ON-SITE FIELD-FEEDING WASTE TO ENERGY CONVERTER

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ABSTRACT

Military field-feeding generates tons of solid waste that is a costly logistic burden, requiring personnel, vehicles, and fuel that could otherwise be used for the war-fighting mission. Such waste also represents a source of chemical energy sufficient to power a field kitchen and/or other force sustainment systems. This research investigated the concept of employing an air-blown downdraft biomass gasifier to convert foodservice waste into useful energy. A prototype system was developed that converts the relatively dry fraction of the waste (i.e., paper and plastic packaging, as well as service items including pulp trays, napkins, and plastic utensils) into combustible producer gas that is used to generate electricity in a diesel engine-generator set adapted for bi-fuel operation. Future work may include enhancements to improve feedstock handling and allow conversion of a greater fraction of the waste stream, including wet food waste.

1. BACKGROUND

Deployed forces and contingency operations generate tons of packaging and other waste that must be buried, burned, or backhauled to disposal sites at great expense. Studies have shown that foodservice solid waste is generated at a rate of 3–4 lb per person per day for Force Provider base camps and Army field exercises (Ruppert, 2004; Rock, 2000). For contingency operations, reliance upon a host nation's often inadequate waste disposal infrastructure presents human health and environmental concerns, force protection challenges, and potential future liabilities.

The ton per day of foodservice solid waste produced by a 550-man Force Provider contingent or maneuver battalion is mostly organic, as shown in Table 1 (Ruppert, 2004). This logistic burden thus also represents a significant source of unutilized energy potential. An On-site Field-feeding Waste to Energy Converter (OFWEC) capability would reduce waste into non-hazardous byproducts and produce useful energy, thereby reducing two logistic burdens, waste and fuel, while enhancing force protection and reducing environmental impact.

The energy content of this waste stream is equivalent to more than 850 gallons of JP-8 fuel each week, although conversion efficiencies will significantly lower the fraction of the energy that can be recovered in a practicable system. Taking this into account, the Force Provider foodservice waste stream theoretically has sufficient heating value to power a 60 kW generator continuously six days per week at a 45 kW average load.

Table 1. Extrapolated Force Provider Waste Characterization Data

Type	Fraction	lb/day	BTU/lb	kW/day
Paper & Cardboard	36%	807	7900	1867
Food	23%	513	2370	356
Slop Food	16%	369	1000	108
Plastic	11%	251	17400	1280
Cooking Oil	5%	110	16800	542
MRE	5%	118	8750	303
Metal, Glass, Misc.	4%	88	-	-
Total	100%	2255	6742	4455

(Fort Polk, June 2000, 4.1 lb/person/day)

2. SYSTEM CONCEPT

The OFWEC objective has been to develop, demonstrate, and transition a full-scale system that generates electricity while reducing the solid waste produced by feeding a battalion. The overall goal is to process 1 ton/day of mixed waste with a system packaged in an 8×8×20' ISO shipping container and weighing less than 10,000 lb for rapid deployment and compatibility with Force Provider transportation assets.

Other perceived requirements include low cost to procure, operate, and maintain; minimal manpower and specialized skills to operate; minimal sorting or segregation of waste to reduce the burden on field-feeding personnel and diners; and, if possible, the use of existing Tactical Quiet Generators (TQGs) for power generation.

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Superficially, the waste to energy conversion process can be broken down into three general challenges: feedstock conditioning, conversion into a fuel product, and power generation. Feedstock conditioning includes actions taken to improve the raw waste stream, including manual operations like sorting and segregation (of glass and metal, for example) and mechanical processes like shredding, drying, and densification. Conversion includes the processes by which the prepared feedstock is transformed into a gaseous or liquid fuel product. Power generation includes the means by which the fuel product is converted into electricity, minimally to self-power the process, but ideally to generate a surplus that can be used to power the kitchen and other organizational equipment.

In response to a Small Business Innovation Research (SBIR) topic prepared to address these requirements, Community Power Corporation (CPC) proposed an effort to explore the suitability of using their BioMax® downdraft gasifier technology for converting relatively dry foodservice trash into useful energy. The concept ultimately included use of a shredder and dryer in conjunction with a gasifier, as well as a standard TQG adapted for bi-fuel operation.

