2011.

**10/1/2010:** Complete final testing of the Boeing unit. Status: Completed 8/1/2011.

**11/1/2010:** Begin deployment of Boeing unit. Status: Boeing performing safety review.

**9/30/2011:** Complete field testing of the Boeing unit. Status: To be completed 9/30/2012.

### DESIGN, CONSTRUCTION, TESTING AND FIELD TESTING OF A FUEL CELL MOBILE LIGHT OPTIMIZED FOR DISNEYLAND

**Objective:** Build and field test one fuel cell mobile light, for use at Disneyland in Anaheim, CA.

**Discussion:** The original plan was to build a fuel cell mobile light for deployment at Disneyland. The purpose is to use the technology and demonstrate in collaboration with Disney in both park maintenance and park theatrical operations. However, after multiple discussions with Disneyland, they decided they were not interested in hydrogen fuel cell technology. The Disney unit was therefore not built. Instead a “show unit” was constructed (see above).

#### *Milestones for Subtask 2.7*

**9/1/2010:** Complete design of the Disney unit. Status: Not executed.

**10/1/2010:** Complete construction of Disney unit. Status: Not executed.

**11/1/2010:** Complete final testing of the Disney unit. Status: Not executed.

**12/1/2010:** Begin deployment of the Disney unit. Status: Not executed.

**9/30/2011:** Complete field testing of the Disney unit. Status: Not executed.

## TASK 3—HYDROGEN ICE BUS DEMONSTRATION AND COMMUNITY OUTREACH

### OBJECTIVE

Partner with LLNL to maintain a hydrogen bus (taxi service) program servicing SNL CA and LLNL sites and continue outreach programs to engage, support, and educate the local community of the Tri-Valley, San Joaquin County, and other East Bay areas on emerging hydrogen technologies.

### DISCUSSION

Our approach to this project was as follows: Prior to receiving the buses, extensive discussions were carried out with LLNL and SNL facilities management, and with the LLNL site manager for the Nuclear National Security Administration to secure "buy-in" for the project. With the project receiving strong acceptance and support, we leased the $H_2$ buses from the Ford Motor Company, followed by an initial certification of them in collaboration with Ford maintenance staff. During this certification phase, we designed appealing "wraps" for the buses to bring attention to their $H_2$ technology. There are no hydrogen stations currently operating in the Tri-Valley area, so we had to establish a mobile refueling station at the LLNL site using an Air Products mobile refueler. With reliable fueling established, the buses were integrated into the LLNL/Sandia taxi service, replacing two buses that were operated on diesel fuel. Thus, use of the $H_2$ buses led to a decrease in diesel fuel use at the two laboratories. Furthermore, the $H_2$ buses were used for educating the local public on the benefits of hydrogen and fuel cell technology. We managed frequent maintenance problems that arose with the buses, these problems being unrelated to the hydrogen technology (except for the need to replace a sensor, with the failure being detected with on-board diagnostics), and many involved traditional bus mechanical systems.

### RESULTS

In November of 2010, the two $H_2$ buses were integrated into the LLNL/SNL fleet. The buses traveled all over the LLNL and SNL sites, as well as to the local commuter train station, picking up LLNL and SNL employees and transporting them to our campuses. The typical ridership per shuttle bus is approximately 80–100 passengers/day with each $H_2$ bus traveling approximately 80–100 miles each day. The $H_2$ buses are "topped off" with approximately 13 kg of hydrogen each day. We put 8,757 miles on the buses in the first six months of operation (as of June 30, 2011). The average number of miles driven by each bus is 730 miles per month. With regard to a

fuel comparison, the average number of gallons of diesel used on our previous buses is 168 gallons per month (per bus), so substantial fuel savings was realized. It is our understanding that this level of use is among the highest for DOE facilities using such buses. Both buses found extensive use in a number of community outreach activities. Two of these are described in more detail below.

