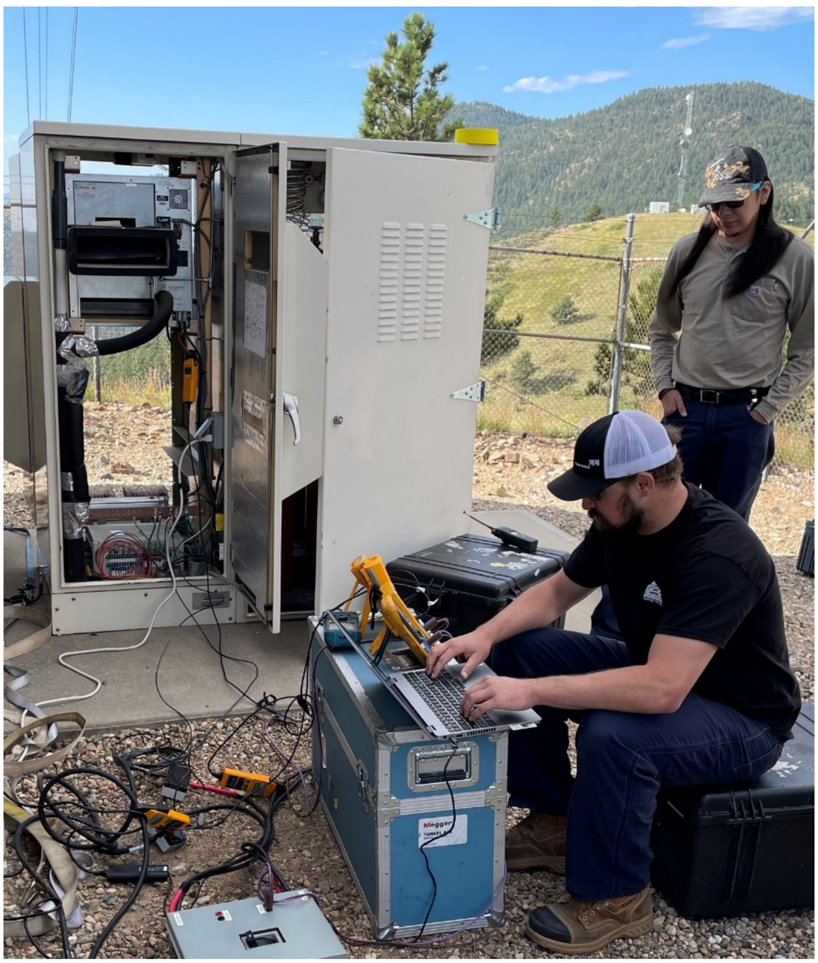
Fuel Cell Project Evaluation

Science and Technology Program
Research and Development Office
Final Report ST-2021-20013-01



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Hydrogen fuel cells have been in operation at Bureau of Reclamation facilities for over 15 years. Starting in 2003, the Eastern Colorado Area Office and Technical Service Center collaborated to install hydrogen fuel cells to provide 48-Volts Direct Current backup power at seven microwave communication sites. The purpose of this study is to evaluate the fuel cells over the approximate 15-year period since their installation and report on their long-term viability, reliability, maintenance cost, and overall cost effectiveness. The study shows fuel cells continue to be cost-effective option for providing backup power at these communication sites and should be considered at other locations that require long-term lower-power backup power.

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Final Report No. ST-2021-20013-01

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Peer Review

Bureau of Reclamation
Research and Development Office
Science and Technology Program

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Fuel Cell Project Evaluation

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Acronyms and Abbreviations

AC	Alternating Current
Ah	Ampere hours
CARMA	Capital Asset and Resource Management Application
CM	Corrective Maintenance
CT	Current Transformer
ECAO	Eastern Colorado Area Office
hr	hour
O&M	Operation and Maintenance
PM	Preventative Maintenance
Reclamation	Bureau of Reclamation
TSC	Technical Service Center
VRLA	Valve Regulated Lead Acid

Measurements

DC	Direct Current
VDC	Volts of Direct Current
W	Watts

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Executive Summary

Hydrogen fuel cells have been in operation at Bureau of Reclamation (Reclamation) facilities for over 15 years. Starting in 2003, the Eastern Colorado Area Office (ECAO) and Technical Service Center (TSC) collaborated to install ReliOn Independence 1000™ hydrogen fuel cells to provide 48-Volts of Direct Current (VDC) backup power at seven microwave communication sites. Fuel cells were chosen for their compact system size, capacity, reliability, and low operation and maintenance (O&M) cost. The purpose of this study is to evaluate the performance of the fuel cells over the approximate 15-year period since their installation was completed and report on their long-term viability, reliability, maintenance cost and overall cost effectiveness. This has been achieved by investigating Reclamation's initial installation and ongoing O&M costs using cost data as entered into Reclamation's Capital Asset and Resource Management Application (CARMA) system, reviewing past manufacturer customer support for the fuel cells, evaluating support and services available today, and conducting fuel cell inspection and load testing at three sites. This research investigation found fuel cells reduce O&M costs, are presently supported by the manufacturer, and continue to provide reliable backup power. The study shows hydrogen fuel cell technology continues to be cost-effective option for providing backup power at these communication sites and should be considered at other locations that require long-term lower-power backup power.

1. Fuel Cell Implementation at ECAO Communication Sites

A search for an alternative emergency backup power supply for communication equipment was launched following battery capacity tests conducted for ECAO in the early 2000's. These tests revealed that eight of twenty-four 48-VDC communication batteries were in need of replacement due to low capacity. A review of maintenance practices at that time also indicated little maintenance was being performed on these batteries due to their remote location. A lack of consistent backup operating time at the various sites was also evident, with some batteries sized to provide up to three days of backup power, while other batteries were sized for as little as six hours of backup time. Space limitation at many communication sites prohibited the installation of a larger battery. The communication system is only as good as its weakest link. These limited battery backup times severely curtail the reliability of the communication system during an extended power outage.

In 2003, Jim DeHaan and Nathan Myers began a research project into backup Direct Current (DC) power systems for small-scale application. They evaluated several technologies including: valve regulated lead-acid batteries, alternative non-lead-based batteries, engine-generators, flywheel storage systems, ultra-capacitors, and fuel cells. This investigation showed that fuel cells had several advantages over alternative systems. Fuel cells were chosen primarily for their compact system size, capacity, reliability, and low O&M cost. They also identified a commercially available system manufactured by ReliOn, formally Avista Labs. The ReliOn Independence 1000™ fuel cell is rated 1000 watts (W) at 48 VDC and is specifically designed as a backup DC power system. Between 2003 and 2008, the ReliOn Independence 1000™ fuel cell was installed at East Portal, Crocker Ranch, Bald Mountain, Pole Hill, Blue Ridge, Hagerman, and Granite communication facilities.

Figure 1 -ReliOn Independence 1000™ Fuel Cell

Figure 2 - ReliOn Independence 1000™ Fuel Cell Cartridges

On October 22, 2003, the first installation of the ReliOn Independence 1000™ was completed at Pole Hill Powerplant. The fuel cell is self-contained in an outdoor enclosure located directly behind the powerplant. This enclosure also houses six hydrogen fuel cylinders that supply enough fuel to provide emergency DC power to the site for at least 72 hours.

Figure 3 - Fuel Cell Hydrogen Bottles

The fuel cell systems are connected to the DC panel (DC bus) and works in parallel with the DC charger (rectifier) and bridge battery bank (see Figures 4, 5, and 6). Under normal operation, the charger will supply the DC power necessary to power the communication equipment and to charge the battery. If the Alternating Current (AC) power to the charger should fail, the bridge battery immediately supplies power to the load, and the fuel cell will initiate its starting procedure. The fuel cell will typically take about one minute to self-check and come online. Once online, it will deliver about 50 percent of rated output (500 W) and will ramp to full output (1000 W) in less than 10 minutes. At this point, the fuel cell is supplying all the load and recharging the bridge battery. The fuel cell will provide approximately three days of backup power given the six fuel cylinders. The fuel cell also monitors the DC bus voltage and will automatically start on low DC voltage.

