FUEL CELL TECHNOLOGY FOR BACKUP AND SUPPLEMENTAL POWER APPLICATIONS

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CSX

6/13/2014

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ABSTRACT

Every year, the railroads are challenged by Mother Nature to keep America moving. She throws hurricanes, ice storms, wind storms, lightning and floods at us in her attempts to shut us down. When she does throw one of the weather punches at us, we usually respond in the same way every time. We deploy our troops in the worst weather conditions to place generators and then have to constantly refuel them several times each day until commercial power service is restored.

Fuel cell technology dates back to the early 1800's, but did not achieve commercial use until the mid-1900s with the NASA Space program. Since then, fuel cells have improved in both cost and design and are now utilized in many different industries to provide highly reliable power solutions. The opportunities to improve the reliability of the railroad infrastructure are tremendous.

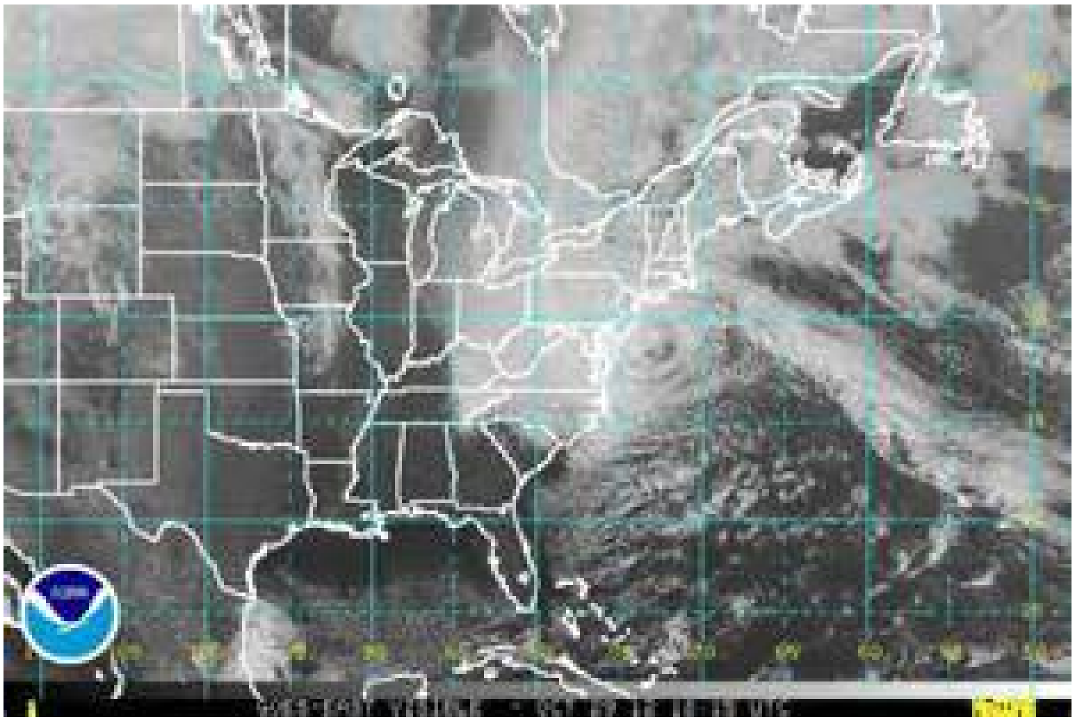
Over the last three years, CSX began deploying nearly 200 PEM (hydrogen) and solid oxide (propane) fuel cells to vital wayside signal, communication and grade crossing assets. The fuel cells are installed at locations where they constantly monitor power levels and come on automatically as needed during a crisis without any human interaction. The three to four weeks of continuous standby power that they provide on a single fuel load keeps our employees off the roads and out of the elements when a severe weather system knocks out commercial power. These vandal resistant units keep our systems up and running autonomously, and maintain public safety without the need for human interaction. They are the future of sustained reliability.

First RR fuel cell deployment at Collins Rd. Jacksonville, Fl.

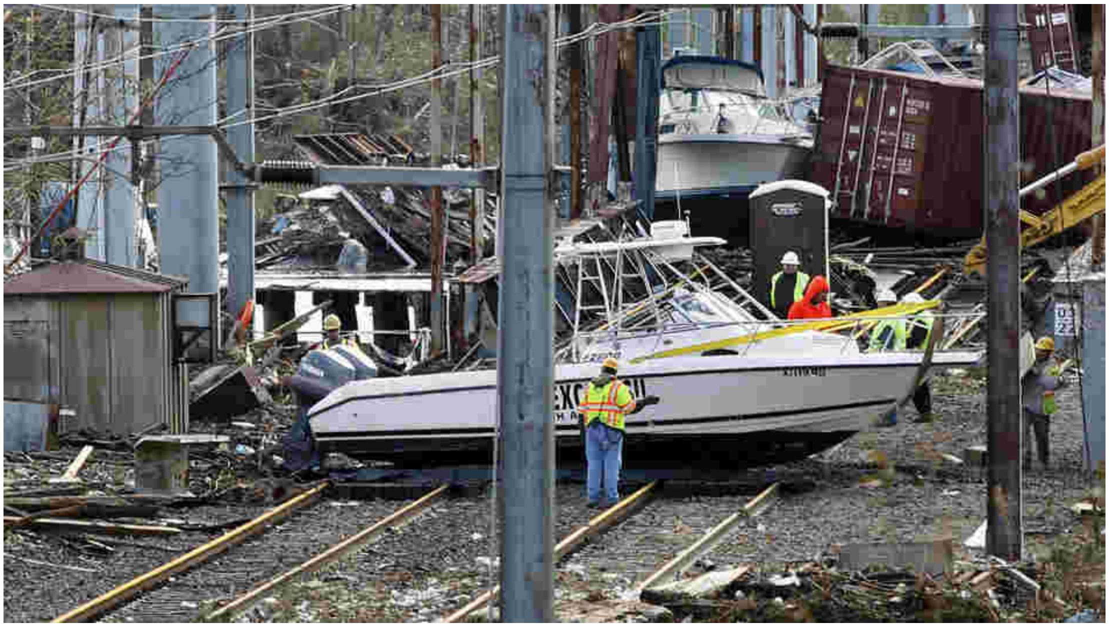
Introduction -

Every year, the railroads are repeatedly crippled by storms that destroy the commercial power grid and shut down our signal and communications systems. Each time we react the same way, with massive deployments of generators and personnel. This effort involves the locating and procurement of generators, deployment, connection, refueling and rotation strategies. It is typically an "all hands on deck" emergency response approach.