CPC previously developed a line of pre-commercial BioMax® downdraft gasifiers for converting woody biomass into electricity and heat for small industrial, agroprocessing, and rural electrification markets. New challenges imposed by the OFWEC effort included packaging a complete system within a 20' ISO shipping container, processing unconditioned feedstock (versus wood chips, for example), feedstock containing a substantial fraction of plastic materials, and power generation using an off-the-shelf 60 kW TQG.

3. BIOMASS GASIFICATION

Air-blown gasification is a thermochemical decomposition process in which the feedstock is reacted with controlled amounts of air at high temperatures to produce a synthetic flammable gas. The gasification reaction in CPC's BioMax® gasifier is fully automated via control algorithms that have been developed and refined through thousands of hours of operational testing. The gasification process is driven by the fuel demands of an internal-combustion engine that establishes the producer-gas flow rate. As the gasification process consumes feedstock and char, the raw feedstock moves slowly down through the gasifier.

As shown in Figure 1, the reactions in the BioMax® downdraft gasifier can be broken down into four different zones: feedstock drying, flaming pyrolysis, char oxidation, and char reduction. Also shown is the temperature profile through the gasifier.

The gasifier is typically started using residual char from the previous operation. The char bed is ignited by a resistance heater, after which feedstock can be added. The low thermal mass of the gasifier allows it to produce a combustible fuel gas from biomass only a few minutes after ignition.

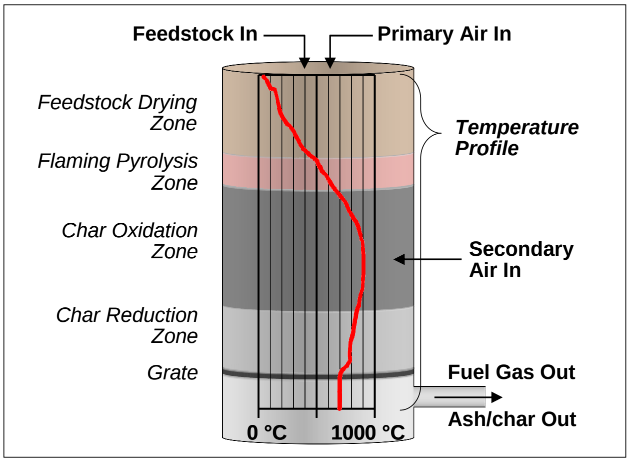

Figure 1. BioMax® gasifier fundamentals

The feedstock and part of the air needed for gasification enter through the open top of the downdraft gasifier. The motive force for the air supply is the engine vacuum or an inline blower located downstream. The control system meters feedstock into the gasifier as needed to keep it full. As the feedstock particles approach the flaming pyrolysis zone, they are heated and dried, losing their moisture as steam. This steam and the primary gasification air traverse quickly to the flaming pyrolysis zone below.

As the feedstock particles continue downward, they are heated to pyrolysis temperatures and begin to emit pyrolysis vapors, which burn in the primary air. The combustion gases and residual tar vapors then traverse down to the char oxidation zone, along with the char formed in the flaming pyrolysis zone.

In the char oxidation zone, secondary air is added at multiple locations to oxidize the char, producing carbon dioxide and heat. In the steady-state condition of the gasifier, the temperatures of this zone are moderated by the endothermic reactions of steam and char to form hydrogen and carbon monoxide ($H_2O + C \rightarrow H_2 + CO$), as well as carbon dioxide reacting with char to form carbon monoxide ($CO_2 + C \rightarrow 2CO$). The destruction of residual tar vapors is catalyzed by the hot char and ash surfaces and free radicals present in this zone.

In the char reduction zone, there is no free oxygen to oxidize the char and release heat. Therefore, the reaction of the hot char is to reduce water to hydrogen and carbon monoxide, as well as to reduce carbon dioxide to carbon monoxide. These endothermic reactions cool the char and the fuel gases at the grate. There is additional tar-vapor destruction in this zone. The ability of the gasifier to produce raw fuel gas having extremely low levels of tars substantially reduces the cost and complexity of downstream gas cleanup operations.

Near the bottom of the gasifier is an active grate that precisely controls the passage of char and ash to maintain high quality gas. The gasifier is periodically vibrated to settle the char bed, collapsing channels and bridges in the feedstock and char. As the char becomes progressively oxidized and frangible, it is broken up and entrained in the fuel gas as it leaves the gasifier. The amount of ash formation is a function of the feedstock; for example, 50 lb of wood chips will produce about 1 lb of ash. Because carbon conversion is in excess of 99%, there is little char remaining in the ash.

