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Executive Summary:

The objective of this project provided with funds through the American Recovery and Reinvestment Act of 2009 (ARRA) was to demonstrate a Solid Oxide Fuel Cell (SOFC) generator capable of operation on propane fuel to improve efficiency and reduce emissions over commercially available portable generators. The key objectives can be summarized as:

- Development of two portable electrical generators in the 1-3kW range utilizing Solid Oxide Fuel Cells and propane fuel
- The development and demonstration of a proof-of-concept electro-mechanical propane fuel interface that provides a user friendly capability for managing propane fuel
- The deployment and use of the fuel cell portable generators to power media production equipment over the course of several months at multiple NASCAR automobile racing events
- The deployment and use of the fuel cell portable generators at scheduled events by first responders (police, fire) of the City of Folsom California
- Capturing data with regard to the systems' ability to meet Department of Energy (DOE) Technical Targets and evaluating the ease of use and potential barriers to further adoption of the systems.

The grant was originally awarded to Jadoo Power systems in 2010 and eventually novated to Acumentrics in 2013. Jadoo Power Systems completed 2.5 years of work on the project scope, but due to unforeseen reasons was unable to complete the program deliverables. The Department of Energy (DOE) requested a novation of the program to Acumentrics SOFC Corporation to complete the build and demonstration phase of the project scope. As such the program became focused on building a smaller generator for television camera support at NASCAR events as well as a larger 1kW cart mounted unit for pit type power applications or higher loads such as spotlight carts.

Acumentrics was able to complete testing in Daytona, Florida at two races including the Rolex24 race that spans a continuous 24 hour period and the Daytona 500 race which kicks off the NASCAR season. The Acumentrics 250W model demonstrated the ability to fully support television camera power needs throughout a 4-day race period while operating on a single 20lb bottle of propane. Comparable power provided by a standard 3kW Honda portable generator would require refueling with portable gas jugs twice per day each day over the same period. The Acumentrics unit also demonstrated it was capable of remote start and control, like many of the NASCAR cameras, and fit well into the ecosystem of the broadcast team. Unfortunately, though successful in demonstration, no further work was performed since the cost of the fuel cell generator still far outweighed that of the portable gas generator and the enhanced features were not sufficient to justify a substantial price increase.

Introduction:

Acumentrics was contracted in 2013 to complete an ongoing ARRA project and work with NASCAR to bring leading edge power generation technology to the broadcast operations of NASCAR The goal of the project was to demonstrate efficiency gains and show that the technology would be a good candidate for replacement of portable gas generators. After initial meetings between Acumentrics and NASCAR personnel, and consultation with DOE, the following scope was developed:

- Acumentrics will deliver two RP1000 and two RP250 systems for demonstration at three NASCAR races
- These units would be operated and supported by Acumentrics personnel
- NASCAR would be responsible for fuel delivery coordination and providing security access
- First demonstration will be at Daytona spring 2014

Each participant had the potential benefit from the tests. For NASCAR, those benefits include:

- Demonstrate cutting edge green technology for broadcast camera power
- Validate reduced noise and vibration allowing closer integration between generator and camera
- Validate potential fuel savings and emission reductions at race events
- Demonstrate “smart” generator control for potentially improved camera and broadcast uptime
- Demonstrate improved race event safety by the reduction of fueling needs during events

For Acumentrics, those benefits include:

- Demonstrate our latest generator products in a new potential market
- Gain greater field data to refine all product platforms
- Leverage public events to benefit both NASCAR and Acumentrics name & brand
- Gain DOE funding to help commercialize all product platforms
- Place both NASCAR and Acumentrics in a favorable light allowing for potential future funding or support

The program was broken into seven major sub-sections. Those sub-sections will be detailed in the following section.

Accomplishments

Task 1.0 Requirements Definition

At the start of the program Acumentrics and NASCAR personnel held discussions to define the load requirements as well as the physical layout and operating conditions required of portable generators at NASCAR events. Participants also reviewed data gathered in Phase I of the project. In addition, Acumentrics personnel visited Charlotte Motor Speedway to get a first hand account of the portable power requirements at a typical NASCAR event. Based on this information and conceptual systems designs, SOFC generators at two different power ratings would be developed and demonstrated as part of this project. The first unit would be a cart mounted 1 kW output system capable of powering ground level multi-camera locations or auxiliary loads in the in-field area. The second unit would be a 250 W man-portable output system capable of powering single camera locations. Its size and weight will allow deployment to roof top and grandstand areas not readily accessible by the larger cart based system. Specifications for each of these systems are presented below:

1000W, Portable Generator

<u>Electrical Performance</u>	
Output Power:	*1000 W Total AC & DC*
Output Voltage:	*110 VAC, 12 VDC (Option 24VDC instead of 110/12)*
Output Current:	*9 amp AC, 10 amp DC*
Over Current Protection:	*Yes*
Output Connectors:	*Duplex AC Outlet, 2 Pin Matt-n-Lock DC Connector (Option: terminal block)*
<u>Fuel Characteristics</u>	
Fuel Type:	*Propane, Liquefied Petroleum Gas (LPG)*
Fuel Composition:	*HD-5*
Maximum Sulfur Content:	*< 125 ppmW S*
Line Pressure:	*14" w.c*
<u>Operation</u>	
Startup Time:	*Full rated output power within 30 minutes*
Efficiency:	*>30% (net AC/LHV basis at 1000 W)*
Fuel Cell Bundle Durability:	*1 year life minimum, 3 year design goal*
Generator System Durability:	*10 year minimum, 20 year design goal*
Thermal cycles:	*10 full cold to hot cycles per year maximum, 50 full cycles per year design goal*
User Interface:	*A user interface panel will provide the following functions:* *System Status Lights* *On/Off Switch* *AC and DC Power Breakers* *Dry contact, normally closed switch that opens when systems is not running*
Communication Protocol:	*Retrievable on board data storage in CSV file format (Satellite and Cellular Communication Capable)*
<u>Physical</u>	
Size:	*33"H x36"W x60"L*
Weight:	*<400 lbs for baseline unit*
Enclosure:	*Removable covers for 3-sided internal access*
Mounting:	*Level surface*
Location:	*Outdoor*

Regulatory Approval:	*None*
Fuel Connection:	*Quick Disconnect*

Environmental

Operating Temperature:	*-22°F to +122°F (-30°C to +50°C)*
Storage Temperature:	*-40°F to +131°F (-40°C to +55°C)*
Altitude:	*0 to 10,000 ft operating, 0 to 40,000 ft non-operating*
Noise:	*58 dB adjacent to unit*

Preventative Maintenance

Service Interval:	*Annual Refurbishment* *Sulfur Canister Replacement: after 200 hours of full load operation or equivalent*
Annual Service Items:	*Fuel Cell Bundle* *Inlet Air Filter – Inspect, clean or replace* *Batteries – Inspect* *Blowers – Inspect* *Fuel Valves - Inspect*
Tools:	*No special tools required*

250 W, Portable Generator

Electrical Performance

Output Power:	*250 W Total AC & DC*
Output Voltage:	*110 VAC, 12 VDC (Optional 24VDC instead of 110/12)*
Output Current:	*2.2 amp AC, 10 amp DC*
Over Current Protection:	*Yes*
Output Connectors:	*Duplex AC Outlet, 2 Pin Matt-n-Lock DC Connector* *(Optional terminal block)*

Fuel Characteristics

Fuel Type:	*Propane, LPG*
Fuel Composition:	*HD-5*
Maximum Sulfur Content:	*< 125 ppmW S*
Line Pressure:	*14" w.c*

Operation

Startup Time:	*Full rated output power within 30 minutes*
Efficiency:	*>20% (net AC/LHV basis at 200 W)* *>25% (net DC/LHV basis at 250 W)*
Fuel Cell Bundle Durability:	*1 year life minimum, 3 year design goal*
Generator System Durability:	*10 year minimum, 20 year design goal*
Thermal cycles:	*10 full cold to hot cycles per year maximum, 50 full cycles per year design goal*
User Interface:	*A user interface panel will provide the following functions::* *System Status Lights* *On/Off Switch* *AC and DC Power Breakers* *Dry contact, normally closed switch that opens when systems is not running*
Communication Protocol:	*Retrievable on board data storage in CSV file format* *(Satellite and Cellular Communication Capable)*

Physical

Size:	*18"H x 22"W x 32"L (Length Goal 26")*
Weight:	*<125 lbs for baseline unit (Goal 99 lbs)*
Enclosure:	*Removable covers for 3-sided internal access*

Mounting:	*Level surface (concrete slab/block with stand off the ground)*
Location:	*Outdoor*
Regulatory Approval:	*None*
Fuel Connection:	*Quick Disconnect*

<u>Environmental</u>

Operating Temperature:	*-22°F to +122°F (-30°C to +50°C)*
Storage Temperature:	*-40°F to +131°F (-40°C to +55°C)*
Altitude:	*0 to 10,000 ft operating, 0 to 40,000 ft non-operating*
Noise:	*58 dB adjacent to unit*

<u>Preventative Maintenance</u>

Service Interval:	*Annual Refurbishment* *Sulfur Canister Replacement: after 48 hours of full load operation or equivalent*
Annual Service Items:	*Fuel Cell Bundle* *Inlet Air Filter – Inspect, clean or replace* *Batteries – Inspect* *Blowers – Inspect* *Fuel Valves - Inspect*
Tools:	*No special tools required*.

During this task, Acumentrics also addressed desulfurization of propane. LPG and Natural Gas (NG) are not chemically pure gases although quite often they are considered as propane and methane for simple sizing calculations. These fuels are defined not by their chemical composition in so much as their physical and thermodynamic properties, thus the chemical makeup can be different as long as the physical properties are within certain bounds.

The chemical composition of liquefied petroleum gas (LPG) differs around the world, although in all cases the physical property and thermodynamics requirements will limit it to a mixture of all or some of the following components; propane, propylene, butane, and ethane, along with minor contributions of derivative olefins and di-olefins. That there is no precise definition is owed to the final commercial application, which seldom requires composition definition or gas purity, and commercial availability; the price of the different components in LPG are quite different around the world depending on the fuel sources and the local industry.

