Waste-to-Energy

Hawaii and Guam Energy Improvement Technology Demonstration Project

J. Davis, R. Gelman, G. Tomberlin, and R. Bain
National Renewable Energy Laboratory

Produced under direction of Naval Facilities Engineering Command (NAVFAC) by the National Renewable Energy Laboratory (NREL) under Interagency Agreement 11-01829 and Task Nos. WFK3.6000 and WFK3.6020.

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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

Technical Report
NREL/TP-7A40-60868
March 2014

Contract No. DE-AC36-8GO28308

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NATIONAL RENEWABLE ENERGY LABORATORY

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The National Renewable Energy Laboratory (NREL) is grateful for the significant efforts expended by the Naval Facilities Engineering Command (NAVFAC) Headquarters and the Pacific and Hawaii teams in preparation for deploying this waste-to-energy (WTE) system to the Joint Base Pearl Harbor-Hickam, Hawaii.

NREL would also like to thank several Army organizations for their critical role in enabling and supporting this project. We are grateful to the Army Research Laboratory for allowing the WTE system to be used for this demonstration, to the Natick Soldier Research Development and Engineering Center for their role in developing and funding part of the system, and to the U.S. Army Installation Management Command, Pacific for facilitating the initial discussions regarding the project.

We would also like to express our sincere gratitude to the staff of the Hickam Commissary and the Defense Commissary Agency headquarters for their motivation to implement this project. While the project did not make it to the field demonstration phase, the progress made during the year and a half of discussions between stakeholders would not have been possible without the support of all participants mentioned above.

List of Abbreviations and Acronyms

ARL	Army Research Laboratory
Btu	British thermal unit
CF	capacity factor
CO	carbon monoxide
CPC	Community Power Corporation
DAG	Defense Acquisition Guidebook
DECA	Defense Commissary Agency
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EROI	energy return on investment
ESTCP	Environmental Security Technology Certification Program
FY	fiscal year
GEM	Green Energy Machine
H_2S	hydrogen sulfide
HECO	Hawaii Electric Company
HEDWEC	high-energy densification waste-to-energy conversion
HHV	higher heating value
IBC	International Building Code
IC	internal combustion
IPT	Integrated Product Team
JPBHH	Joint Base Pearl Harbor-Hickam
kg	kilogram
kW	kilowatt
kW_e	kilowatts electric

kW_{th}	kilowatts thermal
m^3	cubic meter
MOA	memorandum of agreement
MPM	material processing module
MSW	municipal solid waste
MTBF	mean time between failures
MTTR	mean time to repair
NASA	U.S. National Aeronautics and Space Administration
NAVFAC	Naval Facilities Engineering Command
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
Nm^3/hr	normal cubic meters per hour
NO_x	nitrogen oxide
NREL	National Renewable Energy Laboratory
NSRDEC	Natick Soldier Research Development and Engineering Center
O&M	operation and maintenance
OPNAVINST	Office of the Chief of Naval Operations Instruction
PE	professional engineer
PM	particle matter
PUC	Public Utility Commission
scf	standard cubic feet
SO_2	sulfur dioxide
SO_x	sulfur oxides
TCLP	toxicity characteristic leaching procedure
TRL	technology readiness level
UFGS	Unified Facilities Guide Specifications

UFC	Unified Facilities Criteria
WWTP	wastewater treatment plant
WTE	waste-to-energy

Executive Summary

The National Renewable Energy Laboratory (NREL) and the U.S. Navy have worked together to demonstrate new or leading-edge commercial energy technologies whose deployment will support the U.S. Department of Defense (DOD) in meeting its energy efficiency and renewable energy goals while enhancing installation energy security. This is consistent with the 2010 Quadrennial Defense Review report[1] that encourages the use of "military installations as a test bed to demonstrate and create a market for innovative energy efficiency and renewable energy technologies coming out of the private sector and DOD and Department of Energy laboratories," as well as the July 2010 memorandum of understanding between DOD and the U.S. Department of Energy (DOE) that documents the intent to "maximize DOD access to DOE technical expertise and assistance through cooperation in the deployment and pilot testing of emerging energy technologies."

As part of this joint initiative, a promising waste-to-energy (WTE) technology was selected for demonstration at the Hickam Commissary aboard the Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii. The WTE technology chosen is called high-energy densification waste-to-energy conversion (HEDWEC). HEDWEC technology is the result of significant U.S. Army investment in the development of WTE technology for forward operating bases. For example, the high cost of transporting fuel combined with the impractical and hazardous practice of solid waste disposal in burn pits or burn boxes led Natick Soldier Research Development and Engineering Center to initiate a WTE program in 2004. Several years of development and further support from the Army Research Laboratory resulted in HEDWEC's completion in 2010.

The technology provider, Community Power Corporation (CPC), developed HEDWEC from existing biomass gasification technology called BioMax, which had been successfully operated using biomass feedstock for over 10,000 hours of operating time. Gasification of certain biomass feedstocks is a relatively mature technology, with existing commercial applications around the world. Even more so, WTE using combustion is a mature technology, with hundreds of existing facilities operating around the world. The use of gasification to process municipal solid waste (MSW), however, is a WTE application that is not yet proven in commercial applications.

In the final stages of development for HEDWEC, CPC visited several remote locations that it believed would be good locations for demonstrating HEDWEC. With support from the U.S. Army and the Defense Commissary Agency (DeCA), and in coordination with Naval Facilities Engineering Command (NAVFAC) Hawaii, CPC proposed a concept for demonstrating HEDWEC at the Hickam Commissary. During initial scoping meetings for the Navy-NREL technology demonstration initiative, the Navy-NREL team identified the commissary project as a candidate for the Hawaii-Guam demonstration initiative. After conducting an initial viability assessment, the project was selected to be included in the program and an Integrated Product Team (IPT) was established to implement the concept.

The project was designed to use residual organic materials at the Hickam Commissary as feedstock, or fuel, for the HEDWEC system. DeCA routinely incurs high costs for disposal of these materials, estimated at $88,000 in 2010. Based on CPC's past success with biomass feedstocks, such as woodchips or nut shells, the proposed concept involved processing the heterogeneous residual materials at the commissary to make them similar to the homogenous biomass feedstocks on which HEDWEC's predecessor WTE systems have operated successfully. The proposed materials included butcher scraps,

[1] For more information, see: www.defense.gov/qdr/.

such as meat and bones; expired dairy and produce products; damaged packaged products; and waxed and recyclable cardboard. The recyclable cardboard is a revenue-generating product for DeCA but was believed to be a good biomass feedstock that would provide a better economic and environmental return by converting to energy on-site rather than shipping overseas for recycling. Due to the variation of feedstocks, wet and dry materials required dual processing pathways for the HEDWEC system, as shown in Figure ES-1.

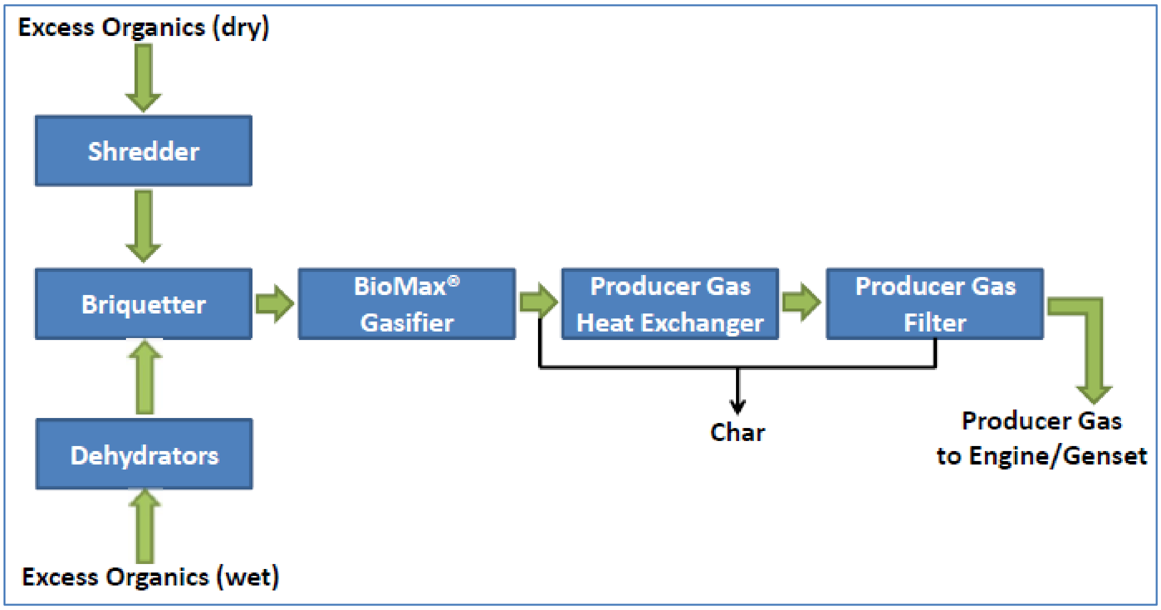

Figure ES-1. Block diagram of the flow path for materials and gas through HEDWEC

The demonstration was designed with the fundamental steps of baseline establishment, factory acceptance testing at CPC, commissioning at JBPHH, and a field demonstration period at JBPHH, which would have included controlled testing, operational testing, and stress testing. The primary step taken in establishing the baseline was a characterization of the commissary's residual organic materials. This helped establish a blend of representative feedstock that was used at CPC's facility for factory acceptance testing. With unexpectedly low power generation and high operating labor requirements, HEDWEC was unable to pass factory acceptance testing.

The technical issues are primarily attributed to incompatibility of the feedstock processing system with the selected feedstock for the demonstration. An oversized shredder and briquetter created high parasitic load while inadequately preparing feedstock in a suitable manner for the gasifier. Briquettes did not flow as expected, and the gasifier did not produce the volume of fuel expected. Further complications in controlling sulfur content of the producer gas led to pressure differentials, which were a challenge to the designed dual engine operation. The net effect of the technical challenges was a drastic reduction in performance from 70 kilowatts (kW) of electric generation to 6 kW of electrical draw, creating an additional load to the host's electrical system instead of contributing power to it. The technical challenges also created a need for additional operating labor. Rather than the originally proposed intermittent feeding and monitoring of the system, it was determined to need consistent and skilled operator attention. The inability to create a net surplus of power and the increased labor costs for operating HEDWEC created an insurmountable economic burden for this system. Upon completion of factory acceptance testing, the IPT met and decided not to proceed with commissioning at the Hickam Commissary.

Even though HEDWEC did not ship or undergo the controlled, operational, or stress testing components of the field demonstration at JBPHH, significant lessons were learned regarding deployment of small-scale WTE projects to DOD installations. Those lessons learned are as follows:

- The U.S. Environmental Protection Agency (EPA) does not offer air emissions permit guidance for the syngas-fired engines that are typically used in a system such as HEDWEC. This complicates air permitting discussions with state and local environmental regulatory agencies. Further outreach and education regarding these systems with the EPA would streamline future installations of WTE gasification systems.
- There is no clear guidance for setbacks applying to modular syngas-fired engine-generator sets. The presence of carbon monoxide in the syngas alarmed U.S. Navy safety representatives. Early discussions regarding the operation of systems like HEDWEC and installed safety features should be held with appropriate safety personnel to establish required setbacks or implementation of safety features.
- From a general perspective, gasification systems must go through extensive testing using representative feedstocks to validate performance prior to field demonstration. Prior performance using different feedstocks is not a reliable indicator of system performance.
- Older facilities, such as the Hickam Commissary, may not have current electrical drawings and circuit load information necessary for interconnection of distributed generation devices, such as HEDWEC. Efforts should be made early in the development of a project to evaluate available electrical information and identify new information that must be attained.
- Technology providers inexperienced with military construction and site restrictions may face a challenge with understanding compliance requirements. This is particularly likely if their past deployments were conducted in programs that did not require full compliance with these specifications.

The administrative and operational challenges encountered during this demonstration pose significant challenges to small-scale WTE gasification technology (defined as less than 10 tons per day in this report). Other systems were identified in this range and seem to have high potential for success, yet these systems must be further validated to operate adequately in representative environments. NREL could not find any other small-scale WTE gasification systems in the United States utilizing true waste material feedstock in a commercial application.

Many of the challenges of small-scale WTE relate to the feedstock preparation needed to create a more homogeneous fuel. This issue is not as critical in larger systems because the fluctuations are less prevalent at higher volumes and more processing options exist at these scales. Larger-scale systems, from approximately 30-100 tons per day, may be suitable for larger DOD installations, which typically have this volume of feedstock available. Various research efforts into WTE systems of this scale have been conducted in the past and have found dozens of candidate technologies. NREL is not aware, however, of any true gasification WTE systems currently operating with raw municipal solid waste at any scale within the United States. Further validation of these larger technologies is necessary, and at costs of over $6 per watt,[2] these multi-megawatt systems will cost tens of millions of dollars to procure for demonstration.

[2] Estimate from Jerry Davis of NREL after researching the small-scale WTE industry, presented July 13, 2011. Presentation available online at: www1.eere.energy.gov/hydrogenandfuelcells/pdfs/wte_dod-doe_wkshp71311_davis.pdf.

Large municipalities, such as New York City[3] and the County of Los Angeles,[4] are currently leading the evaluation of these larger WTE systems.

NREL assesses the technology readiness level (TRL) of small-scale WTE gasification to be in the TRL 6-7 range, with this HEDWEC application at TRL 6. NREL recommends a "partner" strategy, per the guidelines in the Defense Acquisition Guidebook, to advance the technology to higher TRLs. It is unlikely the TRL of small-scale WTE gasification systems will advance without support from the DOD or another federal agency. For larger gasification systems, more options exist, and these are progressing faster toward commercial viability. However, cost issues lead NREL to recommend the DOD establish a "watch" strategy and track the development of these technologies by other organizations.

[3] For more information, refer to an online press release at: www.nyc.gov/portal/site/nycgov/menuitem.c0935b9a57bb4ef3daf2f1c701c789a0/index.jsp?pageID=mayor_press_release&catID=1194&doc_name=http%3A%2F%2Fwww.nyc.gov%2Fhtml%2Fom%2Fhtml%2F2012a%2Fpr077-12.html&cc=unused1978&rc=1194&ndi=1.
[4] For more information, refer to Los Angeles County's outreach site at: www.socalconversion.org/.