The gasifier produces fuel gas with roughly equal amounts of H_2 (20%) and CO (20%) and a small amount of CH_4 (2–10%). The largest non-fuel gas in the mixture is N_2 (~45%). The energy content of this producer gas is typically 125–175 BTU/scf, depending on its initial moisture and the specific feedstock.

4. OFWEC DEVELOPMENT

Following successful proof-of-principle testing in Phase I, CPC was awarded an SBIR Phase II contract in 2006 to continue development of the OFWEC system. Their system concept includes a BioMax® 25 downdraft gasifier mounted in an ISO shipping container along with feedstock shredding, drying, and conveying systems. The OFWEC is operated inside the container, which provides shelter, facilitating rapid deployment. The producer gas output is mixed with air and burned in a TQG adapted for bi-fuel operation. A block diagram for the system is shown in Figure 2. A full-scale prototype system has been built and operated in a research and development environment and is designed for operation in the field by relatively unskilled operators.

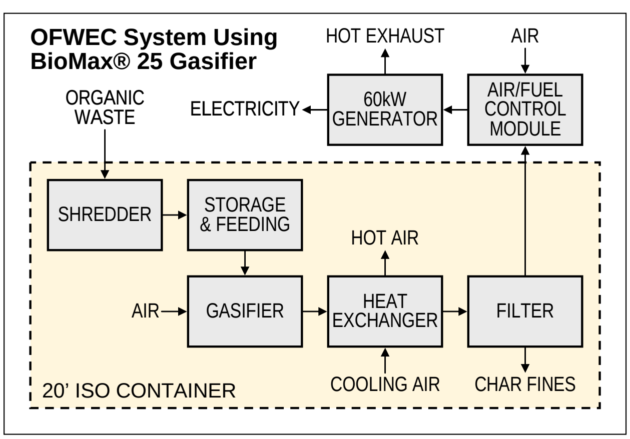

Figure 2. Flow diagram of the OFWEC system

An often repeated analogy is that the system should ideally be nearly as easy to operate as a dumpster. To that end, care has been taken to minimize the required user interaction with the system, as illustrated in Figure 3. The operator's duty is to feed relatively dry paper and plastic trash into the OFWEC's shredder, having previously separated cans, glass bottles, and bulk food and slop from the waste stream.

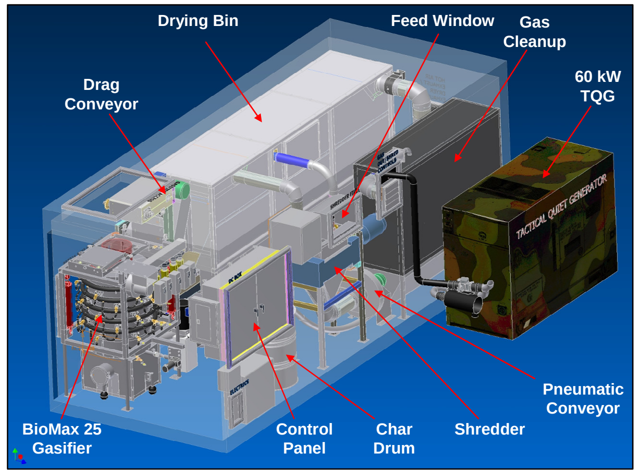

Figure 3. 3-D layout of the OFWEC system

After shredding, the feedstock is conveyed pneumatically into a storage and drying bin. A drag conveyor transports the material automatically into the open top of the downdraft gasifier. The feedstock progresses through the gasifier, where it is dried, de-volatized into char, and converted into producer gases. The hot gases and entrained char particles exit the gasifier and are cooled from 700 °C to 100 °C in a shell-and-tube heat exchanger. The cooled gases are filtered to remove the entrained char, resulting in a clean gas with negligible tar content. The filter is self-cleaning, and the char is automatically removed from the filter enclosure to a drum for disposal.

4.1 Feedstock Preparation

In CPC's Phase I research, it was assumed that feedstock densification, such as pelletizing or briquetting, would be necessary to prepare foodservice waste for processing in the BioMax® gasifier. Experiments were carried out to identity low-power pre-processing alternatives, and quantities of cookie-like discs were prepared and successfully tested in the gasifier. It was feared that the added cost, size, weight, and complexity might preclude successful Phase II prototyping and demonstration, and another SBIR topic was written to address the pre-processing challenge separately.