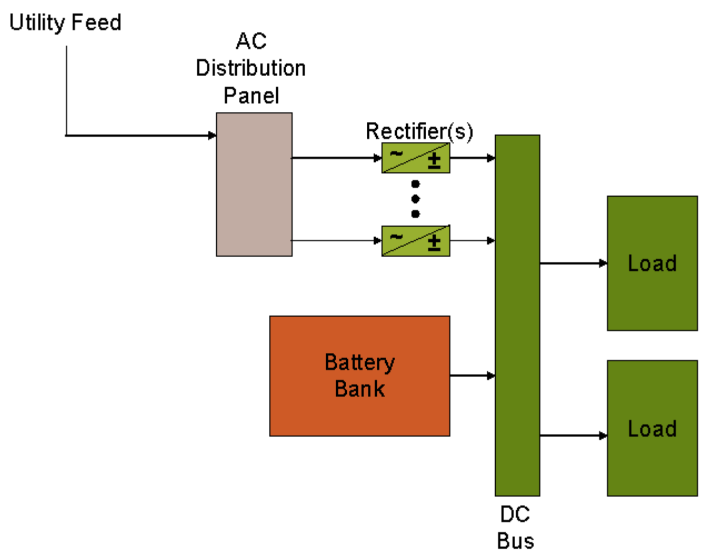

Figure 4 - Previous Battery Backup System

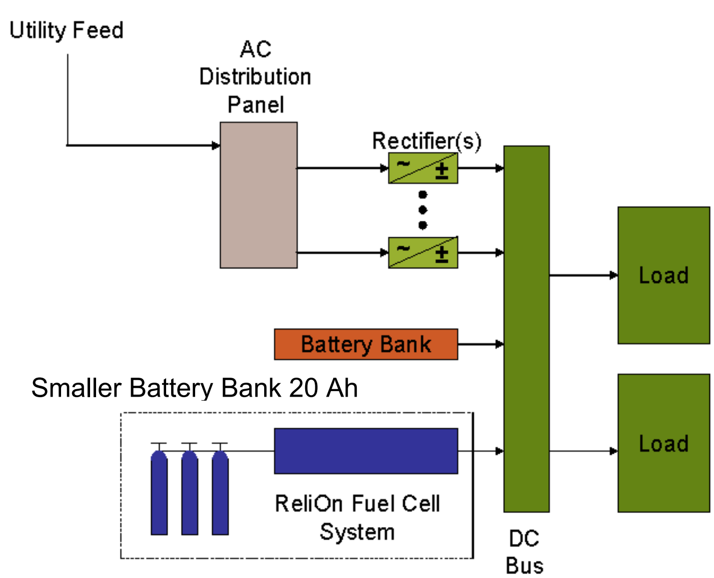

Figure 5 - Existing ReliOn Fuel Cell Backup System

Figure 6 - Pole Hill Bridge Battery

The inclusion of the fuel cell allows the original large site battery to be replaced with a lower capacity bridge battery. The battery needs only to provide power to "bridge" the gap when the fuel cell is starting, thus its name- bridge battery. The fuel cell manufacturer recommends a 20-Ampere hour (Ah) battery be used. Thus, the original failing batteries at the above-mentioned sites were replaced with this low-capacity, low-cost battery ($1,250 installed). To further reduce maintenance costs, a limited amount of preventive maintenance can be performed on the bridge battery and it can simply be replaced approximately every three to five years.

Following the initial pilot installation at Pole Hill, the decision was made to install fuel cells at the remaining six communication sites. These installations were completed in 2008. The fuel cell systems have now been in service for 13 to 18 years and this research study was performed to evaluate their long-term viability, reliability, maintenance, and overall cost effectiveness. This research focused on investigating initial installation and ongoing O&M costs, comparing these costs to an equivalently sized battery system (72-hour Valve Regulated Lead Acid (VRLA) backup battery system), load testing three fuel cell installations, and investigating manufacturer technical support availability. The data collected is also compared to the projected costs contained in Project Notes 8450-2004-05 to evaluate the accuracy of prediction made in that report. VRLA batteries were chosen for comparison in Project Notes 8450-2004-05 and in this report as they are the most likely alternative backup power solution due to their cost and compact size.

2. Evaluation of Installation Costs

Construction labor costs were available in CARMA for six sites and have been indexed to 2021 dollars.[1] Labor cost for Pole Hill were used from Project Notes 8450-2004-05 and were also indexed to 2021 dollars. Material costs were not available in CARMA, and plant material cost data was incomplete or not found. Material costs for Pole Hill were available in Project Notes 8450-2004-05. Pole Hill material costs from this report have been used in this analysis for the remaining six sites as material costs should not vary significantly between sites. Installation costs are detailed in Table 1. Project Notes 8450-2004-05 shows Pole Hill installation labor cost at $33,940. The report predicted the labor costs to decreased to $17,677 for subsequent installations due to additional training being unnecessary, increased installation efficiency as personnel gained experience, and reduced debugging and troubleshooting. CARMA labor installation data shows each installation after Pole Hill cost $21,579 more on average than anticipated with the average installation labor cost at $39,256. The remote location of some of these sites could help explain the increase in installation costs.

Table 1 - Fuel Cell Installation Costs Per Site

<table>
<tr><th colspan="7">Installation Cost</th></tr>
<tr><th>Location</th><th>Installation Year</th><th>Labor*</th><th>Materials*</th><th>Labor Cost Index to 2021</th><th>Materials Cost Index to 2021</th><th>Total Cost 2021</th></tr>
<tr><td>Pole Hill</td><td>2003</td><td>$24,000</td><td>$19,150</td><td>$33,940</td><td>$30,203</td><td>$64,143</td></tr>
<tr><td>Bald Mountain</td><td>2008</td><td>$29,879</td><td>$23,509</td><td>$35,836</td><td>$30,203</td><td>$66,040</td></tr>
<tr><td>Blue Ridge</td><td>2008</td><td>$31,835</td><td>$23,509</td><td>$38,182</td><td>$30,203</td><td>$68,386</td></tr>
<tr><td>Crocker Ranch</td><td>2006</td><td>$41,699</td><td>$27,719</td><td>$52,680</td><td>$30,203</td><td>$82,884</td></tr>
<tr><td>East Portal</td><td>2006</td><td>$12,348</td><td>N/A</td><td rowspan="2">$43,954</td><td rowspan="2">$30,203</td><td rowspan="2">$74,158</td></tr>
<tr><td>East Portal</td><td>2008</td><td>$23,641</td><td>$23,509</td></tr>
<tr><td>Hagerman Peak</td><td>2006</td><td>$4,579</td><td>N/A</td><td rowspan="2">$28,393</td><td rowspan="2">$30,203</td><td rowspan="2">$58,597</td></tr>
<tr><td>Hagerman Peak</td><td>2008</td><td>$18,850</td><td>$23,509</td></tr>
<tr><td>Granite Peak</td><td>2006</td><td>$4,536</td><td>N/A</td><td rowspan="2">$36,491</td><td rowspan="2">$30,203</td><td rowspan="2">$66,694</td></tr>
<tr><td>Granite Peak</td><td>2008</td><td>$25,646</td><td>$23,509</td></tr>
</table>

**Labor Costs are from CARMA. Material Costs were known for Pole Hill and indexed to 2008 dollars (installation year) for remaining sites.*

[1]Unless noted, all dollar values presented in this report have been indexed to 2021 dollars using the USBR Construction Cost Trends index spread sheet provided by the Economic Analysis Group (86-68270) at the TSC.

3. Evaluation of O&M Costs

O&M costs were available for seven sites. Of the seven sites, Pole Hill, Bald Mountain, and Blue Ridge were the most complete and were used for this analysis. All O&M costs have been indexed to 2021 dollars. Hydrogen bottle replacement costs were not included in this analysis as bottle purchase data was incomplete, plant personnel indicated bottle change outs were rare, and bottle change out costs should not greatly impact this analysis.

Preventative Maintenance (PM) labor costs are higher than expected when compared to Project Notes 8450-2004-05, see Table 2. The report anticipated a monthly PM cost of $707. Pole Hill and Bald Mountain CARMA monthly PM costs are approximately twice than expected with Blue Ridge at nine times the expected cost. This difference in O&M costs can likely be attributed to not including all the overhead associated with PMs and not including travel time to remote sites in the Project Notes 8450-2004-05 PM estimate cost.

Fuel cell monthly PM involves checking bottle pressure, occasionally changing air filters and bottles, and running the fuel cell for 30 minutes to hydrate the fuel cell membrane. Field personnel indicated this work is quick and they can work on other tasks while the fuel cell is running. With that, monthly PMs should take about one hour (hr) to complete. Additional PM labor costs to cover PM overhead tasks and travel time would increase the monthly PM to approximately 1.5 hours to complete. The 1.5 hours per PM per month is in alignment with the CARMA labor cost at Pole Hill and Bald Mountain. Blue Ridge CARMA labor cost is still much higher. Increased O&M Costs attributed to travel is another factor to consider as Blue Ridge is very remote and has the greatest PM cost per year with Pole Hill being the least remote and having the lowest PM cost per year. It should be noted that the use of CARMA is not consistent at all Reclamation facilities and it is possible that the fuel cell PM job was used to cover additional tasks at the Blue Ridge site thus increasing the hours recorded under this PM.

Of the seven communication sites, Bald Mountain is the only site that incurred a Corrective Maintenance (CM) charge with one work order following installation. The $2,331 CM labor charge in 2011 was for repairs to the enclosure door after a gust of wind removed the door from the enclosure. These charges were not included in Table 2.