The first community event was a joint SNL/LLNL Celebration of Hydrogen Technology in downtown Livermore on February 22, 2011. This event was organized by the project and LLNL and SNL protocol and public relations personnel. Approximately 70 members of the public, media, local dignitaries, and LLNL and SNL management and staff were on hand to see the two $H_2$ buses, along with the $H_2$ Fuel Cell Mobile Light, the cryocompressed hydrogen vehicle from LLNL, and a number of posters on hydrogen research and development being conducted at the labs. Speakers included:

1. Ron Cochrane, Executive Officer from LLNL and Bob Carling, Director of the Transportation Energy Center from SNL.
2. John Garbak, DOE Technology Development Manager
3. John Marchand, Vice Mayor, City of Livermore
4. Alice Williams, Nuclear National Security Administration Site Manager

KPIX television (San Francisco) broadcast video from the celebration on their evening news including an interview with the Sandia PI Klebanoff, and press from two local newspapers attended as well. Representatives from Congressmen Garamendi's and McNerney's offices and California State Assembly member Joan Buchanan were also in attendance. Members of the public were given rides on the buses and had a chance to talk with LLNL and SNL staff scientists about the hydrogen technology depicted in the posters. In another community outreach event one of the $H_2$ buses was on display at the Expanding Your Horizons conference on Saturday February 26, 2011, at the Diablo Valley Community College, San Ramon campus, with rides given to attendees. The Expanding Your Horizons conference serves to:

- Increase the interest of young women in math and science through positive hands-on experience (over 300 present).
- Foster awareness in math- and science-related careers.
- Provide young women with opportunities to meet and interact with positive role models who are active in math- and science-related careers.

Other outreach events included the John Muir Birthday-Earth Day Celebration in Martinez, California, on April 16, 2011. This event provided a shuttle service from the parking area to the event main gate. Over 1,000 people attended this event. In addition, lectures were given on hydrogen technology (fuel cells, hydrogen storage, $H_2$ bus, $H_2$ mobile light) to an environmental science class at Las Positas Community College in Livermore on April 12, 2011. One of the buses was also used at the SNL "Take Your Daughters and Sons to Work Day" on April 28, 2011. The buses were on display at the Bay Area American Chemical Society meeting in Oakland, California on April 30, 2011. The buses were also highlighted at the LLNL internal

safety fair on June 22, 2011. Finally, the buses were on display at the opening of the Innovation for the Green Advanced Transportation Center in Livermore, which is located near the laboratories, on June 30, 2011. The opening was attended by 300 people including Congressman John Garamendi. At all of these events we handed out brochures that explain the DOE Hydrogen Market Transformation sub-program and information about the buses. We were on hand to answer questions about the buses.

### CONCLUSIONS

Two Ford $H_2$ buses were successfully integrated in the LLNL/SNL taxi fleet. They have been extensively used for transporting laboratory staff both within the LLNL/SNL campuses and also to a local commuter rail stop. To our knowledge, the LLNL/SNL buses have received the most use (highest number of miles driven, greatest number of refuelings) of any $H_2$ bus effort in the DOE program.

In fall of 2011, the buses were returned to Ford because of ongoing maintenance problems not associated with the hydrogen technology. It was deemed by LLNL that local Ford maintenance support for the buses was not sufficient to continue the project. With that, the project ended.

### MILESTONES

**9/30/2012:** Final project report on bus use, GHG savings, energy savings, community response, employee response, possible employee survey. Joint with LLNL.

## TASK 5—ANALYSIS OF USE OF PEM FUEL CELLS ON BOARD COMMERCIAL AIRCRAFT

This task is now closed, but the following summaries are included from FY2011 for completeness.

**Principal Investigator:** Lennie Klebanoff

The primary focus of this task is to examine the use of proton exchange membrane (PEM) fuel cells onboard commercial aircraft. The analysis will be performed in three pieces. The first piece will consider the engineering embodiments of such a system that takes into consideration weight and volume issues associated with deployment. The second piece will consider a thermodynamic and engineering analysis of the consequences of using waste emissions from the fuel cells (waste heat and water) onboard the aircraft. The third piece will consider the aircraft electrical architecture that incorporates fuel cells, and how that electrical architecture performs to meet the dynamic electrical requirements of the aircraft.

## SUMMARY OF ACTIVITIES IN Q2 OF FY11

**Task contributors**: Lennie Klebanoff, Joe Pratt, Karina Munoz-Ramos, and Abbas Akhil, Ben Schenkman

This quarter of work focused on finalizing the electrical systems analysis and preparing reporting material.