Treacherous hurricanes, blizzards, derechos, ice storms, lightning storms, tornados and floods are just some of the conditions that our railroaders have to conquer. Let's face it; the mailman has it easy in comparison. We routinely call upon our employees to head out in the worst road conditions possible to try to recover or maintain our operations. Each year, railroad employees suffer numerous vehicular accidents and work related injuries that occur as a direct result of the emergency response activities.



Satellite imagry of Superstorm Sandy making landfall

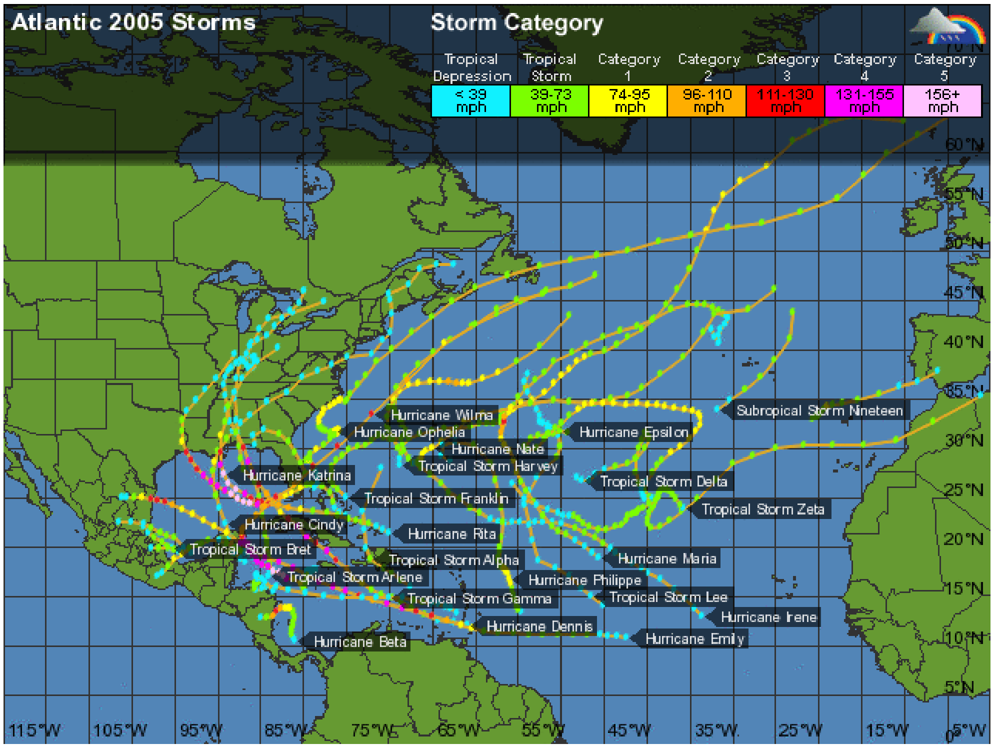


Aftermath of Superstorm Sandy

Mechanical generators have been a critical part of our emergency response plans for decades. CSX deployed upwards of 800 individual generators across their network during Superstorm Sandy in 2012. This includes lease units, rentals and locally acquired units. These all had to be put in place with great haste prior to, during and after the storm. Unfortunately, many of these generators had to be reconfigured onsite with new cables and plugs. Even though we had fuel trucks standing by, we struggled to keep all of those units running despite our scheduled refueling intervals. We had to constantly rotate generators from one asset to another while trying to keep track of them. All of these efforts occurred during the immense chaos of the storm.

Emergency generators are often difficult start due to fuel degradation or simple lack of maintenance. The ones that do start are often stolen or siphoned of fuel. In some instances, adjacent home owners or businesses cut our cables and plug in their own extension cords.

Like everyone else, CSX has been exploring different ways to overcome the insanity (doing the same thing over and over expecting different results). We have made improvements to our generator deployment process to make it more efficient and less painful. We have contracted lease fleets and deployment agreements with numerous suppliers. We have streamlined the refueling process with centralized fueling stations and have tried to make them vandal resistant by adding massive concrete bases. Even with these improvements, we still run into the same pains as before, but on a reduced scale. We have continued to challenge our employees and our suppliers to come up with ideas to alleviate these issues.



Atlantic 2005 Tropical System Paths

While our wounds were still relatively fresh from the damages dealt from the last few hurricane seasons that delivered the likes of Hurricane Katrina, CSX was aggressively exploring every conceivable option to prepare ourselves for the next bout. Everything from wind generators (ironically) to piezoelectric generators was on the table.

In 2008, CSX began researching the developments of fuel cell systems for the purpose of backup power for our signals, crossings and radio base stations. There were several companies that offered expensive, oversized units that had been designed for telecommunications and utility applications. However, our signaling loads were much lower than the minimum output of these units. We knew we needed to find a solution that was safe, efficient, reliable and cost effective.

In 2009, we found a company to design a railroad-specific hydrogen fuel cell that answered all of these requirements. After 4 years of collaboration with ReliOn on a Proton Exchange Membrane (PEM) hydrogen fuel cell, we now have nearly 200 locations with backup systems installed. We started developing a Solid Oxide Fuel Cell (SOFC) with AMI last year, and currently have 3 locations with backup/supplemental power installed.

Fuel cells have allowed CSX to provide many of our systems with ample backup power to cover power outages of nearly three weeks without the need to refuel. This has given us the ability to keep our people safe and keep our trains moving during the worst conditions from ice storms, tornadoes, floods or hurricanes. We will continue to refine the application to maintain our backup power strategy with these types of systems. Fuel cell technology gives us the opportunity to be proactive rather than reactive. It is a solution that can keep our systems running for several weeks without refueling, which keeps our maintenance teams focused on recovery duties and also keeps our trains moving and public travelers safe.