It was later experimentally validated that if the feedstock was limited to dry paper and plastic materials, shredding alone would be sufficient feedstock conditioning for the gasifier. In the course of the Phase II development, both a Franklin-Miller 5 hp shredder and a Munson 20 hp shredder were used successfully, with most of the testing using the former.

4.2 Feedstock Conveyance

The shredded cardboard and plastic feedstock proved very challenging to handle. It was found to have rough edges and pack densely, readily forming bridges and channels, and therefore was difficult to recover from the drying bin, feed into the gasifier, and gasify. Design changes and an extended iterative development period were required before adequate reliability was attained. Several material flow solutions were explored, including air cannons, vibratory devices, and passive bin activators. The solution ultimately implemented, due to cost, effectiveness, and other factors, was to add helical screw augers at key locations to break up bridges and provide positive displacement of feedstock where gravity would ordinarily have been sufficient for a more dense, free flowing material.

4.3 Bi-fuel Power Generation

BioMax® gasifiers are usually paired with spark-ignition gaseous fuel engine-generator sets, but a goal for this effort was to use a standard Army TQG. Fortunately, the throughput of the BioMax® 25 gasifier is an excellent match for pairing with 60 kW TQGs, which are used by Force Provider.

A diesel engine can burn producer gas as a fuel if it is mixed with the combustion air, provided a small amount of JP-8 is injected as a pilot fuel for compression ignition. For this effort, a gasifier-TQG interface module was developed to adapt a TQG for bi-fuel operation, as diagrammed in Figure 4. The module is connected to the engine's air intake, and controls are interfaced with the speed controller, governor signal, and fuel tank gauge. With this engine, up to 85% of the JP-8 normally burned can be displaced by producer gas, depending on the load.

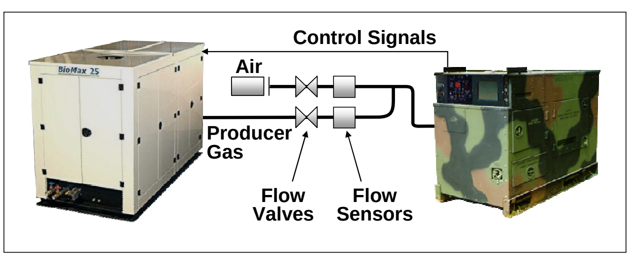

Figure 4. TQG bi-fuel adaptation

In operation, producer gas is piped from the gasifier to the interface module. It is mixed with the combustion air before entering the TQG, where the gas/air mixture is compressed by the turbocharger and distributed to the cylinders. The amount of JP-8 injected depends on the signal from the governor controlling the engine speed, as originally designed by the manufacturer. Within limits, the load following capability of the TQG is unchanged from normal operation of a stock TQG with JP-8. The transition to and from power generation using producer gas occurs smoothly without operator intervention.

4.4 Deployment Scenario

When deployed with a Force Provider or similar encampment, it is envisioned that the OFWEC will be stationed near a field kitchen and an available 60 kW TQG. Location near the waste generation point is key to minimize labor and helpful for maintaining some control over the feedstock.

Because the OFWEC is operated with the equipment mounted inside the shipping container, which also functions as a shelter for the system, the time and effort required for setup and tear down is minimized. Aside from the initial installation of the gasifier-TQG interface module, setup has been demonstrated to be possible by two experienced operators in less than two hours.

To install the gasifier-TQG interface module, the air cleaner is removed from the TQG and installed in the interface module, followed by fitting the interface module's gas/air output hose and adapter to the TQG's air cleaner housing. A quick-disconnect wiring harness must also be installed in the TQG to relay information to the OFWEC computer control; this is estimated to require two hours by an experienced operator, but would not be recurring if the same TQG can accompany the OFWEC when it is relocated.

5. TESTING AND RESULTS

Under CPC's SBIR Phase II contract, a full-scale prototype OFWEC system, as shown in Figure 5, was developed and tested at their facility. The extensive testing conducted during the development system has resulted in significant design changes compared to CPC's standard BioMax® configuration, especially related to feedstock handling.

