Applications of Mobile Off-Grid Infrastructure Solutions:
Modular Packaged Systems to Provide Sustainable Alternatives for Long Term Off Grid Energy Production, Water Conservation and Waste Treatment.

Master of Science Architecture
Sustainable Design Track
Plan B Project

By

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Abstract:

This paper explores off-grid infrastructure with regards to the technological capacity of portable, small scale, renewable energy systems to meet a specific demand. The MERS program, which is a division of FEMA, is being used to test the merits of off-grid infrastructure with regards to mobile applications due to it's specific and demanding program. The MERS program is estimated to consume 64,500 kWh and approximately 95,000 gallons of water over a 30 day period. By evaluating the resource loads of MERS, insights can be made in order to assess the appropriateness of renewable energy production and storage, grey water capture and treatment. A grey water cycle along with chemical toilets will reduce to amount of replacement water to nearly 2000 gallons. Renewable energy sources include vertical axis wind turbines and folding solar panels that can be used directly to supply energy for MERS and/or energy for hydrogen gas production as means for energy storage. If hydrogen fuel cells are to be used as a source of energy it will be in the best interest of MERS to transport hydrogen made off-site using renewable energy rather than produce it on site. The most efficient use of on-site renewable energy is to reduce the energy load of the MERS program. The most efficient use of diesel fuel is to use a micro centralized energy distribution system to keep generators running near capacity.

Introduction:

This research paper will investigate the potential of mobile, technological systems to provide energy, water, and waste management without grid-tied services. In this investigation the Mobile Emergency Response Support (MERS) detachment, a division of the Federal Emergency Management Agency (FEMA), will be used as a programmatic template to simulate a condition that offers demanding energy use while remaining autonomous in a regional climate condition. This however, will not directly assess the programmatic means and implications of MERS, but rather determine how this type of program could perform in a more sustainable way in the context of emergency response, by using currently available technologies. Maintaining a mobile platform that can operate without being location-specific or being permanently tied to local resources has greater implications for any program that would benefit from the adaptability of on-site life support function and maintain a low ecological footprint. The investigation will ascertain the technical feasibility of using sustainable technologies and strategies as a means to generate renewable energy, clean and re use water, and manage waste as an example of how to maintain itself, while reducing dependence on finite resources. It will also investigate a more efficient use of diesel fuel, by way of estimating and managing peak load demands.

Through the quantitative analysis of evaluating the programmatic resource demands of the MERS detachment, information will be generated to asses the various options for on-site resource management. This information, as to how to provide or augment autonomous support for 30 days with a crew of 100 people, can be used to shift from a mitigative strategy to one that is adaptive. While the feasibility of an on-site renewable energy solution for the direct application of disaster relief may falter for a number of reasons, the investigation of the energy and water demand at this scale is valuable for the design of autonomous programs with limited access to resources or related applications where supply of resources has become severed.

Mobile infrastructure is useful for disaster relief so that the equipment is readily deployable to the disaster location. The concept is that the services such as water purification, water reuse, energy production, hydrogen generation can be modularized into components and packaged by function. The modular delivery method is also important so these stand alone components are able to be set up quickly and efficiently. The number of service packages may not be linearly related to the number people using them since the scale of efficiencies can vary from service to service. Conceptually, the modularized solutions that allow for mobility also allow the program to adapt to a particular climate or need by adding packages. Components can be added in series to increase capacity or arranged to increase efficiency. For example, a solar thermal package could be set in line with a water storage tank or locations with less sun would bring more wind turbine packages. The packages and technologies are designed to fit the dimensional constraints of intermodal shipping containers to take advantage of current transportation infrastructure to reach the intended recipients nearly any place where a train, truck, or ship has access.

Removing services from traditional, centralized grid connections implies the use of decentralized or micro centralized, on-site services to provide access to clean water, to generate and store energy at sufficient levels, and the ability to manage and treat waste, while remaining self sufficient. Although conservation will reduce demand, either through technological refinement and/or behavioral adaptation, the requirement of those basic services that the grid provides will be needed. Inquiries about how and to what degree these technological systems will provide these decentralized services, while remaining relatively small so that they can remain mobile, will impact the scale at which they operate. These systems could work together synergistically to increase efficiency, or to adjust scale in proportion to each other to adapt to various climates and seasonality. For example, a water treatment system could store water in a solar thermal tank to reduce demand for heating water with fuel. These systems can take advantage of renewable resources such as the sun or wind to generate energy and should be scalable to adjust accordingly to local natural energy resources. It may be more advantageous for example, for a deployment to the southwest to be fitted with more “solar cell units” than a deployment to the northern plains where “wind turbine units” are better suited.

In order to evaluate the general feasibility of mobile off-grid infrastructure in the application of mobile disaster relief, this investigation will work with a manageable and defined set of variables, not tailored to a specific location but an average assumption based in the region where the majority of disasters occur. When a disaster of great magnitude occurs, federal organizations deploy aid in the form of mobile, self-contained and self-sufficient packages such as mobile clinics, offices, and communications to render assistance and provide life support functions. Analyzing the energy and water requirements of these universal solutions will test the limits and advantages of existing technologies to meet the demands of a baseline condition that is currently carried out by the conventional methods of diesel powered generators and packaged water. By using this baseline condition, the metric of a 30 day autonomous deployment can be used to ascertain the effectiveness of sustainable technologies in this application.

Background: *The FEMA agency organization and the MERS mission as a comprehensive test.*

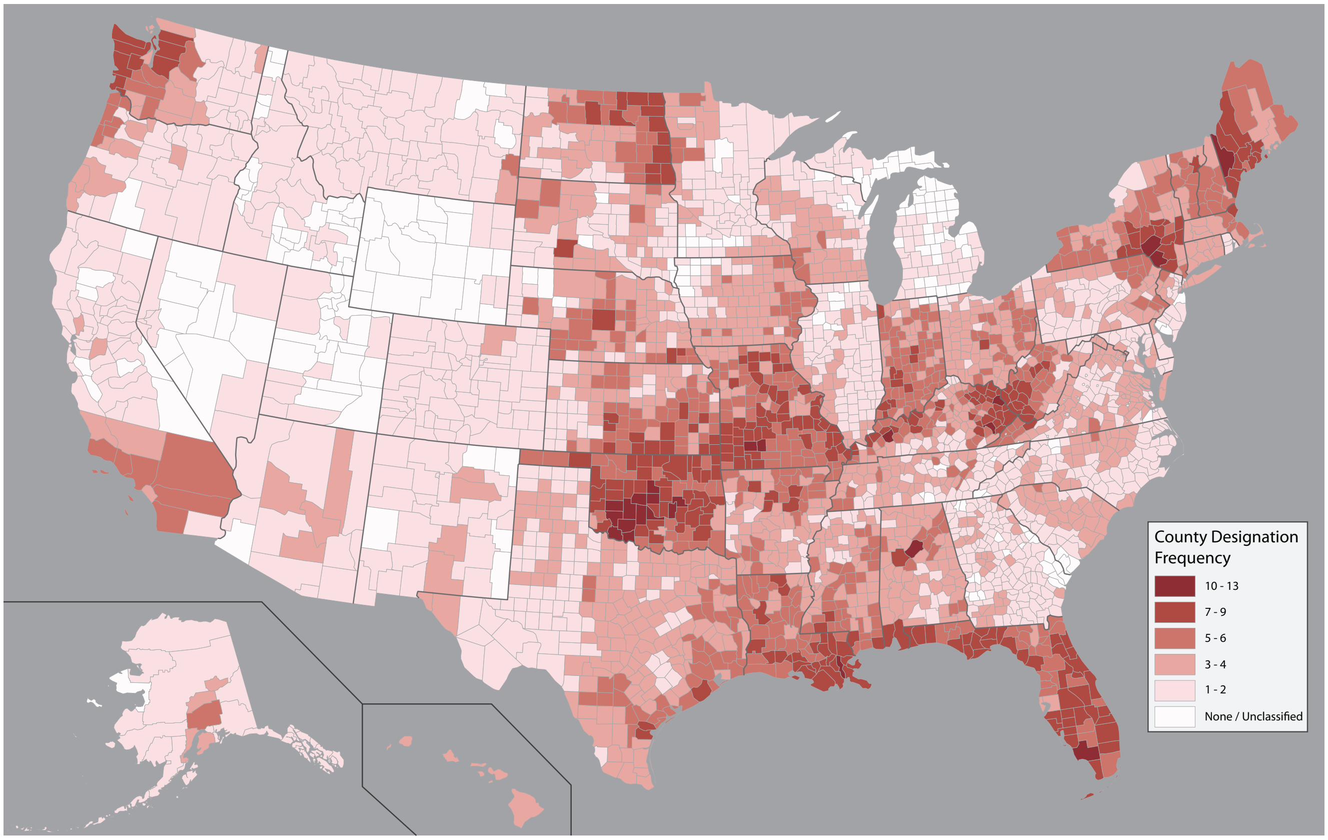
The Federal Emergency Management Agency (FEMA) is not a first responder to a disaster. First response to a natural disaster or terrorist attack is always handled by local police, fire, and emergency personal. Their job is to rescue and aid those injured, suppress fire, secure and restore order to the disaster area. If the event is so large that it overwhelms local agencies, the assistance will involve State Government and the National Guard to render aid and help with recovery efforts. If the event exceeds the State's capacity to respond, an application is filed by the governor of that state and reviewed in Washington D.C. Once the President has reviewed the application and has declared a national disaster, the National Response Plan (NRP) is set in motion. FEMA, operating from that region's office (there are 10 regions to serve the United States) along with the Red Cross and other federal departments are activated to direct and assist local operations. [Ch.4 from FEMA EMI]

Within FEMA, there is a division called the Mobile Emergency Response Support (MERS). The mission of MERS is to provide prompt and rapid multimedia communications, information processing, logistics and operations support, power generation and life support required for the on-site management of disaster response activities during catastrophic emergencies and disasters for government response and recovery operations. MERS has with it highly specialized equipment and trained personal. They are self sustaining and fully operational in austere conditions. MERS operates with local authorities to assist the aid workers that support the Federal, State, and local responders, not the disaster victims. [FEMA web site]. Each MERS Detachment is headquartered in five geographically dispersed locations each covering 2 FEMA regions. The detachment consists of a variety of modified trucks and trailers that can be shipped overseas, air lifted by military aircraft or driven cross county. The estimated speed of delivery is an average of 50 miles per hour. It is critical to maintain the flexibility of this delivery method as a containerized system that can be transported across the county with the same time constraints.

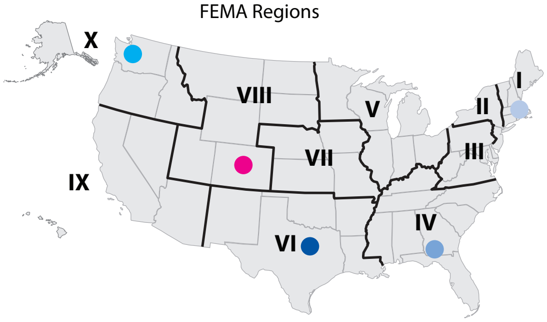
The MERS program offers a framework for testing the feasibility of other mobile self sustaining endeavors by evaluating the capabilities of sustainable systems in terms of ability to meet FEMA's requirements for MERS with regard to transit logistics and 30 day resource autonomy. Using this criteria allows for a measurable test application as opposed to disaster relief at the State level with many more variables. The MERS unit is outfitted to meet a specific mission and its energy demands for providing communications, logistics, resource allocation/ connections and conservation can be used to accurately define assumptions. Extrapolations can be made to these and various other scenarios if it is indeed feasible to provide off-grid life support without conventional power sources dependant on the use of diesel generators. The overall metric of fuel consumption will be to evaluate the amount resources required to maintain operations. The secondary goal is to help FEMA become more effective by either using less fuel, refueling less often, or to not need diesel fuel at all. By reducing the amount of diesel power generation done on site, an added benefit is noise reduction as diesel generators add noise and fumes to an already stressful situation.

Chapter 4, Response from FEMA's Emergency Management Institute, http://training.fema.gov/EMI/
MERS Logistics, Support Considerations, and Mission, http://www.fema.gov/emergency/mers/

Disaster Declarations
from January 19, 2000 to January 1, 2010



FEMA Regions



By FEMA Region

Region I	= 41
Region II	= 35
Region III	= 49
Region IV	= 111
Region V	= 64
Region VI	= 76
Region VII	= 67
Region VIII	= 38
Region IX	= 45
Region X	= 34

Disaster Type

Severe Storm	= 400
Hurricane	= 48
Sevvre Ice Storm	= 27
Flood	= 23
Typhoon	= 14
Fire	= 15
Tornado	= 10
Earthquake	= 8
Snow	= 6
Coastal Storm	= 4
Other	= 5

Total = 560

MERS Detachments:

Region I & II	Maynard, MA
Region III & IV	Thomasville, GA
Region VI & VII	Denton, TX
Region V & VIII	Denver, CO
Region IX & X	Bothell, WA

In Minnesota the MERS detachment comes from Denver, CO and also responds to Illinois, Indiana, Michigan, Ohio, Wisconsin, Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming.

Information for presidential disaster declaration from FEMA, http://www.gismaps.fema.gov/recent.pdf

It is important to note that disaster response and aid can be carried out by a number of federal agencies as unique disasters warrant varying levels of federal intervention. Additionally, various functions and responsibilities can be assigned to the same agency. The actions of disaster relief are divided into 15 Emergency Support Functions (ESF) and can be carried out by various divisions within FEMA or by FEMA directly. FEMA may operate as the primary agency to carry out these missions, work as a support agency, or as an ESF coordinator. Other agencies that can and will act as a primary agency (depending on the EFS) are the Department of Homeland Security, Department of Housing and Urban Development, U.S. Department of Agriculture, or the U.S. Coast Guard. EFS missions are assigned by the Incident Command System to be carried out by in conjunction with the Joint Field Office or the Regional Response Coordination Center.

FEMA response centers are given operational command over 10 different disaster zones defined by state boundaries. These zones are divided by state boundaries and most zones cross several different climate regions. Each MERS detachment brings with it enough supplies and diesel fuel to be independent regardless of location. While FEMA's allocation of diesel fuel would remain a top priority, renewable energy options need to be explored so that MERS can continue it's operational goals should the ongoing transport of this fuel and water supply be interrupted. These renewable options need to be specified in a manner that allows them to respond to events in any location with quick, minimal set-up and remain autonomous for at least 30 days.

	Emergency Support Functions														
Agency	**#1 - Transportation**	**#2 - Communications**	**#3 - Public Works and Engineering**	**#4 - Firefighting**	**#5 - Emergency Management**	**#6 - Mass Care, Emergency Assistance, Housing, and Human Services**	**#7 – Logistics Management and Resource Support**	**#8 - Public Health and Medical Services**	**#9 - Search and Rescue**	**#10 - Oil and Hazardous Materials Response**	**#11 - Agriculture and Natural Resources**	**#12 - Energy**	**#13 - Public Safety and Security**	**#14 - Long-Term Community Recovery**	**#15 - External Affairs**
DOT	C/P		S		S	S	S	S		S	S	S		S	S
TREAS					S	S							S	S	S
VA			S		S	S	S	S					S		S
EPA			S	S	S			S		C/P	S	S	S	S	S
FCC		S			S										S
GSA	S	S	S		S	S	C/P	S		S	S				S
NASA					S		S		S				S		S
NRC			S		S					S		S			S
OPM					S		S								S
SBA					S	S								P	S
SSA						S							S		S
TVA			S		S							S			S
USAID								S	S						S
USPS	S				S	S		S			S		S		S
ACHP											S				
ARC			S		S	S		S			S			S	
CNCS			S			S								S	
DRA														S	
HENTF											S				
NARA											S				
NVOAD						S								S	

C = ESF coordinator **P = Primary agency** **S = Support agency**

Note: Components or offices within a department or agency are not listed on this chart unless they are the ESF coordinator or a primary agency. Refer to the ESF Annexes for details.

EFS: Emergency Support Function Annexes: Introduction, 2008, http://www.fema.gov/pdf/emergency/nrf/nrf-esf-intro.pdf

ESF	Scope
ESF #1 – Transportation	Aviation/airspace management and control Transportation safety Restoration/recovery of transportation infrastructure Movement restrictions Damage and impact assessment
ESF #2 – Communications	Coordination with telecommunications and information technology industries Restoration and repair of telecommunications infrastructure Protection, restoration, and sustainment of national cyber and information technology resources Oversight of communications within the Federal incident management and response structures
ESF #3 – Public Works and Engineering	Infrastructure protection and emergency repair Infrastructure restoration Engineering services and construction management Emergency contracting support for life-saving and life-sustaining services
ESF #4 – Firefighting	Coordination of Federal firefighting activities Support to wildland, rural, and urban firefighting operations
ESF #5 – Emergency Management	Coordination of incident management and response efforts Issuance of mission assignments Resource and human capital Incident action planning Financial management
ESF #6 – Mass Care, Emergency Assistance, Housing, and Human Services	Mass care Emergency assistance Disaster housing Human services
ESF #7 – Logistics Management and Resource Support	Comprehensive, national incident logistics planning, management, and sustainment capability Resource support (facility space, office equipment and supplies, contracting services, etc.)
ESF #8 – Public Health and Medical Services	Public health Medical Mental health services Mass fatality management
ESF #9 – Search and Rescue	Life-saving assistance Search and rescue operations
ESF #10 – Oil and Hazardous Materials Response	Oil and hazardous materials (chemical, biological, radiological, etc.) response Environmental short- and long-term cleanup
ESF #11 – Agriculture and Natural Resources	Nutrition assistance Animal and plant disease and pest response Food safety and security Natural and cultural resources and historic properties protection and restoration Safety and well-being of household pets
ESF #12 – Energy	Energy infrastructure assessment, repair, and restoration Energy industry utilities coordination Energy forecast
ESF #13 – Public Safety and Security	Facility and resource security Security planning and technical resource assistance Public safety and security support Support to access, traffic, and crowd control
ESF #14 – Long-Term Community Recovery	Social and economic community impact assessment Long-term community recovery assistance to States, local governments, and the private sector Analysis and review of mitigation program implementation
ESF #15 – External Affairs	Emergency public information and protective action guidance Media and community relations Congressional and international affairs Tribal and insular affairs

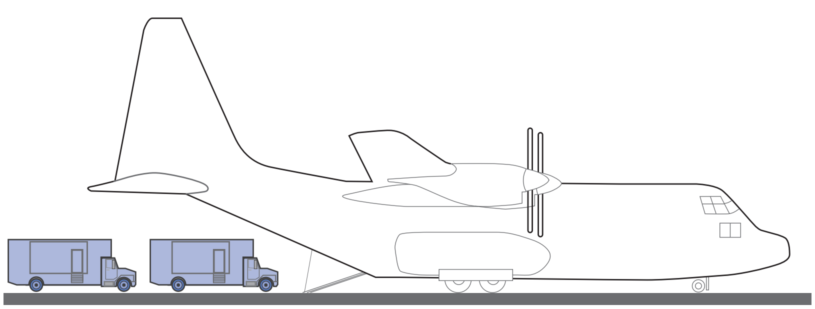
Transit Logistics: *current delivery method and alternatives using intermodal shipping concepts*

A MERS detachment is a collection of specialized trailers and utility vehicles to provide water, fuel, and supplies. When a MERS detachment is dispatched, the trailers are either flown over a distance of approximately 1,100 miles (from Denver CO to Columbus OH) or driven a similar distance of approximately 1,300 miles. In addition to the amount of equipment MERS typically brings, any other equipment brought to aid in energy production or waste water treatment would also need to be transported in this way. Other transport options may include intermodal rail service due to it ability to transport large volumes of goods relatively quickly over long distances. The design considerations for mobile package solutions are in line with intermodal shipping standards to lend themselves to a variety of transport.