This paper explores the fuel cell development and application in the railroad environment. It addresses the similarities and differences of traditional battery and generator backups. It addresses some of the myths surrounding fuel cell technology and .discusses CSX's experience with fuel cells, including both the challenges and the opportunities for the present and future.

History –

Fuel cell technology is hardly a new concept. The first fuel cell was actually built by Welsh physicist William Grove in 1839. While the different concepts and prototypes developed over the years, it was not until the 1950's that General Electric engineers were able to develop the basis for the modern Proton Exchange Membrane (PEM) fuel cell that would become the first commercially application of fuel cells. The hydrogen fuel cell was made famous in the 1960's when NASA began using it for generation of electricity and drinking water onboard the NASA space craft.

- 1839 - William Grove invented the first fuel cell and called it the "gas battery"
- 1950s – GE invents the proton exchange membrane (PEM) fuel cell
- 1960s – NASA uses fuel cells in space for electricity and drinking water
- 1970s – The oil crisis prompts accelerated development of fuel cells
- 1980s – U.S. Navy uses fuel cells on submarines
- 1990s – Large stationary fuel cells are developed for commercial and industrial power
- 2003 – Fuel cells are sold commercially as backup power for telecommunications
- 2007 – Fuel cells are sold commercially as auxiliary power units (APU)
- 2008 – Honda begins leasing the FCX Clarity fuel cell electric vehicle
- 2009 – CSX begins working with suppliers to develop a low wattage fuel cell for signal backup applications
- 2010 – CSX deploys first RR fuel cell at Collins Road in Jacksonville, FL
- 2011 – CSX deploys 12 fuel cell locations in North Baltimore, OH.
- 2012 – CSX deploys 38 additional fuel cell locations for communications backup service
- 2013 – Massive storms interrupt commercial power service to greater Northwest Ohio region for over 3 weeks. All assets quickly deplete backup battery power and have to have portable generators deployed - except for the North Baltimore assets with fuel cells which continued to function without any interruption
- CSX purchases 140 more fuel cells for signal and communications.
- 2014 – CSX deploys three SOFC near Baltimore, MD. in hybrid solar applications

Definitions and Differences - Fuel Cell vs. Battery vs. Photovoltaic vs. Generator

While the applications of fuel cells, batteries, solar and generators may be very similar, there are distinct differences between each technology. Each one has its niche benefits and inherent problems.

By definition, a battery is a device that converts stored chemical energy into useful electrical energy. Basically, a battery stores electricity. When it runs out, it must be recharged with an external charger or disposed of. Nearly every railroad asset has some form of battery to supply short term backup power.

Photovoltaic (PV) arrays create electricity by converting sunlight into electricity. They usually have to be used in conjunction with storage batteries and only make electricity when directly exposed to sunlight. Simply stated, PV arrays only make power during daylight hours and when directly exposed. If obstructed by any foliage, buildings, etc. that would cast a shadow on the arrays, the output is dramatically reduced. They are also very prone to vandalism from guns (PVs are covered by cross hairs!) and rock damage. They are very limited by geography and real estate.

A generator (or alternator) is a device that converts mechanical energy into electrical energy. For the purposes of this paper, we will exclude the large turbines used for commercial power generation and focus mainly on the smaller engine driven devices used for local power generation. These generators are usually turned by an integrated piston type internal combustion engine that uses a gasoline, diesel or propane as a fuel source to produce electricity. As long as it has fuel, it will continue to produce electricity until mechanical failure occurs. They must have lube oil servicing and must be manually started and stopped. Generators tend to be noisy and are extremely prone to theft or vandalism.

A fuel cell is a device that converts the chemical energy from an external fuel into electricity through a chemical reaction with oxygen or an oxidizing agent. You can think of it like a generator with no moving parts. It is usually used in conjunction with storage batteries. It will continue to produce electricity as long as it has fuel and air. Fuel cells are not prone to theft or vandalism because they make almost no sound and very few people are familiar with what they are and what they can do.

Fuel types -

People use fuel every day for a variety of applications including driving a gasoline-fueled automobile to work, grilling dinner over a propane-fueled barbeque and heating and cooking in the home with natural gas-fueled appliances. A fuel cell is just another appliance like any of these and, like each of these, it is important to know the rules for safe operation.

The primary fuel types used for fuel cell generation are compressed hydrogen, propane, CNG, and methanol. The primary fuel for generators is usually gasoline, diesel or propane.

Hydrogen Volume	Propane BTUs (1 Gallon = 91,600 Btu's)	Diesel BTUs (1 Gallon 139,000)
1 Cubic Foot = 275 Btu	Equivalent Gallons	Equivalent Gallons
1 Cylinder = 260 Cu Ft	0.8	0.5
Fuel Wing = 6 Cylinders	4.7	3.1
HFM-16	24.6	16.2
HFM-25	36.9	24.3

Gasoline and Diesel –

These liquid fuels have been the most commonly used fuels for generators for decades. They are petroleum based and are extremely toxic. Gasoline is extremely flammable. Both fuels are potential environmental nightmares if spilled. They are both transported most often in small three or five gallon containers that are prone to tipping over and leaking even under ideal circumstances. Both fuels produce very toxic exhaust soot, fumes and vapors. These fuels are very prone to theft because the everyday citizen has multiple uses for these fuels. While the general public has become very complacent about transporting gasoline, it is *extremely* dangerous to do so.

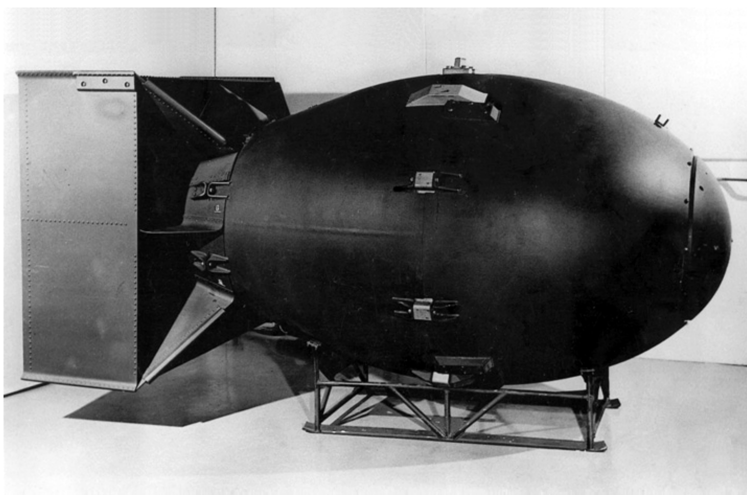
These liquid fuels are usually easy to acquire during normal times. Once a crisis is on the horizon, there can be lines at the pump that are literally miles long. Often times after a major weather event the commercial power is interrupted. Without power, the pumps cannot dispense the fuel to consumers.