Testing objectives included evaluation of baseline performance under controlled conditions, sensitivity to different feedstock compositions, residuals and emissions, and the impact of undesirable materials in the feedstock, as well as data for performance projections of system efficiency and fuel savings, and ongoing extended operation to determine if the system is robust and reliable for field demonstration in an operational environment.

5.1 Baseline Testing

In one baseline test, shredded cardboard was fed into the BioMax® gasifier at a rate of nearly 1300 lb/day, on a

Exterior, with 60 kW TQG | **Interior**

Figure 5. OFWEC prototype detail

dry basis. The producer gas made from this cardboard was fed to the 60 kW TQG, which produced 50 kW_e of electricity by burning the gas and diesel fuel. The char yield from this test was 10%.

In another baseline test, the containerized prototype OFWEC BioMax® 25 gasifier system consumed a shredded mixture of 77% cardboard, 18% polypropylene steam trays, and 5% polyethylene. The gasifier consumed this mixture at the rate of 39 dry lb/h, producing 60 Nm^3/h of producer gas. This gas and pilot diesel fuel were fed to the 60 kW TQG to produce a little over 50 kW_e. The amount of diesel fuel displaced was 2.0 gal/h. Thus, it required 19 lb of the mixed trash to displace one gallon of diesel fuel. Based on feeding 56 lb/h of similar mixed trash to the gasifier for 6 days per week, the extrapolated JP-8 displacement is 2.9 gal/h, with a projected savings of 420 gal/week. The char yield from this test was 7.8%.

Based on this experimental gasifier data, a BioMax® 25 gasifier will produce about 86 Nm^3/h of producer gas while consuming the available 56 lb/h of dry trash. This is an increase of 43% over how the gasifier has been operated with shredded feedstock. However, historically, a similar BioMax® 25 gasifier has been operated with woodchips at 75 Nm^3/h, so the upper limits of this gasifier with densified trash should be explored. The increased porosity of densified trash, compared to wood chips, suggests that even higher throughputs may be possible.

As a reality check, the amount of energy contained in the daily paper and plastic trash as shown in Table 1 is equivalent to the energy contained in 87 gallons of JP-8. If the producer gas burns as efficiently as JP-8 in the TQG, then the gasifier needs a conservative 69% conversion efficiency of trash to producer gas to displace 420 gal/week of JP-8. This required efficiency is quite reasonable and reinforces the above projections based on CPC's experimental data. These numbers are very sensitive to the plastic content of the trash, due to the high energy density of plastics.

5.2 Solid Residuals

The char/ash yield in the baseline testing using cardboard and plastics was 7.8% of the dry shredded feed, for a 92.2% reduction in the weight of the trash processed. This is calculated to be 74 lb of char/ash per day for a battalion-scale encampment. This material has a bulk density of 9 lb/ft^3, so about 61 gallons per day of char will be generated.

Based on leaching tests conducted with char made from biomass, the char's suitability for disposal in a landfill is expected to be very good. However, the gasifier will serve to concentrate contaminants in the char. If, for example, heavy metals or insecticides are included in the trash stream, then the benign nature of the char will be adversely affected.

5.3 Liquid Effluents

The OFWEC does not use liquid scrubbers to clean the producer gas, and the gas is kept above its dew point to prevent condensation of water vapors. Thus, the OFWEC does not use or generate liquids for disposal.

5.4 Emissions

The BioMax® gasifier produces a clean gas that normally burns cleanly in an internal combustion engine with no discernable odors or harmful emissions. Suggested future work includes quantification and reduction, if necessary, of the emissions from the TQG's diesel engine when burning producer gas.

In contrast, the common practice in theater of open pit burning of wet trash results in slow, smoky, odorous incomplete combustion that leaves large amounts of charred residuals. Such burning is known to release significant amounts of air-borne pollutants such as particulate matter, dioxins, polycyclic aromatic hydrocarbons, and volatile organic compounds.

5.5 Tramp Material Handling

Although operators will be trained to separate metal, glass, and Meal, Ready to Eat (MRE) chemical heaters from the combustible cardboard and plastic trash, it is inevitable that some of these unwanted tramp materials will find their way into the OFWEC system. If metals and glass are in the feedstock, they will accumulate in various parts of the system and increase maintenance needs. Expected tramp materials include metal cans, glass pepper sauce bottles, unused MRE heaters, disposable batteries, and safety matches.