A primary delivery method could be rail so that the convoy (along with it's renewable power generation array and various other programs such as supply trucks and assist vehicles) could arrive at a nearby intermodal yard for a more precise and direct delivery to the Disaster Care Center (DCC) by tractor trailer. The benefit that rail offers is the ability to move large amounts of resources quickly and efficiently over long distances versus driving that distance or arranging for multiple cargo aircraft flights. By using rail the convoy of approximately 50 rail cars can save 151 tons of CO2 over the same distance that 50 tractor trailers will drive. [American Association of Railroads - Carbon Calculator]. In addition, specialized rail cars could serve as a mobile base of operations while in transit to further increase the effectiveness of operations once dispatched. Having these units as mobile as possible by using current intermodal shipping practices insures the maximum amount of flexibility in terms of a final delivery system. Using rail as a transportation option and optimizing that process would be valuable in an event where traveling long distances by road or air is not a option.

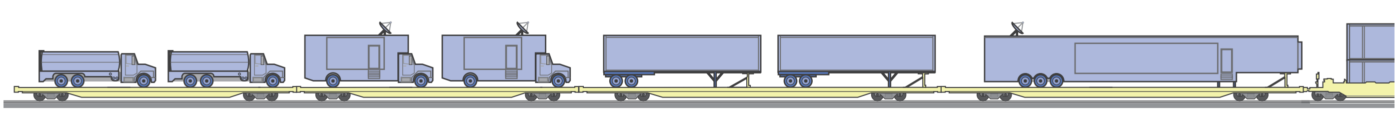
Capacity and specifications of cargo airplanes:

	air speed	range	cargo weight	cargo capacity and size
C-130	345 mph	1,438 mi	36,500 lbs	6 pallets (L,40 ft x W,10 ft x H,9 ft)
C-5	518 mph	6,320 mi	270,000 lbs	36 pallets (L,143 ft x W,19 ft x H,13 ft)



Short list of possible Cargo and Equipment for MERS Program:

EOV	Hydrogen
COMM	RE packages
Clinic	Water treatment
Power	Laundry unit
HVAC	Crew quarters
Fuel	Digester
Food	Hydrogen PEM +
Water	Electrolyzer
Supplies	Lavatory unit
Vechicles	Field Equipment

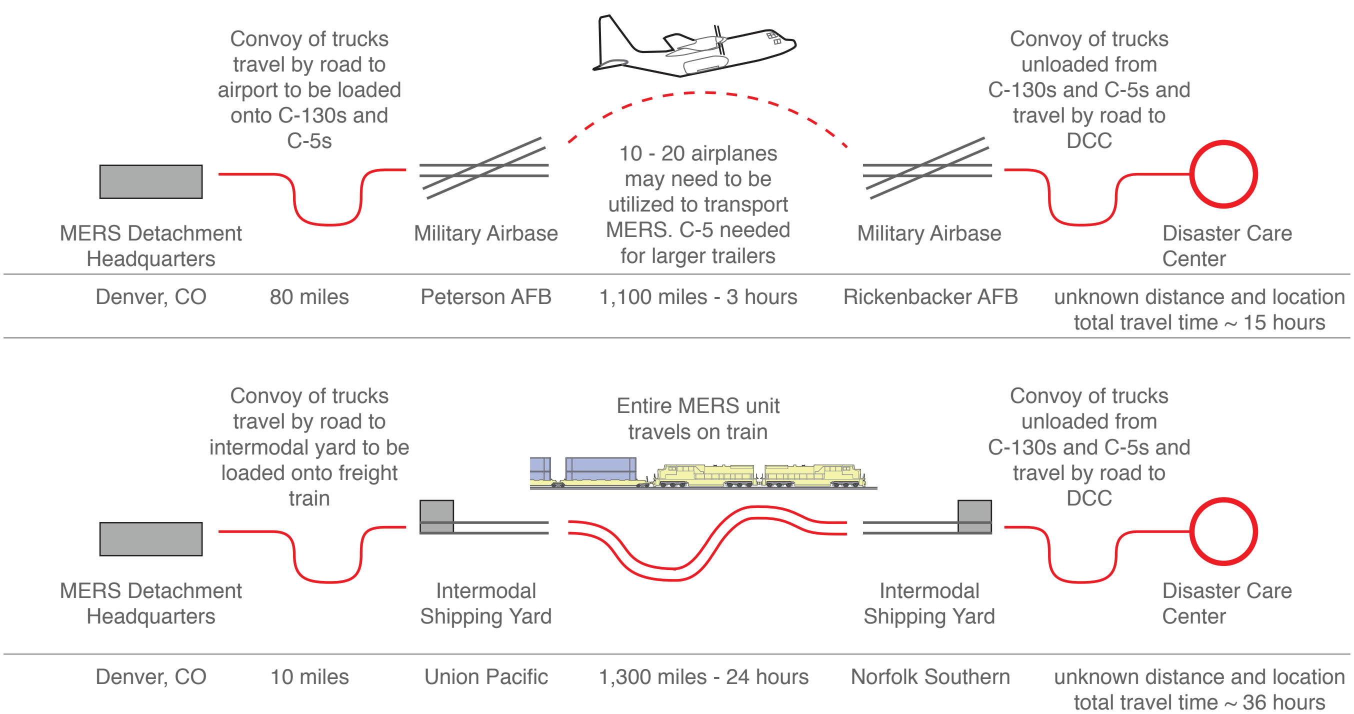


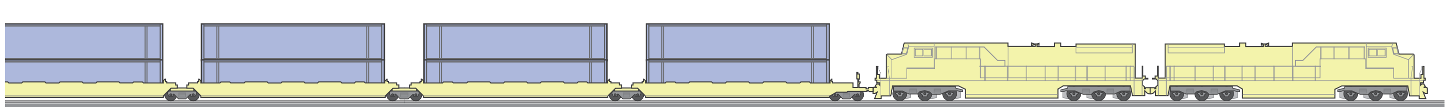
American Association of Railroads Carbon Calculator, 2011, http://www.aar.org/Environment/Carbon-Calculator.aspx
U.S. Air Force Fact Sheet for C-130 and C-5, 12/29/2011, http://www.af.mil/information/factsheets/

However, rail lines are susceptible to natural disasters. They can be washed out by floods made impassable by debris or wild fire, bridges can be taken out and equipment can be damaged by a storm. It would however, be plausible that the entire convoy can be transported by rail near the destination and be off loaded on to tractor trailer rigs at an intermodal shipping yard and be transported via roadway for the shortest possible trip. More often than not, the FEMA Disaster Care Center will be situated near a population center and not necessarily near a rail line. These care centers are typically set near other large buildings such as gymnasiums to serve the influx of victims.

Containerization of off-grid technology systems proves to be the most flexible way to transport operations by air, land, or sea, to the site of the care center. For example, Hawaii is accessible by intermodal transit but and would likely be flown in by military cargo aircraft for expediency. In the event of a declared emergency, freight rail can be used and right of way can be cleared for use by the federal government. Overall air transit is faster but the logistics of allocating aircraft if not at the base may take time. The additional amount of equipment that may be brought for on-site energy production will further complicate air transit as more planes will be needed. Intermodal transit by rail offers the ability to add as much equipment as needed without much additional effort.

Transit of MERS program by air compared to rail:





Scope and Methods Overview:

In this investigation a review of the equipment taken by the MERS program and their requirements, will establish a baseline for evaluating the type of off-grid technologies that are appropriate for deployment. A review of the available systems and technologies will estimate the production capabilities. To estimate the quantities needed to sustain the MERS program, an evaluation and estimation of the energy and water demands of MERS over the course of an average day will be extrapolated for the duration of a month. Using this information, a review of the options will be possible by calculating the expected durations and space requirements for options ranging from diesel operation to renewable energy arrays to replenish used hydrogen on-site. An assessment will be made of the amount of equipment taken along with the MERS unit compared to the possible benefit they provide in terms of resource autonomy and efficiency.

By researching the specifications of various systems and products, an evaluation for how to achieve the energy and water demands for the MERS criteria is possible. The investigation of various strategies highlights the limitations and capabilities of these technologies as they are applied to a specific scale. By doing a quantitative analysis of the technological systems capable of serving the needs of deployable, self sustaining response efforts, an assessment of the systems capability to generate power, filter and treat water, manage waste and sanitation, will determine if these systems can indeed self-sustain the program or even prolong their duration of stay without resupply. Systems may interact synergistically with each other to increase efficiencies of scale, for redundancy or to meet more specialized needs. From these findings an overview can be given as to which systems are most suitable for use based on program demands by determining to what extent these systems can be modularized or packaged for inter-connectivity and future scalability.

One of the options in the investigation is to see if the MERS program can be run off of stored hydrogen and if that hydrogen can be generated on site by electricity via electrolysis by using renewable resources such as wind and solar power units that are brought along. These systems need to be mobilized for this application and be interconnected to achieve optimum results. However, Disaster Care Centers are typically set up in urban parking lots where space may be at a premium. It may hinder the ability to set up large installations of renewable energy generation units such as photo voltaic (PV) arrays at a scale that could support such an energy intensive operation. Another option is to reduce power demand with a smaller scale renewable array. Several services will be examined such as a clinic and an Emergency Operations Vehicle to determine how well the power sources will support those functions given the energy loads and what modifications may be necessary to do so.

The evaluation of the program and technology will be carried out by establishing an estimated, realistic base load for energy and determining potential water use by the MERS program over a 30 period. Then calculating how the program can be supplemented with renewable strategies to extend the duration of stay before needing to resupply. The assessment will focus on how to meet that load with renewable energy and additionally how much renewable energy it would take to produce enough hydrogen to meet those energy demands on-site. This can also be a way to reduce the amount to diesel fuel brought to the DCC. An evaluation metric will consist of hydrogen production potential, amount of energy recaptured from hydrogen fuel cells, number of days self-sustaining, and space requirement considerations. Analysis correlating the amount of energy that can be produced using mobile systems to meet the estimated energy demand will determine the possible dimensional footprint that would be required. It may be determined that hydrogen provides a favorable alternative to diesel fuel, but on-site generation of hydrogen is simply not feasible.

While it may not be a viable option to rely solely on hydrogen, a look at how to offset the baseline use by using both diesel generators and renewable without any hydrogen storage is worth while. Overall a reduction in electric use would also improve how both of these scenarios operate. Evaluating when the peak load occurs will inform the effectiveness of some renewable systems to be able to meet those loads. Recommendations for energy savings may be difficult to detail without further specifics on the energy use profiles of the operation. However behavioral peak load management and resources management schedules could serve to even out the peak load use. For example, choosing to shower in the evening when more solar hot water is available, or doing laundry at night when demand for electricity may be lower.

Examining water cycles and water resource use with regard to grey water recycling may yield operational improvements and energy savings by not importing water. Waste streams can also be used to generate some energy but the primarily goal is to determine if organic waste can be managed on site as well without being a burden to a possibly crippled district waste treatment system.

The scope for the project is to determine if the systems and procedures for self sustaining, off-grid life support is feasible either logistically or technically. Isolating the MERS program as a defined scope will prove useful when analyzing the usefulness and function of the outcomes in relatable terms. In addition, the assessment of options that fall between all diesel generator power and on site renewable will be considered. A general metric of 30 days operation for 100 people will be considered for all applicable calculations. This duration of stay may be extended by using any combination of diesel, hydrogen, using the hydrogen as a battery for the renewable array, or using the renewable array without hydrogen production. For example, a stay of 30 days using a combination of diesel and renewable energy, or the 30 day duration can be calculated with diesel fuel as a backup only and renewable being the primary energy source. Water use will be calculated in the gallons of water lost per day, as that water would need to be replaced when it leaves the grey water cycle.

The options for energy configurations will be as follows. On-site renewable energy array is a assembly of wind and solar photo voltaic packages to provide an alternate source of energy. This array can not be used as the sole source of energy for the MERS program.

- [ ] All Diesel
- [ ] All hydrogen
- [ ] Hydrogen + Renewable Energy Array
- [ ] Diesel + Renewable Energy Array
- [ ] Hydrogen + Diesel

Program: *assessing what equipment and operations will be considered as part of the MERS resource load.*

For the purpose of this investigation, a predefined program will be used to assess the feasibility of taking a program that typically requires the use of on-site diesel power generators and instead use sustainable off-grid power. Adding up a number of diesel generators as outlined in the equipment specifications will be used to estimate electrical power use. A target goal of sustaining 100 people for approximately one month will be used as it is within the scope of the Mobile Emergency Response Support (MERS). This example will not detail issues such as: security, shelter, food production/supply, and maintenance. By adding renewable energy production, not only is the electricity generated clean energy, it may also be possible for the MERS detachment to extend the duration of stay long term without needing resupply. By using the defined scope of MERS, off-grid systems can be scaled to meet definable program requirements and have measurable results. As MERS is a temporary deployment, it would be conceivable that the sustainable solutions that aid the MERS unit could be left behind to assist other EFS functions as the mission changes in the aftermath of a disaster such as rebuilding efforts.

Each MERS Detachment brings with them additional power generation to support one or more facilities within the disaster area, and can provide the heating, ventilation, and cooling for a large office building. To do this they provide tanker trucks of diesel fuel and have large generator trucks varying in size from 20 kW to 400 kW. They can also provide the HVAC requirements of a large office building up to 16,000 square feet with temporary duct work and can generate up to 475,000 BTU per hour. Each MERS Detachment can provide potable water for the disaster area by using 3,000 gallon tanker trucks to transport non potable water to a Reverse Osmosis Water Purification Unit (ROWPU) that can treat 300 - 480 gallons of water per hour. MERS brings with it additional diesel fuel and regular gasoline to aid in transportation and distribution efforts.

The requirements to power external facilities other than the MERS detachment itself in this fashion are beyond the scope of this investigation. MERS programs include water purification, the Emergency Operations Vehicle (EOV), Mobile Clinic (although not specifically part of the MERS detachment, but can be dispatched with the MERS unit as part of the Disaster Medical Assistance Team (DMAT) and will therefore be considered), and communications trucks with additional office space. MERS detachments also carry with them preloaded deployment packages that may arrive in conjunction with, or as stand alone units depending on the scale of the event. They are trucks of various sizes carrying with them communications, life support (food, water, first aid, clothing, tools, lumber, hygiene items, office supplies and other equipment) and power generation capabilities. To supplement the MERS detachment, this investigation will include these and several other functions in the form of similar scaled converted semi trailer spaces. To provide a place for those who are not working to rest, do laundry, and sleep, a 50 foot long crew quarters container will be added. To provide opportunities for hygiene and sanitation when district water services have been interrupted, a combined shower and rest room trailer will be present and will be the primary source of water use within the MERS program. Additional resources may include field lighting for night time operations and external power support.

MERS operations support information, http://www.fema.gov/emergency/mers/mers08.shtm

Images of MERS and DMAT Equipment courtesy of FEMA. Shown Above are examples of an EOV galled the “Green Hornet”, a mobile clinic, various communication and command trucks, and a MERS detachment headquarters

Review of Off-Grid Systems and Machines:

Critical to this analysis is an underlying understanding of the capabilities of off the shelf, readily mobilized systems to generate renewable energy, treat water and manage waste. Implying that a program such as MERS can be self-sustained or even increase deployment duration without resupply, using renewable energy technologies and resource conservation requires an estimated baseline measurement of the amount of resources that are to be consumed. Using that baseline as a performance goal, the type of renewable technologies that are the most appropriate and the implications of those systems can be evaluated. The benefits of hydrogen will be explored as well as case study research to assist in the evaluation of the energy cycle involved in the production of hydrogen. Using renewable energy as the source of electricity to produce hydrogen, results in the lowest possible carbon footprint of hydrogen used as a fuel source. In order to use hydrogen as an on-site fuel for clean fuel cell energy the gas must be compressed for efficient transport. A durable storage solution is provided in the form of an ISO certified shipping container.

Hydrogen: production, use, and storage

The primary drawback with typical renewable technologies is that their rated output is reliant on either the amount of sunshine or the wind speed available over a given time. This drawback is highlighted more so when the program application such as Mobile Emergency Response Support (MERS) potentially requires operational capacity 24 hours a day. A typical solution for this scenario would be to store the power that isn't being used at that moment into a dry cell battery for later use. These batteries are not without problems. Primarily, these batteries rely on the chemistry of rare earth metals and degrade with use. The large number and size of these batteries present a strain on environmental resources and has made the energy storage potential of hydrogen an attractive alternative. While the amount of energy put into the production of hydrogen does not equal the amount of energy that can be extracted through a current of electrons via a Proton Exchange Membrane (PEM), hydrogen can serve as a sustainable long term energy storage solution for a number of reasons. Hydrogen has a high power to weight ratio compared to diesel fuel (142 mega joules per kg for hydrogen vs. 44 mega joules per kg for diesel) and can be stored for days or months with no energy discharge. Hydrogen can also be transferred with no transmission loss. If the production of hydrogen is done via electrolysis and the energy for that process is generated with renewable energy the net result is carbon neutral.