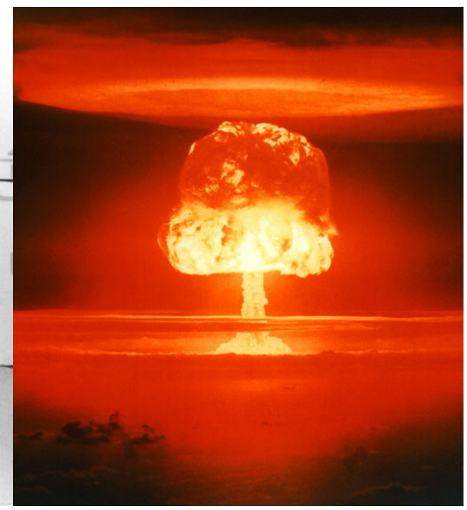
Propane –

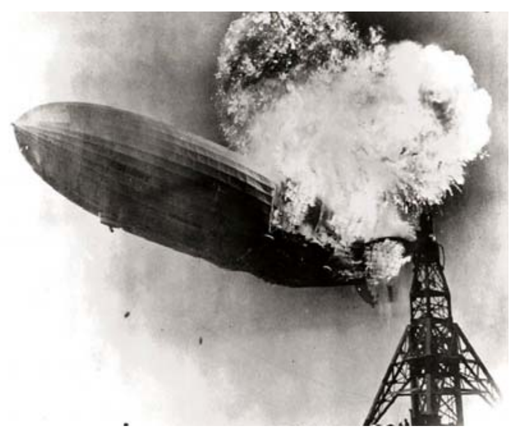
Propane is a hydrocarbon fuel that is a derivative of both natural gas processing and crude oil refining. It is relatively nontoxic, colorless and virtually odorless. It does have a commercial additive to give it a detectable scent. Propane is a vapor; it cannot be dispensed as a liquid. This means that it cannot be spilled. However, because it is denser than air, without proper ventilation, it can sink to ground level and form a pool of flammable vapor. Its ignition temperature is at least 940 F, which is roughly twice as hot as what is required to ignite gasoline.

One of the most attractive benefits to propane is availability. It is extremely easy to find at nearly every gas station, grocery store, hardware store and your neighbor's grill. Even if the power is out, propane can still be easily acquired and transported. Since it is in a sealed and pressurized container, it cannot be spilled if knocked over. The bottles also have built in check valves that eliminate leaks caused by forgetting to close the main valve.

Hydrogen myths and facts -







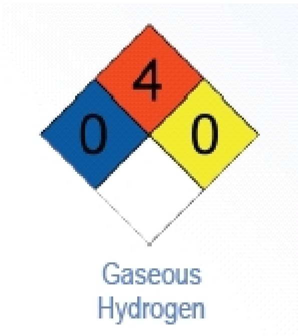
Little Boy, an M-80 and The Hindenburg

Even today, the word "hydrogen", evokes images of conflagration and destruction. Fuel cell manufacturers are well aware of this fact, which is why safety tops the list of their priorities. Working with codes and standards organizations to ensure safe deployment of these technologies, many states and jurisdictions are enjoying the benefits that fuel cells deliver.

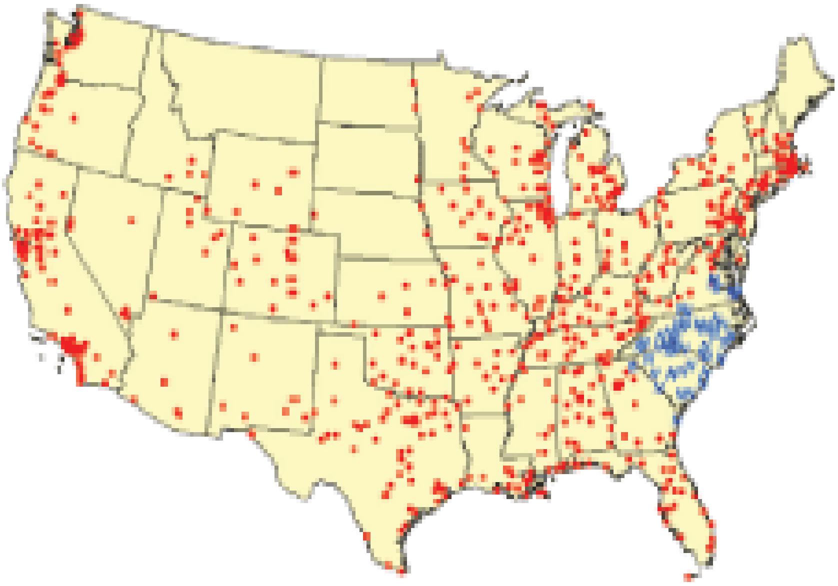
That said, more education is needed, as the 1937 Hindenburg air ship accident has been a major public relations nightmare for hydrogen. Interestingly, many questions regarding the cause of the disaster remain. Theories include that the skin of the airship had been painted with a highly flammable compound that was chemically equivalent to rocket fuel or napalm which ignited due to sabotage, static electricity or lightning strike. The facts are two thirds of those on board survived the crash. Of the 36 who died, many were burned by the diesel fuel used by the propulsion system (Bain A. and VanVorst W.D. (1999) “The Hindenburg tragedy revisited: the fatal flaw found”, International Journal of Hydrogen Energy, 24(3), 399-403.). The reality is that any ship filled with a gas to which an ignition source is applied will burn. In the aftermath of highly visible disasters such as the Titanic sinking, no one has suggested to discontinue trans-Atlantic ship crossings. Technological breakthroughs and judicious application of lessons learned can ensure safe and reliable use of nearly any asset. The job of investigators and engineers is to garner lessons learned and design safety into systems and procedures. Hydrogen is the lightest known gas, with a flammable range from 4% - 74% by concentration. It is useful to compare this to a known quantity. By way of comparison, propane has a flammable range from 2.4% - 9.6%. Propane’s flammability concentration is nearly 2 times lower than that of hydrogen. While hydrogen has a wider flammability range, it can be argued that the more important metric is the lower flammability limit.