The major potential issues in using such an unregulated fuel for the SOFC are: 1) metering of the fuel 2) gumming of the reformer and 3) sulfur poisoning of the cell. While most commercial LP gas in the United States is readily usable, as discussed above, there is no commercial reason for stricter regulation of LPG composition. The strictest specification for LPG in the US is HD-5, aimed at defining an LPG better suited for motor applications. Since the SOFC is still regarded as a nascent technology, Acumentrics currently limits the LPG used in their products to HD-5 specification In the future, Acumentrics expects that the SOFC will be certified for both commercial and HD-5 specifications in the US, but in the meantime HD-5 is widely available and its adoption limits the possibility of anomalous fuel compositions avoiding complications of the first two issues raised. HD-5 for instance states that the propane content must also be at least 90% and limits the propylene content to 5%. The HD-5 specification also limits the sulfur content to ~125ppmW.

Sulfur and the Solid Oxide Fuel cell

Sulfur, ubiquitous in petroleum fuels, is a particularly acute poison to fuel cell anodes and reforming catalysts alike and thus is one of the impediments in the use of hydrocarbon fuels in fuel cells. Of all the fuel cells, the low temperature polymer electrolyte fuel cell generally has the

strictest requirement for sulfur (<0.2ppmV) while the SOFC is generally accepted to have the highest tolerance to sulfur at ~1ppm V mostly due to its high operating temperature.
It is universally accepted that sulfur will efficiently bind to active sites on most metals poisoning the catalyst function. This affects the SOFC primarily in two ways: First, it poisons the reforming catalyst so that hydrocarbon carbon conversion to syngas is incomplete increasing the risk of carbon fouling of pipes and manifolds. Secondly, it poisons the nickel anode so that water gas shift reaction and electrochemical oxidation kinetics are retarded. The effect of sulfur on the cell is demonstrated in Figure 1. With ~1ppmV H_2S the nickel anode is shown to be poisoned, in this case, over a 50 hour time frame. Nevertheless the cell performance abruptly stabilizes, and a slow recovery occurs if clean fuel is added. Subsequent poisoning at ~2ppmV and 5ppmV results in only slightly lower performance. Thus low level sulfur poisoning results in a depreciation in performance, with the strongest effects occurring at the lowest levels, *i.e.* the relative poisoning effect at 1 ppm is substantially stronger than for 2ppm V. At 10ppmV it is noticeable that the cell performance does not appear to stabilize. Recovery from sulfur poisoning starts as soon as the sulfur is removed from the feed, and at least at the 0-10ppm V levels, the recovery has been shown to be complete (not shown in Figure 1).

It is useful to consider the hypothetical case of no LPG desulfurization, for instance with the sulfur level at 125ppmW. Under standard CPOX conditions, at the reformer *inlet* the sulfur concentration will be 18ppmV due to the dilution with air, and *after* the reformer ~12.5ppm V due to the breakdown of the larger molecules into syngas. Active site blocking of metal catalysts by sulfur in general is reduced at elevated temperatures, and thus precious metal catalysts can maintain high conversion and selectivity at ~10 ppmV. The sulfur level in the cell however is high enough to start causing a slow degradation in performance.

This example demonstrates the obvious need for desulfurization, but it also suggests that the cells are relatively tolerant to sulfur. While a depreciation in performance is unavoidable if there is an upset in the desulfurizer performance, performance can still be completely recovered.

Various desulfurization unit operations have been used in the chemical process and petroleum industries in order to protect expensive catalysts, or to meet environmental standards for fuels. The standard method for desulfurization of hydrocarbon feed streams is based on hydro-desulfurization which uses hydrogen to help convert the organic sulfur to H_2S. The H_2S can be subsequently removed by a number of processes such as amine scrubbing or adsorption in a Zinc oxide (or mixed metal oxide) bed.

The desulfurization challenge for fuel cells is that it must occur *at the point of use* and the techniques available at large processing scales are not always practically possible or efficient at small scales. However, in contrast to the chemical process industries, the economics of sulfur adsorption in fixed non-regenerable beds are feasible in small fuel cells, due to the relatively low levels of sulfur in the fuel and the low fuel flows.