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1 Introduction

In order to meet its energy goals, the U.S. Department of Defense (DOD) has partnered with the Department of Energy's (DOE's) National Renewable Energy Laboratory to rapidly demonstrate and deploy cost-effective renewable energy and energy efficiency technologies. The waste-to-energy (WTE) system explored in this report is one of several demonstrations of new or underutilized commercial energy technologies selected for demonstration. The proposed high-energy densification waste-to-energy conversion (HEDWEC) WTE demonstration concept originated several years ago in discussions between the U.S. Army, the Defense Commissary Agency (DeCA), Naval Facilities Engineering Command (NAVFAC) Hawaii, and Community Power Corporation (CPC) stakeholders.

HEDWEC technology is the result of significant U.S. Army investment in the development of WTE technology for forward operating bases. The high cost of transporting fuel combined with the impractical and hazardous practice of solid waste disposal in burn pits or burn boxes led Natick Soldier Research Development and Engineering Center (NSRDEC) to initiate a WTE program in 2004. NSRDEC has explored or considered several different types of WTE processes from biological (composting, fermentation, and biodigestors) to thermochemical (pyrolysis, plasma, supercritical water, and downdraft and updraft gasifiers) and has concluded that downdraft gasifiers offer the best combination of size, lack of complexity, and life-cycle cost for small-scale WTE (<10 ton/day). HEDWEC is the latest technology to be investigated under this program and was developed with funds from the Army Research Laboratory (ARL), which authorized use of the system for this demonstration. In addition to ARL's in-kind contribution of HEDWEC for this demonstration, NSRDEC directly funded CPC for procurement of a unique, spark-ignited, engine-generator to enable interconnection of the system to the grid.

As the technology developer and manufacturer for HEDWEC, CPC conducted site visits to remote locations around the world to identify potential sources of feedstock for such a system. Considering the high costs of energy and solid waste disposal for remote locations, CPC identified DOD sites on Hawaii as candidates. Through connections made in Hawaii, CPC met representatives from the Hickam Commissary and began discussing the use of organic waste materials as feedstock for HEDWEC.

DeCA operates 247 commissaries at DOD installations around the world. Solid waste disposal costs at these sites are significant, and even more so at remote and island locations. In 2010, DeCA paid nearly half a million dollars for disposal of solid waste at its stores on Hawaii, with over $88,000 of this cost attributed to the Hickam Commissary waste stream. In 2011, DeCA conducted a waste characterization study and estimated 70% of the waste material to be compostable or convertible into energy. These materials include dairy products, meats, breads, fruits, vegetables, waxed boxes, and small amounts of wood. In an effort to reduce these disposal costs, DeCA began exploring alternative options for use of its solid waste, including the discussion with CPC to install and operate a gasifier at the Hickam Commissary.

As the Facilities Engineering Command responsible for Joint Base Pearl Harbor-Hickam (JBPHH) and the Hickam Commissary, the NAVFAC Hawaii energy management team was made aware of this project. When NAVFAC Headquarters, NAVFAC Pacific, and NREL originally met to evaluate WTE project ideas, NAVFAC Hawaii brought this project to the group's attention, and it was selected for participation in this program.

2 Demonstration Objective

Small-scale (up to 10 tons per day) waste-to-energy systems hold promise to convert expensive-to-dispose of waste materials into useful energy. This is especially true in locations with high tipping (trash disposal) fees, such as islands and densely populated areas.

The objective of this project was to demonstrate and validate the performance of a HEDWEC 70-kilowatt (kW) modular biopower waste-to-energy system as a representative small-scale WTE system. The project proposed the use of HEDWEC to convert a variety of low-value, organic, nonhazardous surplus materials from the Hickam Commissary JBPHH to on-site power. The project was designed to test and document the operational viability, emissions performance, and economics of the HEDWEC system for this type of application. While the project was not fully executed, it provided insight into the current state of the small-scale WTE industry.

2.1 System Description

The conversion process to create energy from the surplus organic materials (feedstock) requires several interlinked processes. Figure 1 illustrates the various steps, from shredding the excess organic materials to making a synthetic fuel gas (syngas) used to produce electricity and heat in engine/gensets. The very wet organics are first dehydrated so that the overall mixture will have between 10% to 15% moisture. The excess organic material is then shredded and formed into briquettes, which are fed to the gasifier. The miscellaneous organics are gasified to form syngas in the HEDWEC gasifier.

The downdraft gasifier is designed to convert organic materials into syngas and a small amount of solid char/ash. The tars and most of the char formed during thermal decomposition of the organic materials near the entrance of the gasifier are converted to syngas in the lower section of the gasifier.

The system employs a heat exchanger to cool the syngas leaving the gasifier to 110°C and a filter to remove char and soot. The gasifier and gas cleanup operate under negative (sub-atmospheric) pressure to preclude the possibility of fugitive emissions from the gasification equipment. This is an important safety feature due to the health hazards of the carbon monoxide (CO) in the syngas.

Downstream of the gas cooling and filtering equipment, the pressure of the gas is raised to atmospheric pressure. The gas is then mixed with combustion air before reaching a set of two stationary spark ignition engines. There it is combusted, resulting in exhaust gases having low levels of residual carbon monoxide, volatile organics, particle matter (PM), sulfur dioxide (SO_2), and nitrogen oxide (NO_x). Emissions were expected to be below the criteria outlined in 40 Code of Federal Regulations (CFR) 60, Subpart JJJJ, Standards of Performance for Stationary Spark Ignition Internal Combustion Engines, as presented in Table 12. The landfill gas criteria from 40 CFR 60, Subpart JJJJ were used because this guidance does not yet address syngas-fueled fueled engines.

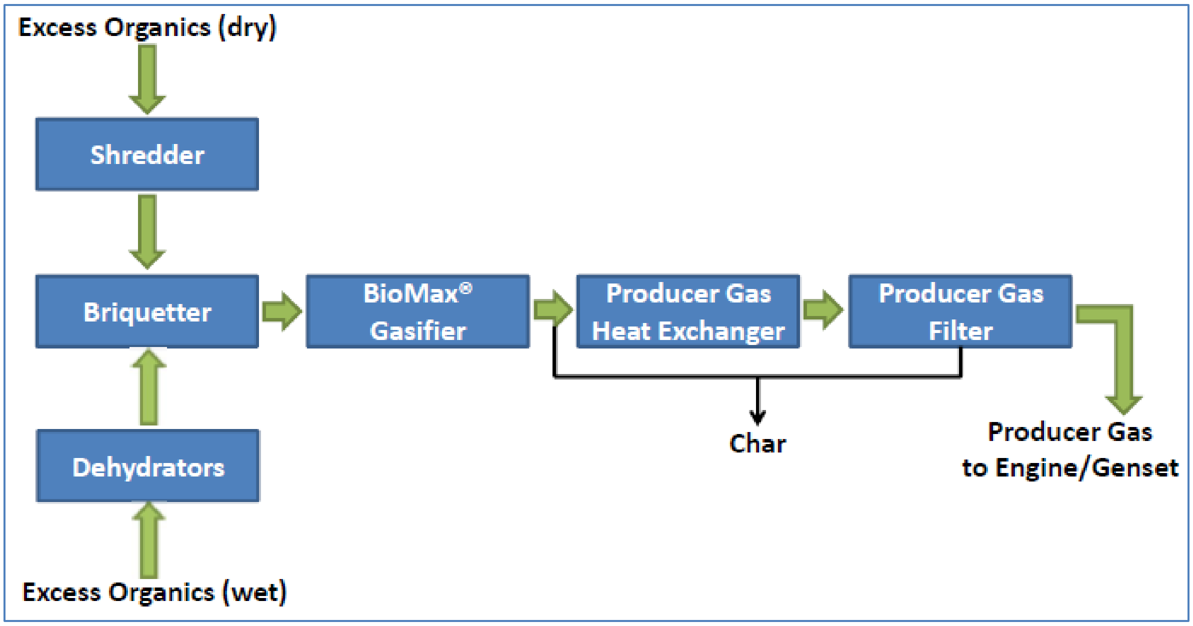

Figure 1. Block diagram of the flow path for materials and gas through HEDWEC

3 Demonstration Design

The demonstration was designed with the fundamental steps of baseline establishment, factory acceptance testing at CPC, commissioning at JBPHH, and a field demonstration at JBPHH, which would have included controlled, operational, and stress testing of HEDWEC.

3.1 Baseline Establishment

The Hickam Commissary does not currently operate a WTE system, so its baseline process is to recycle and landfill its waste. The baseline amount and types of waste, along with the labor, tipping fees, and recycling revenue associated with handling that waste were obtained from existing DeCA studies of Hickam and similar commissaries, and supplemented with additional site-specific measurements and surveys.

3.2 Factory Acceptance Testing (Community Power Corporation Location)

Having been originally designed for energy production in expeditionary environments, the HEDWEC system required configuring for a fixed-installation application. In order to align with DeCA operations, non-developmental (i.e., "off-the-shelf") items were incorporated into the project to accommodate the waste characterization expectations of the site and facilitate air permitting. This included removal of a flare, increasing the briquette-maker capacity, and the integration of a large shredder to process full bales of cardboard when necessary. System adjustments were made at CPC's facility in Littleton, Colorado, where all factory acceptance testing was conducted.

The factory acceptance testing at CPC was designed to provide quantitative data on the performance of the HEDWEC system that were needed to determine the technical and economic viability of the technology prior to shipping the system to Hawaii. It was to be evaluated on a subset of the performance objectives planned for the demonstration, including:

- Determine required operating staff
- Measure the gross kilowatts
- Measure net kilowatts electric (kW_e)
- Measure the flow rate and temperatures of the coolant into and out of the engine's radiator and calculate the recoverable waste heat from the engine's coolant in kilowatts thermal (kW_{th})
- Determine the engine exhaust emissions and flow rate
- Validate emissions using a third-party testing firm to determine the levels of NO_x, CO, SO_2, hydrogen sulfide (H_2S), and PM
- Assess the drier performance under various loadings and moisture contents
- Analyze the producer gas quality, tars and particulates
- Measure the syngas flow rate in normal cubic meters per hour (Nm^3/h), feedstock moisture, and consumption rate, and calculate syngas flow rate per kilogram (kg) of dry feedstock processed
- Measure the char production per amount of feedstock, kilogram bio-char/kilogram dry biomass
- Test the char for toxicity using the toxicity characteristic leaching procedure (TCLP).

The factory acceptance testing was performed using a similar fuel source to that to be used at Hickam Commissary.

Unfortunately, many of the performance goals were not met during the factory acceptance testing phase of this demonstration, and the decision was made not to proceed to later phases of testing at the Hickam Commissary (see Table 3 for an overview of performance results). The canceled portion of the demonstration included commissioning, operational testing, and stress testing of the HEDWEC system to evaluate performance in varying real world environments (see Table 1 for the originally-planned duration of each phase).

Table 1. Proposed Duration of Demonstration Phases

Test	Duration	Comments
Baseline establishment	3 weeks	Includes study of current disposal processes at Hickam Commissary
Factory acceptance testing	3 months	Conducted at CPC facility
Commissioning[a]	3 weeks	Includes receipt of unit at the Hickam Commissary, installation, interconnection, and initial startup
Controlled testing[a]	3 weeks	Commence upon completion of commissioning until unit is operating within normal operating parameters
Operational testing[a]	12 months	Actual operating time, excluding commissioning
Stress tests[a]	four stress tests	Stress the system using different feedstocks and operating conditions

[a] Canceled due to performance goals not being met during factory acceptance testing

3.3 Itemized Performance Objectives

The objective of the demonstration was to operate a WTE system under realistic conditions on a DOD installation to allow for meaningful data collection and analyses of the technical and economic viability. To facilitate this objective, the key performance metrics listed in Table 2 were developed, with their respective success criteria determined in the right hand column.

Table 2. Summary of Performance Metrics and Targets

Performance Objective	Metric	Data Requirements	Success Criteria
Net power production	kW_e	Electrical power meter	>70 kW_e average output
Operational availability	Percent of time system is operational with guaranteed fuel supply	Monthly operational log	>70% for 30 consecutive days of demonstration
Payback	Years to payback	System efficiencies, availability, energy costs and usage, capital, and recurring costs	Not determined
Briquette maker performance	lbs/hour	Feedstock weight and rate of throughput into system	>140 lbs/hour (or all available feedstock, whichever is less)
Dehydrator performance	Moisture content and throughput	Feedstock weight and moisture measurements	Process a minimum of 400 lbs (or all available material, whichever is less) per day of wet feedstock
Shredder performance	lbs/day, particle sizes, run time	Feedstock weight and rate of throughput into system, size of shredded particles, time of shredder operation	Throughput >3,360 lbs/day (or all available feedstock, whichever is less) >95% of shredded material (by volume) <2 inches in any dimension Shredder actively shredding <3 hours per day
Char generation	Weight of char and carbon content	Weight of feedstock input and char output from HEDWEC; percent carbon by weight	<20% of incoming feedstock by weight
Ease of use	Number of operators, skill level and training requirements	Time of assisted operation, operational support requirements, factory support requirements	One operator trained and maintaining required availability within one month after field commissioning
Reliability of technology	Maintenance requirements, mean time between failures (MTBF), mean time to repair (MTTR)	Documentation of maintenance, failures, and repairs	Maintenance ≤3 days/month, plus 1 hour per day routine maintenance MTBF >21 days MTTR <6 days

Performance Objective	Metric	Data Requirements	Success Criteria
Emissions quality	g/hp-hr	Exhaust gas analysis for CO, NO_x, SO_2, PM, and total hydrocarbon emissions; exhaust gas flow rate	<.32 g/hp-hr CO <.85 g/hp-hr NO_x <.05 g/hp-hr VOC <.03 g/hp-hr SO_2 <.05 g/hp-hr PM
User satisfaction	Survey of DeCA staff to compare processes of feeding and operating HEDWEC to previous processes	Feedback from appropriate DeCA staff at Hickam Commissary	Able to feed and operate HEDWEC with one DeCA staff member monitoring in a way such that no more than 25% of his or her time is occupied with HEDWEC operation
Char toxicity	Pass/fail	TCLP analysis Heavy metal analysis	Pass (declared non-hazardous)

3.4 Performance Objective Descriptions

The follow items describe the performance objectives used in this demonstration:

- **Net power and heat production.** The goal was to produce the maximum amount of net power and calculate the recoverable waste heat from the HEDWEC system (theoretically calculated for waste heat, since there was no actual load at the commissary). The net power exported from the system was monitored with a power meter. The recovered waste heat in kilowatts thermal was calculated from the flow rate of engine coolant water and the change in temperature of the water as it passed through the heat exchanger. The minimum expectation was to deliver 70 kW_e while generating 88 kW_{th} (300,000 British thermal units [Btu]/hr) of heat. Potential heat recovery from the engine exhaust gas was not considered during this project.
- **Operational availability.** To have the maximum beneficial presence in the field, the HEDWEC system must be operated on a continuous 24/7 basis with a minimal amount of down time for maintenance and repair. Previous experience has shown that after the first few months of the deployment of a new system, monthly operational availability can average over 70%. A log of gasifier operational time and of down time was to be maintained to establish the monthly availability of this new HEDWEC system. The goal was to achieve a minimum of 70% operational availability for 30 consecutive days of demonstration.
- **Payback.** An economic model was developed using the U.S. Navy's energy return on investment (eROI) tool. A specific payback goal was not determined for this project.
- **Briquette maker performance.** To support the overall throughput of fuel needed to generate 70 kW_e, approximately 140 pounds per hour of briquettes are needed. For the purposes of this demonstration, input feedstock was to be weighed to determine the throughput of the briquette maker.
- **Dehydrator performance.** The HEDWEC dehydrators were sized to process all allowable wet food wastes from the commissary. Throughput, cycle times, and ease of operation were to be evaluated to determine if the dehydrators were optimum to meet the performance specifications of the project, which included processing up to 400 pounds per day of wet feedstock. The effluent of the dehydrators was also to be tested to ensure it could be processed at the JBPHH wastewater treatment plant.
- **Shredder performance.** To provide an adequate amount of fuel for the generation of 70 kW_e by HEDWEC, it was expected that at least 3,360 pounds per day of material sized to a specification that can easily be processed by HEDWEC's briquette maker were necessary. For purposes of this demonstration, the weight of feedstock fed into the system was to be used to determine throughput. To minimize parasitic loads and duration of noise, the time of active shredding was to be scheduled for several daytime batches and be tracked and logged by the HEDWEC system operator. CPC had planned to document noise levels during shredding operations at 10-foot, 25-foot, and 50-foot distances using industry-accepted test equipment.
- **Char generation.** The amount of residual char material was to be weighed and correlated to the weight of input feedstock for the operating period in which the char was created. The goal was to have residual char weighing less than 20% of the input materials' dry weight.
- **Ease of use.** With the exception of the feedstock processing module, HEDWEC systems are fully automated, allowing for unattended operation. Labor requirements to feed excess organic materials into HEDWEC were to be documented. These labor requirements were to be compared

to business-as-usual solid waste handling and disposal requirements to determine the incremental increase (or decrease) of labor requirements for commissary staff.

- **Reliability.** The reliability of the system was to be measured by the mean time between maintenance or repair of the subsystems that require shutting down the HEDWEC system. A log would have been maintained of every component failure or subsystem requiring maintenance to determine the robustness of the system and to identify subsystems in need of improvement. Continuous gasifier operation for over 21 days between system maintenance, an average of 3 days or less per month down time for maintenance, and an average "mean time to repair" of 6 days or less would have been needed to achieve the minimum operational availability of 70% and the ease-of-use objectives.
- **Emissions quality.** It is imperative that a system such as HEDWEC operate in an environmentally compliant manner with minimal emissions of NO_x, CO, H_2S, SO_2, PM, and hydrocarbons. To measure these low levels of emissions accurately requires specialized equipment, best maintained by a dedicated outside subcontractor. An outside environmental contractor was to be utilized to measure the key pollutants during the commissioning period at Hickam Commissary. Uncertified measuring devices were to be used on a continuous basis to ensure the unit emissions were within an acceptable range.
- **User satisfaction.** Feedback would have been solicited from the staff of the Hickam Commissary to determine if they were satisfied with 1) the ability to safely and efficiently transfer materials to HEDWEC, 2) on-site storage of materials, 3) aesthetic impact of the system, 4) additional noise created by the system, and 5) other impacts of utilizing HEDWEC. The objective was for the system to be operated reliably with one commissary staff member who committed no more than 25% of his or her time to operating the HEDWEC system for transferring feedstock materials to HEDWEC and performing other duties associated with HEDWEC operation (e.g., char disposal).
- **Char toxicity.** The most significant byproduct from the HEDWEC gasification systems is char produced from the feedstock. Char generated during the field demonstration was to be tested using standard U.S. Environmental Protection Agency (EPA) tests for heavy metals and leaching (TCLP), to determine if it could be handled and disposed of as nonhazardous material, allowing disposal in the on-site commissary dumpster. Other byproducts, including dehydrator effluent and carbon from the sulfur mitigation system, were identified during factory acceptance testing, but plans for further testing and handling of these byproducts were not developed.

4 Technical Performance Analysis and Assessment

The HEDWEC technical performance during its factory acceptance testing did not show sufficient promise to warrant conducting the demonstration at JBPHH. The data and assessments in this section are derived from the baseline data gathered by DeCA and NREL, and the factory acceptance tests performed by CPC at their test facility.

Table 3 is an overview of the itemized performance objectives for the demonstration test and an assessment of whether they met the respective targets as part of the factory test. The most significant shortfalls of performance targets were in the net power production and ease of use categories. Net power production was -6 kW (acting as a load on the host electrical system) and the operating labor requirements were much greater than originally anticipated. Due to recurring issues with feedstock flow through the system, constant operator intervention was required by a technician familiar with HEDWEC's operation.

Table 3. Summary of HEDWEC Factory Tests Performance

Performance Objective	Metric	Success Criteria	Test Performance Final Baseline Test	Criteria Pass/Fail
Net power production	kW_e	>70 kW_e average output	-6 kW average output	Fail, negative output
Operational availability	Percent of time system is operational with guaranteed fuel supply	>70% for 30 consecutive days of demonstration	8-hour baseline test	N/A
Payback	Years to payback	TBD	TBD	N/A
Briquette maker performance	lbs/hr	>140 lbs/hr	133 lbs/hr	Fail
Dehydrator performance	Moisture content and throughput	Process a minimum of 400 lbs per day of wet feedstock	156 lbs per 17-hour cycle per machine; estimated 440 lbs per day	Pass
Shredder performance	lbs/day, particle sizes, run time	Throughput >3,360lbs/day; shredder actively shredding <3 hours per day	Performance not reported	N/A
Char generation	Weight of char and carbon content	<20% of incoming feedstock by weight	Char yield 12% Carbon content not reported	Conditional pass
Ease of use	Number of operators, skill level and training requirements	One operator trained and maintaining required availability within one month after field commissioning	24 hour/day technician coverage needed	Fail
Reliability of technology	Maintenance requirements, mean time between failures, mean time to repair	Maintenance ≤3 days/month, plus 1 hour per day routine maintenance MTBF >21 days MTTR <6 days	N/A (unit did not get field tested)	N/A
Emissions quality	g/hp-hr	<.32 g/hp-hr CO <.85 g/hp-hr NO_x <.05 g/hp-hr VOC	Not tested	TBD

Performance Objective	Metric	Success Criteria	Test Performance Final Baseline Test	Criteria Pass/Fail
		<.03 g/hp-hr SO_2 <.05 g/hp-hr PM		
User satisfaction	Survey of DeCA staff to compare processes of feeding and operating HEDWEC to previous processes	Able to feed and operate HEDWEC with one DeCA staff member monitoring in a way such that no more than 25% of his or her time is occupied with HEDWEC operation	N/A (unit did not get field tested)	N/A
Char toxicity	Pass/fail	Pass (declared non-hazardous)	Not tested	TBD

4.1 Baseline Results

The Hickam Commissary does not currently operate a WTE system, so its baseline process is to recycle or landfill its waste. The baseline amount and types of waste, tipping fees, and recycling revenue associated with handling that waste were obtained from existing DeCA studies of Hickam and similar commissaries, and supplemented with additional site-specific measurements and surveys. Table 4 provides an overview.

Table 4. Feedstock Quantity and Economic Overview

Feedstock	Estimated Availability (wet lbs/day)	Annual Cost or Revenue	Unit Cost/Revenue ($/ton)
Produce	368	($21,695)	($323)
Fats/bones	171	($41,652)	($1,335)
Salvage (expired/damaged products, lose 50% from moisture)	2,000		
Waxed cardboard and other packaging currently sent to landfill (if 40% usable)	1,829	($25,000)	($36)
Total solid waste	4,368	($88,347)	$644 (average)
Recyclable cardboard	4,200	$48,272	$63
Total feedstock	8,568	($40,075)	N/A

The labor costs associated with solid waste management and disposal costs were considered but not accounted for after discussion with commissary staff. Hickam staff estimated the labor for transferring solid waste and recycling materials to their current locations (dumpsters, disposal containers, and cardboard balers) to be similar to labor for transferring materials to HEDWEC's dehydrators and in-feed bin.

Table 4 demonstrates the economic opportunity. Solid waste disposal costs for the Hickam Commissary were estimated at $644/ton, with most of the costs incurred for disposal of produce, fats and bones. The cardboard is a revenue-generating material but was originally thought to be a prime feedstock for HEDWEC. It was also noted that recyclable cardboard is currently shipped to Korea, providing an environmental opportunity if a beneficial use could be found on-site.

The original intention was to dispose of all produce, fats and bones with HEDWEC, which would have provided a significant economic benefit because these combined disposal costs ($63,347) greatly outweigh the $48,272 estimated revenue from cardboard.

The values shown in Table 4 also indicated sufficient feedstock available to fuel HEDWEC, estimated to need approximately 3,360 lbs per day for operation at 70 kW_e. With an estimated 8,568 lbs/day available, there was believed to be some flexibility in selecting feedstock, though the focus was to remain on feedstock with high disposal costs. The actual feedstock blend used is discussed in more detail below with economic implications in Section 5.

A feedstock characterization was conducted on the actual commissary materials to understand their chemical makeup. This was important to understand because the elements contained in these materials affect the ability of the material to be gasified, will become constituents of the producer gas, and will influence the products of the final combustion process if they are not filtered out. The results of these analyses are presented in Table 5.

Table 5. Feedstock Characterization

Component	As Discarded Moisture	Dry Basis Elemental Composition (%)							
		C	H	O	N	S	Ashes	HHV (dry)	HHV (wet)
Produce	78.29	49.18	6.64	37.58	1.69	0.02	4.89	4,594	2,855
Fat/bone	38.74	59.59	9.47	24.65	1.02	0.19	5.08	16,110	8,651
Salvage	29.00	73.14	11.54	14.82	0.43	0.07	0.00	11,295	6,065
Waxed cardboard	5.20	43.73	5.70	44.93	0.09	0.21	5.34	7,823	7,158
Unwaxed cardboard	5.20	43.73	5.70	44.93	0.09	0.21	5.34	7,950	7,527
Final waste stream (as received)	14.54	42.20	5.84	33.26	0.23	0.15	3.78	-----	7,002
Final waste stream (dry basis)	0.00	49.38	6.83	38.92	0.27	0.17	4.42	8,520	-----

The high ash content of the feedstock, relative to the typical woody biomass feedstock used in HEDWEC's predecessors, created issues that will be discussed further below and in later sections of this report.

4.2 Technical Performance Results—Factory Acceptance

CPC completed its 8-hour factory acceptance test at its facility on April 11, 2013. The results of this test run are summarized in Table 6. The feedstock mixture was based on representative feedstock available at the Hickam Commissary. The feedstock included 69% dry cardboard, 15% broken pallets (from salvage waste), 8% waxed cardboard, and 8% dehydrated organic material (wet basis—produce, meats, fats, bones).

The HEDWEC system processed 133 pounds of waste per hour during the 8-hour test. As previously noted, the goal was for the HEDWEC system to be able to process 140 pounds of waste per hour (3,360 pounds per day) as measured by throughput through the shredder and briquette maker in the front-end feedstock processing module. While this front-end feedstock processing system is sized for 200 pounds per hour, the HEDWEC system had trouble maintaining this rate.

Char ash production was 16 pounds per hour. This was more than expected for the unit (CPC estimated 4 pounds per hour based on other systems), but is below the 20% (by weight) threshold established as the level of success for this project.

The elapsed time for the final baseline test was 9 hours, with actual run time of 8 hours and 50 minutes. The average generator power output was 29 kW, while the goal was 70 kW. Due to parasitic loads, the net electrical generation was negative 6.5 kW, meaning the system was an additional 6.5 kW load when viewed as a whole. Including the theoretical thermal generation, however, the system was estimated to have a net energy output of 48.9 kW. Table 6 identifies the measured energy balance for electrical generation and theoretical for the heat generation.

Table 6. HEDWEC Energy Balance

Feedstock	Unit	Description	Notes
110	lbs/hr	Feedrate—dry basis	Sustainable feedstock processing rate
8,520	Btu/lb	Feedstock energy content—dry basis	From Hickam fuel analysis (includes composted wet food, wood, etc.)
937,200	Btu/hr	Feedstock energy content	
122	Btu/scf	Typical producer gas energy content	Calculated from actual gas composition data
3,001	scf/hr	Producer gas flow rate of BioMax (300 m^3/hr vs. 125 m^3/hr)	Measured average flow rate during baseline test
366,122	Btu/hr	Producer gas energy content	
39.1%		**Energy conversion efficiency: feedstock to producer gas**	
107	kW	Producer gas energy content	
25	kW	Generator power output of BioMax	Sustainable generator power output
23.4%		**Energy conversion efficiency: producer gas to electricity**	**Lower efficiency due to engine operating at low output levels**
5	kW	Internal parasitic losses within the gasification system	Includes blowers, pumps, etc.
20	kW	Net power output of BioMax	Parasitic losses do NOT include power used by the material processing module (MPM)
18.6%		**Energy conversion efficiency: feedstock to electricity, prior to external MPM parasitics**	

Parasitic Loads (average power draw based on duty cycles)			
6.0	kW	Dehydrators	
3.5	kW	Shredder components	
16.5	kW	Briquetter components	
0.6	kW	Accessory lights	
26.5	kW	Total external MPM parasitics	
(6.5)	**kW**	**Net electric output of HEDWEC system**	
Overall Energy Calculations			
274.6	kW	Feedstock equivalent kW	
(6.5)	kW	Net electric output of HEDWEC system	
N/A		**Net overall electric efficiency**	
18.0	kW	Recoverable exhaust gas available energy (500°C to 200°C)	Estimated from heat transfer calculations using exhaust and engine jacket as heat sources
37.4	kW	Recoverable engine block available energy (500°C to 200°C)	
55.4	kW	Total thermal output of HEDWEC system	
48.9	kW	Net electrical and thermal output of HEDWEC system	
17.8%		**Net overall electric and thermal efficiency**	

Figure 2 provides an overview of the electrical generation portion of the system. This depiction shows the sources of losses during the conversion of producer gas (from the gasification process) to electricity, presenting the net negative output and no electricity available for export.