Hydrogen is 0.0695 the density of air, or 14 times less than the density of air. Hydrogen cylinder storage enclosures are designed with multiple venting holes to ensure that in the event of a hydrogen leak, the hydrogen gas is safely vented to the atmosphere and allowed to disperse. Without vents, the gas could rise and pool in the upper portions of the enclosure. Hydrogen’s dispersion characteristics will ensure that as the distance from the leak source increases, the density of hydrogen will quickly drop below the flammable limit. (Companion Guide to Hydrogen: The Matter of Safety)

Hydrogen is colorless, odorless, tasteless and non-toxic. Therefore, it is necessary to utilize gas detection equipment when using or handling hydrogen gas. The NFPA Hazard Diamond classification for hydrogen is shown here. Fuel cells and fuel storage generally contain hydrogen safety sensors, which activate and shut the systems down in case of a leak. Best practice recommends the use of a hand-held combustible gas detector to verify that there is no leakage when exchanging or refilling fuel. Hydrogen gas detectors are commercially available and affordable. Liquid soap solution also works effectively to locate any leaks.



Hydrogen must be delivered to a fuel cell site, if it has not been produced on-site. Storing hydrogen in pressurized steel or composite cylinders is technically straightforward and widely used. The gas supply industry routinely stores multiple gases in cylinders for customers in a variety of industries. Compressed, bottled hydrogen is the most readily available commercial source of industrial grade hydrogen and can be found throughout the world and at over 2,500 locations in the U.S. alone. Compressed hydrogen is a versatile fuel having a wide operating temperature range. The benefits of gas cylinders are simplicity and indefinite storage time. The downside is the inconvenience of exchanging cylinders weighing about 135 pounds each. The delivering agent will usually deliver and install the bottles into the cabinet. Railroad employees typically only have to connect the supply lines and check for leaks.



Industrial Grade Hydrogen Availability Map

Similarities/differences between PEM and SOFC -

Both technologies, Proton Exchange Membrane and Solid Oxide Fuel Cell, have advantages and disadvantages.

ReliOn E-200 Fuel Cell System (PEM)

AMI ROAMIO P250 (SOFC)

PEM - Uses compressed hydrogen

SOFC - Uses propane or natural gas

PEM – Low temperature operation (<120 C)

SOFC – High temperature operation (500 C to 1000 C)

PEM - Requires the purchase or annual rental of at least 6 hydrogen bottles from gas supplier

SOFC - Requires 2 standard 20lb. propane tanks. Propane requires filters that must be changed out based on the amount of fuel used

PEM - Hydrogen must be supplied and delivered by the gas supplier (Airgas). Hydrogen infrastructure has dramatically improved over the past decade and is suitable for reliable supply usually within 24 hours after order is placed

SOFC - Propane is available at nearly any gas station, grocery store or hardware store. Does not have to be delivered and is easy to maintain spare tanks. Propane may also be tapped off of nearby propane switch heater tanks.

PEM – Requires approximately one minute to start supplying 60-70% of maximum output and approximately 30 minutes to reach 100% output

SOFC – Requires approximately thirty minutes to reach operating temperature and online at which time it is at 100% of maximum output

PEM – Requires periodic (usually 2-4 weeks) exercise cycles to maintain hydration of membrane. Small amount of fuel consumed during each cycle

SOFC – Can remain in standby mode infinitely without intervention

Both types have ~ 15-20 years of reliable lifecycle

Both units are very suitable for railroad standby and hybrid (solar) applications

Both units provide remote monitoring and alarming capabilities

Both units can send messages to the maintainers when they are getting low on fuel

Both units operate on demand without any human intervention

Both provide approximately 3 weeks of off grid power on a single fuel load (6 bottles of hydrogen or 2 bottles of propane)

Both require only maintaining fuel and annual inspection/replacement of air filter.

Both types are connected directly to the battery buss and utilize the voltage levels to initiate the command to turn on as well as targeted float voltage to return to standby operation. For example, on a standard twelve volt signal battery bank, the "turn on" voltage would be set at 10.5 VDC to 11.0 VDC (this is dependent on the type of battery and number of cells). The "return to standby" or float voltage must be set slightly lower than that of the primary charger so that when commercial service returns, the fuel cell will be prompted to turn off. These settings are based on the battery types, capacities and manufacturer recommendations.

Fuel cell applications –

Currently, fuel cells are used in a wide range of applications including space exploration, telecommunications base stations, military and commercial aviation, military UAVs and submarines, automobiles, motorcycles, buses, forklifts, boats, residential power and commercial power. Basically, anything that uses electricity can be powered by a fuel cell.

Railroad applications –

CSX first considered fuel cells to provide backup power at our control points, interlockings, defect detectors and communications base stations where sustained service is the most critical. These locations can be very isolated and difficult, if not impossible, to access in poor weather. Highway grade crossings and solar/ fuel cell hybrid applications quickly showed potential for reliability improvements as well.

Fuel cells can also be used in hybrid solar applications where sunlight is limited or obstructed by foliage or other obstructions. Often times, increases in traffic or short winter days combined with extended periods of overcast skies create a condition that solar arrays were not originally designed to overcome. A fuel cell can be added to complement the solar array as opposed to using a generator or adding arrays.

When determining where to deploy a fuel cell, we strategically rated each potential candidate site based on location, traffic, type and amount of equipment, level of risk, accessibility, age, condition of commercial grid, and historical reliability of the location. Our strategy for deployment was to provide reliable backup power to our most critical, susceptible, and hard to access locations.

Generator issues –

As railroads continue to learn time and time again, generators are very expensive, unreliable and labor intensive to deploy. Even with the best strategies, once deployed, they are extremely expensive to operate and maintain as well as highly susceptible to vandalism and theft. Each one must be refueled several times per day. We often have to rotate them between multiple assets to maintain railroad operations, due a shortage of available operational units.