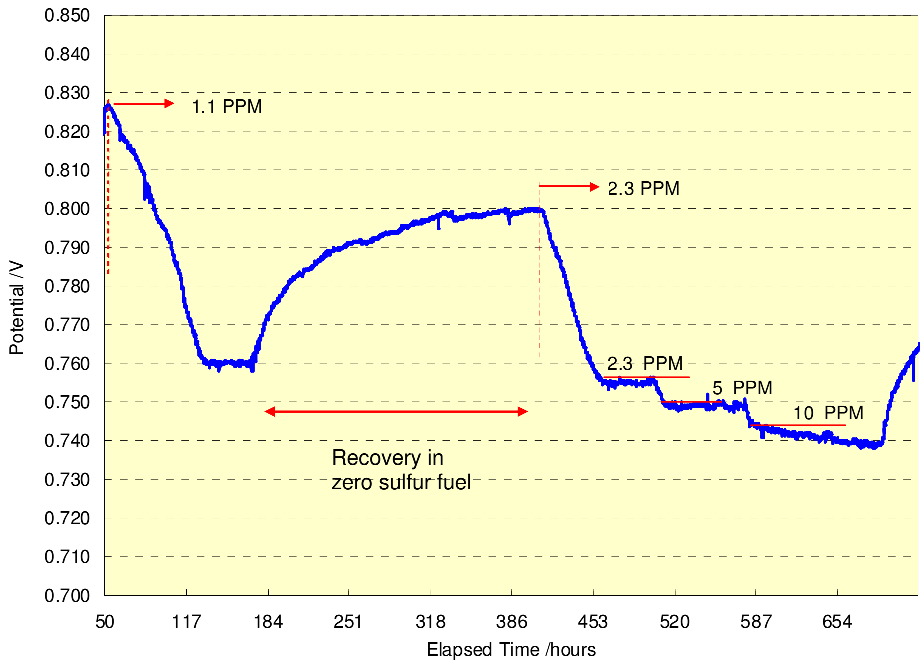

Figure 1: Sulfur poisoning of SOFC Ni based anode with H_2S (Acumentrics data)

Sulfur in LPG

As previously noted LPG composition varies and the sulfur limit even for HD-5 is broad. The sulfur content of LPG is highly variable and will be made up of odorants and naturally occurring sulfur. Mandated odorization of the gas allows for detection in the event of a leak. In the US and Europe the sulfur component used for odorizing the gas is ethyl mercaptan. The required level should be *at least* 1.5lbs/10,000 gal to ensure its stench at all conditions (full and empty) and in dilute air /fuel mixtures. Depending on the LPG supplier this level could even be a factor of 2-3 times higher due to expectations of odorant fade (*i.e.* reaction of the mercaptan to form non volatile species). Thus one might expect on average a maximum sulfur level of ~75ppmV due to odorants.

Naturally occurring sulfur is difficult to assess as it is dependent on the source of the gas. A small survey of some gas fields in Texas for instance determined naturally occurring sulfurs ranging from 0-50ppmV with the makeup biased towards mercaptans (65-71%) and di-substituted sulfides (~23-26%) followed by inorganics such as hydrogen sulfide (H2S), carbonyl sulfide (COS) and carbonyl disulfide (CS2) (3-13%), and thiophene (1-2%).

However, when natural gas (the primary LPG source) or the products of hydrocarbon cracking are separated into its hydrocarbon constituents, carbonyl sulfide will tend to separate at the depropanizer stage with the propane fraction. Based on the data from our limited survey, if the COS was separated with the propane fraction its concentration would be ~22ppmV. However, in our experience the COS concentrations can be much greater with concentrations as high as 150 ppm V observed at different operating sites in both Canada and the northeastern US.

The actual sulfur species emanating from an LPG tank is further complicated by two other factors, both based on the fact that the LPG bottle is a "batch" of fuel. Thus the fuel composition and the sulfur concentration will change as the bottle is emptied, and further sulfur species will react in the tank, both with the tank wall and with each other to generally form less volatile species. The heavier sulfur species will accumulate and concentrate in the bottom of the tank, if the tank is not completely emptied, and given time will start to form polysulfides. When the tank is full the dominant sulfur species is the volatile COS. Near the end of the tank life the concentration of ethyl mercaptan and diethyl disulfide (and other heavier species) rapidly increase reaching concentrations of ~300ppmV.

The considerations of LPG for fuel cells are decidedly more complex than for natural gas, however, when all these complications are distilled, the primary concern is simply the presence of COS . COS is the limiting sulfur compound found in US LPG supplies , i.e. the sulfur component most difficult to remove using standard bed technology. While anecdotal data suggest that COS concentration should be at most 30 ppmV, there are clear instances where its concentration can be abnormally high, even in the case of the more stringently regulated HD-5 grade.

Desulfurizer Specification

Fuel Type:	*Propane, LPG*
Fuel Composition:	*HD-5*
Average Sulfur Content:	*<125 ppmW S*
Peak Sulfur Content:	*250 ppmW S*
Sulfur Species Considered:	*Carbonyl Sulfide* *Mercaptans* *Di-substituted Sulfides* *Thiophane (THT)* *Hydrogen Sulfide*
Replaceable Desulfurizer Cartridge:	
Cartridge Life (250W)	20 lbs propane (4 days operation)
Cartridge Life (1000 W)	200 lbs propane (16 days operation)
Desulfurizer Outlet Sulfur Content:	<0.1 ppmW S
Operating Temperature	>10^{o}C
Pressure Drop:	<1" w.c.
Operating Pressure:	0.5 – 5 psig

Task 2.0 System Design - Generator

Task 2.1 Initial System Level Design

Preliminary design layouts were prepared for both the 1 kW and 250 watt generators. Figure 2 shows the 1 kW system configuration. The 1 kW Fuel Cell Generator Module is a scale up of an Acumentrics 500 Watt commercially available remote power generator. The number of cells utilized will be increased proportionately and the balance of plant components such as the cathode air recuperator and fuel reformer will be resized accordingly. The Generator Module with regulated DC output will be coupled with an Acumentrics Power Conditioner which will produce 110 AC and 12 VDC outputs. The propane compartment will house two 20 lb propane tanks with appropriate connection hoses and regulators with an overall estimated weight of 400 lbs.