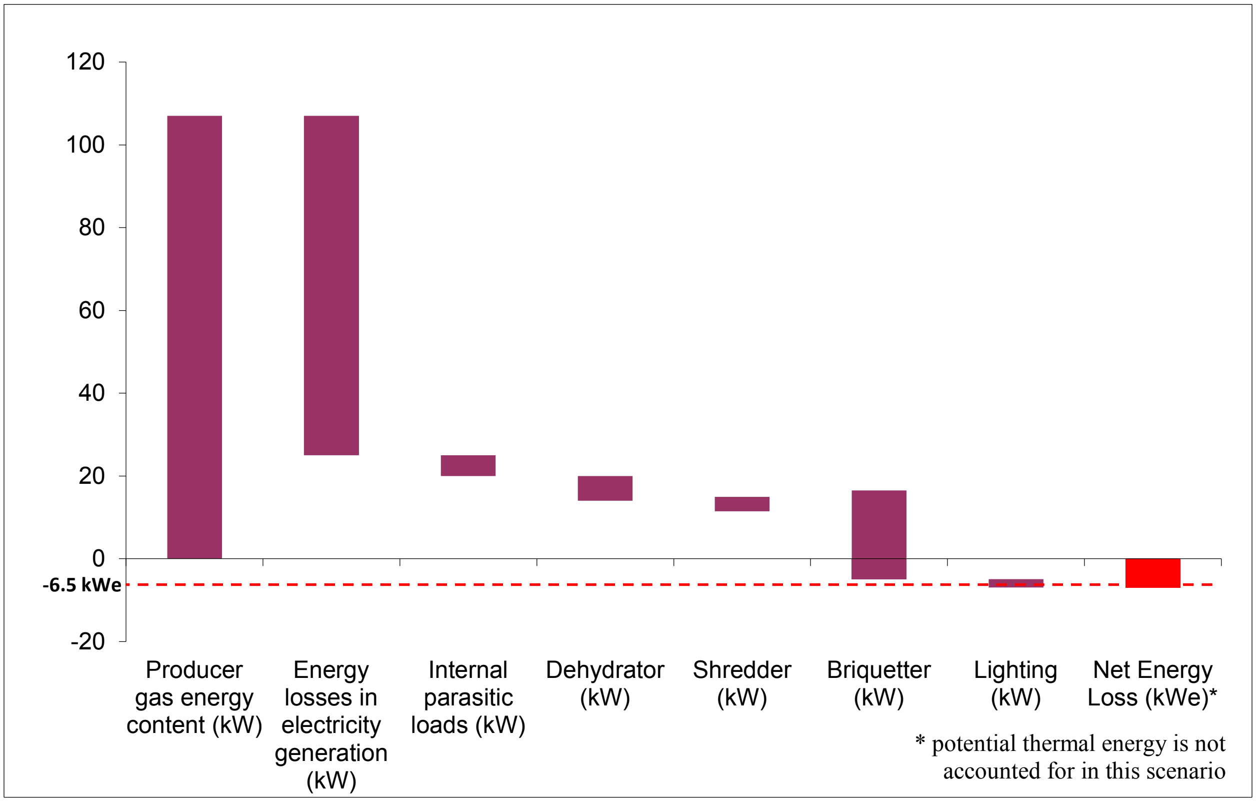

Figure 2. Graphical depiction of losses in the electrical generation portion of HEDWEC

4.3 Technical Challenges

CPC and NREL believed cardboard feedstock would be a good fuel for HEDWEC because the system evolved from a biomass-fueled gasifier system that had been successfully deployed in the past. This was not the case, however. Unforeseen issues with cardboard feedstock, as well as other unanticipated issues, created significant technical challenges for the system.

- **Shredder**. The commissary compresses cardboard into 700-pound bales, which are stacked on a loading dock to await pickup by a recycler. To minimize disruption to the current operations, a shredder was selected that could receive and process entire bales. This added significant parasitic load to the system. The high surge current for starting the shredder also created a challenge for the installation design, which is further discussed in Section 6.
- **Briquette maker.** A typical challenge for small-scale gasifiers is the need for energy densification to allow storage of a surge capacity, as well as to maximize Btu input into the gasifier. HEDWEC utilized a briquette maker for this purpose. The size of the briquette maker was increased from 1 ½ inches to 2 inches during the initial phases of this project to increase the energy input into the gasifier. This, however, had the unintended consequence of incomplete gasification of the larger briquettes, with a partially successful mitigation measure proposed to shorten the length of the briquette. As noted in the energy balance of Table 6, the briquette-maker also added a significant parasitic load to the system.
- **Component integration.** The shredder and briquette maker, also called the "front end" of a system like HEDWEC, are key components of the feedstock processing module. While these components are commercially proven to operate effectively for other applications, the particular items selected for HEDWEC had not been integrated into a WTE system before. The integration of the controls for these items was more complicated than anticipated, and the alignment of their respective performance with other HEDWEC components was not ideal. For example, the capacity of the shredder was much higher than necessary (to support processing of full bales, as discussed). To minimize parasitic load, the intention was to use operator monitoring to cycle the shredder and minimize runtime. This is a viable strategy but requires additional operator monitoring, and any labor increase for a small-scale system like HEDWEC has detrimental effects.
- **Gasifier.** The combination of the cardboard-based fuel and new briquette size contributed to gasification challenges. High ash content of the feedstock (see Table 5) contributed to the formation of "clinkers," vitrified noncombustible material that form into clumps and must be removed from the gasifier prior to further operation. To mitigate this issue, the rate at which feedstock was passed through the gasifier was increased, which decreased the ability of the system to gasify the material and lowered the conversion efficiency. The increased briquette size also contributed to poor flow through the gasifier and further affected the performance of the gasifier. Poor flow contributed to "rat-holing," or gaps in the fuel bed that allow producer gas to flow directly through, which can combust prematurely. This alters the gasifier's performance from the typical profile shown in Figure 3.

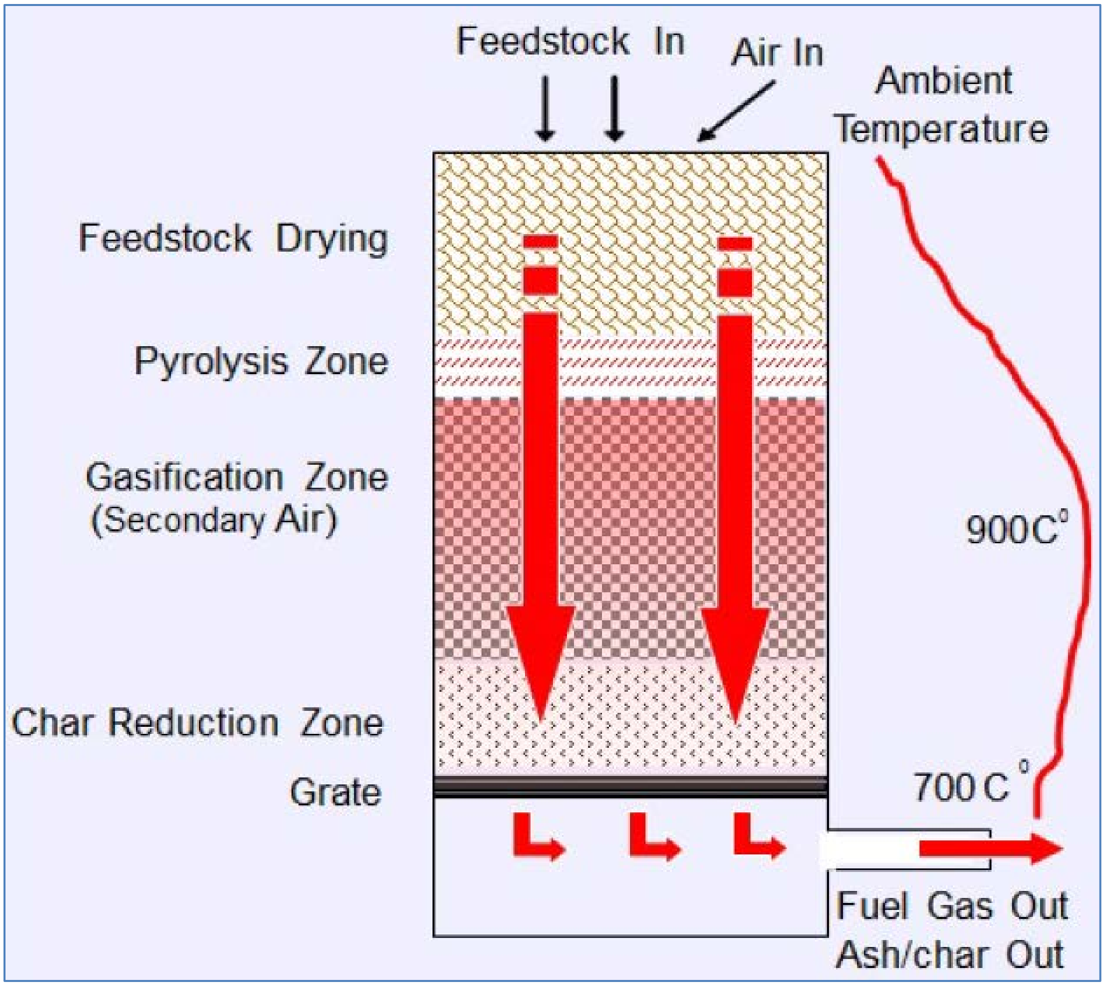

Figure 3. HEDWEC gasifier process and temperature profile

Source: Community Power Corporation

The changed behavior due to the feedstock creates instability of the gasifier's performance. To help mitigate the instability from rat-holing and increase the throughput to minimize clinker formation, additional agitation of the feedstock bed was initiated, which introduced a new set of mechanical stress issues into the gasifier and led to repeated weld failures within the gasifier structure.

- **Sulfur.** The cardboard feedstock contained an unexpectedly high amount of sulfur. This sulfur was evident as H_2S in the producer gas and SO_2 in the air emissions. To meet the emissions expectations of the Hawaii Department of Health (discussed in Section 6), a sulfur mitigation system was needed. CPC integrated a system using dual 55-gallon drums with activated carbon for filtering sulfur from the producer gas. This system had challenges from condensation and high differential pressures, which created issues with the fuel flow to the internal combustion (IC) engines and made parallel operation of the engines difficult. Due to challenges in operating the IC engines in parallel, the system was often operated with one engine, restricting potential power output.

NREL and CPC proposals for addressing these challenges are included in Section 7 as part of the commercial readiness assessment.

5 Economic Performance Analysis and Assessment

The poor technical performance of HEDWEC also translated into poor economic performance for the proposed application at the Hickam Commissary. Based on factory acceptance testing, HEDWEC had a negative return on investment because its net increase in electricity consumption and large operating costs overshadowed estimated solid waste disposal savings. The system was originally designed for use in expeditionary environments, such as DOD's forward operating bases. As such, some of the operating characteristics may provide benefit in an expeditionary environment but were found not to be viable for operating at a fixed installation, such as JBPHH. The unexpectedly low power generation, high amount of dedicated labor, and need for skilled operators were primary factors leading to the early termination of the HEDWEC demonstration. Mitigating factors to increase power generation and lower labor requirements for future iterations of this technology will be discussed in later sections of this report.

The original economic assessment conducted using eROI and in support of the Form 1391 application showed a strong economic return for the U.S. Navy. This return was driven by three key features of the project:

- No capital cost for the original HEDWEC unit provided by the U.S. Army. The 1391 estimated a total U.S. Navy cost of $24,000 for the project to account for installation and contingency costs.
- Estimated electrical savings of $140,000 per year were projected. The assumptions for these savings were 100 kW net electric output, a capacity factor (online time) of 80%, and electricity costs of $0.20/kWh.
- Estimated solid waste disposal cost savings of $15,075. This estimate was derived from a total solid waste disposal cost savings of $63,347 with an adjustment to account for $48,272 of lost revenue from cardboard recycling.

The actual performance of the HEDWEC system affected the electrical savings opportunity significantly. As described in Table 6 of Section 4, the system was estimated to be a 6 kW load on the commissary rather than a 100 kW generation source. With electricity costs projected to increase at JBPHH as high as $.59/kWh in fiscal year 2014, the value of on-site generation becomes significantly greater. Unfortunately, in the case of HEDWEC, the electric cost to operate the system becomes significantly higher.

After factory acceptance testing, the capacity factor (CF) for HEDWEC was revised to 55%. Using this and the 6 kW net load, the electricity cost to operate HEDWEC can be derived using the equation below.

$$8{,}760 \text{ hours per year} * .55 * 6 \text{ kW} * \$.59/\text{kWh} = \$17{,}056 \text{ per year}$$

This estimate negates the $15,075 per year economic opportunity in solid waste disposal costs. Operation and maintenance (O&M) costs were estimated to be approximately $100-150 per megawatt-hour of generation, based on input from CPC and NREL experience with other WTE systems. For a 70-kW system operating at 55% CF, this results in approximately $37,000-$50,000 annual O&M costs. CPC estimated the cost to manufacture HEDWEC at $1.8 million, though this does not consider an economy of scale possibly afforded by a rollout of these systems. The capital and O&M costs are not investigated in detail because these would simply apply an additional burden to the already unfavorable business case for the HEDWEC system.

5.1 Dehydrator-Only Operation

The majority of the economic benefit of reduced solid waste disposal costs is provided by the HEDWEC's dehydrators, which can operate independently of the HEDWEC system. To help evaluate the potential benefits, the commissary's solid waste disposal costs are broken down into dollars per pound and dollars per ton in Table 7. Of note, the average $644 per ton for residual organics is nearly 15 times the average tipping fee in the United States.