To address this issue, a tee was installed in the pneumatic conveying line after the primary shredder to encourage inertial separation of the dense shredded materials. To increase the probability of intercepting and retaining the ferrous tramp materials, magnets were attached to the bottom of the tee on the capped-off end.

In testing, all of these tramp materials passed through the shredder without adverse incident. However, post-shredding examination revealed that about 10% of the matches ignited and were immediately extinguished by the rush of conveying air (these matches can be ignited by the energy imparted by a sharp blow). All of the shredded batteries and much of the MRE heater metallic powder were trapped by the tee and the magnets. Only a very small fraction of the glass particles escaped collection as a fine powder. It was concluded that much of the MRE heaters and nearly all of the metals and glass can be intercepted and retained in selected locations for periodic removal. In addition, to reduce the chance for fire in the feed storage bin, matches should not be allowed in the feedstock.

5.6 Performance Projections

Based on CPC's previous experience with the BioMax® gasifier and testing performed on the OFWEC prototype, it is possible to make credible projections of system performance in terms of useful energy output, thermal conversion efficiency, and fuel savings versus time. To help visualize, a simplified energy balance of the OFWEC is depicted in Figure 6. The values used are based on steady state operation at maximum throughput, and assume demand for all electrical power generated.

During steady state operation, feedstock is added to the gasifier at a rate of 172 kW_{th}. The average parasitic electrical requirement for all subsystems, including the shredder, is 4 kW_e. The gasifier is about 70% efficient and delivers producer gas to the TQG at a rate of 120 kW_{th}. The exhaust from the heat exchanger and dryer holds 20 kW_{th}, and the remaining 36 kW_{th} is lost as char, evaporation of moisture in the feedstock, heat losses to the environment, etc. In addition to the producer gas from the gasifier, the TQG requires JP-8 pilot fuel at a rate of 28 kW_{th} to generate 50 kW_e gross, of which 46 kW_e net is available after accounting for parasitic electrical requirements. Another 80 kW_{th} is present in the exhaust and cooling system, some of which is potentially recoverable, and 18 kW_{th} is lost as heat transfer from the engine.

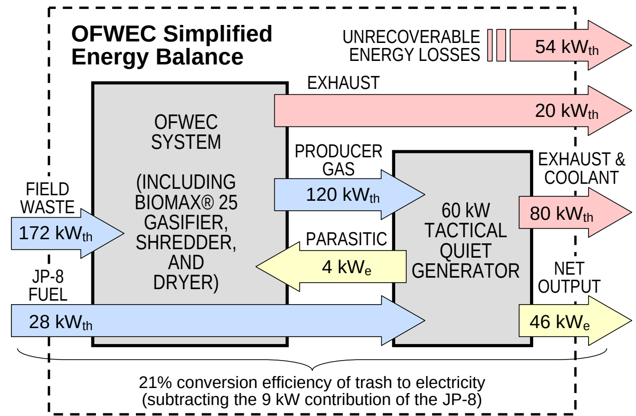

Figure 6. Energy balance of the OFWEC system

Accounting for the trash input, JP-8 input, and net electrical output, the system is about 23% efficient. But assuming that the JP-8 could otherwise have been used to generate power at an efficiency of 33% in a TQG, it makes sense to exclude its contribution to the power produced, which would be 9 kW_e. Thus, the net power from the trash is 37 kW_e, and the overall efficiency of converting trash into electricity is 21%, which is actually quite an accomplishment at this small scale. Another way to reflect on this is that compared to burning the fuel directly in a TQG, each gallon of JP-8 invested for the process delivers a nearly 5:1 return on investment in terms of energy while also eliminating field waste.

Another tool for understanding OFWEC performance is a timeline that tracks the energy output and fuel usage of the system, accounting for different power demands during startup and feedstock conditioning, for instance. The projected energy timeline shown in Figure 7 was generated assuming that the OFWEC would run continuously for 6 days each week, followed by a day for cooling off and performance of scheduled maintenance.