Electrolysis is the method of using an electrical charge to separate water into hydrogen and oxygen, One gallon of water contains 420.6 grams of hydrogen. Other methods exist for extracting hydrogen, from natural gas or methane and other materials such as phosphoric acid acting as the electrolyte in place of the PEM. These processes use other chemicals and require high operating temperatures in the range of 212-1800 degrees Fahrenheit; meaning that they require more energy to run. While natural gas can be used as a source for fuel in PEM fuel cells, generating hydrogen from renewable sources is end to end a more long term sustainable option. Further research and case study analysis will yield more accurate or realistic figures for this application.

Summary of Electrolytic Hydrogen Production, Sept 2004, Johanna Ivy, National Renewable Energy Laboratory/Department of Energy

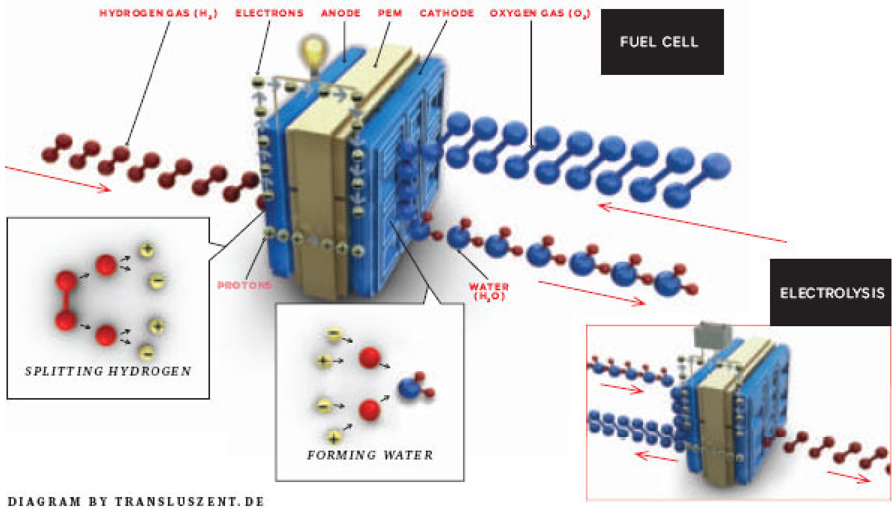


DIAGRAM BY TRANSLUSZENT.DE

The above diagram shows a depiction of the process for generating (or capturing) electricity from the electrons contained within diatomic hydrogen. The process creates .7 volts and therefore these fuel cells are stacked to create greater usable voltage. With a flow of diatomic oxygen the output is water.

Due to the variety of ways in which hydrogen can be produced, and the variety of electrolytes used for fuel cells, finding consistent, reliable, detailed data for pure hydrogen PEM fuel cells has been difficult. The Department of Energy (DOE) sites that a fuel cell using a PEM should see an efficiency rating of 50-60%. By examining various sources, and making educated judgements, approximately 50 kWh of electricity is needed to generate 1 kg of diatomic hydrogen. The National Renewable Energy Laboratory sites that ideally 39 kWh of electricity would be needed to produce 1 kg of hydrogen at 25 degrees Celsius at 1 atmosphere of pressure. However the actual rated efficiencies of commercially available electrolyzers range from 56% - 70%. Through a PEM fuel cell approximately 30 kWh can be generated with the same 1 kg of hydrogen (the theoretical energy value of 1 kg of hydrogen is 39.4 kWh when converting joules to kWh).

Case Study: U of M hydrogen Fuel Cell Project: Principal Investigator Dr. Louise F. Goldberg.

In 2004 the PV array on the roof of Rapson Hall was used to generate hydrogen gas as a research exercise. Over the course of the 3 day (73.9 hours) test period 13.6 lb (or 2413 standard cubic feet) of hydrogen was produced using 45.7 kWh of electricity. The net energy production was 28.5 kWh with a solar effectiveness of 53%. However, this study finds that the parasitic energy consumption was 45.7 kWh for generating 13.6 lb of hydrogen (or 6.17 kg of hydrogen) which calculates to 7.4 kWh per kg. This 7.4 kWh figure was far lower than other estimates ranging in the amount of 50 kWh per kg. Furthermore the amount of energy produced as a result of processing 6.17 kg of hydrogen was 28.5 kWh or 4.6 kWh per kg. Both of these numbers indicate a far lower than expected energy value for the production and processing of hydrogen when compared to sources within the Department of Energy and the National Renewable Energy Laboratory. While according to these results, it would take much less energy to produce 1 kg of hydrogen, much less electricity would be produced from 1 kg of hydrogen. However, the experiment has at the same time yielded the same ratio of energy to produce hydrogen and process hydrogen to energy (50 kWh in to 30 kWh out or 60% efficient versus 7.4 kWh in to 4.6 kWh out or 62% efficient). This indicates that the specific production values can vary for many reasons, but the efficiency between hydrogen production and hydrogen consumption is relatively reliable.

Solar Hydrogen Fuel Cell Demonstration Project, 2004, Principal Investigator, Dr. Louise F. Goldberg

Portable Hydrogen Storage Solution:

Lincoln Composites, Hydrogen storage - ISO standard tanks

This ISO certified container is designed for standardized transportation and has been tested for extreme durability due to the volatile nature of pressurized diatomic hydrogen gas. This container has an ISO (International Organization for Standardization) shipping frame with 4 Cylinders in Horizontal 2x2 Arrangement. The tanks store a total of 600 kg of hydrogen gas at a pressure of 3600 psi. Progress is being made towards increasing the service pressure rating of the tanks to 8300 psi allowing the container to hold 1150 kg of hydrogen by the year 2017. Developing a bulk storage unit that can be transported on an ISO frame is a critical part the strategy of using hydrogen as a fuel source on-site.

Vertical Axis Wind: energy generation potential average

A vertical axis wind turbine can harvest wind energy regardless of it orientation and at lower speeds. This will allow for a more flexible arrangement with a minimal footprint. It will also ensure that if the minimum required wind is blowing, the turbine will be generating energy regardless of orientation. Vertical axis wind turbines allow for shipment in containers, if disassembled and laid on their side. By examining the capabilities of three separate wind turbines, an better approximation can be gauged for a typical deployment in a realistic application.

Windspire:

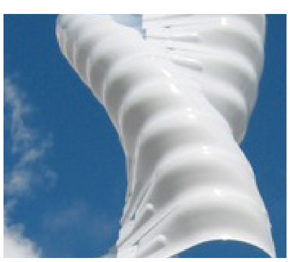
This company produces two models, a standard unit and a high wind unit. The standard unit has an operational range in winds of 8.5 mph to 28 mph. The rated power output of 1.2 kW is achieved at 24.6 mph. The high wind unit has an operational range of 7 mph to 45 mph and achieves it's rated power of 1.2 kW at 26.8 mph. Although the high wind unit will produce electricity above 26 mph, it's power curve yields less electricity generated at speeds less than 26 mph, while the standard unit is already producing it's rated power output at 24.6 mph. At 16 mph the standard unit is generating 400 watts of electricity. The calculations for the renewable production array will use the annual average of 2000 kW. However it should be noted that these conditions are based on an annual wind speed average of 11.2 mph and actual wind speed will yield far different results. The windspire stands 30 feet tall with a rotor height of 20 feet. the foundation for typical installation is poured concrete, yet other installation methods would need to be created for this application that would require temporary installations. The total weight is 624 lbs.

Windspire, 2011 http://www.windspireenergy.com/


DOE, Development of High Pressure Hydrogen Storage Tank for Storage and Gaseous Truck Delivery, Lincoln Composites , May 2011

Tangarie, Gale T5-R15:

This particular model from Tangarie is a vertical axis wind turbine that has a larger rotor profile. The total weight for one unit is 2,882 lbs. and has an overall height of 16.5 feet. It's annual output is 5785 kWh/yr with an average wind speed of 15.6 mph. The information that is available for the Gale T5 unit does not have a power curve graph, nor does it have a rated power output. It is however interesting to note that given a relatively similar annual average wind speed (11.2 -15.6) the annual output is effectively larger (2.000 - 5.785 kWh / yr). Another important detail is that the cut in speed for the Gale turbine is 4.25 mph where as the cut in speed for the Windspire is 8.5. This may be an indication that the rated power for the Gale T5 unit my be higher than the Windspire at a similar speed.



Helix Wind, S594 Wind Turbine:

This vertical axis wind turbine has an annual average of 3,362 kWh with an average wind speed of 15.6 mph. The peak rated power is 4.5 kW although it is unclear at what wind velocity that power output occurs. The cut in speed (or the minimum wind speed required for operation) is 11.1 mph which indicates that the minimal operational speed for this turbine is higher than other wind turbines and may not be as flexible for use in areas where wind speed is less than this amount. The turbine is 16 ft tall and requires a pole for installed operation.

Tangarie Wind Generators, 2011, http://www.tangarie.com/products/gale_vertical_axis_wind_turbine.php
Helix Wind, 2011, http://www.helixwind.com/en/S594.php#s594specs

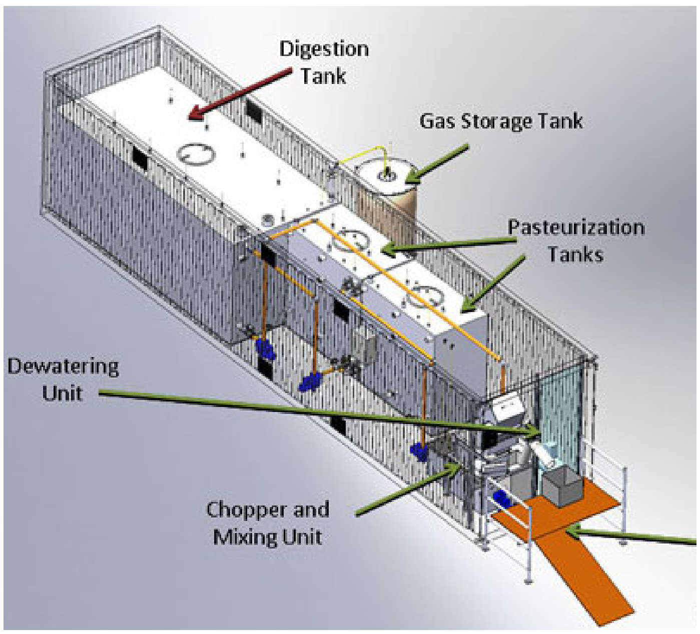
On-Site Organic and Septic Waste Management: the SEaB, Muckbuster 400

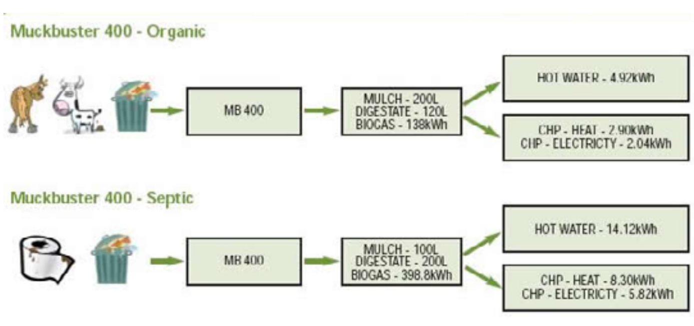
Rather than using resources to transport waste away from the disaster site, organic and septic waste can be dealt with on site with a digester that can be shipped as a self contained unit. This digester uses a re-purposed shipping container with a adjacent bio gas tank. As opposed to other digesters seen in stationary projects of a larger scale, this particular unit can be transported in much the same way as an intermodal shipping container, and comes to the site ready to use as a self contained solution for generating heat and or electricity from biological waste. It does however, require 4 weeks of operation to begin producing energy from the breakdown of organic waste into methane gas. It would be conceivable for the unit to arrive already in use thus negating the need to wait 4 weeks to gain benefits of energy production, however no documentation can be found to support this.

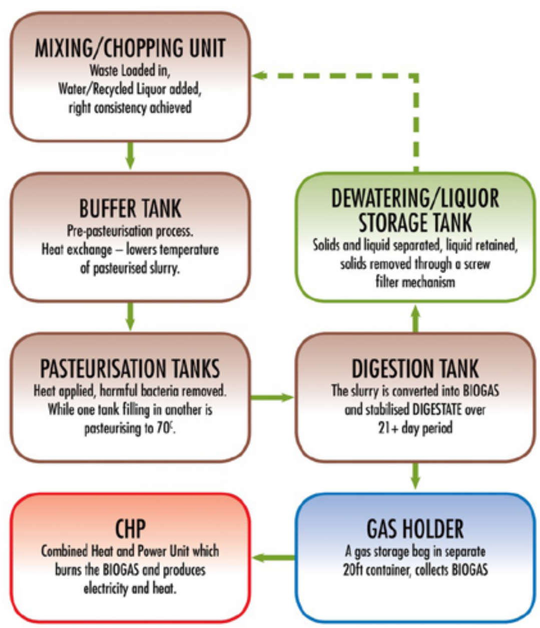
The primary benefit for this investigation is that it offers a solution for waste management as it can handle approximately 300 liters of waste per day (~80 gallons). The amount of waste that can be input per day by type varies depending on the model (MB 400 organic or MB 400 Septic). The rated power after the initial operating period is 2kWh per 100 gallons of waste. With the amount of energy required for the MERS program 2kWh would make little impact on the energy budget for the scope of this investigation (30 day deployment) it will only be considered as either a primary or alternative means for removing organic waste from the waste stream. No information is available on how much parasitic energy is being consumed by the unit to transform the waste into methane gas, which is then used to generate electricity. It is also unclear if waste separating toilets would be required for it's operation. The process diagram indicates that liquid must be added, if not already present, in order to achieve the proper constancy. The information also describes that waste bound for the septic tank is an acceptable input for the digester, however the specifics of septic waste is not detailed.

A partner company with SEaB, called Tanglewood Organics, describes the Muckbusters as able to handle 1/2 to 2.5 tons of organic waste per day. For a simplified gallon to weight conversion, 100 gallons of water weighs approximately 835 lbs or .4175 tons. It would seem that the Muckbuster can indeed handle more than 100 gallons of waste per day depending on the consistency of the waste product. For a detachment of 100 people it seems reasonable to assume to each person would produce roughly 1 gallon on average of waste per day (not including the water used to flush) in addition to the amount of organic waste produced by food scraps by the MERS staff. With approximate waste estimations it would be reasonable to assume that multiple Muckbusters would be needed on site to adequately manage the potential amount of septic and organic waste. The amount of water in the septic waste stream would need to kept to a minimum, otherwise the number of Muckbusters needed on site to handle approximately 1000 gallons of waste (100 ppl x 1.6 gpf x 6) would be far larger. Adding to the difficulty of sizing how many Muckbusters would ensure optimal results, is the amount of contradictory information about this product in regards to it operational capabilities.

Tanglewood Organics, 2011, http://tanglewoodorganics.com/?page_id=69







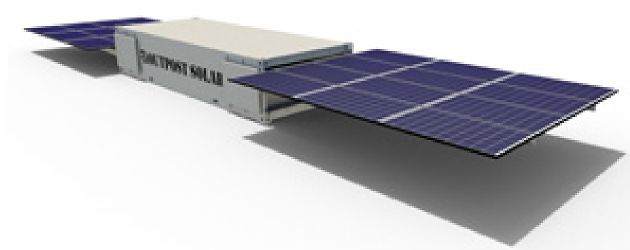
Images and diagrams of Mucbuster models and processes, http://seabenergy.com/products/anaerobic-digesters/

Deployable Solar: Outpost Solar AMS-6

Portable photo voltaic arrays that can shipped as self contained units have been developed with remote military outposts in mind and will serve the MERS program well in disaster situations. Outpost Solar is an example of a company that specializes in containerized solar power energy collection packages. Designed with emergency power generation in mind for forward military applications, these units are extremely durable as they are armored against small arms fire and all weather operation. The rated output for one of these units is 5.76 kW (assuming full sun). They can be connected in series or parallel for increased energy production as a micro grid. Each unit includes 28 internal batteries that can sustain a daily load of 12.4 kWh for approximately 5 days without needing recharge from the sun. For the purpose of calculating the renewable energy production array these battery capabilities are not factored in due to the desire to not depend on dry cell batteries for energy storage in favor of hydrogen production.

However, when assessing a solution alternative that does not include the production and storage of hydrogen, these units offer valuable flexibility to run critical programs without the need of a diesel generator. While one or two of these units my not be enough to handle the entire load of a particular program such as the EOV, it can be setup on a smaller scale to ensure that the refrigerators in a trauma clinic remain operational in between resupply, that communication equipment stays online, or that remote water pumps maintain operations without needing to refill a generator at regular intervals. It can also be used to run less critical equipment such as area lights to ensure that diesel fuel or hydrogen is used only used for priority applications.

Each unit weighs 19,400 pounds and is self contained in a 20 foot long by 4 foot high ISO (International Organization for Standardization) container. Four of these units can stack in the same space as a standard shipping container 40 feet long and 8 feet high. The units can be deployed by one or more individuals in about 10 minutes or less.



Outpost Solar deployable solar array, 2011 http://outpostsolar.com/modularsolarsystems.html

On-Site Water Treatment and Grey Water Cycle Components:

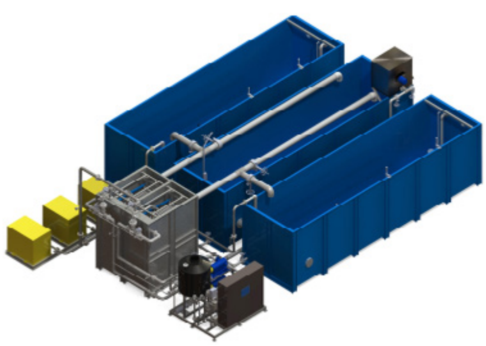
Koch Membrane Systems, HF-4 package water treatment system:

As water treatment is a vital component to self reliance and may be used to extend the water supply brought into the DCC site, portable water treatment systems are part of an overall grey water treatment package brought on-site. Water may also be filtered from nearby sources for potable use as it filters out giardia and cryptosporidium. It is able to treat 11,400 to 84,000 gallons per day, but the power draw for filtration is unknown. This unit is 10’ x 5’ x 6’ and weighs 3500 pounds.

General Electric, Mobile Combination Unit:

This mobile unit provides pre-filtration, and reverse osmosis water treatment for low flow applications (60-90 psi) in an ISO standard 40 foot shipping container, weighing 50,000 lbs. The unit is designed for an output of 200 gallons per minute in single pass mode or 100 gallons per minute in double pass mode (a maximum of 288,000 gallons a day under continuous operation). The installed motor is a 75 Hp (56kW) totally enclosed, fan cooled motor. In one hour this unit could filter 12,000 gallons of water.

with both units, a separate tank storage system for surge capacity and treatment would be needed. Addionally, both of these water treatment systems are more than large enough to filter the water needed by the MERS unit of 100 people. However, it is within the MERS mission to provide water treatment capabilities to the DCC and that specific volume of water is unknown and likely to vary from situation to situation. In the unlikely event that more water treatment capacity is needed, additional water treatment packages may be brought along.