Table 7. Solid Waste Disposal Costs at the Hickam Commissary[a]

Feedstock	Estimated Availability (wet lbs/day[a])	Annual Cost or Revenue	Unit Cost/Revenue ($/lb)	Unit Cost/Revenue ($/ton)
Residual organics	539	($63,347)	($0.32)	($644)
Recyclable cardboard	4,200	$48,272	$0.03	$63
Total feedstock	8,568	($15,075.00)	($0.29)	($581.01)

[a] See Table 4 for more detail regarding the breakout of residual organics

To consider the economic benefit of operating these independently at the Hickam Commissary, the dehydrators' technical performance must be considered as well. Table 8 provides an overview of CPC's observations on the Somat-brand dehydrators' performance during factory acceptance testing.

Table 8. Somat Performance

Attribute	UOM	Somat Factory Specification	CPC Test Results
Input capacity	lbs	110-220	156
Average reduction rate	%	83-93	60
Treatment time	hrs	12-18	17

Using CPC's observations of the dehydrator, the economic assessment of using the dehydrators as stand-alone units is evaluated in Tables 9 and 10. Scenarios are presented for three different rates of electricity.

Table 9. Dehydrator Analysis: Food Disposal Costs[a]

Electricity rate ($/kWh)	$0.59	$0.40	$0.30
Power (kW)	3	3	3
Cycle time (hrs)	17	17	17
Cost per cycle	$30.09	$20.40	$15.30
Capacity (lbs)	150	150	150
Reduction factor (%)	60%	60%	60%
Net reduction (lbs)	90	90	90
$ per lb	**$0.33**	**$0.23**	**$0.17**

[a] Simplified calculation does not include maintenance costs and assumes no increase in labor costs

Table 10. Dehydrator Payback Calculation

Capital cost	$26,040.00	$26,040.00	$26,040.00
Pounds of organics per year	196,735	196,735	196,735
Annual savings ($)[a]	($945.51)	$10,858.59	$17,941.05
Simple payback (yrs)	**N/A**	**2.4**	**1.5**

[a] Savings calculated using $ per lb disposal costs from Tables 7 and 9, with the assumption of 60% reduction in weight from dehydration

The current business case for the dehydrators as independent units is much stronger than the business case for HEDWEC as a complete system at this time. To improve the economics for HEDWEC, significantly higher electrical generation is required, as well as lower operating labor requirements. It is unclear if HEDWEC's technical and economic performance is attributed to issues with the project's design (e.g., feedstock selection and choice of an expeditionary system) or is indicative of the state of the small-scale WTE gasification industry. This uncertainty will be addressed in later sections of this report.

6 Project Management Considerations

This project required a relatively high degree of project management activity. Implementation of a small-scale gasification system at a general access military facility presented significant administrative and permitting activity, in addition to a focus on quality assurance and site safety. As a partnership between multiple elements of the DOD in concert with NREL, this project also required a unique level of coordination between each partners' expectations and requirements.

A key emphasis of the Integrated Product Team's (IPT's) management approach was to perform a "deep dive" evaluation of the system prior to deployment at JBPHH. The WTE unit intended to be demonstrated was developed for expeditionary operations, and developed using funds and personnel outside the purview of the NAVFAC/NREL initiative. The IPT had limited knowledge of the unit's development history and past performance, with these unknowns presenting inherent risks. Therefore, prior to deploying the system in a high traffic, open access environment, such as the Hickam Commissary, the IPT required significant pre-shipment evaluation and understanding of system design, technical performance, quality, and safety.

From a programmatic standpoint, the project established a successful network of communication between the key stakeholders. These included technical and project management representatives from the U.S. Navy, NREL, DeCA, the U.S. Army, and CPC. The roles of NREL, DeCA, and the U.S. Army participants were defined and formalized in a memorandum of agreement (MOA), fully signed and enacted on Sept. 10, 2012, and included as Appendix A in this report. NAVFAC did not sign this MOA, as it served as a subordinate agreement to the NAVFAC/NREL MOA, signed on June 19, 2012. It clarified the roles of NAVFAC and NREL in execution of the overall joint initiative. Although the project did not reach the field demonstration phase, the active participation of all key stakeholders was critical to addressing the technical and administrative duties mentioned above. Further, the use of factory acceptance testing under representative operational circumstances, as well as the insertion of a stage gate between this testing and field implementation, provided highly beneficial information to the IPT to determine an appropriate course for the project. Structuring the project in this way saved a significant amount of money by identifying critical performance issues leading to the early termination of the demonstration.

Table 11 provides a summary of programmatic elements of this project and a high-level timeline of events.

Table 11. Programmatic Summary

Implementation Method	Installation by Technology Provider
Key contractors	CPC
Period of performance	1 Year, 2 Months
Project Timeline	
Site identification	October 2011-January 2012
Site approval	February 2012-March 2012
Site permitting	March 2012-February 2013
Design/procure/assemble	July 2012-January 2013
Factory acceptance test	January 2013-April 2013

The project life cycle was composed of five sequential tasks.

1. **Site identification**. To initiate this project, an appropriate facility was needed to demonstrate the technology. As this project had previously targeted a site at the Hickam Commissary, the IPT efforts focused on this location.
2. **Site approval**. The IPT collected information for the proposed site at the commissary and completed site approval, DOD form DD1391, and National Environmental Policy Act (NEPA) requirements.
3. **Site permitting**. The intended deployment of the WTE unit on a military installation required substantial administrative focus in execution of appropriate permitting requirements. Significant attention was given by the IPT in achieving a temporary air permit, fire safety, water effluents and hazard materials testing and approval, and an interconnection agreement with the local utility. The time and procedural challenges in achieving these permits were substantial.
4. **Design, procurement, and assembly**. The project leveraged an existing system designed for expeditionary operation. Reconfiguring was required to accommodate operation at the commissary. Project design requirements to accommodate installation of the WTE unit at the Hickam Commissary were moderate. Procurement and readying the WTE unit for factory testing required more time and effort than what was originally anticipated.
5. **Factory acceptance test**. After completing the technical modifications required for operation at the commissary, the fully integrated system was tested at the technology provider's facility using waste representative of that found at the commissary. The system did not operate as expected. The operational data collected during this step were used to develop this report. System quality and safety were also evaluated.

6.1 Lessons Learned Overview

Past demonstrations of small-scale WTE gasification units have been coordinated through programs that have not required compliance with DOD design specifications. Therefore, there was no precedent for design requirements, such as those in the Unified Facilities Guide Specifications (UFGS) or the Unified Facilities Criteria (UFC). While the HEDWEC system never reached the field test stage for deployment at JBPHH, progress was made regarding applicability of military construction specifications to systems such as HEDWEC. Further exploration into the permitting requirements, particularly for air emissions, would also benefit future deployments for systems like HEDWEC. Specific lessons learned are summarized below and explored in more detail later in this section.

- The EPA does not offer air emissions permit guidance for the syngas-fired engines which are typically used in a system such as HEDWEC. This complicates air permitting discussions with state and local environmental regulatory agencies. Further outreach and education regarding these systems with the EPA would streamline future installations of WTE gasification systems.
- There is no clear guidance for setbacks applying to modular syngas-fired engine-generator sets. The presence of carbon monoxide in the syngas alarmed U.S. Navy safety representatives. Early discussions regarding the operation of systems like HEDWEC and installed safety features should be held with appropriate safety personnel to establish required setbacks or implementation of safety features.
- From a general perspective, gasification systems must go through extensive testing using representative feedstocks to validate performance prior to field testing. Prior performance using different feedstocks is not a reliable indicator of system performance.
- Older facilities, such as the Hickam Commissary, may not have current electrical drawings and circuit load information necessary for interconnection of distributed generation devices, such as HEDWEC. This information must be attained, and efforts should be made early in the development of a project to evaluate available electrical information and identify new information.
- Technology providers inexperienced with military construction and site requirements may face a challenge in learning and complying with these requirements. This is particularly likely if their past deployments were conducted in programs that did not require full compliance with these specifications.

6.2 Site Approval, National Environmental Policy Act, and DD1391

Site approval, NEPA, and DD1391 processes were straightforward and did not pose a significant administrative challenge or time constraint to the overall project schedule. The Navy/NREL team performed a quick evaluation of the U.S. Army/DeCA/CPC project concept and selected it for demonstration based on multiple factors including: the likelihood of receiving a NEPA categorical exclusion leveraging previous U.S. Army investment, inclusion of other DOD partners (U.S. Army and DeCA), and the potential for cost-effective energy generation, especially in island locations.

The project was proposed to be implemented behind the Hickam Commissary on an existing concrete pad with sufficient space for all equipment (see Figures 4 and 5).

Figure 4. Site layout

Source: Google Earth (edited by NREL)

Figure 5. Proposed project location

Source: Community Power Corporation

The project was reviewed by NAVFAC Hawaii Environmental Department for NEPA requirements. As it utilized existing infrastructure and would not impede on cultural or historic areas, it was determined (in accordance with the Office of the Chief of Naval Operations Instruction [OPNAVINST] S090.IC Ch-1) to have an insignificant impact on the environment, receiving a categorical exclusion on Feb. 21, 2012. The applicable exclusion language determined to apply to this project is stated below.

> (18) Studies, data, and information gathering that involve no permanent physical change to the environment (e.g., topographic surveys, wetlands mapping, surveys for evaluating environmental damage, and engineering efforts to support environmental analyses)

A DD1391 form was completed, submitted, and approved for this project by the Public Works Officer and Regional Engineer. The project was also reviewed and approved by the JBPHH Facilities Board.

6.3 Contracts and Procurement

The implementation strategy for this project leveraged the expertise of the original developer of the HEDWEC system, CPC. Under contract to NREL, CPC was assigned a broad range of project responsibilities. They were required to configure the HEDWEC system for application to this project, evaluate system performance at their own facilities, ship the unit to JBPHH, perform site project design and installation, and demonstrate (operate) the system at JBPHH over a prescribed number of months. In general terms, CPC served as the technology provider, installation contractor, and service operator.

The implementation approach chosen assigned the majority of project responsibilities to the technology provider. This is in contrast to a more distributed model with separate contracts assigned for technology procurement, site design and installation, and technology operation. Rationale for the approach used was based on three factors:

- **Consistency with future deployments**. For this initiative, the objective was not only to evaluate the performance of the technology, but also the effectiveness of the most likely implementation strategy in further, non-demonstration deployments in a military environment. For near term deployments of this technology offering, the provider will likely play a significant role in site installation and operation and maintenance. The contracting model utilized was structured to be consistent with this near-term implementation strategy for future WTE units. Pending further validation of this technology, a longer-term strategy may entail direct government purchase of WTE systems or use of private sector investment through mechanisms, such as energy savings performance contracts. Upon validation, a small-scale WTE system will be acquired in a similar manner to acquisition for other renewable technologies, such as solar photovoltaic or wind technologies. For WTE, however, feedstock must also be considered to ensure sufficient fuel for the system is secured for the duration of the project. In the case of a third-party financed project, the third party will be responsible for securing sufficient feedstock.
- **Likelihood of project success**. The implementation approach demonstrated must also be chosen to ensure its key performers can succeed under the conditions ascribed by the project. The IPT's initial assumption was the site-related requirements of the project were marginal. Additionally, CPC had previous success performing in a similar role on a prior Office of the Secretary of Defense (OSD)/Environmental Security Technology Certification Program (ESTCP) biomass gasification project. Implementation under the chosen model was therefore viewed as achievable and not placing undue burden on project execution.
- **Unique qualifications of technology provider**. In contributing the HEDWEC system to this demonstration, the ARL provided a unique, cost-savings opportunity to the U.S. Navy/NREL initiative. The system as provided was, however, a demonstration unit developed for operational energy applications. CPC, the original developer of the HEDWEC system, was uniquely qualified to configure and operate the system for application to the Hickam Commissary.

This approach to project implementation worked well with regards to configuring, testing, and evaluating the HEDWEC system for application at the Hickam Commissary. These activities were performed effectively and within a reasonable timeline. As these project elements were technology-centric, these results were to be expected because they aligned well with CPC's core capabilities.

Conversely, the team struggled with executing site-related design and permitting requirements. This was largely attributable to CPC's inexperience with NAVFAC UFC/UFGS and JBPHH-specific requirements. These requirements, although minimal from the perspective of a NAVFAC construction activity, proved more extensive and challenging than CPC had initially realized. The "learning curve" for bringing CPC up to speed was substantial, requiring more time and resources than expected while yielding frustration for both contractor and client.

Ultimately, the project's approach to implementation was reasonably structured to facilitate near-term deployments of the technology. This evaluation, however, is skewed by the technology provider's shortage of experience with and understanding of military construction and site requirements. Having now gained valuable experience from this demonstration, CPC is likely in a better position to fully execute follow-on demonstration and deployment activities. Further deployments should therefore not be affected by similar programmatic challenges.

The CPC subcontract was structured in three phases:

- **Phase 1**. Baseline testing at CPC's facility (also called factory acceptance testing)
- **Phase 2**. Field demonstration at Hickam Commissary
- **Phase 3**. Performance assessment and final reporting.

The contract included an "off-ramp" provision to allow transition directly from Phase 1 to Phase 3 if the initial testing was not successful. This provision proved useful for this demonstration, as HEDWEC did not achieve performance goals during testing at CPC.

Another contractual vehicle used for this demonstration was the MOA (previously addressed in this section). Two key concepts of the MOA which were necessary in allowing the demonstration to proceed were: 1) Army allowing the HEDWEC unit to be used for this purpose and, 2) DeCA allowing recyclable cardboard to be used as feedstock. The recyclable cardboard is a revenue-generating product for DeCA and an initial economic analysis showed higher value in on-site generation to electricity than recycling in foreign markets. This was later found to be inaccurate based on actual performance of the system but was initially a significant determining factor in feedstock availability for the demonstration.

6.4 Design

As discussed in previous sections, the majority of the technology was designed by CPC under a contract with the U.S. Army, with refinements made prior to execution of the NREL subcontract. Most of the design work for this demonstration related to site design and dealing with uncertainties associated with the technology's installation on a DOD site.

6.4.1 Anti-Terrorism and Force Protection

NAVFAC Pacific Safety reviewed photographs of the technology and proposed site. As there would only be one operator and no work was to be done to the adjacent commissary building, Anti-terrorism and Force Protection requirements were not triggered.