Table 2 - Preventative Maintenance Labor Cost

Preventative Maintenance Labor Costs Comparison						
Location	**Total (Over Lifetime of Equipment)**			**Annual**		
	Labor Costs Based On 1.5 Hours Per Month	**Predicted Labor Cost***	**Labor Cost From CARMA**	**Labor Costs Based On 1.5 Hours Per Month**	**Predicted Labor Cost***	**Labor Cost From CARMA**
Pole Hill	$22,185	$10,251	$19,485	$1,530	$707	$1,343
Bald Mountain	$14,535	$6,716	$15,645	$1,530	$707	$1,646
Blue Ridge	$14,535	$6,716	$63,996	$1,530	$707	$6,736

**PM Labor cost predicted in Project Notes 8450-2004-05*

Table 3 - Fuel Cell Total Installation and Preventative Maintenance Cost.

Fuel Cell Total Installation and Preventative Maintenance Cost				
Location	**Years In Service**	**Installation Cost***	**PM Labor Total**	**Total**
Pole Hill	18	$64,143	$19,485	$83,628
Bald Mountain	13	$66,040	$15,645	$81,685
Blue Ridge	13	$68,386	$63,996	$135,382
Crocker Ranch	13	$82,884	N/A	N/A
East Portal	13	$74,158	N/A	N/A
Hagerman Peak	13	$58,597	N/A	N/A
Granite Peak	13	$66,694	N/A	N/A
Average	13.7	$68,700	$33,042	$100,232

**Installation cost includes labor and materials*

4. Cost Comparison – Fuel Cell vs Alternative VRLA Battery

As fuel cell labor costs for installation and O&M were higher than anticipated in Project Notes 8450-2004-05, it is worth some analysis to compare these actual costs to the projected costs of the likely alternative backup power system, namely a VRLA battery system. Project Notes 8450-2004-05 anticipated $57,297 installation costs for a 72-hour VRLA backup battery, which is slightly less than the actual average installation cost for the seven fuel cell sites at $67,674. For this analysis, the annual PM costs should be about the same for both Fuel Cell and 72-hr VRLA battery systems as it is assumed performing minimum maintenance on the VRLA battery and replacing it every 5 years. The 5-year battery replacement for the 72-hr backup battery costs $43,720 while the fuel cell bridge battery replacement costs $1,249. Over a 20-year period (three battery replacements), factoring installation labor and materials, PM labor, and battery replacements at the end of year five, 10, and 15, the fuel cell saves $116,010 per site or a total of $812,070 for the seven communication sites. Presently, Pole Hill has been in service for 18 years with three battery changeouts while the remaining sites are in their 13th year of service with two battery chance outs. To date, the seven fuel cell sites have saved approximately $566,526 compared to 72-hr backup VRLA batteries.

Table 4 - 20 Year Fuel Cell and VRLA Battery Cost Comparison

20 Year Fuel Cell and VRLA Battery Cost Comparison				
System	**Installation Cost**	**PM Labor Cost**	**5 Year Battery Replacement**	**Total**
Fuel Cell	$68,700	$33,042	$3,747	$105,489
VRLA Battery	$57,297	$33,042	$131,160	$221,499

5. Fuel Cell Load Test Results

The present performance of the existing fuel cells system was measured as part of this research effort. In August 2021, load testing was performed at Pole Hill, Bald Mountain, and East Portal utilizing a 48-VDC temporary battery and Torkel 840 DC load test system. Testing was performed by connecting the temporary battery and Torkel 840 in parallel with the fuel cell, charger, and bridge battery. Next, the fuel cell, backup battery, and Torkel 840 were disconnected from the communication equipment leaving the facility battery charger and bridge battery to supply the 48-VDC load. The Torkel 840 was then set to 2.7 ohms and began to draw current from the temporary battery. The fuel cell would initiate startup on low DC battery voltage and began to provide power to the Torkel load and temporary battery once the temporary battery voltage dropped to 48.6 VDC. At Bald Mountain and East Portal, loading was adjusted to increase fuel cell power output. Fluke i30 clamp on Current Transformers (CTs) were used to collect current values from the fuel cell, temporary battery, and Torkel 840. All fuel cells performed well and were able to supply load for the duration of testing. Bald Mountain and East portal were able to supply near rated current and power as loading was adjusted during the test. Based on the test results, it appears the fuel cells have not degraded and will continue to provide reliable backup power.

Table 5 – Fuel Cell Load Testing

Fuel Cell Load Testing				
Location	**Test Time (Minutes)**	**Peak Amps**	**Peak Power (Watts)**	**Ramp time to 500 Watts (Minutes)**
Pole Hill*	130	14.4	702	25
Bald Mountain	124	19.6	925	2
East Portal	68	17.6	841	7

** Pole Hill was first test performed. Test procedure was modified for Bald Mountain and East Portal to obtain higher Peak Power during test.*

Figure 7 - Pole Hill Fuel Cell Load Testing

Figure 8 - Bald Mountain Fuel Cell Load Testing

6. Fuel Cell Manufacturer History and Ongoing Support

ReliOn was established in 1995 as Avista Corp and rebranded to ReliOn in 2003. ReliOn began to seek investors to purchase the company as sales and financial stability declined. In 2014, ReliOn was purchased by Plug Power, a large hydrogen distribution and fuel cell company for approximately four million dollars. Plug Power has increased revenue over the last 10 years and is trending to produce positive profits in the coming years. Continued growth will likely be limited due to the rapid adoption of lithium-ion batteries as an alternative energy source for vehicles and large power system storage systems, rather than hydrogen. Furthermore, conventional sources of energy are still readily available and inexpensive. It appears Plug Power is financially stable and will remain in business well into the future to support their products.

Plug Power no longer supports the ReliOn Independence 1000™; however, the company offers a conversion to the GENSURE E-1100™ fuel cell. The company offers services to support and perform the conversion and offers conversion training to field personnel so the conversion can be completed in house. Although the company no longer supports the ReliOn Independence 1000™, Plug Power fuel cells are a viable option for future installations as Plug Power offers a conversion for unsupported models and continues to support their newer models.

7. Conclusion

The collaboration between ECAO and TSC in the mid 2000's to install fuel cells to supply backup 48-VDC power at communication sites has been shown to be a success. The research shows the installations have been cost effective compared to VRLA backup batteries even though fuel cell installation and O&M costs were higher than originally expected. To data, the seven fuel cells installed at ECAO have saved the project over $500,000. The installed fuel cells also proved to be a reliable backup power source as they continue to supply near rated power during load testing. The Independence 1000™ is no longer supported by Plug Power, but the company does offer support to convert existing Independence 1000™ to the newer GENSURE E-1100™ fuel cell.

As the fuel cells approach end of life at the ECAO communication sites, a cost comparison analysis between VRLA backup batteries and fuel cells should again be considered. This analysis needs to consider that the original microwave system has been replaced by fiber optic communication that requires significantly less power. Because the loading has been reduced, smaller backup power systems would be more appropriate to support the smaller load. This may change whether fuel cells are a most cost-effective solution to provide backup DC power.

Overall, this research effort has shown that fuel cells should still be considered as a viable option when installing a backup DC power system. Reclamation facilities should consider this option when looking to install new long-term, low-power backup DC systems such as those found at communication sites.

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Appendix A

Project Notes 8450-2004-05 Eastern Colorado Area Office Fuel Cell Implementation Recommendations provided on the following pages.

TECHNICAL SERVICE CENTER

Denver, Colorado

Project Notes 8450-2004-05

Eastern Colorado Area Office
Fuel Cell Pilot Project Results and Implementation Recommendations

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Technical Service Center
Hydroelectric Research and Technical Services Group

May 2004

Summary

The Hydroelectric Research and Technical Services Group, in cooperation with the Eastern Colorado Area Office (ECAO), have evaluated, deployed, and demonstrated a fuel cell which provides extended backup power for ECAO microwave communication equipment. This pilot project has demonstrated that a fuel cell (explicitly the Independence 1000 manufactured by ReliOn) can be integrated into an existing DC power supply system consisting of a charger and battery, operates and performs as advertised, and promises to significantly reduce present DC system maintenance costs while also improving the reliability of the DC power supply to the communication system.

Of course, the true test of this system will be how it performs over the next 3 to 7 years of service. However, all factors indicate this product will be very successful. In light of this, we recommend that ECAO proceed with their plans to install fuel cells at their various communication sites instead of replacing/upgrading the present 48-V DC battery systems.

Background Information

A search for an alternative emergency backup power supply for communication equipment was launched following battery capacity tests conducted for ECAO. These tests revealed that eight of twenty-four 48-Vdc communication batteries were in need of replacement due to low capacity (see Project Notes 8450-2002-02 and 8450-2002-09, and the December 30, 2002, memorandum on the subject Battery Capacity Testing Results). A review of maintenance practice also indicated little maintenance was being performed on these batteries. A lack of consistent backup operating time at the various sites was also evident, with some batteries sized to provide up to 3 days of backup power, while other batteries were sized for as little as 6 hours of backup time. Space limitation at many sites prohibited the installation of a larger battery. As noted in the above-mentioned test reports, the communication system is only as good as its weakest link. These limited battery backup times severely curtail the reliability of the communication system.