Koch Membrane Systems HF-4, 2011, http://www.kochmembrane.com/systems_specification_sheets.html
General Electric Mobile Water, 2011, http://www.gewater.com/what_we_do/mobile_water/index.jsp

Investigation:
An estimation of the power generated by the assembled renewable energy package, a power load assessment of the MERS program, Calculation of how hydrogen and renewable energy could meet that demand, and an evaluation of the water cycle for the MERS unit.

Power Generation Estimation of Renewable Energy Package:

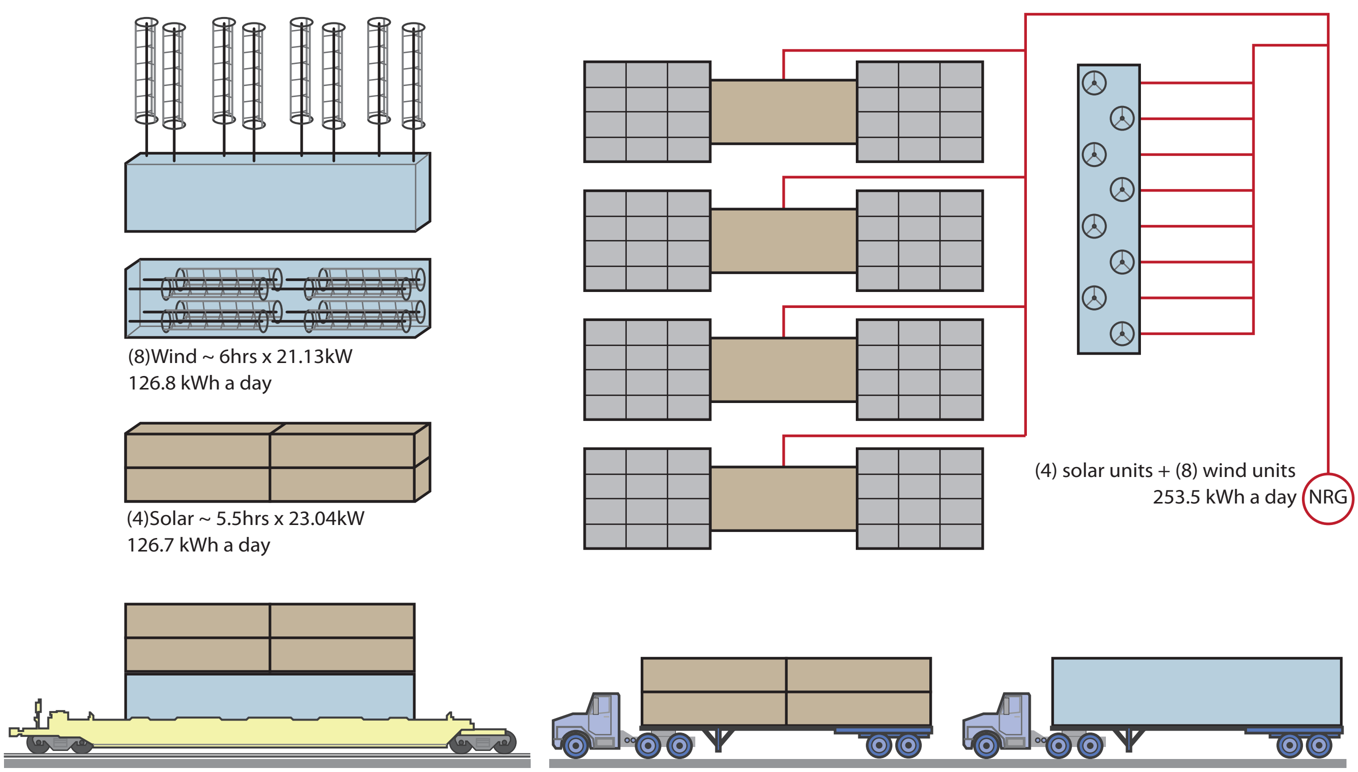
Using “off the shelf” products available for wind and solar power generation, a “package” consists of 4 Outpost Solar units and 8 vertical axis wind turbines. One “package” has the basis of what can be transported in (2) dimensional shipping containers. These (2) containers can stack on to each other for rail freight transit and are therefore considered one package. Additionally the package contains both wind and solar collection for balanced collection potential. On days that are overcast, the average wind speed is typically greater and could potentially make up the difference in lost solar collection.

4 outpost solar solar units stacked 2x2 and are equal to (1) 40 foot container.

8 vertical axis wind turbines (each ~4 ft in diameter and 16 ft long) fit in (1) 40 foot container.

The daily estimation for energy production is 253.5 kWh for one package. The actual output of energy that could be expected varies greatly with the conditions for solar access and wind speed. The daily value was approximated using conservative estimates outlined in the following pages. In the case of wind, a linear reduction in wind speed from 26 mph to 12 mph, reduces to wind turbines effectiveness from 1200 watts to less than 200 watts.

Renewable Energy Collection Package: Wind + Solar

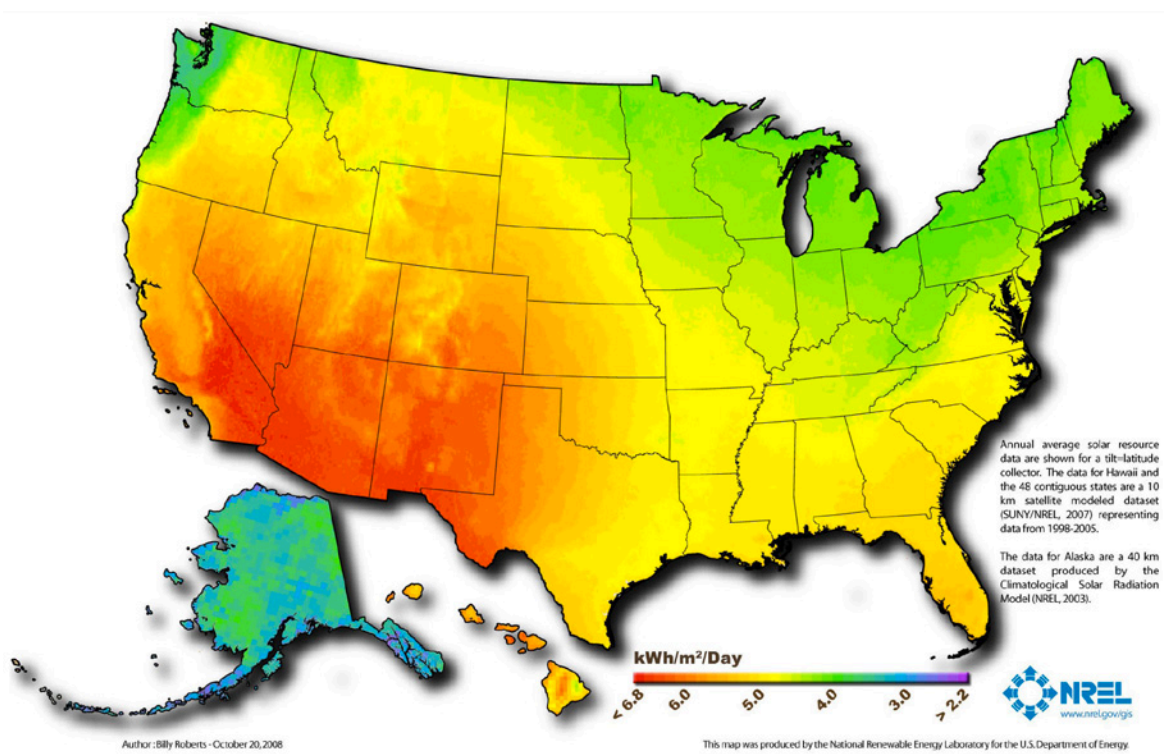


The same can be said for solar power output in relation to solar access. Therefore a realistic approximation of electric output is a combination of both average wind speed, duration of that wind, insolation value (average number of hours per day of usable solar energy). That average value can be used to approximate with a higher degree of accuracy, the amount of electricity that could be yielded from the renewable energy systems (for either direct use or for Hydrogen production). A realistic expectation of the renewable energy production package is broken down by type, the 4 Outpost Solar units, and 8 generalized vertical axis wind turbines.

solar estimation:

The outpost solar unit has approximately 51 square meters of PV surface area (24, 240 watt solar modules). Using the NREL map of approximate kWn/m2/day it can be conservatively estimated that 4 kWh/m2/day can be collected in most areas in the US. With this we can estimate that one outpost solar unit can collect 204 kWh per day. As a package of 4 that would bring the daily estimation to 816 kWh/day. The rated output for the outpost solar unit is 5.76 kW and if it were possible to collect full sun day and night, that would result in only 138 kWh a day collected. This figure is still short of the NREL estimation by 66 kWh and it would be fair to assume that the NREL estimation is not an accurate measure of expected energy production for the outpost solar units. It may also be that the NREL data is contingent upon significantly more efficient solar cells, or serves to illustrate a theoretical potential if solar panels were to be 100% efficient.

U.S. Photovoltaic Solar Resource Map

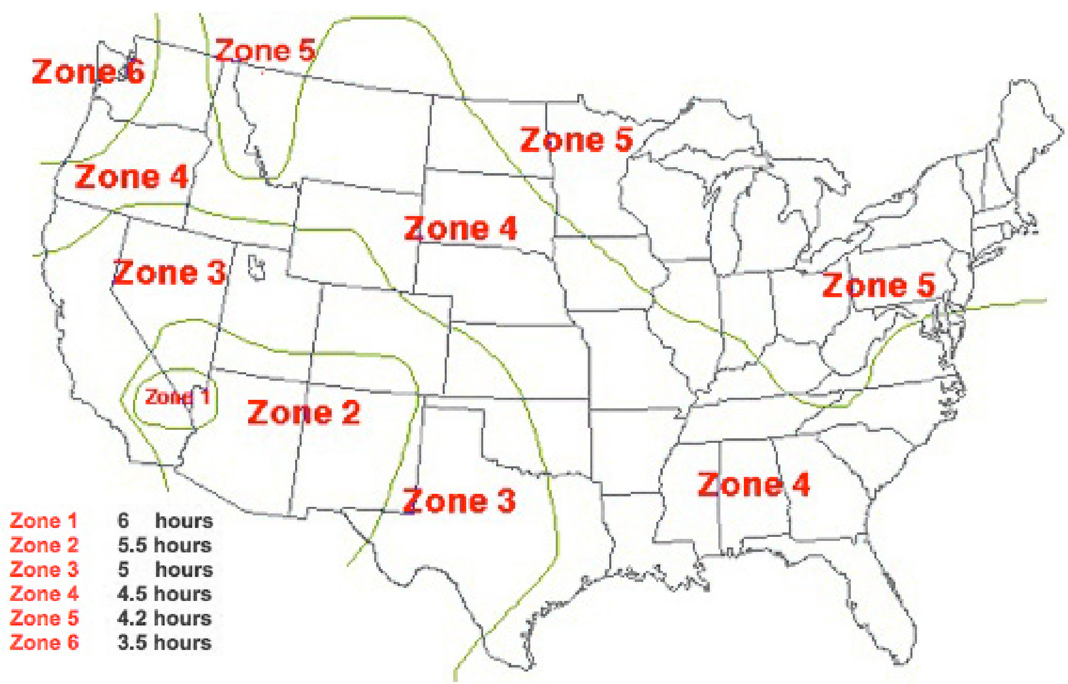


Solar Resource Map. Author: Billy Roberts, October 2008
National Renewable Energy Laboratory for the U.S. Department of Energy. www.nrel.gov/gis

Another method, closely related to an irradiance map, is to use a map describing the number of peak sun hours for a given location, and use the estimated number of peak hours against the rated power of the solar unit. Peak sun hours are hours when the average irradiance is above 1000 w/m2. Outpost solar indicates that it's rated output is 5.76 kW. The next step is to estimate the number of hours that kind of power can be generated over the course of a day (to get an estimation for the number of kWh a day)

The peak sun hours per day average figure in of itself varies greatly depending on the latitude and seasonal cloud cover making it difficult to estimate accurately for a short term duration. An annual average can be used as a reasonable estimation but this figure also varies greatly if it is calculated as a yearly average versus a separate winter and summer average. Across the continental United States the sun hours per day annual average ranges from zone 1 to zone 6 with a value of 3.5 - 6 hours per day respectively. Over the course of that year the winter months average 25% - 50% lower sun hours than the summer months. It should also be noted that the majority of FEMAs ground operations take place in the warmer months, as less than one quarter of disasters are winter storm related. As for the geographic location, the majority of MERS operations can be covered from zone 3 (5 hours per day) to zone 5 (4.2 hours per day). Therefore the insolation hours could be increased about 30% due to the assumption that the majority of the operations will occur in the months (September to November) which include longer days and better, more direct, sun angles. This translates to a non-winter estimate between 6.5 and 5.46 hours of peak sun per day. A conservative estimate of 5.5 hours per day will be used to estimate the daily production value of the solar panels that will be used on-site.

Sun Hours / Day Zone Solar Insolation Map



Map courtesy of wholesale solar: http://www.wholesalesolar.com/Information-SolarFolder/SunHoursUSMap.html

With an estimate of the number of hours that useful sunlight can be gathered, we can multiply this number by the rated power to give us expected number of kWh in a day. 5.5 hours of sunlight x 5.76 kW rated power x 4 (the number of outpost solar units in a package) results in an average of 126.72 kWh a day. The actual value might be much higher or slightly lower depending on actual daylight conditions in the summer. For this estimation the rated power was used, and this figure may also vary over the course of a day.

vertical axis wind estimation:

As the products vary from one to another with different cut in speeds and power curves, establishing an average power rating per day can be challenging. More often than not, the manufacturer will publish the rated power output of their product but fail to inform on the average wind speed to achieve the annual power output. The annual energy production value is not based off the maximum rated power, but as the name implies is an annual average with various wind speeds.

The American Wind Energy Association (AWEA) has guidelines for testing wind turbines. One of these guidelines is that average wind speed is to be 11.2 mph (or 5 m/s). Given this information, the average annual production number does not specify how many hours in a day (on average) the wind turbine must be running to produce that number (in this case 2000 kWh a year for the windspire turbine).

The windspire has a rated power of 1.2 kW, at 24.6 mph. At 11.2 mph the rated power is 100 w. The average annual production is 2000 kWh a year. This amounts to 5.479 kWh a day. However, at an average speed of 11.2 mph it would take 54.79 hours (in a 24 hour day) to produce this much electricity. Since this is not possible, it must be assumed that the average wind speed (a value of 11.2 mph) is not constant and in fact bursts during the day far exceed this for periods of time over the year to produce the annual average figure. If the windspire was running at full capacity of 1.2 kW with a wind speed of 24.6 mph, it would take 4.558 hours to produce the required 5.479 kWh a day. Below is a table for estimating the number of hours of wind at fixed wind speeds to obtain the daily average of 5.479 kWh a day. power ratings are obtained using the windspire power curve provided by the manufacturer.

5.579 kWh/day = .23 kW of power at 13 mph over 24 hours of wind
5.579 kWh/day = .46 kW of power at 17 mph over 12 hours of wind
5.579 kWh/day = .65 kW of power at 19 mph over 8 hours of wind
5.579 kWh/day = .91 kW of power at 21 mph over 6 hours of wind

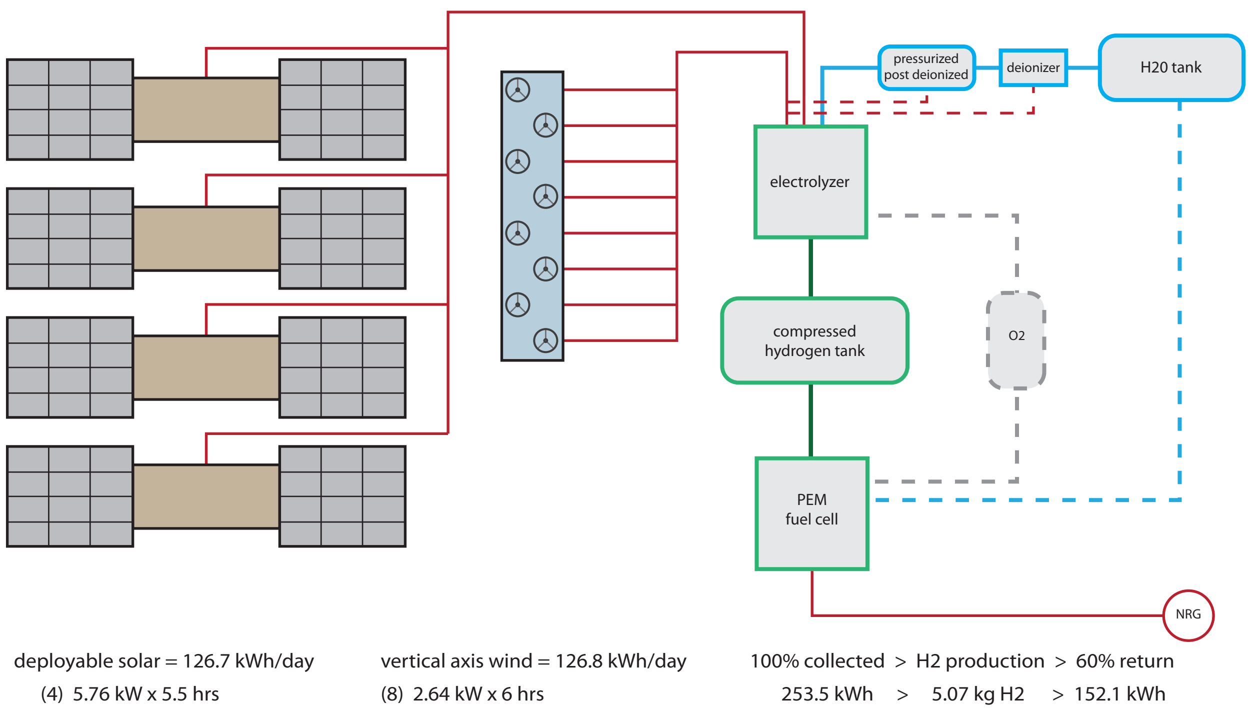
The Gale T5-R15 has an annual power output of 5785 kWh a year at an average wind speed (mandated at 11.2 mph) which results in 15.849 kWh a day. Using the same number of operating hours (4.558 hr) and the same method, we can determine the Gale's rated power to be 3.477 kW.