6.4.2 Fire Protection

NAVFAC Pacific Safety expressed concern for the presence of carbon monoxide in the syngas fuel mixture used by HEDWEC. A detailed and extensive exchange between NAVFAC Pacific and NREL resulted in several questions about how HEDWEC should be categorized. Specifically, questions revolved around the separation distance required between HEDWEC and the commissary building.

Due to the containerization of the system, HEDWEC could be considered a structure and subject to guidance on relocatable buildings from OPNAVINST 11010.33C, which refers to fire protection requirements of the UFC and International Building Code (IBC). Per the IBC, 40 feet of separation is required between containerized structures and adjacent buildings.

The separation distance is determined by evaluating the type of construction, function, occupancy, presence of hazardous materials, and categorization as a building or a structure. UFC 3-600-1 and the National Fire Protection Association standards also provide guidance for separation and fire safety requirements. Conventional energy generation equipment has its own sections in these documents. The unique nature of HEDWEC resulted in an extensive exchange to determine which fire safety specifications should apply. Also compounding the issue was the limited space available on the existing concrete pad proposed to be used for the demonstration. Ultimately, it was determined the HEDWEC system could be placed on the existing pad while maintaining a 40-foot separation distance from the commissary, though there remained uncertainty about the exact classification of the system and relevant safety requirements. Forty feet was determined to be a conservatively safe distance; while this space is available at the Hickam Commissary, it may not be available at future sites. For this technology to be deployed at other locations, further exploration should be conducted to classify systems such as HEDWEC to help determine applicable fire safety requirements. Figure 6 shows an animated rendition of the proposed layout of HEDWEC at the edge of the concrete pad. A portion of the shredder had to be shortened to meet the separation requirements from the commissary building (upper right portion of image).

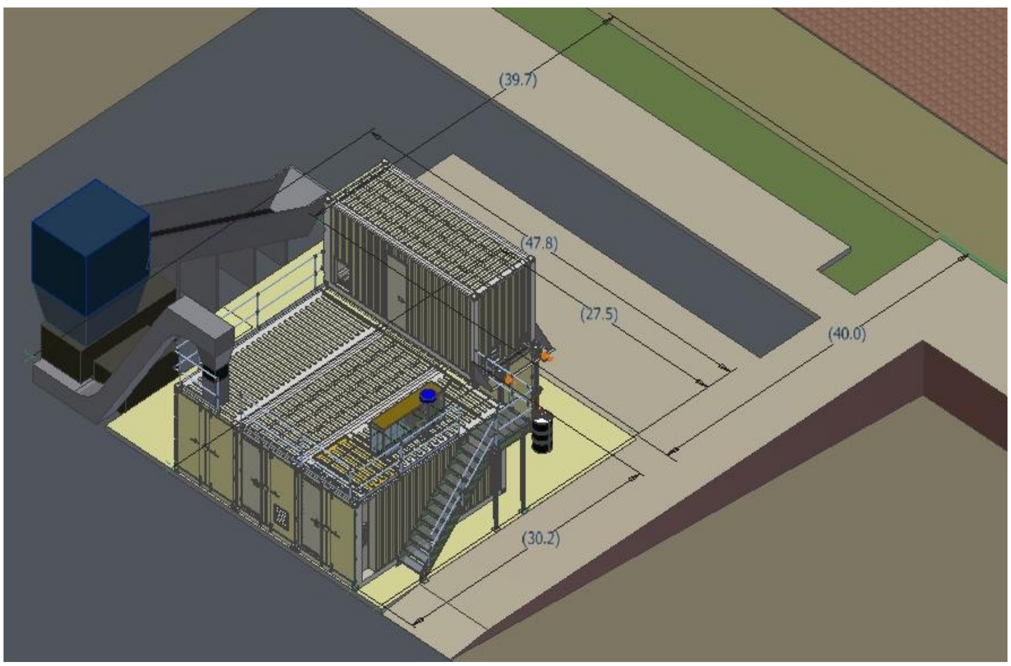

Figure 6. Site design overview

Source: Community Power Corporation

6.4.3 Gasoline Storage

A mid-project design change required a small amount of gasoline (<10 gallons) to be stored at the project site. This change was reviewed by NAVFAC Pacific, and no additional guidance was given.

6.4.4 Other Safety

As a result of an incident at CPC's test site in Colorado, CPC's parent company Afognak Native Corporation conducted an investigation into the safety of HEDWEC's design. The report concluded the root causes of the incident were deviation from, or lack of, proper safety procedures, and that there were no safety issues inherent to the system's design.

As gasification WTE technology matures, it is likely to become more prevalent at DOD installations. The risks inherent with this technology are similar to other thermochemical energy generation technologies, such as diesel generators. For example, hazardous chemicals, such as CO, and high temperatures are likely to be a part of the energy generation process. While the CPC incident investigation found no issues in the design of the safety, it is a reminder to ensure proper safety procedures are in place prior to assembling, installing, or operating gasification WTE systems. It may even be prudent to have an industrial hygienist conduct an inspection of the system design prior to installation at the host facility.

6.4.5 Unified Facilities Guide Specifications

CPC staff encountered a great deal of confusion when trying to determine which UFGS specifications would apply to the HEDWEC demonstration. CPC hired two different professional engineers registered with the state of Hawaii, but neither was familiar with the UFGS specifications. Several months were spent evaluating and contemplating these specifications. The demonstration portion of the project was canceled before the UFGS specifications were determined. A lesson learned from this activity is to ensure technology providers who are unfamiliar with military requirements are properly informed of their importance and significance. Additionally, such providers would benefit from securing assistance from firms familiar with the UFGS specifications, preferably when estimating their costs for a project on a DOD site.

6.5 Installation and Construction

Several aspects of this technology were reviewed for compliance with regulatory requirements. These included air emissions, solid waste handling, ash disposal, hazardous materials handling, and water discharge. Also, because it would be interconnected with the Hickam Commissary, an interconnection agreement with Hawaii Electric Company (HECO) was required. Prior to shipping, the technology underwent testing at the manufacturer's facility to verify performance. HEDWEC was unable to successfully complete this factory acceptance testing, at which point installation and construction activities ceased.

6.5.1 Air Permitting

Due to EPA's lack of guidance for permitting air emissions of syngas-fired engines, the permitting pathway for a system like HEDWEC does not yet have a clear precedent, making the process very challenging. The IPT evaluated several options for permitting the air emissions and ultimately opted to pursue an exemption for the purposes of this demonstration, which was approved by the Hawaii Department of Health March 12, 2012, after nearly five months of evaluation by the IPT.

Gasification-based technologies, such as HEDWEC, are mistaken for incinerators by regulatory authorities who simply understand it as a heat-based process consuming residual solid materials as feedstock. Classification as an incinerator automatically triggers a complex permitting pathway under the EPA's Title V permit program. Attaining a Title V permit can take from 18-24 months, and entails extensive monitoring and reporting requirements. The emissions for a system like HEDWEC come from the engine's exhaust. EPA offers specific guidance for permitting engine exhaust emissions from stationary spark-ignited internal combustion engines such as that used in the HEDWEC system. If the engine can be proven to meet requirements, the permit is much easier to attain and maintain.

The driving factor in determining whether HEDWEC should be permitted as an incinerator or as an alternatively-fueled engine is the classification of the feedstock. If it is determined to be solid waste, a system like HEDWEC will be considered an incinerator. If it is determined to be fuel, it can be permitted as an engine. 40 CFR 241.3 provides guidance regarding the classification of feedstock and states "non-hazardous secondary materials which remain in the control of the (waste) generator and meet the legitimacy criteria of 241.3.d.1 are not considered solid wastes when combusted." Legitimacy criteria are:

- The non-hazardous secondary material must be managed as a valuable commodity based on (A) the processed fuel will not be stored more than a few days on-site and (B) the fuel, once processed, is analogous to other solid fuels and will be handled in a similar manner (storage bins and conveyors with no external release)
- The fuel has meaningful heating value
- The fuel is not expected to have more contaminants than the biomass fuel for which the system was originally designed.

The proposed feedstock for HEDWEC appears to meet the legitimacy criteria allowing for its classification as fuel. This would allow HEDWEC to be permitted as an engine, although there is not specific EPA guidance for engines using syngas as fuel. The most relevant guidance is found in 40 CFR 60 Subpart JJJJ, which provides criteria for regulating emissions from an internal combustion engine fueled by landfill gas. Emissions tests conducted by CPC on previous versions of HEDWEC determined the emissions to be less than the EPA's limits for landfill gas-fired engines. The feedstock was different, however, and new testing was scheduled to be completed using representative feedstock of the Hickam Commissary.

Due to the lack of precedent and uncertainty of air permitting requirements, and due to the temporary nature of the demonstration, the IPT opted for the simplest possible approach and pursued an exemption from air permitting requirements from Hawaii's Department of Health. With guidance from NAVFAC Pacific Environmental, DeCA submitted the request for an exemption, which included submission of expected emissions for five criteria pollutants: CO, SO_2, NO_x, volatile organic compounds (VOC), and PM. The specifications were based on previous testing of a CPC gasifier using biomass feedstock and are shown in Table 12, along with EPA guidelines.

Table 12. Air Emissions Specifications Submitted to Hawaii Department of Health

Pollutant	HEDWEC Estimate	Federal Standard 40 CFR 60, Subpart JJJJ (g/hp-hr)
CO	0.32	5
NO_x	0.85	3
VOC	0.05	1
SO_2	0.03	-
PM	0.05	-

Meeting these specifications using the proposed feedstock for this demonstration was difficult, particularly for sulfur. These technical challenges are addressed in Section 4. EPA does not currently limit emissions for SO_2 and PM from stationary internal combustion engines, so these pollutants may not have to be reported to attain an operating permit in the future. For the purpose of attaining the exemption, however, the IPT opted to report all available air emissions information.

This request for an exemption was approved within a month of submission, and the entire process took approximately five months to review options and attain the exemption. Further investigation into classification of the system was suspended. A later objective for this demonstration was to reach out to the Hawaii Department of Health and the EPA to discuss classification of systems like HEDWEC. More detailed discussion in this area would be beneficial to establishing a predictable permitting pathway for systems like this in the future.

Other Permits

Several other permits were considered for this demonstration.

- **Solid waste permit.** For this project, it was determined that a single source exemption would apply because all materials were proposed to come from the Hickam Commissary, and no outside materials would be received.
- **Wastewater discharge permit.** HEDWEC has no water effluent from its gasification process, but the dehydrators used for processing of wet feedstock do have effluent. A discussion was held with the JBPHH Wastewater Treatment Plant (WWTP) operator, and concern was expressed for grease in the dehydrator effluent, which might be present from meat products. Prior to discharge of effluent into the drains of the commissary, effluent from the dehydrator must be tested and verified to meet all specifications of the WWTP. This test must be done using actual materials from Hickam Commissary after the unit is physically onboard JBPHH. The test could not be done at CPC's facility in preparation. As the unit did not ship to JBPHH, the effluent was not tested to determine if discharge to the WWTP would be an issue.

  In future projects producing residual water, consideration must be given for the specifications of the WWTP. The test results from the effluent take several days to receive, so existing disposal methods of high moisture materials must remain in place while the dehydrator effluent is verified to be suitable for discharge.
- **Hazardous materials (HAZMAT)**. HEDWEC produces ash as a residual byproduct at a rate of approximately 15 lbs/hr. Onboard JBPHH, up to 55 gallons of potentially hazardous waste can be stored for up to three days while HAZMAT testing is conducted. For the ash, a TCLP must be conducted using representative feedstock to verify the ash is not hazardous. In previous operations, residual ash was tested to be free of toxic metals using the TCLP, but this test would have to be replicated for HEDWEC while on-site at the Hickam Commissary and using actual commissary feedstock. At maximum production, HEDWEC would take several days to generate 55 gallons of ash. In theory, this would allow sufficient time to get results from the TCLP. Pending a successful (negative) TCLP, the ash can be disposed of in a conventional landfill via a typical dumpster. If the TCLP were to be positive, ash must be handled as HAZMAT and disposed of accordingly. With the termination of this demonstration, actual ash was not tested.

Interconnection

Development of the interconnection agreement application for this project was an unexpectedly challenging process, requiring the coordination of multiple parties. The key aspects of the interconnection are listed below.

- **Interconnection point.** Development of the electrical interconnection drawing package began with collaboration between NREL, CPC, and DeCA Engineering to determine the potential load of HEDWEC (during startup) and interconnection point. CPC estimated the load at 150 amps and DeCA Engineering identified an existing manual transfer switch (previously installed for a backup diesel generator) as a good interconnection point. A simplified electrical drawing of HEDWEC's interconnection to the commissary distribution system (recreated from a DeCA Engineering drawing) is provided in Appendix B.
- **Utility process review.** NREL and CPC held discussions with NAVFAC and HECO to review the utility process. Figure 7 shows a flow chart, provided by HECO, showing the steps necessary for the Hawaii Public Utility Commission (PUC) interconnection process. This figure is extracted from Rule 14H, which outlines the interconnection process.

  The process is fairly straightforward but requires analysis at each step. This analysis requires the vendor to verify that its technology can meet the performance specifications laid out in Rule 14H. It also requires support from the host to determine how the distributed generator's capacity compares to loads on the circuit and other existing on-site generation (distributed generation is to be <15% of a circuit's total load).

  For this demonstration project, the generation of HEDWEC was not expected to leave the commissary's distribution system. Average load at the commissary is over 400 kW, and the peak generation expected during early phases of this demonstration was 70 kW. CPC reviewed the performance specifications of the interconnection agreement and compiled technical documentation for HEDWEC to submit with the interconnection package.

  Also needed for the interconnection application was a drawing package stamped by a professional engineer. Typically, HECO requires the drawing to show the complete electrical pathway between the distributed generator and HECO's system. This would have included the commissary distribution system, commissary transformer, and the appropriate Hickam circuit to the HECO transformer. Due to the relatively small size of the generator compared to the commissary load, HECO authorized a drawing just to the commissary transformer. This proved to be much more challenging than expected, however, because the commissary did not have current electrical drawings.