In 2003, we began a research project into backup DC power systems for small-scale application. We evaluated several technologies including: valve regulated lead-acid batteries, alternative non-lead-based batteries, engine-generators, flywheel storage systems, ultra-capacitors, and fuel cells. Results of this research are documented in the 2004 Reclamation Power O&M workshop paper entitled "Fuel Cells." This investigation showed that fuel cells had several advantages over alternative systems. We also identified a commercially available system manufactured by ReliOn, formally Avista Labs. The ReliOn Independence 1000™ fuel cell is rated 1000 W at 48 V and is specifically designed as a backup DC power system.

Results were shared with ECAO and they agreed to a demonstration project at Pole Hill Powerplant. Installation of the fuel cell was completed October 22, 2003. It has been in service since this time. Appendix A summarizes action items and results of tests conducted to commission and performance test the fuel cell.

Fuel Cell Implementation at ECAO Communication Sites

The capacity tests results referenced above indicated that 8 out of 24 batteries at communication sites required replacement. These sites include:

> Lake Ridge, Green Mountain UHF Building, East Portal, Estes Powerplant, Estes Gatehouse, Crocker Ranch Gauging Station, Granite Radio Tower, and Pole Hill Powerplant.

For the 48-V communication batteries at Estes Powerplant and Estes Gatehouse, we recommend replacing these batteries with a redundant 120-Vdc to 48-Vdc converter. This will utilize the existing 120-Vdc battery at each site. A redundant converter system meets the reliability requirements of the 48-Vdc system. This type of converter system is in use at Mt. Elbert Powerplant.

For the remaining six sites listed above, we recommend installing the ReliOn fuel cell system. The fuel cell will connect to the DC panel (DC bus) and works in parallel with the DC charger (rectifier) and battery bank (see figures 1a and 1b).

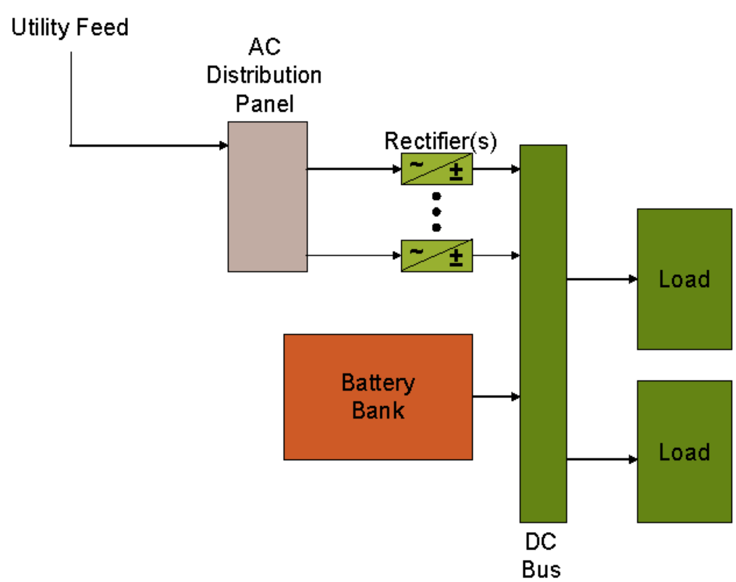

Figure 9a. - Existing Battery Backup System

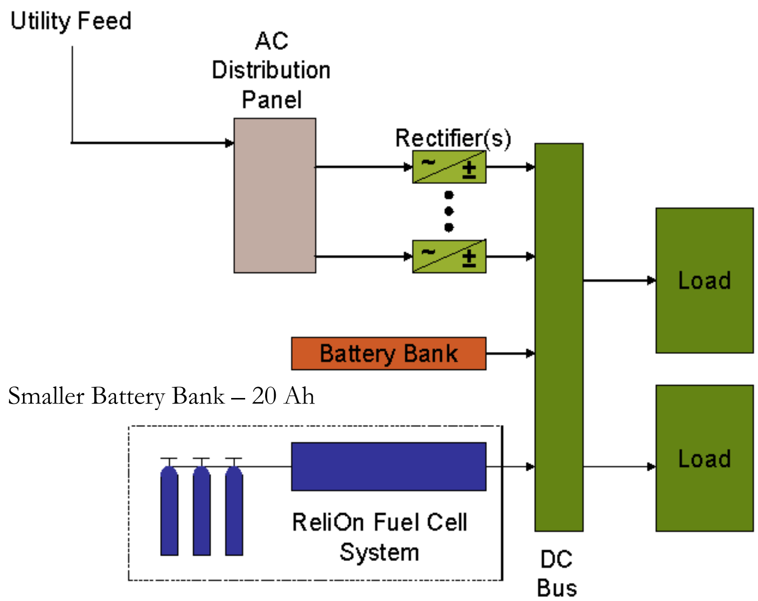

Figure 1b. - ReliOn Fuel Cell Backup System

Under normal operation the charger will supply the DC power necessary to power the communication equipment and to charge the battery. If the AC power to the charger should fail, the battery immediately supplies power to the load and the fuel cell will initiate its starting procedure. The fuel cell will typically take about 1 minute to self check and come on line. Once on-line it will deliver about 50 percent of rated output (500 W) and will ramp to full output (1000 W) in less than 10 minutes. The fuel cell will provide approximately 3 days of backup power. The fuel cell also monitors the DC bus voltage and will automatically start on low DC voltage.

The inclusion of the fuel cell allows the site battery to be replaced with a lower capacity unit. The battery needs only to provide power to bridge the gap when the fuel cell is starting. The fuel cell manufacturer recommends a 20-Ah battery be used. Thus, the failing batteries at the above-mentioned sites should be replaced with this low-capacity, low-cost (approximately $1000 installed) battery. To reduce maintenance costs, a limited amount of preventive maintenance can be performed on the bridge battery and it can simply be replaced approximately every 3-5 years.

The charger can also be replaced with a lower-capacity unit. Chargers are typically sized to handle the DC load plus charge a depleted battery in approximately 8 hours. Depending on the size of the battery, the rated output current capacity of the charger can be one to two orders of magnitude higher than the DC load. By utilizing a 20-Ah battery, the charger output capacity can be reduced to the connected DC load, plus about 3 amps to charge the battery.

The performance of the fuel cells at these sites can then be evaluated over 3-5 years prior to consideration of additional installations. Of the 16 remaining project communication sites, 11 sites would be good candidates for future fuel cell systems. These systems can be installed as the batteries at these sites begin to deteriorate. These sites include:

> West Portal, Shadow Mountain, Table Mountain, Blue Ridge, Giant Track, Prospect Mountain, Panorama, Bald Mountain, Area Office Building, Area Office Communication Shop, Pinewood (Rattle Snake) Dam Gauging Station.

A DC-DC converter would be better suited for the following sites to take advantage of the existing 125-V station battery:

> Farr Pumping Plant, Green Mountain Powerplant, Marys Lake Powerplant, Olympus Dam, and Pole Hill Gatehouse.

Presently, we would not recommend that fuel cells be used in conjunction with 125-Vdc station batteries. These batteries are frequently referred to as the most critical system in a powerplant. Because of their critical nature, we take a very conservative stance and only recommend flooded lead-acid cells. With proper maintenance and testing, flooded lead-acid cells have been proven extremely reliable over many decades of use.

Summary of Fuel Cell Research Evaluation Results

On October 22, 2003, installation of a fuel cell manufactured by ReliOn was completed at Pole Hill Powerplant. The Independence 1000™ fuel cell provides up to 1000 watts of power for the 48-Vdc communication system. The fuel cell is self contained in an outdoor enclosure located directly behind the powerplant. This enclosure also houses six hydrogen fuel cylinders that supply enough fuel to supply emergency DC power to the site for at least 72 hours. (See photos in Appendix B.)

Advantages of ReliOn Independence 1000™ fuel cell:

1. Significantly lower ownership cost than an equivalent battery system over a 10-year period. Predicted cost estimate showed that a fuel cell will cost $37,000 over a 10-year period versus $62,000 for a battery of the same capacity. This is a 40 percent savings. (See 48-hr. battery data versus fuel cell data, Appendix E.)

   For the batteries, the cost includes: battery, rack, installation, monitoring system (Serveron 48 V), monitoring system installation, used battery disposal, annual maintenance, and capacity testing. Battery costs did not include replacing chargers at battery site. For the fuel cell, the costs included fuel cell, enclosure, 7-year warranty, installation, miscellaneous materials, bridge battery and installation, used battery disposal, and annual maintenance. Fuel cell cost does not include cost of DC system modifications including: battery charger, breakers, panels, etc.