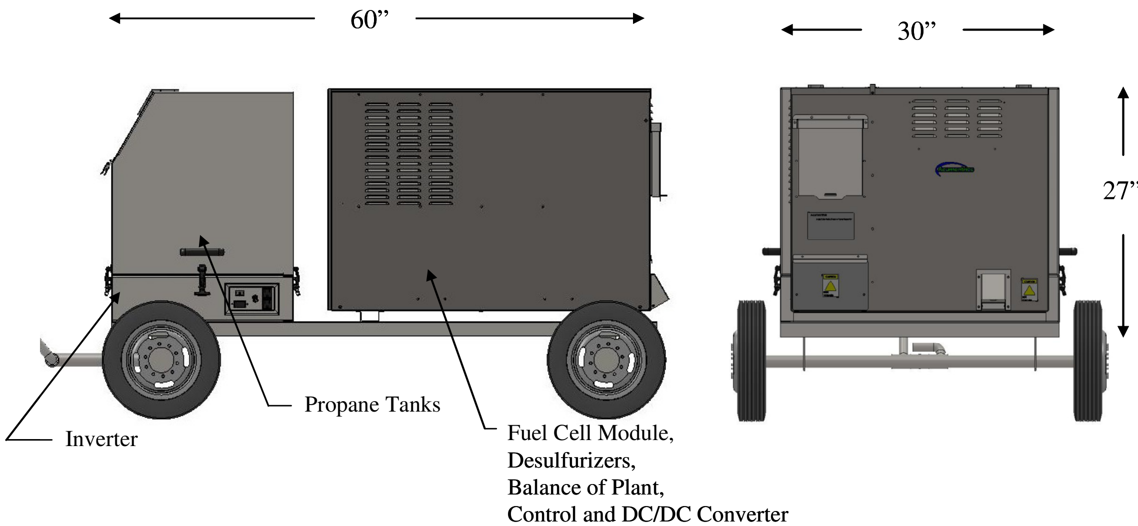

Figure 2 Cart Based 1 kW SOFC Generator

Figure 3 shows the 250W generator configuration. In this case, all system components except for the standard propane tank and regulator will be housed in the fuel cell enclosure. The enclosure size is estimated at 18” x 20x 32” and will weigh approximately 125 lbs.

Figure 3 Man Portable 250 W SOFC Generator

Task 2.2 Modeling of System

Computation Fluid Dynamic Modeling of the cathode air flow for the 250 Watt fuel cell module was completed. This model was used to size the cathode air plenum so that the necessary oxygen and temperature distribution within the fuel cell bundle was achieved.

Energy balances for both systems were prepared to provide state point conditions and a prediction of overall performance.

Task 3.0 System Design – Desulfurizer Report

Sorbent Selection

Section 1.2 defined the fuel requirements for the SOFC generator systems and highlighted the transient nature of the LPG composition when the feed is drawn from the tank vapor space. However this is not considered an issue for the fixed bed desulfurizer which if properly designed, has significant capacitance to cope with transients. Fixed bed technology is first sized for the average sulfur concentration of each species and their equilibrium pickup, with allowances then made for the adsorption kinetics as well as 2^{nd} order mixing phenomenon in the bed[1].

Adsorbents are typically designed to have as high a pickup as possible, and depending on the sulfur species capacities as high as 40% can be reached, although 1-6% is closer to the norm. There are at least three material classes of adsorbents that are frequently used; molecular sieve/activated carbon, mixed metal oxides, and zeolites. Even within these classes of materials there is sufficient heterogeneity in the final products of different manufacturers based on the active site dispersion and promotion in the pellets. The three classes of materials utilize different adsorption mechanisms for binding sulfur ranging from chemical reaction of the sulfur species, and chemisorptions to physisorption. In order to design an LPG desulfurizer for the US it is sufficient to consider the dominant species, including ethyl mercaptan, diethyl disulfide and carbonyl sulfide. In practice there is a very significant difference between the adsorption strengths of these species with the ordering as,

$$\text{COS} \ll \text{EM} \leq \text{DEDS}$$

Carbonyl sulfide is only weakly adsorbing and amongst the sulfur species present in fuel gases, proves to be one of the more difficult to remove. Due to the low polarity of COS it will not significantly adsorb on most materials. Furthermore, more polar molecules such as H2O which always have a significant presence in NG and LPG will displace COS from those sites that depend on physisorption for their efficacy[2]. To efficiently remove COS it is necessary to resort to other techniques[3] such as:

1) Chemically reactive adsorbent that binds the sulfur via a non-reversible reaction. (*i.e.* $CuO + COS \rightarrow CuS + CO_2$)

2) Hydrolysis of COS to H2S (*i.e.* $H_2O + COS \rightarrow H_2S + CO_2$) with removal of H_2S in a chemically reactive adsorbent material.

Both techniques are possible in principal for small fuel cell applications. The latter does require water well in excess of the concentration of COS, but some water is usually present in LPG. The various catalysts that can be used for COS removal have been summarized by Archer *et al*. for the process industries. Acumentrics has explored various adsorbents suggested by this study as well as by other partners and found that the best performance *at room temperature* and below is a commercially available mixed metal oxide to remove COS through the first process above. For proprietary reasons the alternative solutions and catalysts tested will not be discussed, other than to say that other mixed metal oxide systems also based on Zn and Cu, and hydrolysis catalysts, were also investigated.