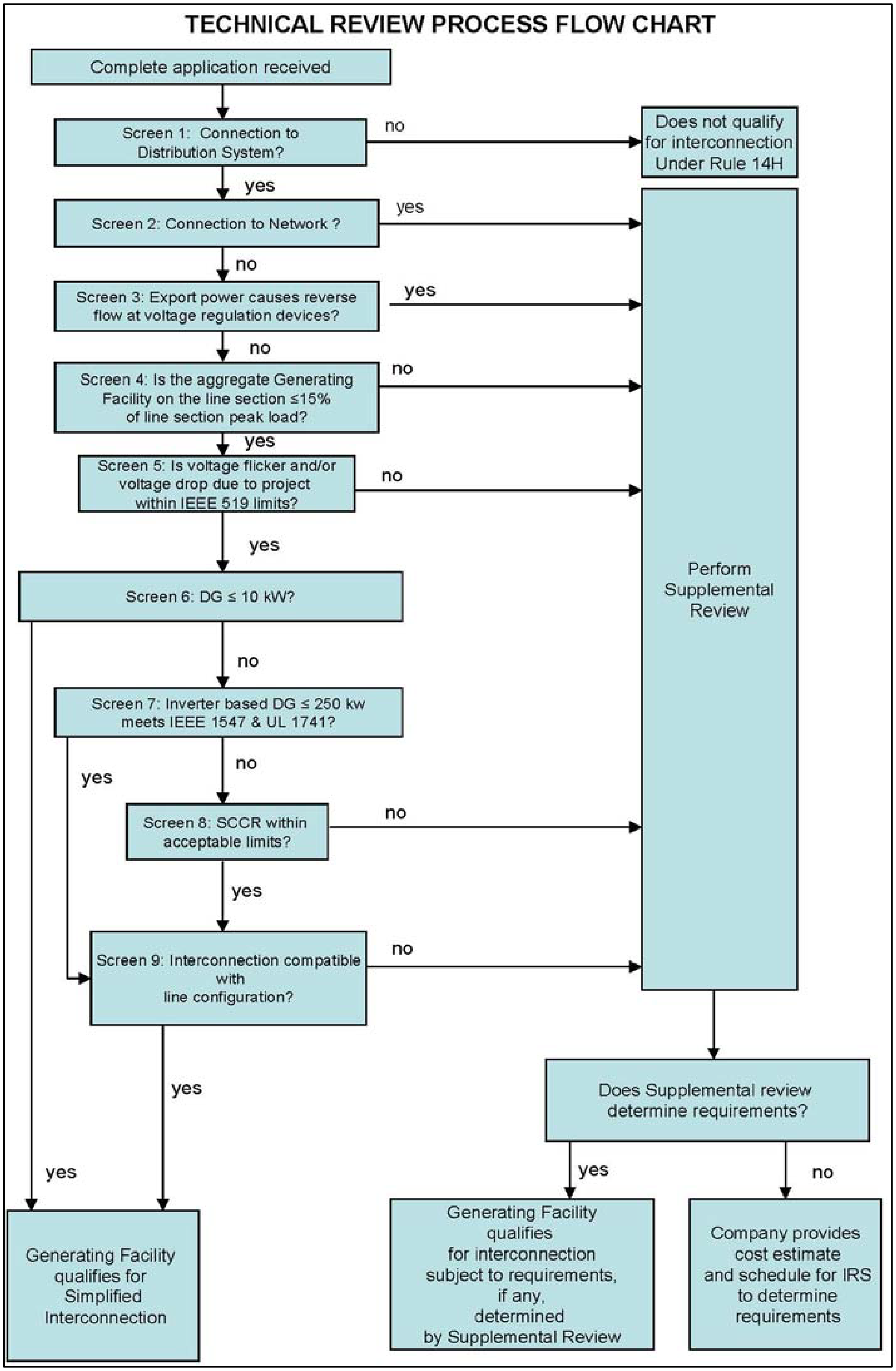

Figure 7. Technical process review chart

Source: Hawaiian Electric Company

- **Commissary drawings.** Hickam Commissary did not have accurate drawings or electrical information for CPC's professional engineer (PE) to review. The commissary had an electrical upgrade for its refrigeration system that included a significant addition to its main switchgear. Neither the commissary nor DeCA Engineering had access to load information for this portion of the electrical system, to which HEDWEC was proposed for interconnection. Appendix B contains a partial drawing of the commissary's electrical distribution system, with comments from CPC's PE regarding load monitoring. A complicating factor in this effort was a revised estimate by CPC that HEDWEC would need 600 amps of available capacity for startup. This figure was driven by the new shredder and briquette maker installed for feedstock processing. With little electrical information available from the commissary and a significantly higher capacity requested for interconnection, CPC coordinated monitoring of the interconnection circuit to determine the existing electrical load and available capacity. This occurred over a 30-day period to meet the requests of CPC's PE.
- **NAVFAC Hawaii review.** It took approximately six months of time for the project team to identify all requirements and provide materials for the interconnection application. The majority of this time was spent in developing electrical drawings. All HECO requirements were believed to have been met when the interconnection application package was submitted to NAVFAC Pacific. Per a relatively new step in this process, NAVFAC Hawaii commenced a technical review of the package, required before submitting to HECO. Upon receipt of the HECO interconnection application form, NAVFAC Hawaii requested a new interconnection application form to be filled out. This form had several differences from the HECO form, most notably requiring the completion of an arc flash analysis for the commissary distribution system. CPC's PE estimated the cost for this analysis at $30,000 and a time frame of 90 days to complete. This is very important lesson learned, as the requirement was not stated in the HECO interconnection application but entails significant time and expense that must be planned into the project. The arc flash analysis was not completed for this project due to its early termination.

6.6 Operation and Maintenance

6.6.1 Factory Acceptance Testing

During factory acceptance testing, CPC determined the level of skill and the time needed for operating HEDWEC would be much higher than previously expected. This was a primary contributing factor in terminating the demonstration. Originally, the expectation was for 10-12 minutes per hour for an operator to feed materials into the system, check for system alarms and occasionally empty the ash container. Issues with material flow and system malfunctions created a need for continuous monitoring of the system by a skilled technician who could troubleshoot recurring issues.

6.7 Training

Little training was actually conducted as part of this demonstration project. The original intent was for CPC to develop a training plan for Hickam Commissary staff who would serve as operators for HEDWEC. With the termination of the project prior to shipping, no training for commissary staff was conducted.

CPC did identify courses needed by its field supervisor prior to commencing the demonstration. These included safety and quality control courses. The courses were not taken by CPC staff, however, due to uncertainty and eventual termination of the field demonstration aboard JBPHH.

7 Commercial Readiness Qualitative Assessment

As discussed in Sections 4 and 5, the current HEDWEC system was determined not to be ideal for application in using the proposed feedstock at the Hickam Commissary. Technical recommendations for improving the performance of the HEDWEC system are discussed in Appendix C. Appendix D is a general assessment of the current technical and institutional barriers challenging the WTE and biomass industry.

The objective of this particular demonstration was to evaluate the performance of a small-scale gasification system using solid waste materials that would be typical at a U.S. Navy installation. While HEDWEC's predecessors have proven to operate successfully using homogeneous biomass feedstocks (e.g., walnut shells) in other applications, these feedstocks are not readily available at most U.S. Navy installations, and therefore, were not relevant to this project. HEDWEC's transition from biomass to other solid waste materials was found to be more difficult than anticipated and is a theme demonstrated by other technologies that have tried to make similar feedstock transitions. NREL could not find any small-scale WTE gasification systems in the United States utilizing true waste material feedstock in a commercial application.

During the course of this project, other technologies were identified that will compete with HEDWEC to establish themselves as the first commercially ready, small-scale gasifier capable of using solid waste materials (ideally unprocessed municipal solid waste).

The first is the Green Energy Machine (GEM), developed by MSW Power in the previously mentioned NSRDEC program, which also developed HEDWEC. Versions of GEM have been demonstrated twice. GEM is reported to have successfully operated using solid waste materials found at forward-operating bases (food waste, paper, cardboard, and plastic) in 2012 at Edwards Air Force Base under the ESTCP.[5] Next, it was demonstrated in 2013 at a correctional institute in Massachusetts using the same types of feedstock (food waste, paper, cardboard, and plastic) from the institute's dining facility. The gasification approach of GEM is similar to HEDWEC in that they both process feedstock by shredding and compressing it, and then feed it into a downdraft gasifier (air flowing down in the same direction as the flow of feedstock) to create syngas. GEM mixes the wet and dry feedstock before shredding, and uses waste heat to drive excess moisture from the feedstock before gasification. GEM uses the syngas differently, however, by feeding it into a diesel engine-generator set to offset diesel fuel consumption. So, GEM requires a continuous (but small) supply of diesel throughout its operation, while HEDWEC uses gasoline only during startup and shutdown. Similar to HEDWEC, GEM consumes 2-3 tons per day of mixed wet and dry waste and produces a net 70 kW electrical output. More information was provided by MSW Power regarding the technology and is provided in Appendix E.

Another small-scale gasification technology has been developed by Sierra Energy and is beginning a demonstration phase at Fort Hunter Liggett under the ESTCP program. Sierra's technology is a gasifier reactor derived from blast furnace technology. It differs from HEDWEC and GEM in that it 1) is an updraft gasifier (oxygen and steam flowing upward, against the flow of feedstock), 2) operates at higher temperatures, creating slag from inert materials instead of ash, 3) consumes more feedstock, approximately 12 tons per day, and 4) is projected to generate more electricity at 400 kW net output. The

[5] The final ESTCP report indicated a 13-year simple payback if the system had been operated at full capacity. The report is available online at: www.serdp.org/Program-Areas/Energy-and-Water/Energy/Distributed-Generation/EW-200932/EW-200932/(language)/eng-US.

creation of slag is an advantage because it essentially cools to stone and captures any hazardous materials introduced with the feedstock within it. The use of syngas is expected to be similar to HEDWEC and GEM in that it will be used as a fuel for a distributed generator, though the exact method is not yet known by NREL. The demonstration is expected to be operating early in 2014.

Many challenges exist in using MSW as feedstock, though most relate to the ability of the system to process the feedstock in a way that makes it suitable for use in downstream gasification and energy conversion processes. The feedstock processing challenges become less of an issue at larger scales because the fluctuations are less prevalent at higher volumes. Also, industry's past focus on large systems has created more options for commercially available feedstock-processing components. As part of an evaluation of WTE gasification systems suitable for a waste stream of 30 tons per day, NREL received responses from nine technology providers claiming to have viable systems. This list is provided in Appendix F.

The BioEnergy Producers Organization maintains a database of non-incineration WTE technologies (gasification, pyrolysis, anaerobic digestion) and has identified over 50 possible technology providers around the world. In 2010, staff from NAVFAC Southwest visited several large-scale gasification WTE operations in Europe, Asia, and Australia to evaluate the state of the industry. The findings from this trip, as well as a broad assessment of the WTE industry, were published by NAVFAC Engineering Services Center in 2011.[6] In addition, several large municipalities, including the City and County of Los Angeles[7] and New York City[8] have conducted evaluations of large-scale, non-incineration WTE technologies and identified several options.

Larger-scale gasification WTE options were not evaluated during this project but appear to be closer to commercial viability for operation in the United States. From past research, NREL has estimated waste streams at DOD installations in a typical range of 10-30 tons per day, with some as high as several hundred tons per day at fleet homeports, such as Norfolk, Virginia, or San Diego, California. There could be a fit in utilizing the larger WTE gasification systems for the larger installation waste streams. While many of the larger-scale systems are moving forward at a faster pace than their small-scale counterparts, NREL is not aware of any true gasification system that is currently operating commercially on raw MSW at any scale in the United States. Because of this, the larger-scale systems will also need further performance validation. For the U.S. Navy, however, demonstration of these larger systems may be cost-prohibitive. At over $6 million per megawatt, procurement of these multi-megawatt systems will cost tens of millions of dollars, which does not include other installation and operating costs associated with a demonstration.

HEDWEC represents the most challenging segment (<10 tons per day) of the challenging WTE gasification industry. Systems like this may be viable for use in expeditionary environments or locations with extraordinarily high disposal costs for solid wastes. Evaluating larger WTE technologies, which are still sized appropriately for DOD installation waste streams, would open up new options but at much higher validation costs.

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[6] For more information, see: Tseng, E. *Initiation Decision Report (IDR): Waste to Clean Energy.* Port Hueneme, California: Naval Facilities Engineering Command, September 20, 2011. http://dpw.lacounty.gov/epd/conversiontechnology/download/NAVFAC_CT_Report.pdf.

[7] Los Angeles County maintains an outreach and educational WTE website at: www.socalconversion.org/.

[8] A copy of the press release regarding New York City's WTE initiatives is available online at: www.nyc.gov/portal/site/nycgov/menuitem.c0935b9a57bb4ef3daf2f1c701c789a0/index.jsp?pageID=mayor_press_release&catID=1194&doc_name=http%3A%2F%2Fwww.nyc.gov%2Fhtml%2Fom%2Fhtml%2F2012a%2Fpr077-12.html&cc=unused1978&rc=1194&ndi=1.

8 Recommended Next Steps

The WTE industry has received a lot of attention in recent years, and the pace of innovation will be rapid. Within DOD, this is particularly true for the small-scale WTE industry for which DOD sees application at forward-operating bases. An example of this focused attention is the formation of the Joint Deployable Waste-to-Energy Working Group, chaired by U.S. Pacific Command. The intention of the group is to develop specifications for small-scale deployable WTE systems. At larger scales, municipalities, such as Los Angeles and New York City, are likely to lead in the implementation of WTE technology. The WTE systems evaluated by these municipalities may be a fit for the largest U.S. Navy installations producing over 100 tons per day.

Given the technology readiness descriptions from the Defense Acquisition Guidebook (DAG), NREL believes the HEDWEC system to have a technology readiness level (TRL) of six. The feedstock processing component of this system is not yet ready for field testing in a representative environment, as determined during the course of this project. That said, the challenges identified during this project may be mitigated by revisiting the equipment selected for processing feedstock. Shredders and densification equipment (the briquette maker in the current version for HEDWEC) are commercial technology. Pairing this equipment with the right selection of feedstock may mitigate issues identified during this project.

The DOD's renewable energy and waste reduction goals, as well as the liabilities of solid waste disposal in expeditionary environments, make it a key beneficiary to the development of small-scale WTE. It is unlikely the technology will advance to higher TRLs without DOD's direct support. Because of the huge potential for the U.S. Navy to benefit from small-scale WTE, NREL recommends a "partner" strategy, per the DAG, for this technology. NREL further recommends the U.S. Navy maintain participation in appropriate DOD working groups and task forces focused on small-scale WTE gasification. This is appropriate for technologies focused on waste streams of 2-30 tons per day, a range that would likely find a suitable volume of solid waste feedstock at nearly all U.S. Navy installations. For larger systems capable of processing 30-300 tons per day, development will likely be led by large municipalities, and NREL recommends the U.S. Navy establish a "watch" strategy to track progress of these technologies, which might be a fit for larger U.S. Navy installations.