2. Nearly identical initial capital cost when compared to an equivalent battery system with 48 hours of backup power. (See 48-hr. battery data versus fuel cell data, Appendix E, and Fuel Cell Capital and Installation Cost Evaluation, Appendix D.)

3. Low maintenance cost – Fuel cell maintenance consists of monthly test starts (can be done remotely) and 6-month inspection and cleaning. Battery systems require monthly, quarterly, and annual maintenance. Battery maintenance cost (excluding battery capacity tests) can be reduced to about the same level as fuel cell maintenance costs by adding a battery monitoring system.

4. Provides extended backup runtime compared to presently installed batteries (at Pole Hill the fuel cell backup operating time is at least 3 days, compared to the present battery with a backup operating time of less than 1 day).

5. Small physical footprint relative to long backup times - Backup time related to amount of hydrogen stored onsite and not the physical size, as in the case of a battery.

6. High reliability - Unlike a motor-generator set, a fuel cell has no moving parts. A fuel cell works by simply applying hydrogen to the fuel cell membrane, and the resulting chemical reaction produces electrical energy.

7. Modular cartridge technology. ReliOn's modular fuel cell design adds redundancy by placing six fuel cell modules in parallel. A module can fail without significantly affecting the unit's output capacity. Fuel cell modules can be replaced in literally 5 seconds. Spare modules can be stored on site and are available for approximately $345. This eliminates a single-point failure of one fuel cell from taking out the whole system.

8. Long life - As an emergency power system, ReliOn predicts a minimum life expectancy of 10 years. The modular cartridge design will also make future repairs/upgrades much easier to implement. (See memo from ReliOn, Appendix C.) A 7-year warranty is available from ReliOn.

9. The system is in compliance with our Nation's energy policy regarding the use of alternative energy sources. (Reference the President's 2003 State of the Union address where he promoted the development and implementation of hydrogen-based fuel cells.)

10. Battery hazards are reduced because larger station batteries can be replaced with a small bridge battery. These hazards include acid exposure, spill containment, and very high short circuit currents.

11. With respect to ReliOn, customer service has been exceptional. When necessary, they have modified their design to meet our needs and have promptly resolved any issue we bring to them.

Some disadvantages include:

1. Hydrogen – Hydrogen is a flammable gas that can be ignited if concentration levels reach 4 percent or greater.
   Resolution – The unit and hydrogen gas cylinders are self contained in an outdoor enclosure. The enclosure is well ventilated and contains a gas sensor that will shut off the gas flow from the cylinders if a leak is detected. Note: Batteries also produce hydrogen when being charged. Thus, this hazard is common to both systems.

2. Proven technology – Commercially available fuel cells are a relatively new technology.
   Resolution – ReliOn incorporates a Proton Exchange Membrane (PEM) fuel cell. Fuel cells have been around for a long time. They were first demonstrated in 1839. In 1967, the PEM was first introduced. Significant advances in fuel cell technology were made in the late 1980s which lower production costs.
   -ReliOn uses a patented modular cartridge technology that adds N+1 redundancy to the PEM. This eliminates the possibility that a single-point membrane failure will shut down the whole system.
   -ReliOn has targeted the backup DC power market and has specifically designed their fuel cells for this application. ReliOn has been incorporated since 1995. This particular model, the Independence 1000™ fuel cell, has been on the market for 3 years.
   -See references in Appendix C.
   -A 7-year warranty is available from ReliOn
   -Network Equipment Building Systems (NEBS) Testing – the fuel cell has undergone and passed NEBS tests – contact manufacturer for more information

Appendix A - Pole Hill Pilot Fuel Cell Performance Test Results

The following problems, issues, or items were identified during commissioning tests conducted at Pole Hill Powerplant on October 22, 2003, and a follow-up performance test conducted on December 9, 2003. Extensive testing has been conducted on this fuel cell during its first 3 months of operation. We have logged approximately 30 hours of operation time and approximately 50 test starts. This is equivalent to several years of service as a backup power source. Most items listed below are the result of incorporating the fuel cell into the existing DC system and working out the issues of installing a technology on which we have no previous experience to rely. To date, all problems, issues, or items listed have been resolved to our satisfaction and solutions installed as noted.

Item 1: When the Independence 1000™ is configured for "Low DC Bus Voltage Start-Up" mode, the cabinet fans and hydrogen feed solenoids are active and the fuel cell running contact is closed.

> Resolution: ReliOn installed an external circuit and implemented a firmware change to correct this problem. Our December 9 visit verified correct operation.

Item 2: Is it possible to change the float voltage on the system?

> Response: This is a firmware change in the system and can be accommodated. This can be accomplished by Reclamation personnel on-site.

Item 3: With a sudden loss of load, the fuel cell voltage increases to about 60 V and takes about 30 seconds to settle back to the float voltage level.

> Resolution: The firmware was modified to reduce the overvoltage response time of the fuel cell to approximately 5 seconds. Our December 9 visit verified correct operation.

Item 4: Short Circuit Response: What is the response of the ReliOn system to a short circuit? How long does it take for the output breaker to activate? What is the fuel circuit short circuit rating? Verify that the fuel cell will survive multiple short circuit events.

> Response: The output current and voltage of the fuel cell is controlled by a DC-to-DC converter. This circuit is current limited. Factory tests verified correct operation of the converter and output breaker during a fault. No damage occurred to the fuel cell or associated electronics. The maximum fault current was measured at <u>400 amps</u>. The DC breaker opened at 0.4 millisecond.

Item 5: What is the shelf life of ReliOn's systems?

> Response: Based on the testing performed to date regarding accelerated aging testing of the cartridges, and cycle testing the system and components, ReliOn anticipates a 10-year-life minimum of the overall system (Appendix C).

Item 6: Ensure the Airgas representative is providing Reclamation the proper hydrogen at the negotiated pricing established for ReliOn Labs customers.

> Resolution: Three hydrogen cylinders were purchased from Airgas at the end of December at a reduced price of approximately $25/cylinder.

Item 7: Fuel cell did not start when lowering DC bus voltage to 45.0 Vdc as required by specification during the December 9 test.

> Resolution: Operator error. The fuel cell was not in the "low DC voltage startup" mode. Subsequent tests on February 24-25 verified correct operation.

Item 8: The fuel cell took about 60 minutes to reach the full load of 1kW.

- Outside temperature was 22 °F
- Moisture appeared to be frozen within unit
- Internal enclosure temperature estimated below 32 °F.

> Resolution: ReliOn has determined the heater in the outdoor enclosure was undersized. A larger heater and additional insulation were installed in the outdoor enclosure on February 23.

Item 9: Following a loss of AC, the fuel cell major/minor alarm contact toggles close when AC is returned to the charger (remote start/stop function).

> Resolution: A timing race between the fuel cell running and major/minor alarm contact was identified. A small time delay was added to the alarm relay that corrected this problem.

Item 10: During testing on December 9, the fuel cell on two occasions closed its major/minor alarm while the unit was ramping to full output.

> Resolution: Repeated short term off/on cycling the fuel cell flooded some of the fuel cell modules. ReliOn recommends the fuel cell be run for a minimum of 30 minutes per cycle. A logic change was made to Reclamation's fuel cell logic along with the addition of a time delay relay to incorporate a minimum run time of 30 minutes. In addition, the alarm time delay, as identified in item 9, will also prevent momentary alarms from the fuel cell picking up the Reclamation annunciator board.

Item 11: Unit shuts down abruptly when AC is returned to the charger.

> Response: The fuel cell has multiple shutdown procedures. This is the normal shutdown procedure when AC is returned to the charger. Time delay relay, item 10, will ensure unit operates for a minimum of 30 minutes.

Item 12: High-side pressure gauge and alarm . Upon first inspection on December 9, the low-pressure alarm was not picked up while the hydrogen pressure gauge on the high-side cylinders was indicating low pressure. After several hours of testing, the low- pressure alarm picked up.

> Response: The pressure gauge indicates pressure above 500 psi. The low- pressure alarm picks up below this value. We happened to read the gauge when the pressure was between these two values. On February 24, a ReliOn representative adjusted the alarm set point to pick up at slightly above 500 psi.

Item 13: After several hours of testing and repeated start/stop cycles the unit would not come back online.

> Resolution: ReliOn recommended a minimum run time of 30 minutes. By repeated cycling of the unit, we had flooded the fuel cell modules. It took repeated start attempts to flush out the modules. We added a minimum run timer (item 10) to Reclamation's start logic to prevent future occurrences of this problem.

Item 14: Cabinet wiring is less than adequate

> Response: ReliOn has improved terminal locations and wiring methods on their latest enclosure design. Reclamation's issues concerning butt splices in wire ways, using wire smaller than 18 gauge, and separate terminal blocks for user connections have been incorporated into this design. ReliOn will work with Reclamation to improve the enclosure wiring at the Pole Hill installation.

Item 15: Error messages on front LCD scroll too quickly to read

> Response: Lower scroll rate will be adopted by ReliOn. Implementation to be determined.