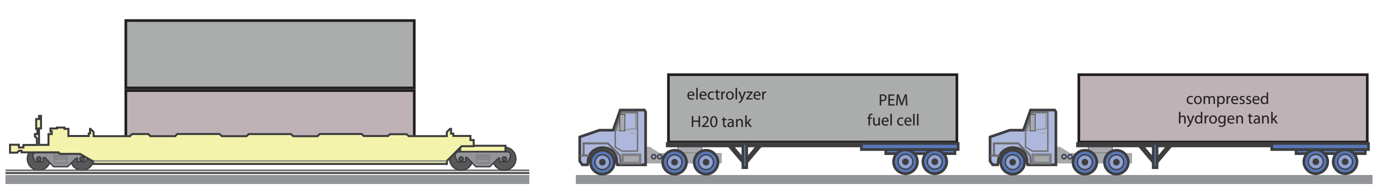
Using the shortest amount of wind time per day (6 hours) we can determine that the power output is 2.64 kW but we also assume that wind speed average over that time is 21 mph. Since the power curve is exponentially greater for bursts of high wind, the average speed is a value dependant on longer periods of constant low speed wind. This gives a better approximation of the expected energy output on a day to day basis using averages from other wind turbines (~75%) less than the rated power over a shorter interval.

AWEA Small Wind Turbine Performance and Saftey Standard, 2009
Analysis of Wind Generation Impact on ERCOT Ancillary Services Requirements, 2008, GE Energy

In summary, the vertical wind turbine can generate 2.64 kW over a 6 hour period of time (during a 24 hour day) when it is estimated that the wind is blowing at a rate that would result in the average annual production estimate by the manufacturer. This estimates an average of 15.85 kWh per day and is multiplied by the number of vertical axis wind turbines (8) in a package resulting in 126.8 kWh per day. It is more likely to be windy during the morning and evening hours, but when calculating the daily average the specific peak production times are not a factor. Additionally, it should noted that if the weather is overcast it is typically more windy and therefore it could be assumed that the loss in solar production could be made up by an increase in wind energy production. The package together with the solar then produces an estimated 252.52 kWh per day. This figure is an estimate and can vary greatly, if over a 24 hour period the average wind speed is less than expected or if there aren't bursts of higher wind. The average power of the package will be more accurate estimation over the 30 period than the daily figure due to possible daily fluctuations.

Renewable Energy Collection Package with Hydrogen Production:





Power Load Assessment: Determining Capacity and Estimating Electric Use Over 24 Hours

To be able to assess the power demands of the MERS detachment, first a baseline assessment of the MERS program and their rated power use must be established. Assumptions have been made due to the lack of specific information available, however the base load is a variable that is easily accounted for in the equations. The only information readily available in regards to energy consumption is for the largest Emergency Operations Vehicle (Green Hornet EOV) which has two 40 kW generators to provide all of its power. It should be noted that having two generators may be for reasons of redundancy rather than continuous demand for all 80 kW of power. Therefore 40 kW of power will be used in the assessment as a worst case load. A 40 kW load, although high, is not outside the scope of a possible resource draw considering the amount of specialized equipment on board, as the EOV has a plethora of workstations, communications equipment and various other devices within it to carry out it's mission. This rated power consumption of 40 kW results in an energy use of 32 watts per sq. foot (the 'Green Hornet' is an 82 foot trailer that expands in some sections to 22 feet wide giving an estimated maximum area of approximately 1,300 sq. ft).

The specifics for the energy consumption of the MERS unit is difficult to ascertain. The type of equipment such as a KU band satellite transceiver, or Land Mobile Radio (LMR), operating at 800 MHz is specifically generic and therefore difficult to account for. For this reason the largest assumption of baseline power use is driven by the size and number the generators used by the largest EOV units (two 40kW generators) that are in place to power the it's operations and this type of equipment. Also, given the nature of operations to be potentially continuous 24 hours a day, this measurement spread across other energy intensive programs gives a high possible energy draw for the MERS unit. The same can be applied to the program of the mobile clinic. A list of equipment and operational capacities outline a potential for high energy use (wireless x-ray systems, cardiovascular monitors, minor surgery bay and a small pharmacy) a similar approximation of 40 kW is used. A better approximation could be achieved if a known amount of diesel spent over a deployment period and cross checked with the efficiency of the generator. Using an approximation of diesel efficiency along with an estimation of generator capacity, yields an approximate volume of diesel fuel used over a 30 day deployment. Additionally, inefficiencies can be seen when using many smaller generators not running at full capacity and an alternative may be to run a larger, micro centralized generator.

diesel: fuel burning calculations of a 40 kW generator

A 40 kW generator will consume 3.37 gallons of diesel per hour. This is according to a generalized diesel burn calculation where gallons per hour is based on the formula [.08433 x kW rating of generator]. This equation is a generalization because each generator has different fuel burn characteristics and larger generators have larger cooling fans and water pumps that consume more energy than smaller generators. In short, a 100 kW generator only producing 10 kW of power will use more fuel than a 10 kW generator at maximum output.

Hardy Diesel Company - A large distributor of diesel generator products ranging from 7 kW to 275 kW and up. 2011, http://www.hardydiesel.com/generator-fuel-consumption-calculator.html

There are others ways to estimate these values. The Brake Specific Fuel Consumption (BSFC), is an equation relating fuel consumption in pounds, to rated horsepower output (which is converted to grams per kWh). The estimated consumption of a diesel engine is approximately 250g per kWh. The estimated fuel consumption for a 40 kW generator in this manor is 10 kg of fuel per hour or approximately 10 liters or 2.64 gallons per hour. This is a purely theoretical value as actual fuel efficiency is subject to air temperature and barometric pressure. The heating value of diesel is .0119531 kWh per gram, therefore the efficiency of a diesel engine is 1/(BSFC x 0.0119531). Since the BSFC is specific to each engine, the actual efficiency of the generators used is difficult to determine. If a thermodynamic efficiency of 35% is used, than the rate of diesel consumed in a 40 kW generator (BSFC) is solvable: 35% = 1/(BSFC x .0116531) where BSFC = 239.03 grams per kWh. The fuel used is 0.23903 kg per kWh or approximately 0.23903 liters per kWh or .063 gallons per kWh. Therefore a 40 kW generator is using 2.52 gallons per hour with this calculation.

With the various ways to estimate fuel efficiency to in turn estimate the rate of fuel consumption, for the purpose of this investigation the rate of .08433 gallons per kWh will be used as an indication of a worst case scenario of fuel consumption. This would indicate that a 40 kW generator is using 3.37 gallons per hour. In addition to being a more conservative estimate, the source of the equation is from a manufacturer of diesel generators and it would be a fair assumption that actual efficiency rating are factored in as opposed to theoretical averages. In particular the calculator is considered accurate for a 65-100% load on the generator. If the amount of fuel used by the MERS detachment can be ascertained, this process can be used in reverse to estimate the approximate loads generated to sustain the electrical needs. For example, if it is determined that for a 30 day duration the MERS unit consumed 12,000 gallons of diesel, which amounts to 400 gallons per 24 hour day, or 16.6 gallons per hour; this would indicate that the electrical load was approximately 197 kWh generated by various generators operating to a rated output of 197 kW or a sum of 300 kW generators operating at 65% output.

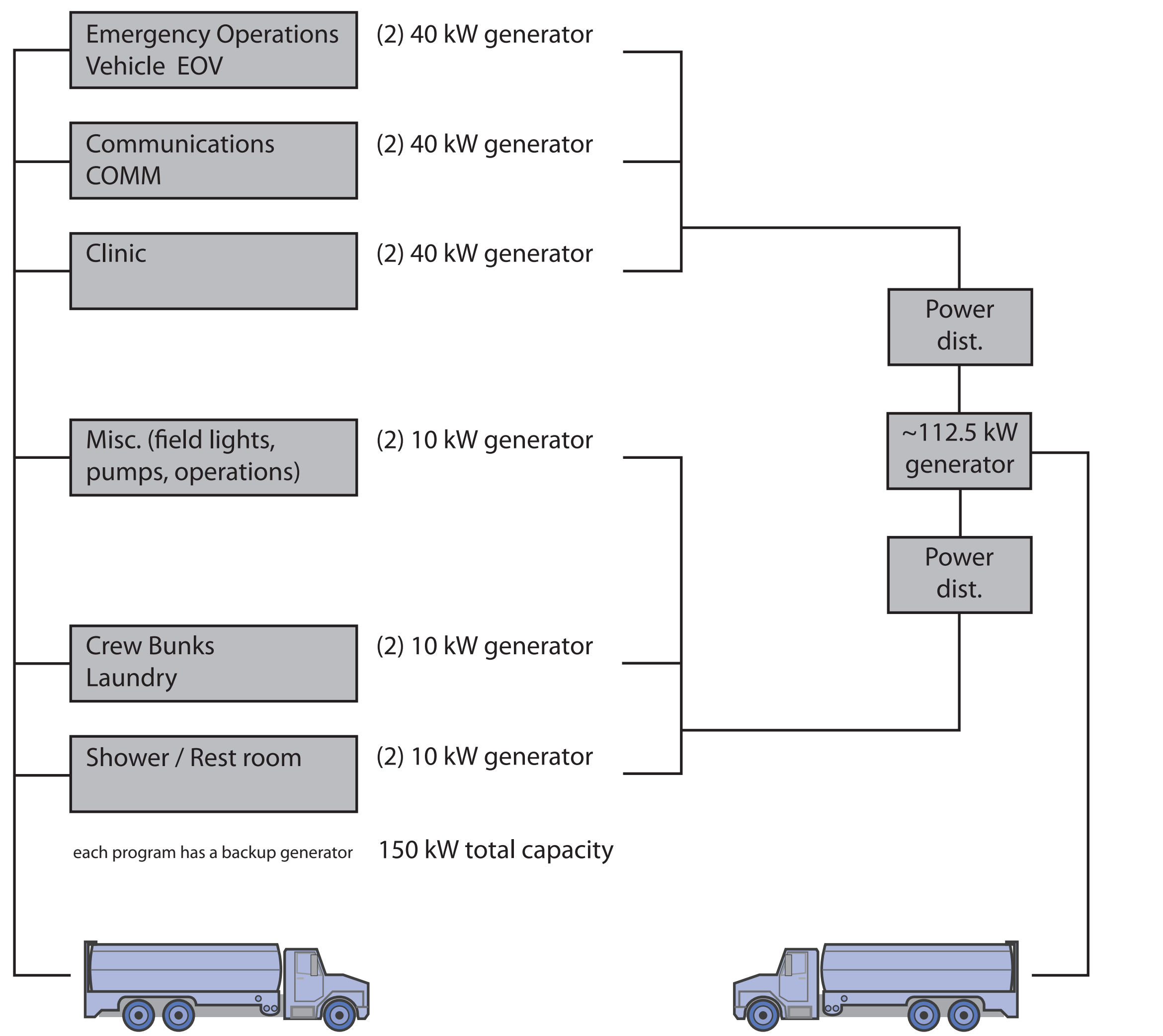
In this investigation the base electrical load for the MERS program is estimated (as a maximum due to rated capacity) of 150 kW of power. Again the amount of fuel being used is dependent on the actual amount of energy being consumed; a generator rated for 40 kW only producing 20 kW will use less fuel than if it were producing 40 kW. Assuming the maximum load of 40 kW for the EOV and 24 hour operations the amount of diesel fuel used over that 24 hour period is ~81 gallons of diesel. The calculations of overall fuel use will be simulated by adding the electrical use of all the programs as if it were one generator, not multiple.

As a method for increased diesel efficiency, one centralized generator that more closely approximates the peak load could be used as a centralized power source for the separate functions of MERS assuming that not all programs would be at maximum load simultaneously. Another option would be to use two generators in series allowing for both generators to be in use near capacity for peak loads, and only one generator to be used near peak capacity during off peak hours. Power could be saved by streamlining operations and may reduce the demand for electricity. However, given the amount specialized equipment and air conditioning inside the trailers, energy savings such as alternative lighting may be minimal. A more custom design solution would be needed in order to take better advantage of daylight and ventilation measures to reduce energy loads by any measurable amount.

Brake Specific Fuel Consumption information, http://en.wikipedia.org/wiki/Brake_specific_fuel_consumption

Current Diesel Operation

Micro-Centralized Diesel Power Option

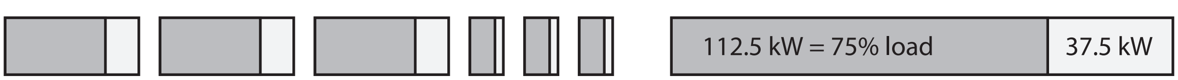


each small generator much be refueled separately
-- *fuel efficiency is however estimated by treating all separate generators as one large one, formula not accurate enough to account for scale of motor*

only one large, generator needs fuel
-- *a larger generator is more efficient due to the cooling system, and efficiency can be further increased by running the generator closer to capacity*

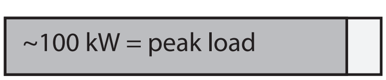
Current Diesel Operation

150 kW total capacity



Since each generator is separate, if one were to exceed capacity, power can not be transferred to other programs. Each generator needs to be sized for peak capacity even if overall there is no need for it.

Central Diesel Power Station 112.5 kW total capacity



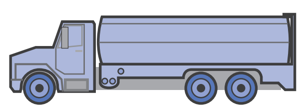
It is unlikely that all programs will simultaneously exceed a 75% load. In such an event the back up generators present within each program can be called to action. (see estimated use load curves)

Diesel Fuel Usage Estimations:

Amount of Diesel Fuel Consumption in Gallons -- 100% Diesel Run
.08433 gallons = 1kWh : fuel consumption per hour = .08433 x (rated kW)

150 kW total capacity 150 kW generator	continuous at 100% 3,600 kWh / day 108,000 kWh / mo 12.7 gl / hr 303.6 gl / day 9,107.6 gl / mo	continuous at 75% 2,700 kWh / day 81,000 kWh / mo 12.7 gl / hr 303.6 gl / day 9,107.6 gl / mo Same amount of fuel calculated due to generator operating within 75% of capacity Actual value may be less	Estimated Use 150 kW generator would be operating less than 75% and fuel use estimation equation only valid for generators operating between 100% and 75% of rated capacity
112.5 kW total capacity ~112.5 kW generator		continuous at "100%" 2,700 kWh / day 81,000 kWh / mo 9.5 gl / hr 227.7 gl / day 6,830.7 gl / mo	Estimated Use 2,150 kWh / day 64,500 kWh / mo 9.5 gl / hr 227.7 gl / day 6,830.7 gl / mo Same amount of fuel calculated due to generator operating within 75% of capacity Actual value may be less

Estimated Use:	2,150 kWh / day 64,500 kWh / mo
Fuel Use Estimated: if generator were sized for that exact load.	7.5 gl / hr 181.3 gl / day 5,439.3 gl / mo



~6,000 gallon tanker truck

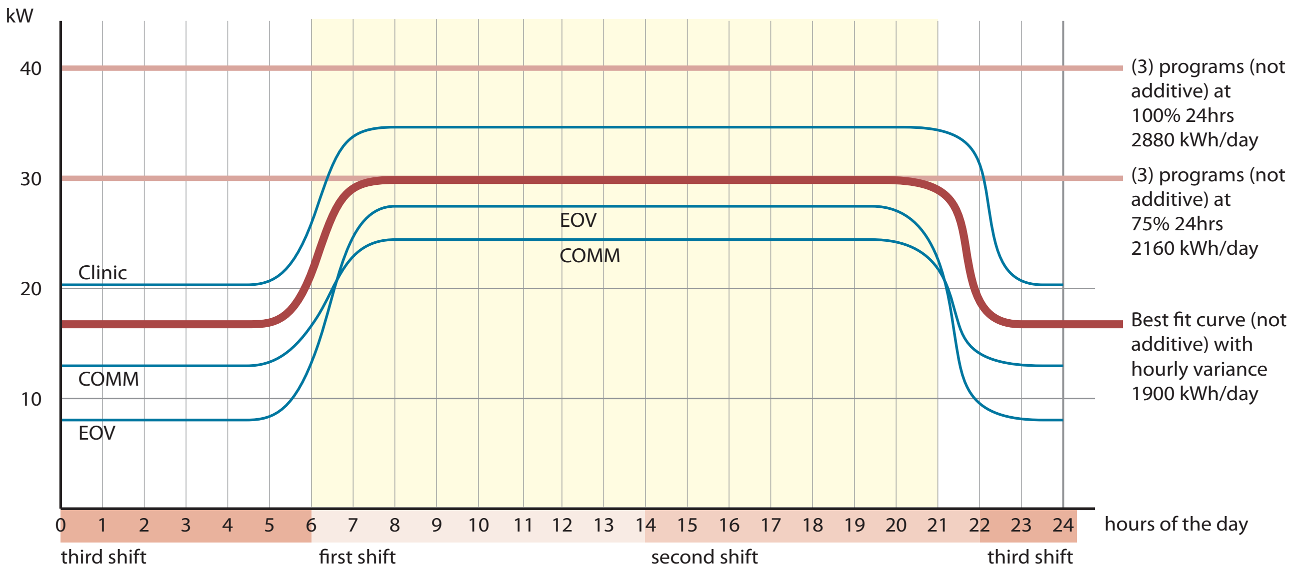
Above [Diesel Fuel Consumption].