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[1] This latter correction accounts for the width of the breakthrough curve

[2] Water adsorption can also interfere with the initial adsorption step of the COS in the vicinity of the chemisorption sites

[3] R. Bret Rhinesmith, P.J. Archer, S.J. Watson, GPA Research No: 991, 11 June, 2001

Experimental testing of beds for the adsorption of specific sulfur species is expensive in terms of both time and money. Tests usually need to run for long times (~500-1000hrs) and calibrated gas mixtures are very expensive. An alternative is to rely on manufacturer specifications, and/or to test sorbents on the actual fuel. The following approaches were used in the evaluation of the mixed metal sorbent:

1) Test the sorbent at room temperature with commercial natural gas in order to conservatively estimate its capacity for mercaptans (isopropyl mercaptan and tert-butyl mercaptan). This test yielded at least 1wt% for mercaptans with steric hindrance
2) Use the manufacturers data; 10ppm COS in (dry) NG at 10,000hr^{-1} GHSV and 38^{o}C yielded a capacity of ~1 wt% sulfur. This is a very high space velocity. Typical space velocities in a practical bed will be closer to ~100-500 hr^{-1}.
3) Test the adsorbent at both high (75 ^{o}C) and low temperatures (0 ^{o}C) using high COS in commercial LPG[4] at 500 hr^{-1} .Testing at 0C showed that the adsorption capacity was *at least* 0.7 wt%.

All manufacturers of the CuO/ZnO systems claim that better performance will be obtained at higher temperatures since the chemisorption reaction is activated.

Sulfur Monitoring

While we have supposed a “worse case” scenario to size our beds, it has been stressed that LPG gas and sulfur compositions are relatively broad. Further protection of the SOFC can be implemented by employing a sulfur sensor to indicate sulfur slip from the bed. Recently TDA Research, Inc has developed a breakthrough product which uses color change to indicate the breakthrough of most, if not all sulfur species. The sensor is available in two forms; either as a simple visual indicator, or by incorporating a light sensor they have been able to create prototype electronic indicators. Acumentrics has specified the use of the visual indicator in the Desulfurizer train for NASCAR (Figure 4). The indicator houses two reagents which change color in the presence of sulfur at ~0.1ppmV. The blue reagent turns brown when exposed all organic sulfur compounds of interest as well as H2S, whereas the white reagent is especially sensitive to COS and darkens on exposure.

The SulfaTrack^{TM} indicator will be located between the main external and a much smaller internal guard bed to give warning if in inadvertent sulfur breakthrough occurs. With such warning the bed can be replaced before the SOFC or reformer are exposed to the sulfur poison.

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[4] Water content was ~1000-2000ppmV

Figure 4: SulfaTrack^{TM} showing a color change on exposure to COS

Desulfurizer Sizing

The Desulfurizer for the NASCAR application has been sized based on the following:

Gas composition: The sulfur concentrations and composition was based on empirical data obtained during the depletion of LPG tanks which had COS concentrations of 84ppmW COS and 25ppmW other sulfur *on average*.

Adsorption Capacity: 1 wt% adsorption capacity was assumed based on the testing of the sorbent by the manufacturer and in house testing.

Space velocity*:* The manufacturer used a space velocity of 10,000 hr^{-1}, and in house testing was performed at conditions of 500-1400 hr^{-1}. A maximum space velocity of 500 hr^{-1} will be used.

Temperature: Satisfactory test results have been obtained at 0C but because water concentration in LPG is not strictly controlled it is advisable to keep the desulfurizers at >10^{o}C
A number of designs are possible with these constraints as long as attention is given to making sure that the fixed bed is designed with in accord with good engineering practice, *e.g.* bed length as long as possible while keeping the bed pressure drop within bounds and keeping particle size/bed diameter>10

Two examples are as follows:

Criterion	D/in	L/in	GHSV	L/D	d/D
200 lbs LPG, 1 kW Unit	3	17	110	5.8	~25
20lb LPG tank, 250 W Unit	1.5	8	414	5.3	~12

Table 1: Bed sizes for two different desulfurization concepts

Task 4.0 System Design – Fuel Interface (Completed by Jadoo in Phase I)

Task 5.0 Build and Test Demonstration Generators

Two 250 Watt man-portable generators were assembled and tested. Figure 5 shows electrical and gas utility side of the unit while Figure 6 shows the fuel cell module side. Figure 7 shows the fully assembled unit. Process and Control (PAC) testing was conducted on the integrated systems followed by hot integrated system tests.