For these projections, the system is assumed to be cold initially. The TQG is started on JP-8, immediately generating 50 kW_e. For 30 minutes, about 18.5 kW_e is diverted to the OFWEC to shred trash and preheat the system to avoid water condensation during startup. Then,

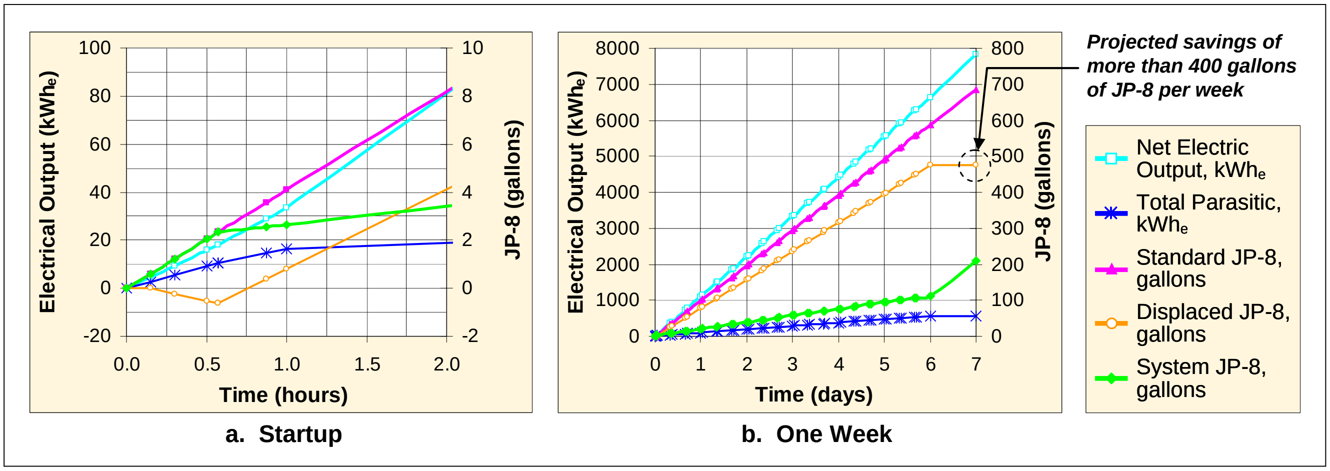

Figure 7. Projected energy timeline for OFWEC operation

the char bed is electrically ignited and the gasifier begins producing combustible producer gas from shredded trash feedstock. After preheating, the parasitic load drops to 13.5 kW_e until shredding is complete, then down to 2.5 kW_e.

Figure 7a shows the first two hours of system operation. The JP-8 used to supply the parasitic power used during startup is prorated from the 50 kW_e output and results in negative JP-8 savings for the first 35 minutes of operation. However, the high rate of fuel displacement quickly compensates for that initial draw of power, and net positive JP-8 savings are achieved within the first hour. The parasitic power requirement is charged to the producer gas after startup and decreases the amount of electrical power available from the TQG by about 8%.

Figure 7b shows that over the course of a week between scheduled maintenance, the high parasitic loads during startup and shredding become less significant. During a week of operation, with sufficient feedstock and power demand, the OFWEC is projected to save up to 475 gallons of JP-8 compared to usual power generation for the same net electrical energy. To maximize trash consumption and system efficiency, the OFWEC will need to be operated at a consistently high power output, so it should be paired with appropriately high electrical loads.

6. FUTURE WORK

To date, the OFWEC system has not yet been demonstrated in an operational environment. Additional testing and refinement are needed to establish robust and reliable operation. For example, the longest continuous operation of the prototype OFWEC system has been 17.5 hours, and during a recent 6-day period, the system was on stream for 48% of the time, showing opportunity for significant improvement.

Additionally, due to lessons learned during OFWEC development and evolving user requirements, there are several areas that should be explored for future systems or prototypes. For example, solid waste elimination is now perceived to be more important than other system attributes like size, weight, complexity, and efficiency. The physical characteristics of the original concept may be flexible in exchange for greater system effectiveness.

The original OFWEC goals included conversion of the organic fraction of the field-feeding solid waste, not just dry paper and plastic materials, and this remains a critical element of the goal to minimize waste requiring disposal and the need for material segregation. There is also debate in the Force Provider community about the actual amount of waste generated, which may be significantly more than shown in Table 1, and an expressed desire for a system to handle all of that waste, not just food-service waste.

6.1 Feedstock Densification

For this effort, using shredded waste as gasifier feedstock appeared to be simpler and more efficient than adding additional pre-processing steps. However, in the course of Phase II development and testing, shredded waste proved to be a very difficult feedstock to handle. It is presently believed that densifying the shredded waste would greatly improve the reliability and availability of the OFWEC system, even if the feedstock remains limited to paper and plastic packaging. Compared to the drying bin required for shredded waste, the storage space required for densified feedstock would be much smaller, leaving space within the ISO container for the additional equipment.