The electrical analysis (Subtask 5.3) was finalized by finishing work on the electrical system models in the Matlab/Simulink platform. Results of that effort showed that the fuel cell system could either act as a stand-alone system or integrate with the airplane's existing electrical system with no adverse effects. Indeed, the fuel cell system was found to not only meet the electrical transient requirements of the airplane, but to follow the load faster than the existing generation system.

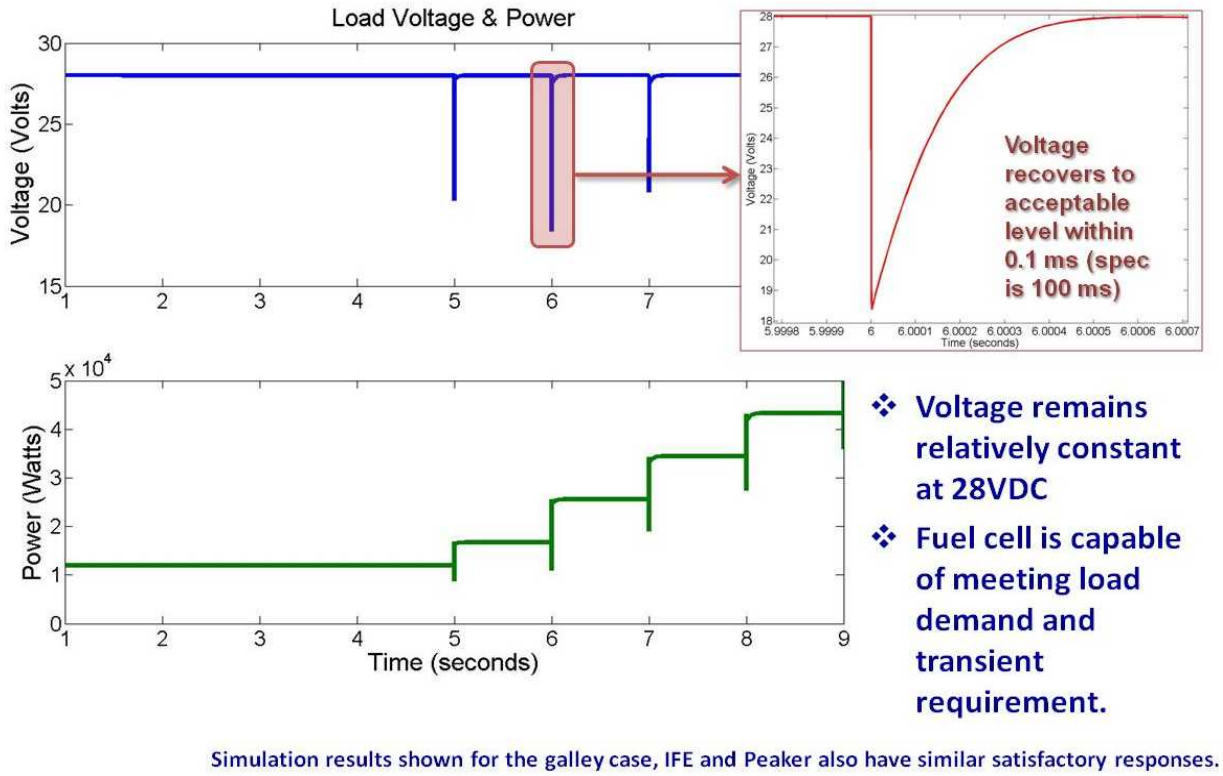


**Figure 1.** Simulation of the load scenarios shows acceptable electrical transient behavior.

The electrical work also included an analysis of the effects of the electrical system on the airplane's weight and volume. This analysis considered the option of using different distribution voltages (230 VAC, +/- 270 VDC, and 50 VDC) to carry the current from the fuel cell to the point of load. The difference between the two higher voltages in terms of wiring was small, but

because the AC system requires an inverter and the DC system only a DC–DC converter, the DC system was smaller and lighter overall. The 50 VDC system was found to be impractical due to the large currents it would be required to carry (possibly greater than 1,000 A), leading to switching and protection problems.