Item 16: Documentation less than adequate

> Resolution: ReliOn has supplied Reclamation a documentation package that includes data sheets for all installed components. We have also updated the schematics to include all control changes.

Item 17: Need to rewire major, minor, and low-pressure alarms.

> Response: We have rewired low-pressure and minor alarms to one annunciator point (Fuel Cell Alarm) and the major alarm to a second point (Fuel Cell Failure).

Item 18: Need runtime and Watt Hour meter

> Response: We have installed a run time and watt display unit for the fuel cell. ReliOn has incorporated this feature on future models.

Item 19: Additional Plant Concerns.

Q: Can Reclamation store hydrogen cylinders in a central location?

A: Yes, NFPA 50A and NFPA 497 outline spacing requirements for the storage of hydrogen cylinders.

Q: Can Reclamation transport hydrogen cylinders?

A: Yes, Reclamation can transport up to 1000 lbs (up to 6 cylinders) without placard. See DOT part 49 CFR173.301A and DOT part 49 CFR 177.840 for more information.

See Appendix G for more information regarding hydrogen storage and transportation.

Appendix B - Photographs of the Pole Hill Fuel Cell Installation

Photograph 1 - Overview of the Fuel Cell Enclosure located directly behind the Pole Hill Powerplant

Photograph 2 - Closeup of the Modular Fuel Cell Cartridges

Photograph 3 - Independence 1000™ Front Panel

Appendix C - ReliOn (formally Avista Labs Inc.) Supporting Documentation

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Facsimile 509-228-6510
www.avistalabs.com

Independence 1000™ System Reliability & Design Life:

This document addresses the estimated minimum system life cycle of the Avista Labs Independence 1000™ fuel cell system. The assumed minimum life on the Independence 1000™ is ten years in a back-up power configuration, however, a significantly longer product life is anticipated. Avista Labs is developing a quantitative theoretical Mean Time Between Failure (MTBF) for the Independence 1000™ system to 10 years and beyond. In the mean time, it is equally accurate to provide a qualitative analysis based on the summation of established MTBFs of components utilized in the Independence 1000™.

The design of the Independence 1000™ maximizes on known reliabilities of existing technologies, while mitigating the potential impact of components utilized in the system with lesser established reliabilities. The Independence 1000™ has four major component categories: electromechanical, electronics, start circuitry, and Avista Labs' patented modular cartridges.

Electromechanical components utilized in the system and associated MTBFs are given below:

- 3 redundant blowers — MTBF = 70,000 hrs
- Solenoid valves — MTBF = 1,000,000 cycles
- Vent/Declassification fan — MTBF = 60,000 hrs
- Exhaust louver actuator — MTBF = 30,000 hrs*

As shown above, the electromechanical components utilized in the system have a life expectancy well in excess of ten years in a back-up power configuration.

Electronic components utilized in the system are standard components with well-established MTBFs. The design of the system electronics focuses on simple topologies to maximize the reliability of these components. The electronic components and circuitry internal to the Independence 1000™ are expected to last well beyond ten years.

Failure in the start-circuitry of the Independence 1000™ would result in a failure of the system to operate when called upon. The components utilized in the start-up circuitry as well as the start-up firmware are based on a simple reliable approach to establish a minimum level of safety prior to start-up while maximizing on reliability of this process. The major safety circuit controlling start-up is the internal hydrogen sensor. This sensor has an MTBF in excess of 250,000 hours.

The final category that will impact the system MTBF is the Proton Exchange Membrane (PEM) core of the fuel cell. Avista Labs' modular cartridge design is utilized in the Independence 1000™. The system is designed to withstand the failure of up to two cartridges during the same run period, without a shutdown of the system. The current operational lifetime of the 650 cartridge utilized in the Independence 1000™ is over 3000 hours of operation. In a back-up power configuration where the systems are expected to operate well below 300 hours per year, the minimum lifetime of a single cartridge will exceed 10 years.

The one component of all PEM-based fuel cell systems that has **by far** the lowest MTBF is the PEM membrane. We have purposely designed our system to place these high-risk components into hot-swappable, redundant cartridges. This design feature of the Avista Labs Independence 1000™ offers inherent reliability when compared to any other fuel cell system as well as other incumbent technologies. The Avista Labs modular cartridge design eliminates the possibility that the PEM-fuel cell component

* The Estimated operational lifetime of this component is 30,000 hrs. Quantitative analysis is on-going.

will result in a single point of failure. Avista Labs continues to perform life cycle tests on a routine basis and a quantitative theoretical analysis is in process. This analysis will further substantiate the qualitative summary given above.

Appendix D – Fuel Cell Capital and Installation Cost Evaluation

ECAO supplied us with a work order total cost report dated February 26, 2004. Per this report, labor costs totaled $24,230.12, and materials $21,681.08, for a total of $45,911.20.

Material costs are as follows:

A. Fuel Cell and Enclosure - $14,010.00
B. Training - $2,750.00
C. Gas Cylinders (12) - $2,304.00
D. Fuel Cell Spare Parts - $558.90
E. Shipping - $465.24
F. Pad - $182.16
G. Miscellaneous - $1,410.78

When reviewing these data, we anticipate that future cost for additional units would breakdown as follows:

A. Fuel Cell and Enclosure – $14,667.00
    a. Based on new GSA pricing
    b. Quantity of five or more
    c. Includes manufacturer's 7-year warranty
B. Training - $0.00
    a. Additional training would not be required
C. Gas Cylinders (6) - $1,132.00
    a. Six spare cylinders are available
D. Fuel Cell Spare Parts – $0.00
    a. Spare parts are available
E. Shipping Costs – $0.00
    a. Shipping costs are included under GSA contract
F. Concrete Pad - $180.00
G. Miscellaneous - $1,521.00
    a. Additional savings possible if parts are purchased in bulk
H. Bridge Battery - $1,000.00

Total - $18,500

The total labor cost to install the fuel cell at Pole Hill Powerplant is approximately $24,230. Of the total labor costs, $17,000 was spent on the installation cost; $5,300 was accrued after the unit was installed to test systems, correct issues that were discovered, and to change control schemes; and $1,700 was spent on training. Most issues have been addressed by ReliOn, and improvements have been made to the system. While no installation would be without problems, the cost to fix, test, and make control changes would be greatly reduced and additional training will not be required.

Labor costs associated with additional units would also decrease if multiple units were installed at the same time. There is an initial learning curve for the installation of the fuel cell. If the same crew was able to perform the work on each installation, the number of hours required to install each fuel cell would decrease. If we estimate a decrease in labor cost of about 25 percent, then labor costs for installation of the fuel cells would be approximately$12,500. Given these estimates of labor and material, a total cost at approximately $31,000 per site would be a good value to use for budgetary purposes.

Appendix E – Battery and Fuel Cell Life Cycle Cost

Backup Battery Economic Evaluation Over 10 Years with a 5-Year Replacement
7% Discount Rate – 4% Inflation

Below is a list of the life cycle costs associated with both battery backup systems and the ReliOn fuel cell. For the batteries, the cost includes:

- Battery Cost
- Battery Rack
- Battery Installation
- Battery Monitoring System (Serveron 48V)
- Battery Monitoring System Installation and Re-installation at 5 years after replacing battery
- Used Battery Disposal
- Annual Maintenance
- Capacity testing at 2, 4, 7, and 9 years

Battery costs did not include replacing chargers at battery sites.

For the fuel cell, the costs included:

- Fuel Cell
- Enclosure
- 7-year Warranty
- Installation
- Miscellaneous Materials
- Bridge Battery and Installation
- Used Battery Disposal
- Annual Maintenance

Fuel cell cost does not include cost of DC system modifications including: battery charger, breakers, panels, etc.