6.2 Feedstock Expansion

Although the original goal of the OFWEC concept was to process all of foodservice organic waste, the present effort focused on the dry paper and plastic materials to reduce prototype complexity and improve the likelihood of successful feasibility demonstrations. Focusing on these materials also maximizes energy recovery with respect to system cost and throughput; wet food waste is much more difficult to process and contains comparatively little energy value.

Focusing on the dry materials with higher energy value would likely be an advantageous strategy for a system that would primarily be operated at remote kitchen sites far from an electric grid where fuel and/or electricity were scarce and alternative energy production was of greater value than waste destruction. However, in the course of this work, it has become evident that, at the current level of technology maturity and the logistical needs of the system, the most appropriate initial application would be for small base camp deployments like the Army's Force Provider. At such locations, the benefit of waste destruction is greater than power generation.

Additional feedstock conditioning, such as drying and pelletizing, can allow a gasifier to process the entire organic fraction of the field-feeding solid waste stream. The penalty for this added functionality is increased system complexity, cost, and parasitic energy requirements. A related SBIR effort is presently developing such a Solid Waste Pre-processor concept that will be able to convert all of the organic foodservice waste into fuel pellets appropriate for gasification. The results of preliminary testing of such pellets in the BioMax® gasifier have been promising.

If similar char yields (i.e., 7.8%) are obtained from the food-containing densified feed and are added to the metals, glass, and miscellaneous materials, this will amount to about 200 lb/day of trash to be backhauled, rather than the current 2255 lb/day. This would be a weight reduction of about 90%, or one ton of trash per day that would no longer need to be backhauled. The volume reduction is considerably greater, due to the much higher density of the char compared to the trash prior to shredding. Furthermore, neither char nor the inorganic materials (e.g., metals cans and glass bottles) putrefy or attract pests, meaning that the residual solids could be accumulated for longer periods of time, if necessary, without the usual sanitation issues.

It is also possible that waste oils, including cooking oil and engine oil, could be added in small amounts that could be absorbed by the dry feedstock. The oils would be evaporated and converted primarily to non-condensable hydrocarbon vapors in the gasifier, and then efficiently burned as fuel in the TQG.

6.3 Increased Throughput

With a processing rate of 56 lb/h of dry feedstock, a BioMax® 25 gasifier operating continuously six days per week will be marginally able to handle the dried food, paper and plastic waste produced by feeding a battalion. However, if additional organic feedstock is available, the capacity will not be adequate.

Future work has been proposed to increase the gasification throughput without exceeding the envelope of an 8×8×20' shipping container. Possibilities include developing a shorter high-capacity gasifier, developing a horizontal gasifier, and packaging more than one gasifier in a single container.

7. CONCLUSIONS

A prototype system was built to convert field-feeding wastes into electrical energy at a practical size for battalion-scale field kitchens and Force Provider camps. Processing selected combustible solid waste materials, the prototype system has been demonstrated to produce a fuel gas that is projected to displace over 400 gallons of JP-8 per week in a stock 60 kW TQG while also realizing about a 90% weight reduction in the amount of associated waste that must be backhauled.

CPC's Phase II work has confirmed much of the promise of the OFWEC concept, demonstrating that downdraft gasification is a viable solution for waste to energy conversion while also identifying future directions for additional development efforts needed to achieve a truly field deployable system.

The OFWEC concept will help reduce the logistic burden of field-feeding in terms of fuel consumed and waste disposal, enhance force protection by reducing the size and frequency of convoys, and help Force Provider work toward a "Zero Footprint Camp" philosophy. OFWEC contributes to more supportable and sustainable deployments, introducing a paradigm shift where waste can be thought of less as a burden and more as a resource.

REFERENCES

Rock, K., et al., 2000: An Analysis of Military Field-Feeding Waste. U. S. Army Natick Soldier RD&E Center Tech. Rep. NATICK/TR-00/021, 24 pp.

Ruppert, W. H., et al., 2004: Force Provider Solid Waste Characterization Study. U. S. Army Natick Soldier RD&E Center Tech. Rep. NATICK/TR-04/017, 135 pp.