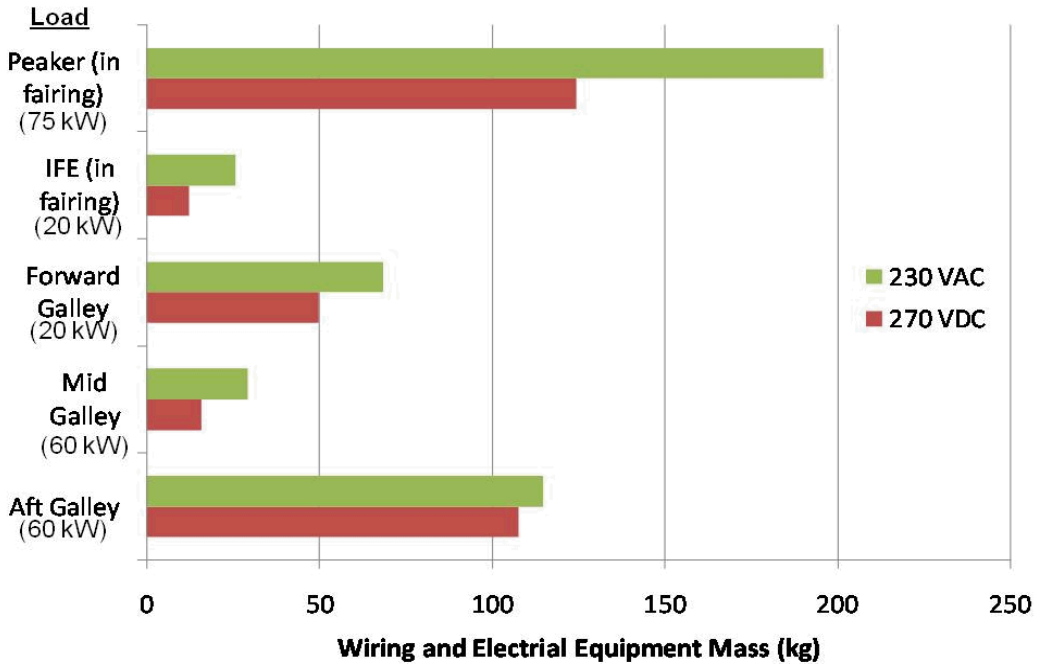


**Figure 2.** Electrical system analysis shows that the lowest mass can be obtained through a +/- 270 VDC distribution system.

The weights and volumes of the electrical system equipment were then used to update the engineering analysis and provide more complete information regarding the effect of the fuel cell on overall airplane performance.

Writing the final report and preparing the final presentation were the other major activities for this quarter. On March 24, the project team presented the results of the study at DOE headquarters to the project sponsors. As a result of feedback from that presentation, small changes were made to the final report, which was finalized in April 2011.

## SUMMARY OF ACTIVITIES IN Q4 OF FY11

**Task contributors:** Lennie Klebanoff, Joe Pratt, Karina Munoz-Ramos, Abbas Akhil, Ben Schenkman

This project concluded all major activities in Q3 of FY11 with the publication and release of Sandia report SAND2011-3119. It is available on the DOE website at: http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pem_onboard_airplane.pdf.

In Q4 of FY2011 the outreach and public dissemination of the projects results continued. On June 27 the project team briefed Sandia senior management on the project, who came away "impressed with the depth of [the] analysis." On August 10 the team briefed the industry partner Boeing Commercial Airplanes in Everett, WA. Following the presentation and lively discussion that accompanied it, Joe Breit of Boeing gave his impressions of this work:

> The airplane level system approach you took on this study was a critical first step to what needs to be done by industry to realistically evaluate the application of fuel cell technology for airplanes.
>
> This technology can potentially be of great benefit, but it is also important that a systems approach be taken in the evaluation. A proper evaluation cannot be accomplished by looking just at the fuel cell system. It is also important to consider the integration of the system into the airplane and its power system.
>
> Sandia has taken this approach in this valuable first step. More importantly, this study serves to communicate to other stakeholders the importance of this type of approach in evaluating fuel cell technology for airplanes.
>
> Please feel free to communicate Boeing's high level of satisfaction with your study to the DOE. We look forward to our continued collaboration on this technology in the future with the goal of reducing greenhouse gas emissions and improving environmental sustainability.

Three journal articles are currently in preparation for further outreach of this study.