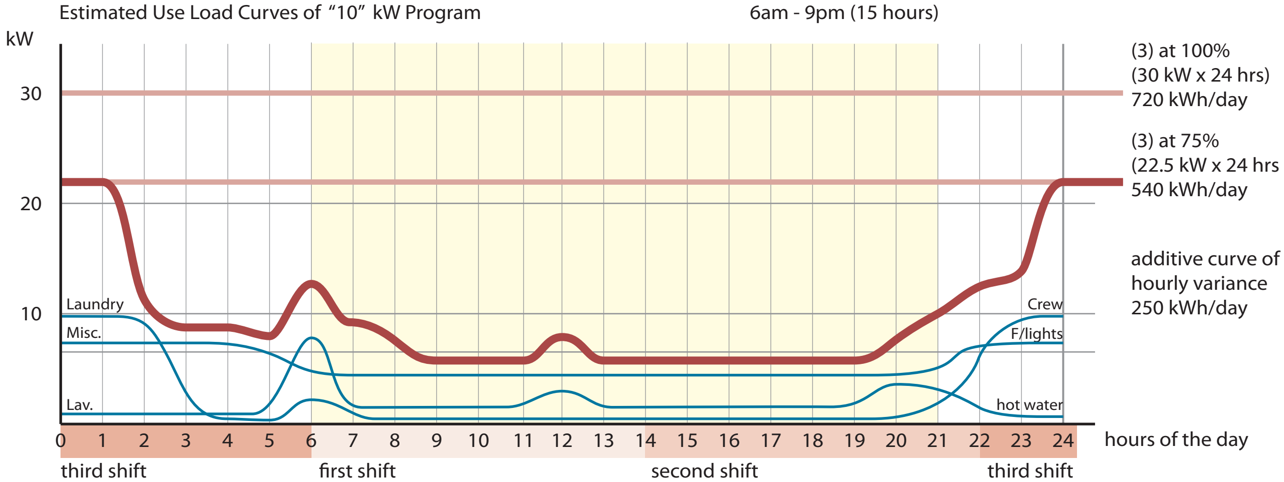
These loads are estimated as a daily average as a function of generator size and ranging power output capacities. To further evaluate the estimated use as a function of estimated peak loads, an analysis was carried out that examined the loads broken down into two categories. The first was examining the '40' kW loads over the course of a 24 hour period and the second was a look at the '10' kW loads over the same time. The load curves were added to give a better approximation of estimated energy use over a 24 hour period and that figure was also used to estimate the amount of energy required for a 30 day duration.

Estimating Power Use Over 24 hours:

Examining the estimated use curves, there is an estimated peak load for the clinic, EOV, and communications during the first and second shift. It was also assumed that the 40 kW rated capacity would not be indicative as a maximum power draw, assuming they were initially oversized for their intended program. The best fit curve averages these loads and the amount of 1900 kWh is the area under the curve and was multiplied by 3 to account for the overall energy use by those programs. For the 10 kW programs, the 250 kWh

Estimated Power Use By MERS Program: separated by load type

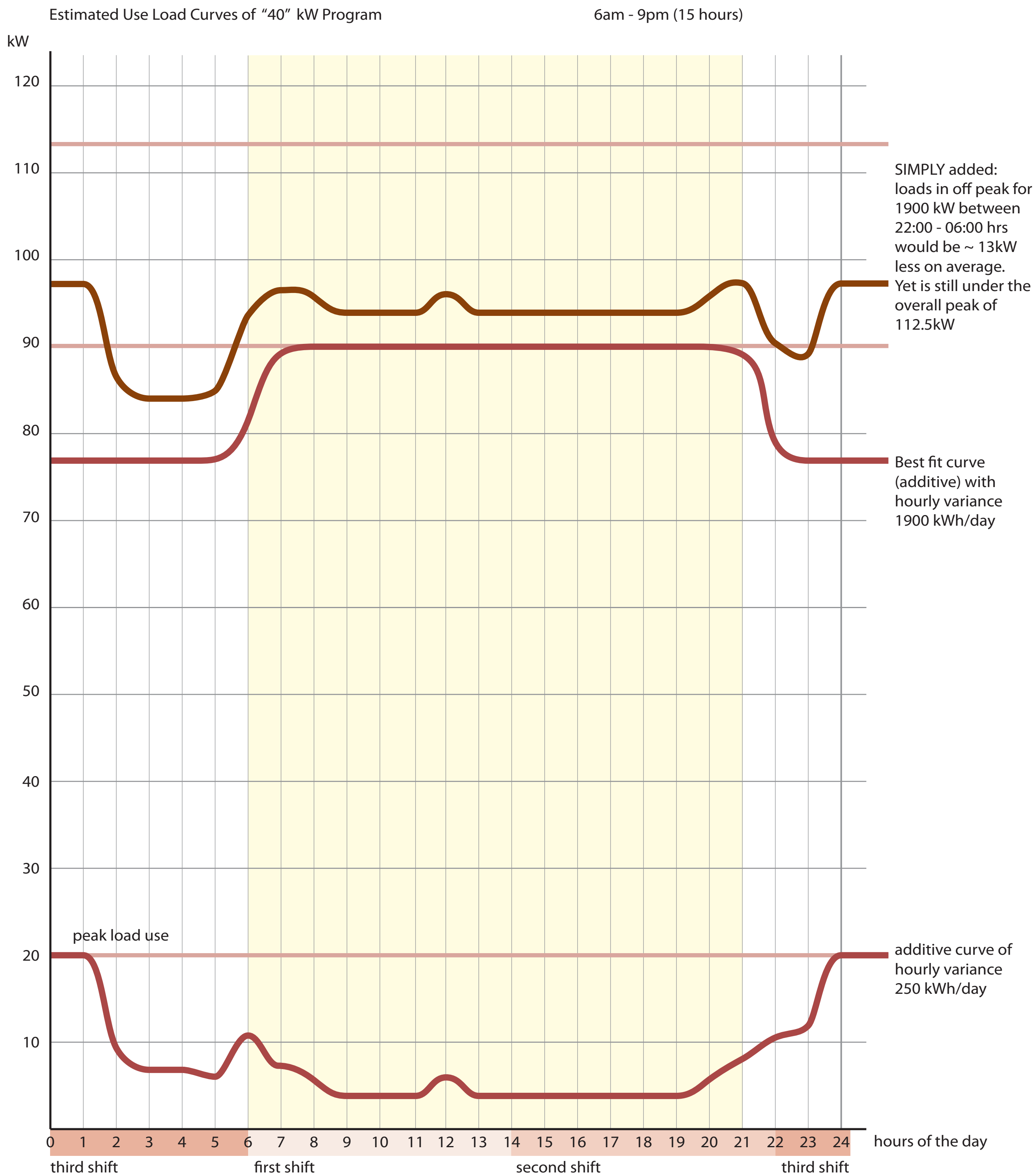




Total Program Loads:	100% 24 hrs (150kW)	75% 24 hrs (112.5kW)	Estimated Use
	3,600 kWh a day	2,700 kWh a day	2,150 kWh a day

line is an additive of all 3 '10' kW programs and can be added to the generated sum of 1900 kWh a day for the '40' kW programs for a total estimated use of 2150 kWh a day. Counter to the peak of the '40' kW programs, these curves reflect an estimation that the peak uses will generally be in the overnight hours with a peak in the morning and evening. This is largely attributed to the laundry usage and the hot water used for the showers. Water filtration for the day or the week can also occur over night reducing the demand for energy during the first and second shifts when demand is higher. On the following page we can see the graph of these peak loads combined together.

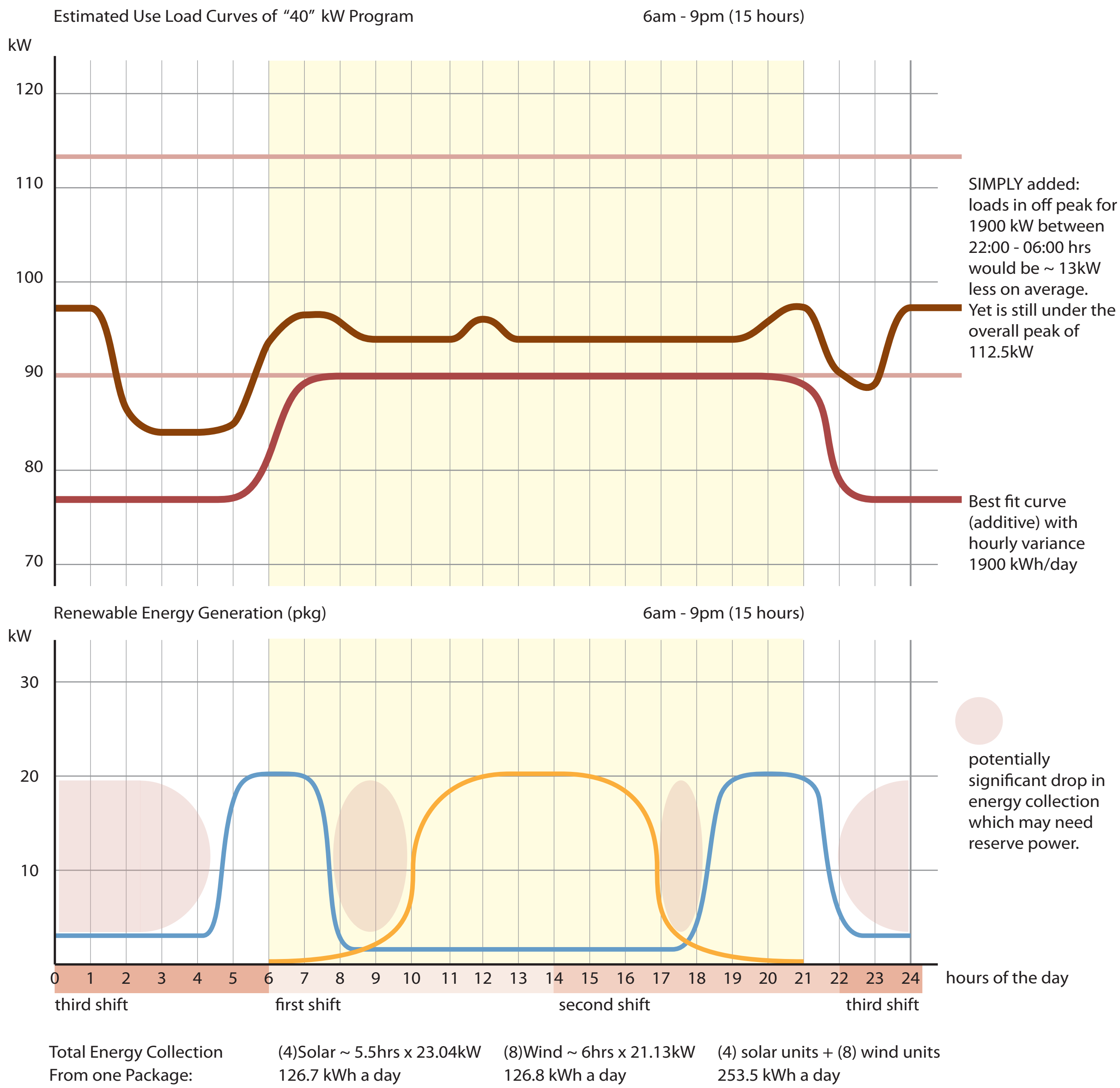
Estimated Power Use By MERS Program: combined total



Total Program Loads:	100% 24 hrs (150kW) 3,600 kWh a day	75% 24 hrs (112.5kW) 2,700 kWh a day	Estimated Use 2,150 kWh a day

With the combination of energy loads averaged, the peaks between the two groups of program begin to average out. In relation to renewable energy production, this implies that energy will be needed even at times when it is unlikely for renewable energy to be collected. The below graph is examining the collection potential for one renewable energy package, yet is indicative of the relative amounts if more than one package were to be used. If diesel generators are to be used as a backup only, power will need to be stored as hydrogen to be used later. It would be possible for wind to be present in the overnight hours, but research indicates [GE energy] that it is statistically more prevalent during the sunrise and sunset hours.

Estimated Power Use By MERS Program Compared with Renewable Energy Potential



Analysis of Wind Generation Impact on ERCOT Ancillary Services Requirements (page 8), 2008, GE Energy

Meeting Estimated Energy Loads with Hydrogen and Renewable Energy:

Below a chart breaks down the estimated amount of energy use for each category based on a 150 kW capacity ranging from 100 percent to an estimated actual use of energy. Further below for each category, an estimated amount of hydrogen is calculated for a 30 day supply and the amount of energy required to generate that amount of hydrogen in kWh. It should be noted again that the amount of energy required to produce 1 kg of hydrogen is 60% greater than the amount of energy can be extracted from that 1 kg of hydrogen when used in a PEM fuel cell. An ISO container of hydrogen (600 kg compressed at 3600 psi) would yield approximately 18,000 kWh. With an estimated use of 2,150 kWh a day, that single container of hydrogen would last 8.4 days.

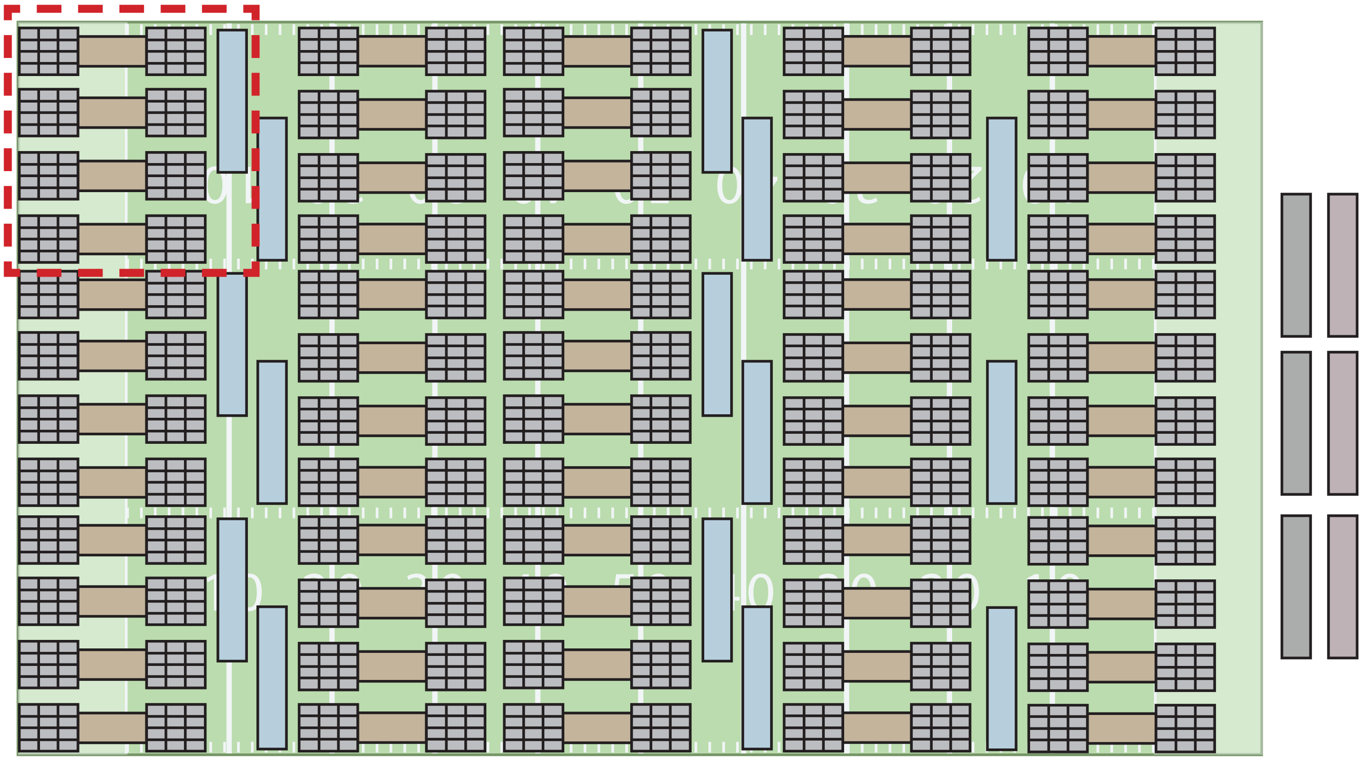
On the next page is a depiction of a renewable energy array that would offer a "break even" scenario where the amount of energy collected as an average, would be enough to produce enough hydrogen to replace the amount of hydrogen that was consumed by the estimated energy load. For scalar reference, the array would be roughly the size of a football field. The containers to the right would be the hydrogen storage tanks, water condenser tanks, electrolyser unit, the fuel cell, and power distribution equipment. Less hydrogen would need to be brought on site in this instance because hydrogen is being generated at roughly the same rate as it's being consumed.

Estimated Electric Load Per Day and 30 Days: 24 and 720 hours

		continuous at 100%	continuous at 75%	Estimated Use
Emergency Operations Vehicle EOV	(2) 40 kW generator			
Communications COMM	(2) 40 kW generator	2,880 kWh / day 86,400 kWh / mo	2,160 kWh / day 64,800 kWh / mo	1,900 kWh / day 57,000 kWh / mo
Clinic	(2) 40 kW generator			
Misc. (field lights, pumps, operations)	(2) 10 kW generator			
Crew Bunks Laundry	(2) 10 kW generator	720 kWh / day 21,600 kWh / mo	540 kWh / day 16,200 kWh / mo	250 kWh / day 7,500 kWh / mo
Shower / Rest room	(2) 10 kW generator			
each program has a backup generator	150 kW total capacity	3,600 kWh / day 108,000 kWh / mo	2,700 kWh / day 81,000 kWh / mo	2,150 kWh / day 64,500 kWh / mo
	Estimated Hydrogen Demand Per Day and 30 days	120 kg H2 / day 3,600 kg H2 / mo	90 kg H2 / day 2,700 kg H2 / mo	~72 kg H2 / day 2,150 kg H2 / mo
	Number of ISO Hydrogen containers for a 30 supply of Hydrogen	(6) 600 kg tanks 6 containers	(4.5) 600 kg tanks 5 containers	(3.58) 600 kg tanks 4 containers
	Estimated Renewable kWh to produce kg H2 Per Day and 30 days	6,000 kWh / day 180,000 kWh / mo	4,500 kWh / day 135,000 kWh / mo	3,600 kWh / day 107,500 kWh / mo

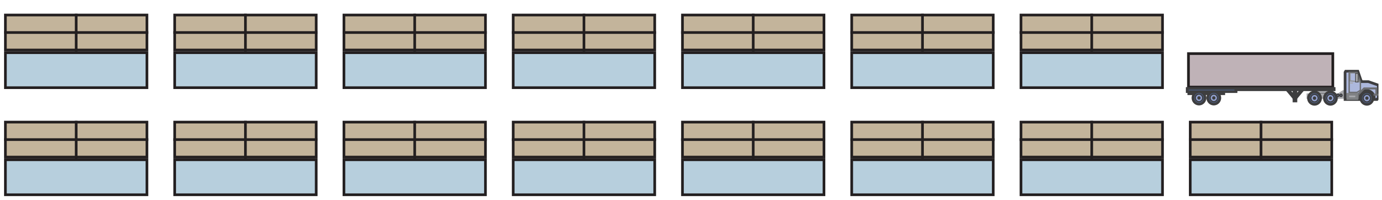
Space Requirements of Renewable Energy Array

Amount of Energy Needed Per Day (by estimated use)	2,150 kWh/day > ~72 kg H2 > need ~3,584 kWh/day collected
renewable energy production array of 15 packages:	253.5 kWh/day x 15 packages = 3,802 kWh/day
Estimated Hydrogen Production and Use:	3,802 kWh/day > 76.04 kg H2 > 2,281 kWh avail.