Deployment of generators has been hit and miss that is often tied to the weather forecasts. While there are typically a handful of small (< 2kW) generators at the local level, most are contracted from a vendor who stores, maintains and deploys a large fleet of ~600 mid-size (2kW – 5kW) generators. Many times, by the time the generators are loaded onto a truck and sent to the field, they have to wait for the storm to hit to know where they actually have to be taken. Often times, the deployments are precautionary. We have the generators deployed to an impact region, but the generators never even make it off the trucks before they are sent back for storage.

When the generators do make it to the right location at the right time, many other issues must be overcome. They must be properly connected to the supply circuit with the correct cable. They must be fueled, and then hopefully they start. Because the generators must be left running to produce power, they have to be refueled aver 6-

8 hours. Each time a generator has to be refueled, it is another at least 2-3 hours of labor and vehicle assets per location. In many instances, operating generators are purposely shut down by outside parties due to the noise produced.

Mechanical generators, at best, only have 60%-80% reliability. They are relatively inexpensive to purchase, but extremely expensive to maintain, deploy and keep running. Total cost of ownership can quickly eclipse that of a fuel cell.

Fuel cell reliability –

Third party testing has shown fuel cells to produce reliability in the range of 96%-99%. This range greatly exceeds that of any other technology being used today.

Cost benefits -

When all factors are taken into consideration, fuel cells are far less expensive to own and maintain than conventional generators.

Environmental benefits -

PEM fuel cells only emit water as a byproduct of the reaction. The SOFC emits water and a relatively small amount of carbon dioxide during its production of electricity. Both types only emit the noise of a small electrical fan running that can barely be heard when the enclosure doors are closed. They also minimize the opportunity for fuel spills on the ground that often occurs during the frequent refueling of generators.

Conclusion –

Insanity: "Doing the same thing over and over again and expecting different results." - Albert Einstein

For years, we have all repeatedly responded to Mother Nature's wrath in the same manner.   We continue to put our employees and the public at risk, "doing what we always do." Our efforts waste millions of dollars in recovery costs and operational losses. While we cannot control the weather, we can control how we prepare for it. Fuel cells offer a viable solution to lessen the effects of unpredictable weather events that plague our operations. Fuel cells provide an opportunity to be proactive rather than reactive, as an industry. As we all know, Rome was not built in a day. However, every time that we take advantage of an opportunity to install a fuel cell, we become better prepared for the next inevitable outage event. Fuel cells have enabled CSX to become increasingly proactive in our emergency response.

Email from Signal Maintainer after extended outage In N.W. Ohio

From: Richey, Robin
Sent: Friday, July 19, 2013 11:26 AM
To: Matthews, Marlin Jr.; Dalton, Rex; Siler, Marlon
Subject: RE: Fuel Cells

Yes certain locations did lose power here and there. Rangeline was one of them. The fuel cells did work as intended. I was confident in that to the point that I told the dispatcher not to be concerned with the power off indication because the location would continue to work properly due to the fuel cells, and they did. No problems what so ever and had no issues with any of the locations during the storms or outages.

Rob Richey

Signal Maintainer

North Baltimore, Ohio 45872

Cell: 419-344-XXXX

Fuel Cell Technology for Backup and Supplemental Power

AREMA® 2014

Annual Conference & Exposition

CHICAGO September 28 - October 1

Landfall of Sandy

Impact of Superstorm Sandy (2012)

Aftermath of Superstorm Sandy

2005 Tropical System Paths

Generators

- Portable mechanical generators are typically dispatched to each location.
- Contracts with lease providers for >800 individual units that includes maintenance.
- Local forces procure residential units at retail stores when available.

What is a generator?

A generator (or alternator) is a device that converts mechanical energy into electrical energy. For the purposes of this paper, we will exclude the large turbines used for commercial power generation and focus mainly on the smaller engine driven devices used for local power generation. These generators are usually turned by an integrated piston type internal combustion engine that uses a gasoline, diesel or propane as a fuel source to produce electricity. As long as it has fuel, it will continue to produce electricity until mechanical failure occurs. They must have lube oil servicing and must be manually started and stopped. Generators tend to be noisy and are extremely prone to theft or vandalism.

Generator Advantages

- Relatively affordable purchase price
- Very portable
- Fuel is usually readily available during non-emergency

Generator Drawbacks

- Requires initial deployment
- Requires manual starting
- Plug compatibility
- Poor reliability
- Destructive vandalism
- Generator theft
- Fuel theft
- Carbon Monoxide poisoning
- Noisy
- Requires storage and maintenance
- Fuel degradation
- Frequent refueling (6-8 hours) during extreme weather
- Requires transporting gasoline in trucks to refuel
- Gas stations cannot pump fuel without power
- Fuel spills
- Lifting injuries

What is a fuel cell?

A fuel cell is a device that converts the chemical energy from an external fuel into electricity through a chemical reaction with oxygen or an oxidizing agent. It is usually used in conjunction with storage batteries. It will continue to produce electricity as long as it has fuel and air. Fuel cells are not prone to theft or vandalism because they make almost no sound and very few people are familiar with what they are and what they can do. You can think of it like a generator with no moving parts

Fuel Cell History

- 1839 - William Grove invented the first fuel cell and called it the “gas battery”
- 1950s – GE invents the proton exchange membrane (PEM) fuel cell
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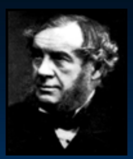
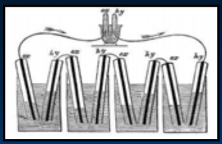
What Is a Fuel Cell?