8-HOUR BATTERY

$2,700.00	BATTERY COST (5-Year Battery Life VRLA)
$600.00	RACKING
$2,000.00	BATTERY INSTALLATION
$4,800.00	MONITOR
$2,800.00	MONITOR INSTALLATION (Re-installation of Leads = $560)
$500.00	USED BATTERY DISPOSAL
$600.00	ANNUAL MAINTENANCE
$2,000.00	CAPACITY TESTING

	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	
	$13,400.00											- INITIAL COST
		$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	- ANNUAL MAINTENANCE
			$2,000.00		$2,000.00			$2,000.00		$2,000.00		- CAPACITY TESTING
						$5,760.00						- BATTERY REPLACEMENT
TOTAL	$30,307.78											

24-HOUR BATTERY

$8,100.00	BATTERY COST (5-Year Battery Life VRLA)
$600.00	RACKING
$2,000.00	BATTERY INSTALLATION
$4,800.00	MONITOR
$2,800.00	MONITOR INSTALLATION (Re-installation of Leads = $560)
$500.00	DISPOSAL
$600.00	ANNUAL MAINTENANCE
$2,000.00	CAPACITY TESTING

Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	
$18,800.00											- INITIAL COST
	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	- ANNUAL MAINTENANCE
		$2,000.00		$2,000.00			$2,000.00		$2,000.00		- CAPACITY TESTING
					$11,160.00						- BATTERY REPLACEMENT

TOTAL $40,365.82

48-HOUR BATTERY

$16,200.00	BATTERY COST (5-Year Battery Life VRLA)
$1,200.00	RACKING
$3,000.00	BATTERY INSTALLATION
$4,800.00	MONITOR
$2,800.00	MONITOR INSTALLATION (Re-installation of Leads = $560)
$1,000.00	USED BATTERY DISPOSAL
$600.00	ANNUAL MAINTENANCE
$3,000.00	CAPACITY TESTING

Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	
$29,000.00											- INITIAL COST
	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	- ANNUAL MAINTENANCE
		$3,000.00		$3,000.00			$3,000.00		$3,000.00		- CAPACITY TESTING
					$20,260.00						- BATTERY REPLACEMENT

TOTAL $61,826.08

72-HOUR BATTERY

$24,300.00	BATTERY COST (5-Year Battery Life VRLA)
$1,800.00	RACKING
$4,000.00	BATTERY INSTALLATION
$4,800.00	MONITOR
$2,800.00	MONITOR INSTALLATION (Re-installation of Leads = $560)
$1,500.00	USED BATTERY DISPOSAL
$600.00	ANNUAL MAINTENANCE
$3,500.00	CAPACITY TESTING

Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	
$39,200.00											- INITIAL COST
	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	- ANNUAL MAINTENANCE
		$3,500.00		$3,500.00			$3,500.00		$3,500.00		- CAPACITY TESTING
					$29,360.00						- BATTERY REPLACEMENT

TOTAL $81,581.04

48-HOUR FUEL CELL

$5,749.00	FUEL CELL
$6,518.00	ENCLOSURE
$2,400.00	7-YEAR WARRANTEE
$12,500.00	INSTALLATION
$2,733.00	MISC MATERIALS
$1,000.00	BRIDGE BATTERY COST AND INSTALLATION
$100.00	USED BATTERY DISPOSAL
$600.00	ANNUAL MAINTENANCE

	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	
	$31,000.00											- INITIAL COST
		$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	- ANNUAL MAINTENANCE
						$1,100.00						- BATTERY REPLACEMENT
TOTAL	$37,066.86											

* - Additional backup time is available by purchasing additional hydrogen cylinders. An additional 24 hour will run about $650.

Appendix F - References Supplied by ReliOn

A - State of Maryland MEIMMS E-911 Microwave Radio System – ReliOn has systems currently installed with the State and are in the midst of a rollout that will total 220 plus installations.

B – Federal Aviation Administration (FAA) - Wheeling, Illinois - This is the first commercial installation with the FAA and four more installations (2 - NW Region, 2 - Great Lakes Region) are currently under construction. Scheduled to be completed by April 2004. ReliOn anticipates several more follow-on installations.

ReliOn can provide specific contacts within these organizations, if necessary.

GSA Pricing

Independence 1000™ Quantity 1 - 4: $6,756.00

Independence 1000™ Quantity 5 - 25: $5,749.00

Outdoor Enclosure Quantity 1 - 99: $6,518.00

These prices include shipping as we are required to do so for the GSA schedule. If further reduction is required for budgetary purposes, the systems can be ordered directly from ReliOn.

Warranty Information

ReliOn offers an additional warranty on the fuel cell and hardware beyond the standard warranty. The extended warranty is based on a 500 hours per year operation and can be purchased for 1, 3, 5, or 7 years. For example, the 7-year warranty would cover the fuel cell for 7 years or 3500 hours, whichever comes first. For more information on pricing see Appendix G.

Appendix G – February 27, 2004, ECAO Fuel Cell Meeting

There were several questions as a result of the Bureau of Reclamation meeting at the EACO on Friday, February 27, 2004. There were five specific questions requiring a response from ReliOn. The questions are listed below and followed by a response.

Questions:

1 – Can the Bureau of Reclamation store hydrogen cylinders at a central location? How many hydrogen cylinders can the Bureau store at a specific location?

Response: Yes, the Bureau of Reclamation can store hydrogen cylinders in a central location. The NFPA, National Fire Protection Agency, provides useful standards in regards to the storage and use of compressed gaseous hydrogen. The recommended storage location is outdoors in a well-ventilated, secured area.

The recommendations put forth by the NFPA specify spacing from openings into buildings, HVAC inlet ducts, and distance to combustibles, etc. The specific standards governing the use and storage of hydrogen are:

> NFPA 50 A: Standard for Gaseous Hydrogen Systems at Consumer Sites, 1999 edition. This standard outlines the spacing requirements for the storage of hydrogen cylinders at a specific location. Table 3-2.2 outlines the suggested spacing between openings and other potential hazards for given amounts of hydrogen.
>
> NFPA 497: Recommended Practice for the Classification of Flammable Liquids, Gases or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas, 1997 Edition. "Section 3-3 Unclassified Areas" discusses suggested engineering practices used to determine area classification. Figure 3-9.27 provides recommendations for the distance from stored hydrogen to non-classified electrical equipment – 15 feet.

Both of these standards are available in pdf format from the NFPA website:

www.nfpa.org

The price for NFPA 50 A is $22.05 and the price for NFPA 497 is $29.03.

2 – Can the Bureau of Reclamation transport cylinders to remote locations where the fuel cells may be installed?

Response: Yes. I have spoken with Airgas regarding this matter, and there are specific rules that apply to the transport of high pressure cylinders.

A. If transporting under 1000 pounds of product, this includes the weight of the cylinders, it is possible to transport the hydrogen without "placarding" the truck.
   1) Each 300 cylinder weighs approximately 160 pounds. This means up to six cylinders can be transported without a placard on the transport vehicle.

B. If the transport is taking place on a private road, DOT rules do not apply. Assuming some of the access roads to the fuel cell installations are public roads, the following general guidelines apply to transport of compressed hydrogen cylinders under 1000 pounds of total weight.
   1) Cylinders should be secured in an upright position.
   2) Hazmat shipping papers are required. The papers should detail the following:
      a) State the quantity of the product on the transport vehicle.
      b) State the date which transportation of the product is occurring.
      c) Provide emergency contact information. This information must be available during the hours transportation is taking place. If the hydrogen is transported at 2 pm, the emergency number must be attended during this time.
   3) On-hand emergency response handbook. This book is available for purchase and should be on hand in the transport vehicle.
      a) 2004 edition now available. This can be purchased directly from the DOT.

C. DOT regulations that apply to the transportation of compressed hydrogen cylinders are as follows:
   1) DOT Part 49 CFR173.301a – Gases, Preparation and Packaging.
      a) Page 552 Subpart G
   2) DOT Part 49 CFR 177.840 – Carriage by public highway
      a) Page 705 & 706

D. Airgas offers training manuals and in some cases can offer a training seminar to highlight applicable sections of the training manuals. Airgas can be contacted directly for this training.
   1) Airgas Representative:
      John Haggerty
      Airgas Corporate
      Phone: (610) 391-1894
      Email: John.haggerty@airgas.com

3 – Is 7-year warranty available?

Response: A 7-year warranty is available at the time of purchase. There are several warranty options available. The warranties are based on time in service, as well as operational hours. Please see ReliOn Appendix A.

4 – Bureau of Reclamation personnel have expressed concern over the number of visits Avista Labs personnel have made to the Pole Hill installation.

Response: There is concern over the number of trips taken by Avista Labs to the Pole Hill installation. The Bureau of Reclamation is concerned these visits may point to a quality issue with Avista Labs systems. In an attempt to address this concern, the visits to the Pole Hill installation are outlined below, as are the reasons for each visit. As can be seen, aside from the initial visit, the majority of visits to the Pole Hill installation have been due to requested upgrades to the systems, and human errors made during maintenance of the system resulting in the requirement for equipment replacement. The Pole Hill installation, being the first Avista Labs field installation with the Bureau of Reclamation, has provided significant learning for both parties regarding the configuration and specific Bureau of Reclamation configuration requirements. Future installations with the Bureau of Reclamation will capitalize on the knowledge gained through the Pole Hill field trial.

Summary of Visits:

Visit Date: 10-8-03

Purpose: There were three purposes for this visit:

1. Perform 4-hour classroom training at the ECAO.
2. Perform 4-hour afternoon equipment training at the site.
3. Qualification testing and commissioning of the installation.

Summary of Visit:

A. Training at the ECAO covered hydrogen basics, introduction to the equipment, and installation specifics.
B. The afternoon equipment training was delayed due to malfunction of the Independence 1000™.
    1) During initial equipment orientation at the site, a temperature sensor on the Independence 1000™ was damaged, resulting in the inability to operate the unit.
    2) A replacement Independence 1000™ was shipped from Avista Labs in Spokane, WA.
        a) The replacement Independence 1000™ was a newer revision of the Independence 1000™. This newer revision was not compatible with the revision level of the Avista Labs outdoor enclosure installed at the site.

b) There was a compatibility issue regarding the current rating of the control relay output of the Independence 1000™ C. The control contact had lower contact current rating than the previously installed Independence 1000™, B version.