Physical Area Constraints (American Football Field for Scale) E-W

15 packages = 60 solar units + 120 wind units



Hydrogen Production Options

deployable solar = 126.7 kWh/day
(4) 5.76 kW x 5.5 hrs

vertical axis wind = 126.8 kWh/day
(8) 2.64 kW x 6 hrs

100% collected > H2 production > 60% return
253.5 kWh > 5.07 kg H2 > 152.1 kWh

Wind collected > H2 production > 60% return
126.8 kWh > 2.54 kg H2 > 76.08 kWh

Solar collected > H2 production > 60% return
126.7 kWh > 2.53 kg H2 > 76.02 kWh

It is clear that in order to meet the energy demands of a potentially continuous 150 kW load or even an estimated use of 2,150 kWh a day, relying completely on renewable technology for on-site hydrogen production becomes a rather distant reality, simply for the sheer area such an installation would consume. A more realistic scenario would be one that attempts to use renewable on-site energy production as a means to extend a duration of stay, either as a supplement to diesel generation (use diesel when energy can't be generated) or to replenish a pre-filled hydrogen supply. Containers of hydrogen and water would come pre filled so that energy is available upon arrival, and water is also available to generate more hydrogen with on-site renewable energy. To source 1 kg of H2, 2.37 gallons of water is needed (8.9 liters) [NREL]. In order to replenish the entire 30 day supply 5,688 gallons of water will be needed. However, when the hydrogen is run though and mixed with O2 that water vapor could be condensed, collected and reused. One container of used hydrogen (600 kg) would require 1,422 gallons of water to be stored on site.

If the evaluation criteria were simply to prolong the duration of stay, regardless of cost or logistics, then bringing a massive renewable power array for the purpose of hydrogen generation would be a clear winner as 15 packages could provided long term energy solutions. However, given the foreseeable restriction of available area this may not be an effective means to generate a hydrogen based energy solution on-site. The most environmentally attractive solution appears to rely on hydrogen that has been cleanly generated off-site for use in this particular application with a large power draw such as this. If the electric load was much smaller, bringing renewable energy production for the purpose of hydrogen generation and storage may become a more viable option.

There are options for extending the duration of stay. Beginning with a more limited supply of hydrogen and using a smaller renewable array to reduce the daily energy use loads so that the smaller supply of hydrogen can last longer. For the running balance to the right, 4 packages of renewable energy were used such that a comparison could be made between using that array for hydrogen production, and direct use by the program. Anything beyond 4 packages with out a battery system would mean that during peak hours the array would be collecting more energy than the program uses but would not be able to store that energy for use later. As the results show, using the renewable energy array to reduce the demand for hydrogen is more effective than generating hydrogen. This configuration where hydrogen is not being produced would also reduce the amount of equipment required on site.

Running Balance Sheet of starting out with 2 containers of H2

Ex. 1 2 containers of H2 = 1200 kg ~ 36,000 kWh of potential energy to start
4 packages of RNRG = (4)253.5 ~ 1,014 kWh per day
every day that passes
2,150 kWh (72 kg H2) is spent daily
1,014 kWh is earned (not for H2 production but is taken from peak load)
results in a net loss of 1,136 kWh a day deducted from 36,000 kWh
the supply of hydrogen would last 31.7 days
-- OR --
20.28 kg of H2 generated (~ 608.4 kWh potential energy added to balance)
results in a net loss of 51.72 kg of H2 a day deducted from 1200 kg H2
the supply of hydrogen would last 23.2 days

NREL, Electrolysis: Information and Opportunities for Electric Power Utilities, Sept 2006, B. Kroposki, J. Levene, and K. Harrison
National Renewable Energy Laboratory Golden, Colorado.

These packages represent the breakdown of different functions that can be added to the MERS program. For example, the function of hydrogen production is separate from the function of hydrogen consumption. All sizing considerations are for 100 people. If the need to serve 200 or 300 people arise some items need to be simply multiplied such as septic waste. Other services like water treatment can handle the extra load far exceeding that number. For the MERS program the principle energy draw is from equipment that is used regardless of the number of people on assignment. Therefore adding more people will increase electric resources draw but not in the same proportion as water use and waste management which has a direct correlation between program use and number of people using it. Maintaining centralized services will reduce the parasitic energy involved in providing water and waste management functions.

Package contents for various functions: (minus MERS equip / supplies, Med unit)

Hydrogen fuel USE:	Hydrogen storage tanks (ISO tanks) Fuel Cells (PEM) Power distribution / management
	+
Produce Hydrogen:	Electrolyzer (Deionizer) compressors (for H2 storage) H2O tanks (condensers)
	+
Renewable Array:	Outpost Solar Vertical Wind Bio Gas (negligible amount due to only a few MB 400s present)
Solar Hot water unit:	For Shower / Lav unit, on demand electric hot water will supplement
Waste Management:	MB 400 Septic (x 2) --Only if lavatory unit is present MB 400 Organic (x 1) --May bring more if needed
Water Treatment:	Surge collection tank (to collect water and treat ~5,000 gallons at a time) Distribution tank (pull water from here for use in hot water and program) Pre-filtration to separate organics to go into MB 400 or waste (hair, lint etc.) Actual filter (GE treatment package comes in 40' container)
Laundry unit:	5 washers and 5 dryers (designed trailer - or 50' container provides 36 bunks)
Shower and Lav unit:	Special toilets not unlike seen in busses, trains, boats. Saves water and possibly better suited for MB 400. Showers are primary use of hot water in volume (2000 gal).

Water Cycle: Use by Type, Grey Water, and Water Savings

When evaluating the water cycle, the majority of the water that is lost and cannot be retreated is the black water from the lavatories. In essence, the only water that needs to be brought in as an external source is the water that escapes through human use (drinking water) and toilet use (nearly a third). If specialized toilets can be used to reduce, or eliminate the amount of water used, and be emptied directly into the septic digester, than nearly all the grey water can be collected in tanks, filtered and treated to be used again. Solutions to extend water supplies by recycling grey water captured from showers, hand washing, and laundry (more difficult to capture water from the dryer exhaust) to be used in the same grey water applications can greatly reduce the amount of water that may need to be transported to the Care Center Site. Hose connections and water distribution system will need to connect the various programs together and be adaptable to shifting scales in order to supply the water to the collection tanks and deliver the water with pressure.

Laundry:

One load per week per person. 30 days or 4 weeks results in 400 loads or 100 per week. Estimating that a front loading washer will use 10 gallons per load, approximately 1000 gallons of water will be used to wash clothing over a given week. In terms of energy use, if each load (washing and drying) takes 2 hours than 100 loads will take 200 hours to finish. If 5 washers and 5 dryers are used than it will take 40 hours to do the weeks laundry. Since washer uses 400 watts and a dryer uses 2200 watts per load [Green Studio Handbook] then the amount of energy to wash a weeks laundry is .4 kW (20 hours) + 2.2 kW (20 hours) = 52 kWh per week. The percentage of energy used to generate hot water for the washing machine is not known, but this could possibly be supplemented by the use of solar thermal to source hot water to increase the efficiency of the washing machines. Additionally, cold water detergent can further reduce the need for hot water, and energy can be saved by line drying clothing instead of using the dryers.

Lavatories:

On average a person uses the lavatory 3 times per 8 hours. Given the nature of 24 hour operations it could be possible for someone to use the lavatory 9 times within that period. However it is likely that on average a person may sleep 8 hours a day, giving an estimate of 6 lavatory visits in 16 hours. With a standard low flow toilet of 1.6 gallons per flush this would give an estimated use of 9.6 gallons of water use, per person, per 24 hour day. Vacuum toilets or toilets with a waste catchment tank such as a chemical toilet will drastically reduce the amount of water leaving the water cycle in the form of black water. A chemical toilet uses approximately 2 percent of the water of a conventional toilet, as chemical tanks are adequate for up to 160 uses before needed to be emptied or replaced [CFANS]. With the additional provision of hand washing the estimation of .5 gallons per 30 seconds of hand washing or .5 gpm multiplied by 3 per person per day is not a significant number but can also be reduced by utilizing sanitary hand wipes instead of using running water and a towel to dry hands.

Information regrading chemical toilet. “Onsite Sewage Treatment Program” University of Minnesota, 2010 CFANS.
Green Studio Handbook, Walter Grondzik, Alison Kwok, Architectural Press 2006 pg. 185, 235

Water Use by MERS Program: input and output

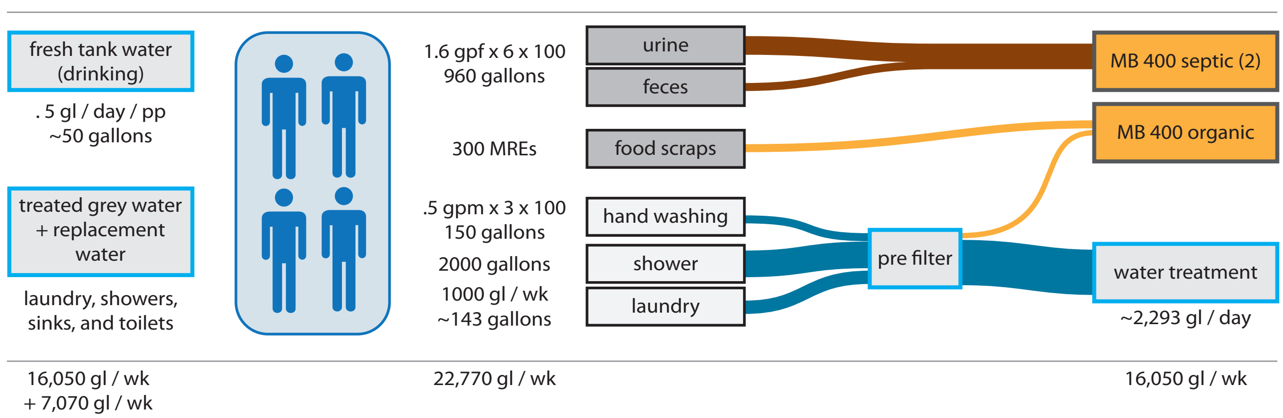
This is using traditional 1.6 gpf toilets. the amount of black water generated and amount of water used for flushing could be greatly reduced by using chemical or composting toilets

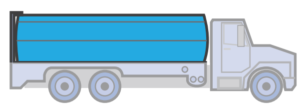
in

Water and Waste Per Day

100 people

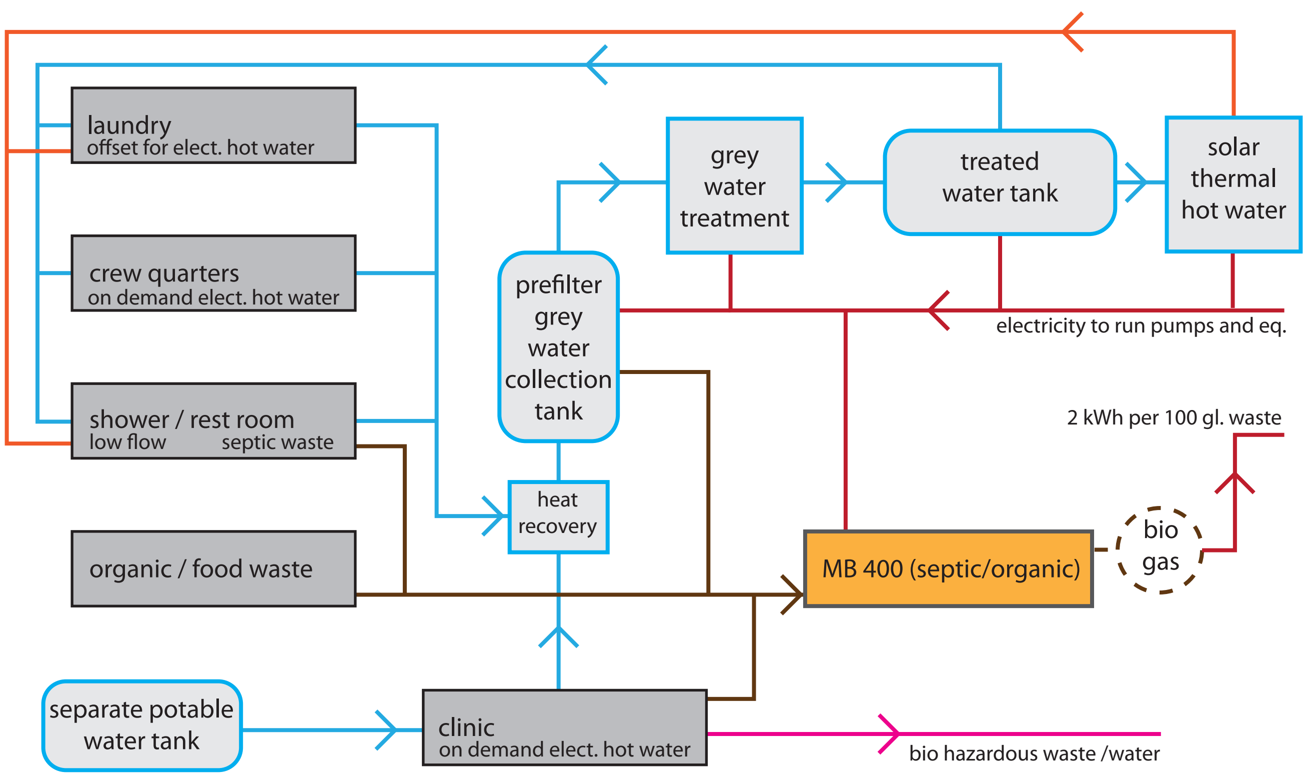
out / day





To increase the efficiency of the water treatment system, this water could be held and treated twice a week (~8,000) gallons at a time.

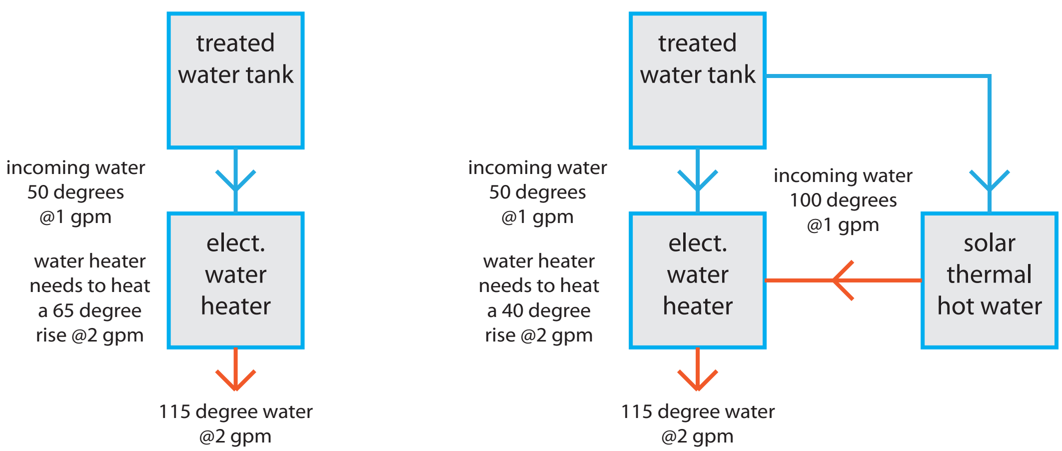
Water and Energy Connections and Flow:



Showers:

20 gallons per person, per day using a low flow fixture [Green Studio Handbook]. 100 people showering over the course of a 24 hour day results in approximately 2000 gallons a day. Naturally if people choose to shower once every other day this would reduce the amount of water in half and would also dramatically reduce the amount of hot water needed. While laundry units have electric water heaters within them and high efficiency units can operate with relatively cold water, Hot water is typically sourced from a hot water tank. Tank less water heaters heat water on demand and can be greatly more efficient than storing hot water. Tankless water heaters can also be used for smaller applications such as a single faucet and can be distributed nearly anywhere.

Below a flow chart describes the process of using a tank-less water heater to heat up the incoming tap water to 115 degrees. It would be possible to use a solar thermal system to either aid the tankless water heater by increasing the temperature of the tap water or it could completely replace it. However, storing hot water becomes an issue for those showering in the morning as the sun has not had an opportunity to heat the water yet. A resource management schedule may dictate that MERS crew, regardless of shift, should only shower in the afternoon or evening to reduce energy demands. Since the supply of hot water could be demanded at nearly any time during the day, or if cloudy weather persists, tank less water heaters will serve as the primary source of hot water.



Mobile Clinic:

The mobile clinic can serve 60-70 patients a day with 12 beds [FEMA DMAT]. The average water use of a hospital is around 200 gallons per day, per bed. That rough estimate includes building services, therefore an estimation of potable water use is difficult to ascertain for this program. It is also an assumption that the water waste coming from the hospital would be considered biologically contaminated and therefore not treated in the grey water treatment cycle. Additionally, grey water treated with on-site purification may not be suitable for hospital sanitation standards. Therefore the water used by the clinic program is not part of the grey water cycle loop and is completely separated. It is however, connected to the Muckbuster should need arise.

Information regarding tankless water heater, http://www.tanklesswaterheaterguide.com/
FEMA DMAT, Mobile Medical Units Vital To Disaster Response And Recovery, press release February 13, 2006
http://www.fema.gov/news/newsrelease.fema?id=23600

Summary:

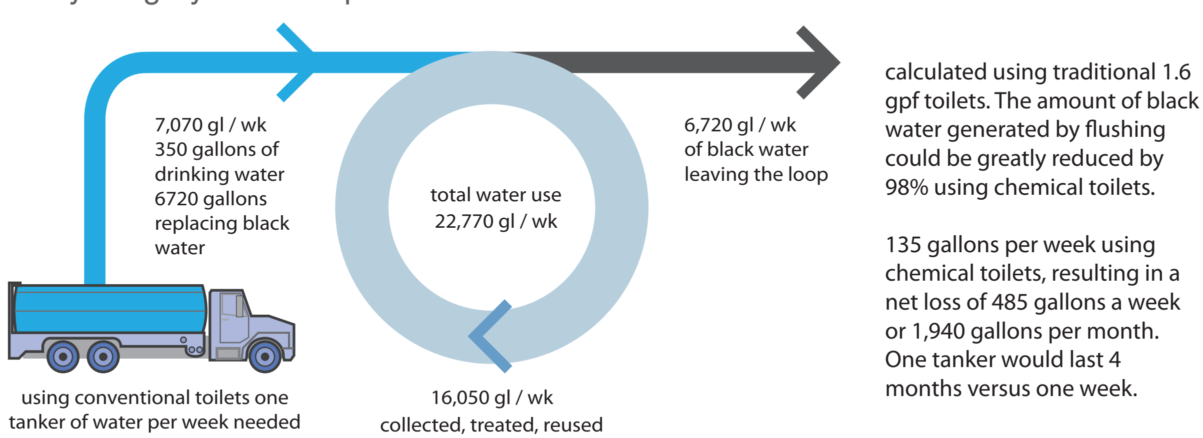
Water Cycle:

The majority of the water use by the MERS program (nearly 14,000 gallons a week) is used for showering. If showers were to be used every other day per person, that number would be cut in half. Since the waste water used by showers is treated as grey water, that water is reused, not lost and has little impact on the water budget. The primary drawback to the high volume of water used is that a proportional amount of energy is used to heat that water to 115 degrees, then to pump, store, and treat that water to be reused. If grey water capture and treatment were not included as part of the MERS program, an estimated 22,770 gallons of water a week would be needed. However, if grey water treatment was not a part of MERS it can be assumed that showering and laundry would occur at a much lower rate than estimated as an effort to ration water supplies.