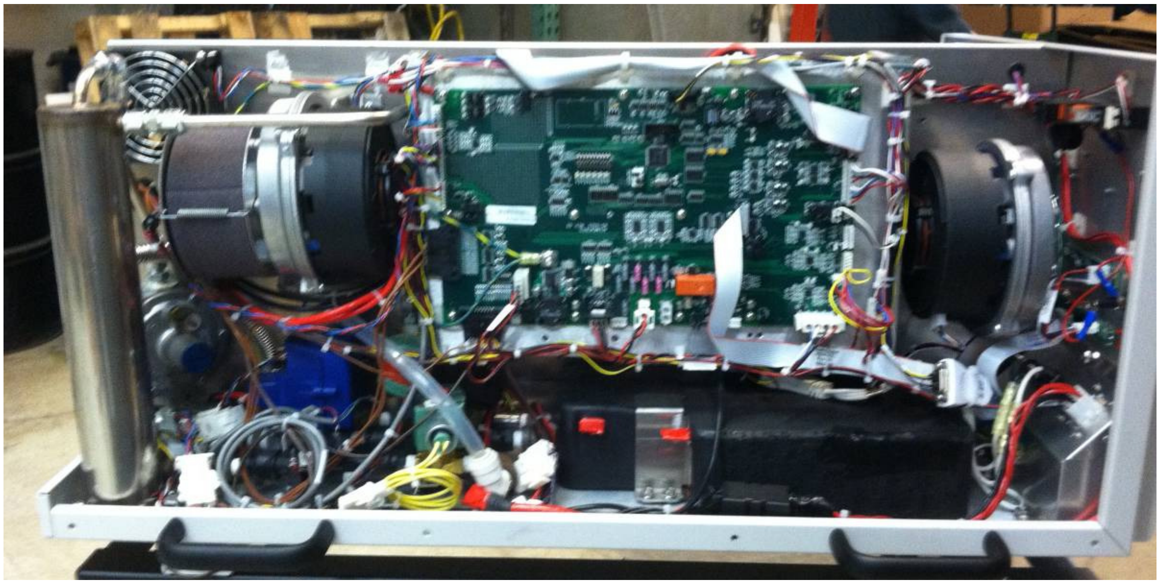

Figure 5 Electrical Compartment of 250 Watt Generator Internals

Figure 6 Fuel Cell Module Compartment of 250 Watt Generator

Figure 7 Fully Assembled 250 Watt Generator

Additional integrated system testing of the 1000 W generators was also conducted. Both 1000 W generators were tested at Acumentrics Westwood facility for several days at a range of power settings from idle conditions to full AC power.

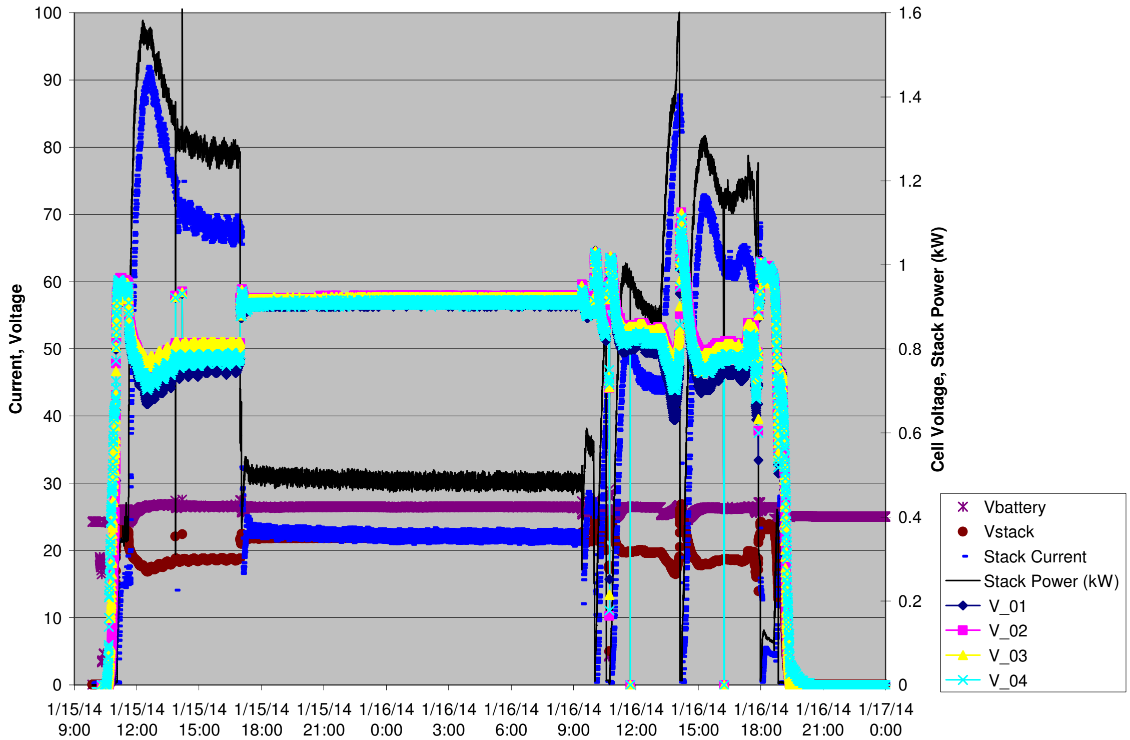

Figure 8 Factory Test Typical Run Conditions 1000W Generator

Task 6.0 Build and Test the Fuel Interface (Completed by Jadoo in Phase I)

Task 7.0 Deployment, Demonstration and Field Test

The SOFC generators were utilized at two race events at Daytona International Speedway. The first race event was the 52nd Rolex 24 which was held January 25th and 26th. Three generators were deployed for this event, two 250 Watt units and one 1000 Watt unit. One 250 Watt unit was utilized to power a television camera located at turn 3 along with an articulated boom and LCD Display. The load ranged from 15 to 200 watts. There were no operational issues over the course of approximately eight hours of on-air broadcasting.