Resolution/Open Items:

A. It was necessary to update the revision level of the outdoor enclosure and increase the output contact current ratings of the Independence 1000™, C version. An upgrade of both systems was scheduled, and installation and commissioning was rescheduled for October 22.

Visit Date: 10-22-03

Purpose: There were three purposes for this visit:

1. Update the Avista Labs outdoor enclosure for operation with the Independence 1000™, version C fuel cell.
2. Install a new Independence 1000™ with upgraded output contact current ratings.
3. Qualification testing and commissioning of the installation.

Summary of Visit:

A. The outdoor enclosure was updated for compatibility with the Avista Labs Independence 1000™, version C fuel cell.
B. Installed an Independence 1000™, version C with upgraded contact current rating.
C. Performed commissioning testing. Site commissioned.

Resolution/Open Items:

A. After commissioning, Reclamation personnel requested to increase the functionality of the installation to allow for the "Low DC Bus Voltage" detect.
    1) 11/12/03 visit scheduled to perform this upgrade.

Visit Date: 11-12-03

Purpose: Upgrade system to include Low DC Voltage Detect Functionality

Summary of Visit:

1. Firmware of Independence 1000™ modified to add "Low DC Bus Voltage Detect" functionality.
2. Outdoor Enclosure modified to add "Low DC Bus Voltage Detect" functionality.

Resolution/Open Items:

A. No known open items after this visit. Modifications performed and system operational.

Visit Date: 2-24-04

Purpose: Avista Labs had been performing ongoing cold weather testing and determined an upgrade to the outdoor enclosure was necessary to increase the operational temperature range of the system installed at Pole Hill. The enclosure was to be upgraded with the colder weather modifications.

Summary of Visit:

1. Cold weather modifications installed in outdoor enclosure.
    a. Upgrade included some electrical modifications.
2. Upon completion of electrical modifications, system was run and found to have a problem with "Low DC Bus Voltage Detect" functionality.
    a. Failure attributed to improper connection of power wiring to enclosure "Low DC Bus Voltage Detect" equipment.
    b. Replaced hardware and tested functionality of system.
    c. Reclamation personnel expressed dissatisfaction with "Low DC Bus Voltage Detect" equipment.

Resolution/Open Items:

A. "Low DC Bus Voltage Detect hardware replaced. "Low DC Bus Voltage Detect" hardware undergoing redesign based on Reclamation recommendations.
    1) Redesign to be completed by end of March 2004.
    2) Once redesign completed and tested, seek Reclamation approval and install.

5 – What system configuration is proposed for the installations?

A. Since the commissioning of the Pole Hill installation, there have been product improvements to both the Independence 1000™ fuel cell system and the Avista Labs outdoor enclosure. Avista Labs proposes to provide a backup power solution capitalizing on these improvements.
    1) Please see ReliOn Appendix A for the specifications of the Avista Labs proposed solution.
    2) Please see ReliOn Appendix A for the GSA pricing for Avista Labs proposed solution
    3) The proposed solution will be compliant to the NEBS testing outlined in ReliOn Appendix B.

ReliOn APPENDIX A

Specifications

Includes:
One Independence 1000™, 1kW fuel cell
Outdoor Enclosure w/spare slot available for additional Independence 1000™
Complete fuel storage and delivery system

Category	Specification
Power Output	1kW @ nominal 48 VDC
Voltage Output	Nominal 24VDC Nominal 48 VDC
Operating Conditions[2]	-40°C to +46°C
Fuel Supply	Standard industrial grade H_2 (99.95%)
Supply Pressure	25-100 psi
Fuel Consumption[3]	15 SLPM @ 1KW 7.5 SLPM @ 500 watts
Start-up Modes	External Dry Contact[4] External Command[5] Low Battery voltage[6] Phone Line Interface[6] Manual switch command
Start-up Time[7]	Instantaneous based on start-up mode selection
Noise	Less than 60dBA @ 1 meter
Size[8]	68" X 62" X 36"
Weight[9]	900 lbs

[1] Specifications for operating Temperature are for Independence 1000™ units when installed inside Avista Labs Outdoor Enclosure.
[2] Consumption specification is based on one Avista Labs Independence 1000™ unit.
[3] External dry contact will initiate system start-up upon contact closure.
[4] External interface via Ethernet connection, each Independence 1000™ unit has an available Ethernet connection.
[5] Voltage sense value for low battery is programmable via user selectable dip switch.
[6] Phone line interface is an option available with optional J-61 control box. See Appendix A.
[7] Start Up time is based upon system being connected to DC bus which includes a 20 A-hour battery string.
[8] Size specified is for a single 1kW unit installed in outdoor enclosure with two fuel storage cabinets.
[9] Weight specified is for a single 1kW unit installed in Outdoor Enclosure with two fuel storage cabinets without fuel cylinders installed.

ReliOn APPENDIX A

GSA PRICING:		
Quantity	**Independence 1000™**	**Outdoor Enclosure**
1 to 4	$6756.00	$6518.00
5 to 25	$5749.00	$6518.00
26 to 99	$4993.00	$6518.00

J61 - Communications Module:

This module allows for phone line connection and communication with the Avista Labs outdoor enclosure and Independence 1000™ fuel cell system. This component is an additional item that can be ordered for increased communication capability. The cost of this Module is $675/ea.

Extended Hardware Warranty Pricing:

Extended hardware warranties are available. This warranty covers the hardware for the duration of the warranty or cumulative operating hours based on 500 hours/year of operation. For example a seven year warranty would cover the hardware for an additional seven years or 3500 hours of operation, whichever came first.

The pricing for the hardware warranty is dependent upon the quantity of initial product purchased as well as the duration of the warranty. Below is extended warranty pricing for various quantity orders. The percentage given is a percentage of the total initial price of the system. For example, if the initial equipment for a five system order were $10,000, a seven year warranty extension would cost an additional $4200.

	1 Year Extension	3 Year Extension	5 Year Extension	7 Year Extension
Quantity = 1 to 4 Price	**10%**	**26%**	**38%**	**47%**
Quantity = 5 to 25 Price	**9%**	**23%**	**33%**	**42%**
Quantity = 26 + Price	**7%**	**18%**	**27%**	**35%**

ReliOn APPENDIX B

NEBS Testing:

Avista Labs systems are currently undergoing NEBS testing. This is stringent testing for used to qualify telecommunications equipment. The NEBS testing encompasses the following tests:

- Transportation Vibration
- Acoustic
- Water Tightness – wind driven rain, rain, sprinklers
- Thermal Shock
- Earthquake
- Environmental Vibration
- Spatial
- EMI/Electrical Safety
- Lifting
- Wind
- Firearms
- Security
- Impact
- Transportation Shock
- Weather tightness - Dust
- Airborne contaminants – hygroscopic
- Low temperature exposure - transportation
- Airborne contaminants - gas
- High Temperature Exposure – transportation
- Altitude Testing
- Solar Testing
- Operational Testing
- Fire Resistance
- Plastics – Chemical Resistance, Fungus, Ozone
- Salt Fog – Long duration testing.

The estimated completion date on this testing is April 15, 2004. NEBS compliant systems would be applicable for the Bureau of Reclamation facilities under consideration.

Note: The NEBS testing encompasses the Avista Labs Independence 1000™ and Avista Labs Outdoor Enclosure. The Bureau of Reclamation has expressed interest in utilizing a system with additional fuel capacity. This system will utilize the NEBS solution with an additional fuel storage wing.

PEER REVIEW DOCUMENTATION

PROJECT AND DOCUMENT INFORMATION

Project Name Pole Hill Fuel Cell – Installation and Acceptance Test Report WOID_________

Document Project Notes 8450-2004-05

Document Date April 2004 Date Transmitted to Client____________________

Team Leader J. DeHaan Leadership Team Member____________________
(Peer Reviewer of Peer Review/QA Plan)

Peer Reviewer____________________ Document Author(s)/Preparer(s) N. Myers

REVIEW REQUIREMENT

Part A: Document Does Not Require Peer Review

Explain____

Part B: Document Requires Peer Review: SCOPE OF PEER REVIEW

Peer Review restricted to the following Items/Section(s): Reviewer:

Technical adequacy ____________________

Group policies B. Milano

REVIEW CERTIFICATION

Peer Reviewer – I have reviewed the assigned Items/Section(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer:____________________ Review Date:____________________
Signature

Reviewer:____________________ Review Date:____________________
Signature

Reviewer:____________________ Review Date:____________________

Preparer – I have discussed the above document and review requirements with the Peer Reviewer and believe that this review is completed, and that the document will meet the requirements of the project.

Team Member:____________________ Date:____________________
Signature