- A fuel cell is a device that converts the chemical energy of a fuel (hydrogen, natural gas, methanol, gasoline, etc.) and an oxidant (air or oxygen) directly into electricity
- Invented in 1839 by Sir William Grove
- First commercial use was with NASA



Sir William Grove



Grove's Gas Battery

Benefits & Features of Fuel Cells

- PEM fuel cells produce electricity directly from hydrogen fuel
  - Highly reliable: 99.7% third-party verified reliability
  - High quality power
  - Clean power
    - Power without combustion
    - No harmful emissions
      - By-product is water
      - CARB zero emission power generator
      - Supports corporate sustainability objectives
    - Superior to batteries and generators
  - Quiet operation compared to combustion generators
- Complementary to solar and wind energy as part of a hybrid solution

- CSX fuel cell applications:
  - Communications base stations
  - Wayside signaling
  - Control points
  - Interlockings
  - Highway grade crossings
  - Defect detectors
  - Slide fence monitoring
  - Switches & signals
  - Solar hybrid

ReliOn E-200 (PEM) Fuel Cell

- Highly reliable, modular
  - 99.7% third-party validated reliability
  - Field proven through hurricanes, ice storms, winter storms, heat and cold
- Scalable to meet multiple power requirements
- Cost-effective
  - Simple field maintenance, repair & upgrade
  - Long runtime solutions allow for weeks between refueling visits
  - Quiet, non-descript operation, not prone to theft

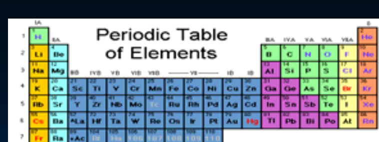
PEM Product Design Philosophy

- Highly reliable, modular, scalable
  - 99.7% third-party validated reliability
  - Product design allows flexibility in configuration to meet project needs
- Field maintenance, repair & upgrade
- Easy integration with OEM power equipment
- Continual focus on reducing manufacturing costs
- R&D focus on improved performance, quality & cost reductions through
  - Technical Innovation
  - Core MEA technology
  - Novel Materials
  - Process Control
  - Quality improvements

Hydrogen Myths

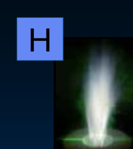
Hydrogen Basics

- H_2 is a diatomic molecule
  - 2 protons, 2 electrons
- Lightest element in the universe
  - Disperses rapidly – 1/14th the density of air
- Hydrogen first discovered 1766
  - Henry Cavendish
  - Named for being a "water former"



Hydrogen Basics (cont.)

- Colorless, odorless and has no taste
- Non-toxic
- Environmentally-friendly
- Flammable from 4% - 75% in air (LFL = 40,000ppm)
  - Comparison: propane 2.2% - 9.6%; gasoline 1.0% – 7.6%
- Burns with a pale blue flame



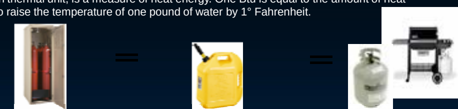
U.S. Hydrogen Availability

- Hydrogen is widely available through multiple gas providers
  - Industrial gas suppliers including Air Products, Airgas, Praxair, Air Liquide
  - Third party providers including IGX

Fuel Comparison: Energy Content

The per unit energy content of the fuel is measured in Btus

- Btu, British thermal unit, is a measure of heat energy. One Btu is equal to the amount of heat required to raise the temperature of one pound of water by 1° Fahrenheit.

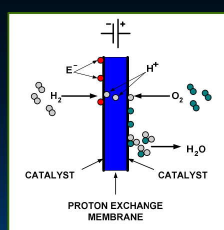


6 Cylinders of Hydrogen (1 Cylinder = 69,000 Btu) = **3.1 Gallons of Diesel** (1 Gallon = 133,000 Btu) = **4.6 Gallons of Propane** (1 gallon = 90,000 Btu)

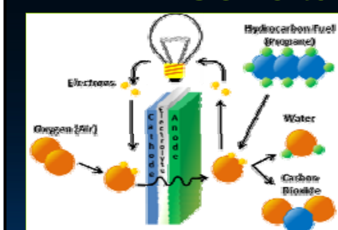
Hydrogen Volume	Diesel Equivalent Gallons	Propane Equivalent Gallons
1 Cylinder	0.5	0.8
Fuel Wing (6 Cylinders)	3.1	4.6
HSM-9 Refillable Module	9.3	13.8
HSM-16 Refillable Module	16.6	24.5

How Does a PEM Fuel Cell Work?

- Operates electrochemically like a battery, but does not run down or require recharging
- Run time determined by quantity of fuel storage (like a generator)
- Uses an electrolyte
  - No moving parts
  - Named by type of electrolyte
- Much more efficient than fuel combustion



SOFC technology



Oxygen through electrolyte
Enables use of hydrocarbon fuels

Tubular Design

- Ceramic fuel cells
  - Inexpensive raw materials
  - Not susceptible to temperature, humidity, or prolonged exposure
- Tubular SOFC architecture
  - Extruded like drinking straws
  - Thermal shock tolerant – rapid start
  - Mechanical shock tolerant - rugged

Propane - Safe & Available

- Highly energy dense and commercially packaged
  - Two BBQ grill tanks supply 14 days of operations without user interaction
- Certified as a clean fuel by Clean Air Act of 1990
  - Similar to carbon dioxide, the only health risk is lack of oxygen
- Safety
  - Will not ignite without high temperature source
  - Narrow flammability range
  - Nontoxic, so it's not harmful to soil and water. Because propane does not endanger the environment, the placement of propane tanks either above or below ground is not regulated by the Environmental Protection Agency.
- Availability
  - 56,000 miles of propane pipeline
  - Millions of daily users
  - 1000's of retail outlets

For additional Information on Propane Safety: http://www.propanecouncil.org/what-is-propane/facts

Applications

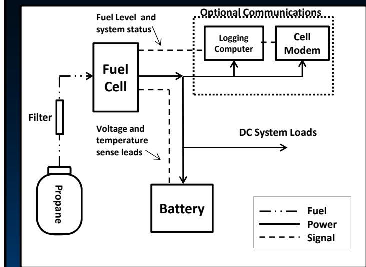
Grid Tied – AC Backup

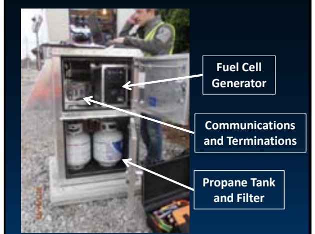
Grade Crossings and Signals

Off Grid - Fuel Cell / Solar Hybrid

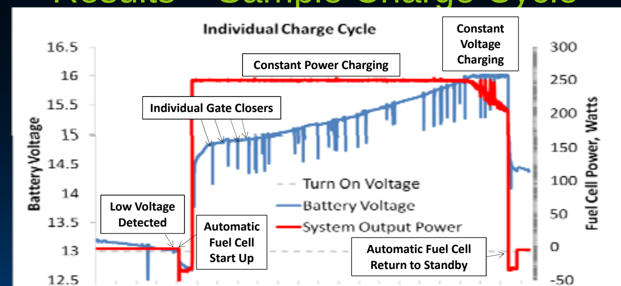
Remote signals and sensors

Simple System Schematic



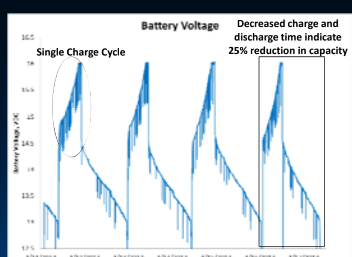


Results – Sample Charge Cycle



Total System Health Monitoring

- Using data reported from fuel cell charge cycles we can estimate the health of the backup batteries remotely
- Monitoring charge and discharge rates results in the identification of a bad cell resulting in 25% drop in battery performance