The largest contributing factor to external water demand is black water waste lost via flush toilets. Nearly a third (6,720 gallons) of the water flow leaves the water cycle and must be replenished. Using alternatives such as chemical toilets can reduce the amount of water lost by as much as 98%. The remaining septic waste can be emptied out into a nearby Muckbuster 400 septic digester. Removing the large excess of water from the septic waste would also ensure a better ratio of solid to liquid volume for the digestion process. However, it is unknown it the digester would still function with the chemicals used in chemical toilets.

By reducing the amount of black water that leaves the water cycle to 135 gallons per week, and adding the approximate demand of 350 gallons of drinking water per week, a total of 1,940 gallons of water per month will need to be supplied to the disaster site. This figure excludes the Clinic program as it's water supply is an open loop and the specific information on it's water budget in unavailable. For any given day the water use will be approximately 2,293 gallons (using chemical toilets). 7,000 gallons of treated water will need to be stored on hand for use and another 7,000 gallon tank will be needed to store water awaiting treatment. Water treatment will be every 3 days to maximize the efficiency of the water treatment. The General Electric MCU water treatment system can treat 12,000 gallons in 1 hour and use approximately 56 kWh of power to do so. Using this system, treating 7,000 gallons in 36 minutes will use approximately 33.6 kWh per use, or 336 kWh per month.

Water Cycle: grey water loop



Electric Power:

The primary drawback to renewable solar and wind energy production is that it is subject to atmospheric and temporal conditions. The energy must be used the moment it is available or stored in some way. The typical storage medium is a dry cell battery. This however, also has it's short comings with chemical degradation and energy discharge over time, along with the use of finite resources. For these, and other reasons, hydrogen was chosen as a storage medium for this investigation. The process of producing hydrogen using electrolysis, and then converting that hydrogen back to usable energy yields an efficiency of 60%. The benefit of using stored hydrogen is that energy can be used independent of energy collection, similar to diesel fuel used in diesel generators. While hydrogen has a greater power to weight ration that diesel, hydrogen is a gas that must be compressed for the transport of any appreciable volume (otherwise the volume of 1 kg of hydrogen at standard atmospheric pressure (ATM) is 3,206 gallons). Utilizing the most efficient diesel generation option, one tanker truck (~6,000 gallons) will last nearly the 30 day deployment, while 4 containers of hydrogen will be needed.

In order to theoretically sustain the MERS operation indefinitely, 15 renewable energy packages will be needed to replenish the hydrogen supply used on a daily basis and will therefore a 30 day supply of hydrogen will not be needed on-site. For periods of roughly 30 days or more, a variety of configurations exist for utilizing hydrogen and renewable energy. The number of pre-filled hydrogen tanks initially brought to the site, and the amount of renewable energy packages brought to either, generate hydrogen or provide a reduction in energy load (and thus a reduction in amount of hydrogen used) work in different ways to provide an energy solution.

When using the renewable energy packages to reduce the amount of energy consumed by the MERS program (either in kg of hydrogen used or in gallons of diesel spent) and not for the purpose of producing hydrogen to store energy, any more than 6 RE packages and the peak collection potential exceeds the estimated peak load of the MERS program. The maximum estimated load is 112.5 kW while 6 RE packages would peak at 120 kW for an estimated 10 hours a day. The hydrogen PEM power source would produce energy the other 14 hours in a day including likely gaps in RE production in late morning and late afternoon. In essence, the amount of hydrogen used drops from 72 kg a day to 44.3 kg a day. It is important to note that sizing RE to the daytime peak load allows for the fuel sources brought in (diesel or hydrogen) to be used at the off-peak rate of approximately 95 kW. Translating to 132.8 gallons of diesel or 3.2 kg of hydrogen used during the overnight hours and the gap in RE collections for 14 hours and RE to be used as a primary source of energy for 10 hours a day. Essentially any more than 6 RE packages and those extra RE packages are used only to produce hydrogen to further offset the reduced amount of daily hydrogen used.

When using the renewable energy packages with diesel generation (with no hydrogen generation on-site), any more than 6 RE packages could result in surplus energy that can not be stored and therefore an inefficient use of space. Using two options for a fuel source (hydrogen and diesel), one would be used as a primary and the other as either a back up or alternate, while the renewable energy would serve to reduce energy demand primarily over the day time hours.

Summary of Different Power Options:

All Diesel:

Actual fuel consumption is difficult to speculate because the equation for calculating estimated fuel use (.08433 gallons per kWh) is accurate within 75% loads-- However it is true that the closer a generator is to maximum capacity the more efficient it is.

:: collection of separate generators (status quo) calculated as one 150 kW generator.
303.6 gallons per day / 9,108 gallons for 30 days

:: one centralized generator of 112.5 KW distributing power to MERS programs.
227.7 gallons per day / 6,831 gallons for 30 days

:: two centralized generators, one of 90 kW rating for off-peak use and one of 25 kW for peak use.
off-peak generation of 90 kW for 6 hours -- peak generation of 115 kW for 18 hours.
220 gallons per day / 6,600 gallons for 30 days

All Hydrogen:

Energy is brought to site with ISO containers filled with 600 kg of pressurized hydrogen (3600 psi) and is produced off-site using renewable energy. One container has roughly 18,000 kWh of potential energy. A PEM fuel cell would be needed to convert the hydrogen to usable power. The estimated load is 2,150 kWh a day or a demand of 72 kg H_2 per day (64,500 kWh or 2,150 kg H_2 per month).

:: 4 containers of hydrogen (2,400 kg) would sustain the estimated electric load for 33 days.

Hydrogen + Renewable Energy Array:

:: Indefinite operation. 15 Renewable Energy packages (RE) + Electroylzer + PEM power unit. RE would theoretically collect enough energy to produce all the hydrogen consumed on a daily basis. One hydrogen storage tank would be needed that is replenished.
15 RE packages collect 3,802 kWh per day producing 76 kg of H_2. A surplus of 4 kg H_2.

:: Hydrogen primary over night with RE primary over day. 2 containers H_2 + 8 RE PEM power over day when gaps in RE production occur. 10 hours during the day RE can supply a maximum of 160 kW. Surplus RE will be stored as H_2 (60%) Hydrogen is being used the other 14 hours, primarily overnight at an estimated rate of 3.2 kg per hour or 44.3 kg per day. .
2 containers of hydrogen (1200 kg) would last 27 days
4 containers of hydrogen (2400 kg) would last 54 days

:: RE for hydrogen production. 4 Renewable Energy packages (RE) + Electroylzer + PEM power unit. 20.28 kg of H_2 is produced on a daily basis resulting in a net loss of 51.72 kg H_2 per day.
2 containers of hydrogen (1200 kg) would last 23.2 days

:: RE for energy load reduction. 4 Renewable Energy packages (RE) + PEM power unit + power dist. 1,014 kWh is collected on a daily basis reducing the demand for PEM power to 1,136 kWh per day.
2 containers of hydrogen (1200 kg) would last 31.7 days

Diesel + Renewable Energy Array:

:: Diesel primary with a 1 RE (light program for RE or critical program backup)
1 RE packages collect 253.5 kWh per day with an estimated peak production of 20 kW.
200.3 gallons per day / 6,009 gallons for 30 days

:: Diesel primary over night with 6 RE primary over day 6 (will need diesel when gaps in RE production occur). For 10 hours RE handles loads and for 14 hours a 112.5 kW generator is used.
6 RE packages collect 1,521 kWh per day producing with a peak production of 120 kW.
132.8 gallons per day / 3,984 gallons for 30 days.

Hydrogen + Diesel

:: Hydrogen at night, diesel during the day. Estimated electric load is 2150 kWh per day
72 kg of hydrogen per day / 2,150 kg per month
227.7 gallons of diesel per day / 6,831 gallons per month

Conclusions:

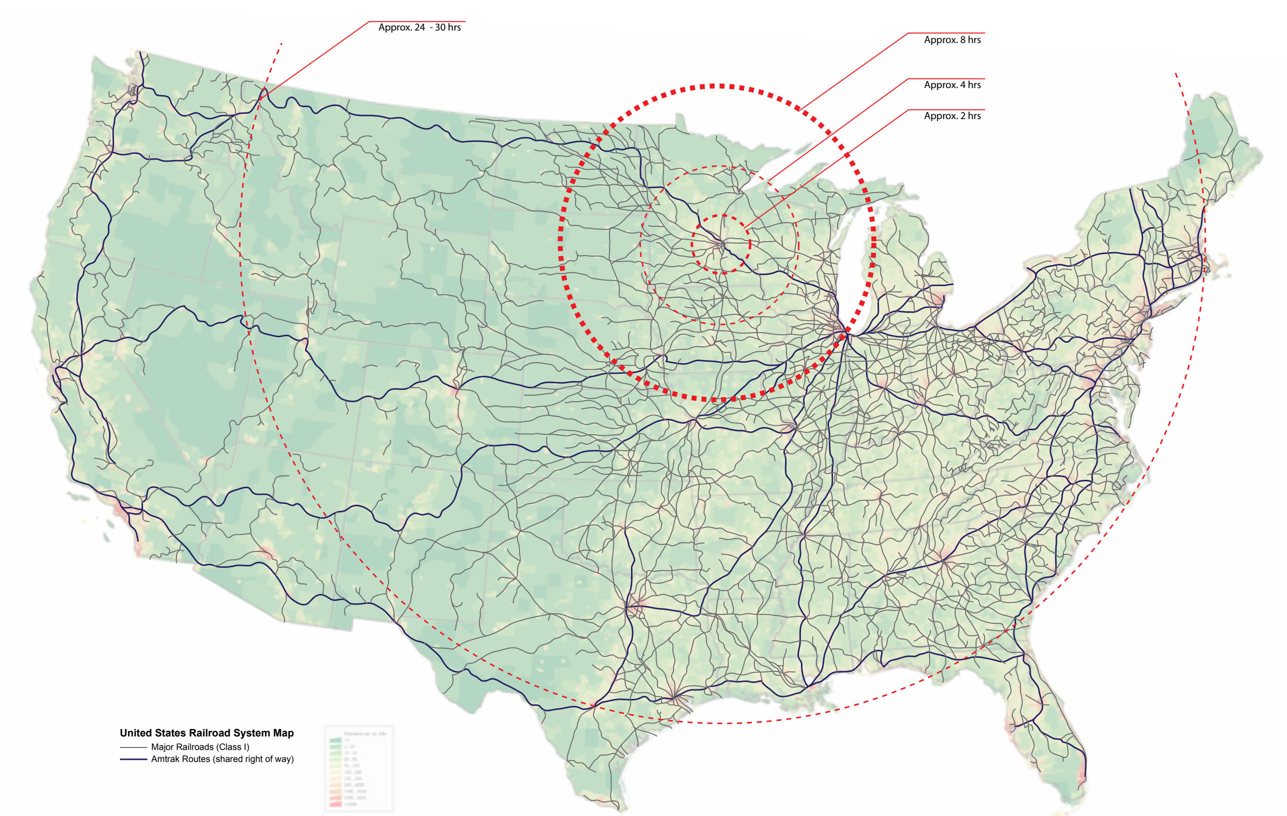
When a federal response to a natural disaster occurs, factors such as response time, reliability, resource efficiency, set up time, operational autonomy, and space requirements for the amount of equipment to carry out functions, all play a role in determining the most appropriate solution. With regard to the specific energy and water requirements of MERS, the deployment duration goal has been 30 days without external resupply. Meaning that the MERS unit must bring with it all the equipment necessary to preform its operational goals for a crew of 100 people, bringing as little equipment as possible. While the concept of on-site renewable energy for either on-site hydrogen production or load reduction is an attractive idea, it is more effective to bring a fuel source to the disaster care center and budget it's use, than to depend on the externalities of renewable energy collection. This is in addition to the fact that a renewable energy array would necessitate a large amount of open area to function to reduce the need for a fuel source for the MERS program by a significant amount. The proven track record and universal nature of diesel generators can not be ignored given the critical nature of the MERS mission. FEMA will make diesel resources a priority for the foreseeable future, for this reason. While the use of hydrogen offers a more sustainable and carbon neutral energy option, it would still require 5 separate, 40 foot long containers (the 4 hydrogen tanks and one PEM fuel cell power source) to offer the same energy duration of 2 tanker trucks filled diesel. This diesel fuel would also be available to other facilities or fleet vehicles should need arise.

The recommendation of diesel fuel and diesel generators however does not imply that the status quo of using multiple generators divided amongst each program is the best option. Recognizing that each program, such as the EOV or the communications truck, carries their own generator suggests a flexibility to mix and match different programs that are each energy independent, implies that the overall energy load may vary from mission to mission. With this particular load estimation, and assembly of program, the most fuel efficient option is to use two generators so that power can be generated at maximum efficiency during peak and off-peak load cycles.

With regard to water usage, any opportunity to re use water is worth the amount of equipment needed to achieve a grey water cycle. Water treatment is already a mission goal of the MERS program and extending this capability to capture and treat the grey water produced is an achievable goal with some planning and consideration. The largest use of water by the MERS program is used for showering. A reduction in the amount of showering will have a negligible impact on the water consumption of the program with a grey water cycle in place, but have a more profound impact on the water heating load and subsequent electric load. A solar thermal package would reduce the electric load for heating but, the if the amount of water used for showering can be reduced by half to a third through behavior changes, than the amount of equipment and set up required to do so may not offset the potential energy savings of an on-demand electric tankless water heater. To further reduce the amount of water needed to replace water lost from of the grey water cycle, chemical toilets will be used. This along with a grey water cycle, will drastically reduce the need for an external water supply. Waste management though containerized digesters are paramount to not burdening a presumably already burdened or crippled site with additional organic and septic waste that must be transported away from the disaster.

Given these recommendations, this investigation serves to examine what the capabilities of these systems are in the most demanding situations as a way to quantify how they might be applied in similar off-grid applications at smaller scales. In essence, this is a viable test of the proof-of-concept relating to mobile off-grid applications at this scale where space requirements, and critical operations are less of a deciding factor. The MERS program offers a method for testing the feasibility of other mobile self sustaining endeavors such as mobile units temporarily aiding a rural community, or mobile clinics and education programs traversing the country. Many of the life support functions relevant to isolated inhabitation or rural support, apply to MERS as they all are in a sense, small self-supporting communities. By evaluating the capabilities of sustainable systems in terms of ability to meet MERS's demands for communications, logistics, resource allocation/connections and conservation; assumptions and extrapolations can be made to these and various other scenarios if it is indeed feasible to provide off-grid life support without the use of diesel generators and limited supplies of water.

One of the primary motivations behind off-grid technologies is to gain independence from distant resources and is an important part in the endeavor to be sustainable. Energy is lost in transmission and providing self sustaining resources puts an emphasis on responsible resource management. A mobile, self sustaining, off-the-grid community has the potential to be a self contained community that does not rely on grid infrastructure and reduces the need for outside supply convoys that may have difficulty reaching the location. It can also temporarily aid a community that has lost grid services by way of natural disaster or provide supplementary programs to a small community without the burden of needing to rely on the community's energy



Above map showing population density and major (class I) rail connectivity for contiguous united States. Rail travel times from St. Paul, MN are indicated in hours and approximated using passenger rail time tables.

and water resources. For long term deployments of months or more, these systems may include a means of food production to gain additional independence in the landscape, further increasing durations between resupply for traveling services. Remaining within the scope of mobile technological systems, depending on external supply, however minimal for either food or water, is expected.

The concept of a mobile, self sustaining off-the-grid community has roots in a proposed “On Rail - Off Grid” concept where rail cars are a means of providing services to rural towns that have basic access and proximity to rail lines. The concept specifies that the location is variable and that the program “applications” are confined to the standard dimensions of a rail car. This also has a more direct application for providing servicing remote places beyond the reach of a grid infrastructure system to begin with. When addressing all aspects of life support, grouping the components into functions such as a “power generation unit” or a “water purification unit” for the specific uses of emergency disaster relief, could be universally applicable.

In relation to rail and disaster relief efforts, it is unlikely for a train to render services directly to a community struck by a natural event as it would be likely that the rail lines would be damaged or made impassable by fallen debris or rail bridge failure. However, the investigation of mobile off-grid infrastructure systems to meet the demands of energy production and life support services at the scale of MERS, remains valid as the knowledge gained is transferable and applicable. Constraining the investigations to life support technologies that are dimensionally similar to intermodal shipping containers, that were designed to be mobile, these components of grid free services will have the ability to be deployed to nearly any place where a train, truck, or ship has access to.

The benefit of rail transit infrastructure is that large amounts of equipment can be transported relatively quickly and efficiently over large distances. Rail networks are present in every major city and many small towns in between granting them access to a majority of the population. In lieu of individuals traveling long distances, specific convoys can bring services ranging from education and research, to health care and disaster relief, to any place that has access to rail infrastructure. Arriving with these convoys are the modular systems providing life support that would be needed when arriving in a place that is not equipped to provide grid tied power or water serves to them. These systems could be strung together along with the program services and arrive on site as a functional unit with little to no “assembly required”. As these systems are independent, yet connected to a unit for providing life support, they can be duplicated and possibly lent out to communities in need who are unable to depend on their grid energy and district resources. In essence, mobile and containerized off-grid solutions for grid-tied services encourages independence from constraints such as infrastructure and climate. Moving from site specific solutions for off-grid strategies, to solutions that are meant to be scaled and sized, results in a universally flexible system that is adaptive to location and climate.