The second 250 watt unit was used mainly to demonstrate that the SOFC generator could reliably power the race cameras through a series of test in the Broadcast Production Area. Although this generator was deployed on the track, it remained at idle during most of the race. This was a result of a fuel leak at the propane tank due to an improperly tightened fitting. The 1000 watt unit was located at Victory Lane and ran at idle to showcase the technology.

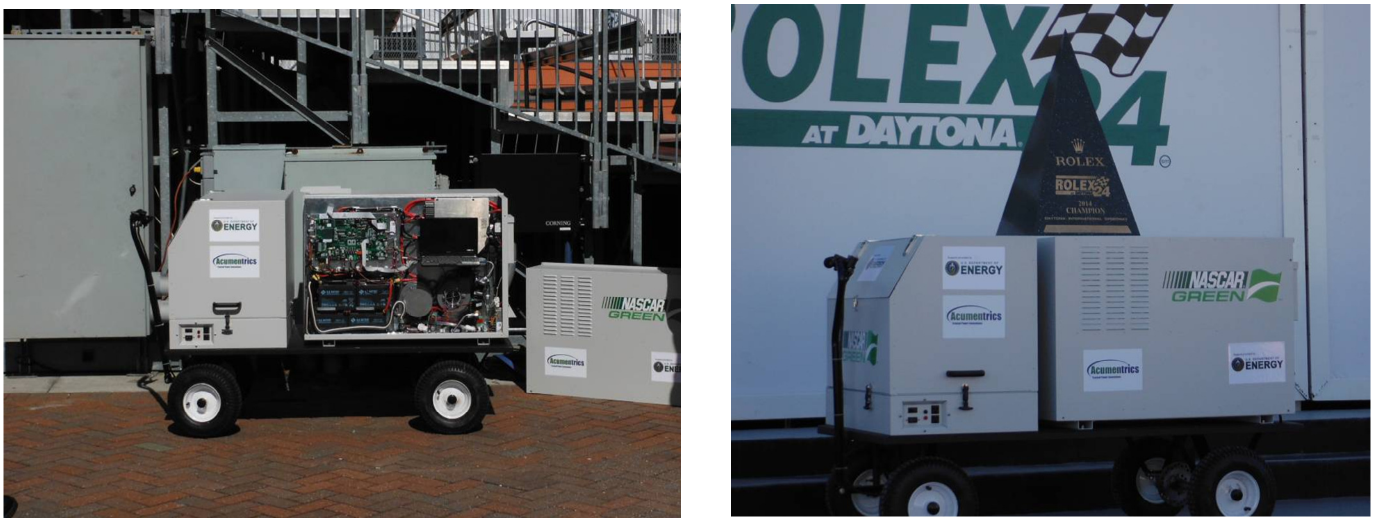

Figure 9 1000 Watt Unit at Trophy Stand

Between race events, the units were returned to Acumentrics where personnel made changes to the 1000 Watt cart to improve maneuverability. For the Daytona Speed Week a 10 day event from February 13th to 23rd culminating in the Daytona 500 Acumentrics deployed the two 250 Watt units and two 1000 Watt units.

The 250 Watts units powered manual cameras and LCD displays. One unit was located on the grandstand roof (see Figure 10) and the other was located at trackside (see Figure 11). Due to the duration of Speed Week, the units were outfitted with dual propane tanks and an automatic change over valve. Acumentrics RUPS units (ACG1252) carried out DC-AC conversion for each unit to provide additional redundancy. The ACG1252 is capable of delivering true sine wave AC power from either a DC source or an AC source and was therefore capable of supplying the camera load from the backup Honda Generators in the event of fuel cell failure. This feature was not needed as the 250W fuel cell generators ran reliably throughout the race week.

Figure 10 Grandstand Roof Location

Figure 11 Track Side In-Field Location

The 1000 Watt cart based systems were also located track side, one in the grandstand at the finish line (see Figure 12) and one at the end of pit row (see Figure 13). These units were primarily utilized for stationary point of use cameras.

Figure 12 Grandstand Location of 1000 Watt Unit

Figure 13 Pit Row Location of 1000 Watt Unit

Conclusions

Acumentrics was able to complete the design, build, and testing Daytona, Florida at two races including the Rolex24 race that spans a continuous 24 hour period and the Daytona 500 race which kicks off the NASCAR season. The Acumentrics 250W model demonstrated the ability to fully support television camera power needs throughout a four day race period while operating on a single 20lb bottle of propane. Comparable power provided by a standard 3kW Honda portable generator would require refueling with portable gas jugs twice per day each day over the same period. The Acumentrics unit also demonstrated the capability of remote start and control, like many of the NASCAR cameras, and was found to fit well into the ecosystem of the broadcast team. Unfortunately, though successful in demonstration, Acumentrics has performed no further work as the cost of the fuel cell generator still far outweighed that of the portable gas generator and the enhanced features were not sufficient to justify a substantial price increase.

As part of the ARRA funding initiative this program did not result in any new jobs created but did help the advancement of the technology and bring it one step further to commercialization.