Fuel Cells vs. Diesel Generators

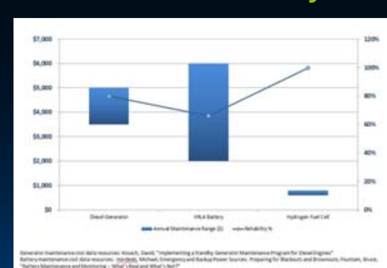
Feature	Diesel Generator	ReliOn fuel cells
Overview	Internal combustion diesel generators deliver medium quality electrical power by burning fossil fuel and using it to drive a rotation generator	Fuel cells offer clean, continuous high quality electrical power resulting from an electrochemical reaction with hydrogen and oxygen from ambient air
Availability	With auto-start capability, available 24/7	Fuel cells are available 24/7
Efficiency	Diesel generators are about 30% efficient	ReliOn fuel cell systems are about 50% efficient
Temperature Sensitivity	Starting and fuel quality issues in cold and warm temperature extremes	ReliOn fuel cells achieve rated power and life at temperatures between 23°F and 122°F ambient or -40°F and 122°F in environmentally hardened cabinet
Reliability	Medium – hundreds of moving and sliding parts offer multiple points of failure. 88.4% third party verified reliability	High – few moving parts. 99.7% third party verified reliability
Environmental	High levels of NOx, CO2, CO and particulate matter emitted. Fuel is toxic to environment when spilled	Clean – heat and water are the only emissions
Cost	Low to moderate capital cost. Moderate to high operating cost with frequent complex maintenance visits required.	Moderate capital cost – at required power, extended runtime provided by increase in amount of hydrogen stored or by refueling trips. Operating cost is low as maintenance is simple
Noise	Exhaust and mechanical noise	Silent, except for fan noise. Fuel cell noise tends to be 10 - 20db lower than diesel generator noise
Size	Significant space required for generator and fuel storage tank	Compact, high power density
Maintenance Requirements	Medium to high – requires complex periodic evaluation and maintenance	Infrequent remote maintenance and on-site filter changes
Life	Typically about 10 years	As backup power, greater than 10 years

Generator Operating Costs

Hurricane Katrina Maintenance Cost Estimates	
No. Technicians	1
No. Hours/Shift	10
Loaded Labor Rate	$75
No. Days	14
Cost/Site	$10,500

Maintenance Cost vs. Reliability

- Fuel cells have much lower annual maintenance costs and higher reliability as compared to diesel generators and VRLA batteries
- Higher value for the railroad for lower continual cost



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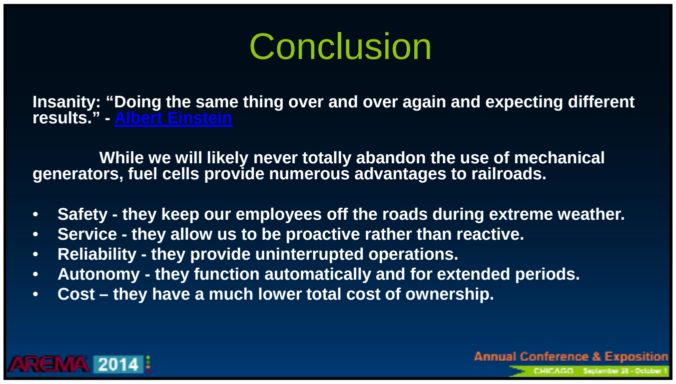
Conclusion
Insanity: “Doing the same thing over and over again and expecting different results.” - Albert Einstein
While we will likely never totally abandon the use of mechanical generators, fuel cells provide numerous advantages to railroads.
• Safety - they keep our employees off the roads during extreme weather.
• Service - they allow us to be proactive rather than reactive.
• Reliability - they provide uninterrupted operations.
• Autonomy - they function automatically and for extended periods.
• Cost – they have a much lower total cost of ownership.
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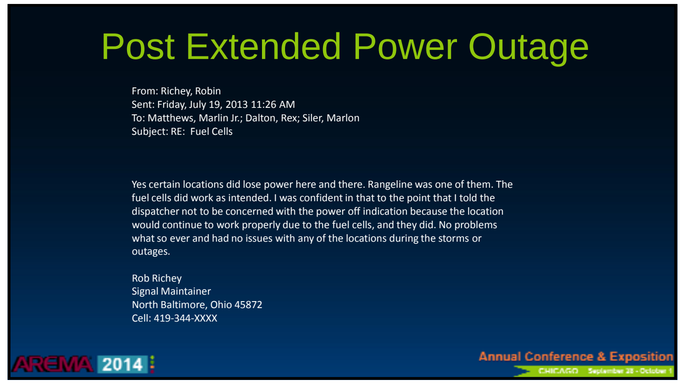
Post Extended Power Outage
From: Richey, Robin
Sent: Friday, July 19, 2013 11:26 AM
To: Matthews, Marlin Jr.; Dalton, Rex; Siler, Marlon
Subject: RE: Fuel Cells
Yes certain locations did lose power here and there. Rangeline was one of them. The fuel cells did work as intended. I was confident in that to the point that I told the dispatcher not to be concerned with the power off indication because the location would continue to work properly due to the fuel cells, and they did. No problems what so ever and had no issues with any of the locations during the storms or outages.
Rob Richey
Signal Maintainer
North Baltimore, Ohio 45872
Cell: 419-344-XXXX
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