Appendix A: Memorandum of Agreement

Alliance/NREL MOA # 12-289

MEMORANDUM OF AGREEMENT
Among
Alliance for Sustainable Energy, LLC
Managing and Operating Contractor for
The National Renewable Energy Laboratory
and
United States Army Research Laboratory
and
United States Army Natick Soldier Research,
Development and Engineering Center
and
Defense Commissary Agency

1. PURPOSE

This Memorandum of Agreement (MOA) documents a mutual agreement among (1) the Alliance for Sustainable Energy, LLC in its capacity as managing and operating contractor for the National Renewable Energy Laboratory (Alliance/NREL); (2) the United States Army Research Laboratory (ARL); (3) the United States Army Natick Soldier Research, Development and Engineering Center (NSRDEC); and (4) the Defense Commissary Agency (DeCA) Hickam Commissary, regarding participant roles and responsibilities, and other terms and conditions pertaining to the design, installation, commissioning, operation and maintenance of an energy saving demonstration of Waste-To-Energy (WTE) technology at the Hickam Commissary at Joint Base Pearl Harbor Hickam (JBPHH) .

2. BACKGROUND

This MOA is intended to clarify roles and responsibilities for work conducted in performance of a WTE demonstration at JBPHH. The demonstration will be a joint collaboration between the Alliance/NREL, ARL, NSRDEC, and DeCA.

The WTE demonstration project will be principally performed and funds furnished under the Interagency Agreement 11-1829, signed and executed between the Department of Energy, Golden Field Office (DoE/GO) and Naval Facilities Engineering Command (NAVFAC), on August 16, 2011. Pursuant to Interagency Agreement 11-1829, the DoE/GO has directed its managing and operating Contractor, Alliance/NREL, to perform the scope of work outlined in the Interagency Agreement. The intent of the Interagency Agreement is to "demonstrate new or leading-edge commercial energy technologies whose subsequent deployment will support Department of Defense (DoD) in meeting its energy efficiency and renewable energy goals while enhancing installation energy security." The WTE demonstration project at Hickam Commissary was recommended by NAVFAC for execution under Interagency Agreement 11-1829 in November 2011.

Collateral to the Interagency Agreement 11-1829, Alliance/NREL entered into Memorandum of Agreement [12-0002] on [date TBD] with Naval Facilities Engineering Command Pacific (NAVFAC PAC) in conjunction with Naval Facilities Engineering Command Hawaii; and Naval Facilities Engineering Command Marianas regarding participant roles and responsibilities, and other terms and conditions pertaining to the design, construction, commissioning, and operating and maintenance of energy saving technologies at DoD facilities in the State of Hawaii and U.S. Territory of Guam (hereafter NAVFAC MOA). Pursuant to the NAVFAC MOA, Alliance NREL retained primary responsibility for leading the technical development of each demonstration, identifying and procuring appropriate technologies, and

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executing and administrating subcontracts necessary for procurement and on-site design and construction of these technologies. NAVFAC retained primary responsibility for coordination of all site related activities, including permitting, technical guidance for integration of demonstration technologies with existing Navy infrastructure, safety, and security.

The system to be demonstrated, referred to as the High Energy Density Waste-to-Energy Convertor (HEDWEC), was developed by the Community Power Corporation (CPC) of Littleton, Colorado, under contract to ARL and NSRDEC. The HEDWEC system was recommended by the U.S. Army for the demonstration based on an evaluation of various WTE technologies, concluding this system was among the most technically and economically viable systems currently available.

The DeCA Hickam Commissary was selected as the location for demonstrating the benefits of ARLs HEDWEC system. This site was selected because the commissary's volume and type of waste is suited to HEDWEC requirements, the commissary has appropriate physical space to accommodate the HEDWEC system and initial estimates indicated the technology, as demonstrated, would yield appreciable cost and energy savings benefits to the commissary.

The WTE demonstration project will be a coordinated effort among the technology and facility providers, ARL, NSRDEC and DeCA respectively, Alliance/NREL and its subcontractors, the demonstration's primary executing party, and NAVFAC, the demonstration's funding agency and steward of JBPHH. The intent of this MOA is to clarify and memorialize the roles, responsibilities, and other specific elements of agreement of this joint demonstration, with the goal of ensuring maximum technical benefit to DoD while ensuring quality workmanship, and the health and safety of all related personnel and property.

In instances when this MOA is in conflict with the terms and conditions of the referenced Interagency Agreement, the Interagency Agreement takes precedence. In instances when this MOA is in conflict with the terms and conditions of the NAVFAC MOA, the NAVFAC MOA takes precedence.

3. GENERAL TERMS OF AGREEMENT

(A) Stop-Work Authority

DeCA has the right to stop any project work, as performed or directly impacting its property or personnel, as necessary to ensure health and safety, or to maintain conformance with security procedures and/or protocols.

DeCA has the right to request remedy of any noise pollution or similar issue presenting significant negative impact on the personnel or customers of the commissary or local neighborhood. If such remedy is not provided by Alliance/NREL through its subcontractor within two business day's notice, DeCA has the right to stop project work until such issue is remedied.

(B) Disposition of Equipment

(i) Post demonstration, Alliance/NREL will remove the HEDWEC system from the DeCA Hickam Commissary and restore site property to its original operating condition. Total cost of work performed for facility restoration and disposition of equipment by Alliance/NREL is not expected to exceed $150,000.

(ii) Six months prior to the end of the WTE demonstration project, and if ARL remains the owner of record for the HEDWEC system, ARL will notify Alliance/NREL of the site for relocation or salvage of the HEDWEC system. If ownership of the system has been transferred prior to this time, NREL will coordinate with the new owner to determine the destination of the system upon conclusion of the demonstration period at the DeCA Hickam Commissary.

(C) Public Affairs and Press Releases

All parties agree to notify each other, in advance, of press releases or other high profile public affairs activities related to this demonstration. Each party will make reasonable efforts to ensure all parties are appropriately recognized for their participation and contributions to this demonstration. NAVFAC, as the funding agency of this demonstration, retains the right to review, and must approve any such public affairs activity directly linked to the demonstration.

(D) Knowledge Sharing

(i) Alliance/NREL will share general results, conclusions, and lessons learned of this demonstration with ARL, NSRDEC, and DeCA. ARL, NSRDEC, and DeCA will be given the opportunity to review these results and provide comment to Alliance/NREL.

(ii) ARL, NSRDEC, and DeCA will support Alliance/NREL in its evaluation of WTE technology and estimating the potential impact/benefit to DoD installation energy. Specific support may include sharing future Army WTE results, working collaboratively to evaluate technology trends, or identifying other commissary locations which would benefit from WTE applications.

(iii) DeCA will provide Alliance/NREL with site information from the Hickam Commissary, as necessary to establish pre-demonstration "baseline" waste streams and associated costs/fees to determine the net benefits of the demonstration.

(iv) ARL, as the owner of the HEDWEC system, and NSRDEC agree to share with Alliance/NREL and its subcontractor, technical materials related to development of the HEDWEC system, such as emissions data, CAD drawings, user manuals, etc., as relevant and useful to the modification, shipment, commissioning, and demonstration of the HEDWEC system.

(E) General Handling of the HEDWEC System

ARL, as the owner of the HEDWEC system, agrees to allow the HEDWEC system to be used as part of this WTE demonstration project.

Specific to this agreement:

(i) ARL, as the owner of the HEDWEC system, grants Alliance/NREL through its subcontractor the right to:

(a) Ship the HEDWEC system to the DeCA Hickam Commissary from CPC facilities in Colorado.

(b) Modify the HEDWEC system as necessary to meet the demonstration's specific performance needs and facility requirements.

(c) Operate and maintain the HEDWEC system throughout the demonstration using solid waste feedstocks from the DeCA Hickam Commissary.

(d) Ship the HEDWEC system, post-demonstration, to a designated location for salvage or future commissioning.

(ii) ARL, as the owner of the HEDWEC system, recognizes the inherent risk of damage that may occur to the HEDWEC system during design modification, shipment, operation, or demonstration. ARL will not hold Alliance/NREL and its subcontractor and DeCA liable for any damages that may occur to the HEDWCEC system during modification, shipping, operation, and demonstration of the HEDWEC system under the WTE demonstration project. Notwithstanding, Alliance/NREL through its subcontractor, will insure the HEDWEC system for damages or loss during shipment for up to $5 million. Alliance/NREL through its subcontractor will not insure the HEDWEC system during the time the HEDWEC system is located on DoD property, located on the CPC facilities in Colorado, or located at the final destination specified by ARL or the new owner at the conclusion of the demonstration period.

(F) Access to Facilities and Feedstocks at the DeCA Hickam Commissary

(i) DeCA, as managing agency of the Hickam Commissary, agrees to allow commissary facilities and real estate to be used as part of this WTE demonstration project. Facilities and real estate to be used will be designated and agreed upon by DeCA prior to shipping of the HEDWEC system from the manufacturer's facility in Littleton, CO.

(ii) DeCA agrees to allow the WTE demonstration project to have full access and use of all cardboard waste materials generated by the Hickam Commissary throughout the demonstration. The period of access to said waste materials will not exceed one year in duration and will begin upon completion of commission of the HEDWEC system.

(iii) DeCA agrees to allow the WTE demonstration project to have access to other waste materials, such as wet food waste, cartons, and some plastics generated by the Hickam Commissary throughout the demonstration. The period of access to said waste materials will not exceed on year in duration.

(iv) DeCA agrees to retain responsibility for handling and disposal of any excess waste materials not used by the WTE demonstration project. This includes waste ash produced by the WTE system after 3rd party testing verifies the ash to be non-hazardous material (test to be coordinated by NAVFAC Hawaii).

(G) Intellectual Property and Modification to the HEDWEC System

Alliance/NREL, ARL, and NSRDEC agree to continue intellectual property ownership and rights derived from modifications of the HEDWEC system under this WTE demonstration project aligned with the same terms and conditions set forth in the ARL and NSRDEC original contracts for the development of the HEDWEC system (Contracts Numbered W911NF-09-C-0029 and W9-

11QY-12-C-0021). The planned modifications of the HEDWEC system are assumed to be sufficiently minor and without appreciable value.

4. WTE DEMONSTRATION ROLES AND RESPONSIBILITIES

(A) Alliance/NREL

(I) Design Modifications to the HEDWEC System

Alliance/NREL through its subcontractor will have responsibility for modifying the HEDWEC system, as necessary, for proper operation during demonstration at the DeCA Hickam Commissary.

(II) Installation and Commissioning of the HEDWEC System

Alliance/NREL through its subcontractor will have responsibility for.

(a) Strictly adhering to on-site health, safety, and security procedures directed by NAVFAC and DeCA.

(b) Shipping the HEDWEC system to the DeCA Hickam Commissary.

(c) Assembling the HEDWEC system and performing some elements of minor construction, such as needed for electrical interfacing of the system with the facility.

(d) Coordinating with NAVFAC and the Hawaiian Electric Company (HECO) to complete the Standard Interconnection Agreement (SIA) and support NAVFAC in receiving HECO's approval to interconnect the HEDWEC system to the Hickam Commissary electrical system.

(e) Commissioning of the HEDWEC system, including initial testing and verification of proper operation.

(III) Operation and Maintenance of the HEDWEC System

Alliance/NREL through its subcontractor will have responsibility for:

(a) Strictly adhering to on-site health, safety, and security procedures directed by NAVFAC and DeCA.

(b) Providing trained personnel for operation and maintenance of the HEDWEC system in accordance with a schedule to be determined with DeCA.

(c) Training DeCA staff (at no cost to DeCA) to support operation and maintenance of the HEDWEC system, including providing a user manual and quick reference job aid for real-time troubleshooting.

(B) Defense Commissary Agency

(I) Design Modifications to the HEDWEC System

DeCA will be given the opportunity for reviewing the final design and performance of the HEDWEC system prior to shipment from Littleton, Colorado (where the HEDWEC system currently resides) to the DeCA Hickam Commissary.

(II) Installation and Commissioning of the HEDWEC System

(a) DeCA will have responsibility for safety, quality control, and coordination of all on-site activities of the HEDWEC system installation, as it relates to the personal safety and technical impacts of the DeCA Hickam Commissary, as necessary and in complementary extension to NAVFAC's role as steward of JBPHH.

(b) DeCA will support development of a Standard Interconnection Agreement (SIA) with HECO, in coordination with NAVFAC and Alliance/NREL, as necessary for proper installation of the HEDWEC system.

(c) DeCA will have responsibility for installation of any equipment, such as dehydrators, as necessary for proper preparation of DeCA Hickam Commissary waste streams for use by the HEDWEC system.

(III) Operation and Maintenance of the HEDWEC System

(a) DeCA will have responsibility for on-site safety, quality control, and coordination of all on-site activities of the HEDWEC system operation and maintenance, as it relates to the personal safety and technical impacts of the Hickam Commissary, as necessary, and in complementary extension to NAVFAC's role as steward of JBPHH.

(b) DeCA will provide staff to operate the HEDWEC system according to a schedule to be determined with Alliance/NREL and its contractor, CPC.

5. PRIMARY POINTS OF CONTACT

For the NSRDEC:
US Army Natick Soldier Research, Development and Engineering Center
Attn: RDNS-XXX (Leigh Knowlton)
15 Kansas Street
Natick, MA 01760
Phone: 508-233-5183
E-mail: leigh.a.knowlton.civ@mail.mil

For ARL:
Robert Mantz, Ph.D.
Program Manager, Electrochemistry
U.S. Army Research Office
E-mail: Robert.a.mantz.civ@mail.mil

For Alliance/NREL:

Jerry Davis
Senior Engineer
NREL Deployment & Market Transformation
Phone: 303-275-3199
E-mail: jerry.davis@nrel.gov

For DeCA:

Mark Leeper
Environmental Engineer
Solid Waste Integrated Management & Environmental Management
Defense Commissary Agency
Phone: 804-734-8000, ext 86276
E-mail: mark.leeper@deca.mil

6. EFFECTIVE DATE, AMENDMENT, AND TERMINATION

This MOA becomes effective on the date of the last signature. The parties to this MOA will meet at the request of any party to review the provisions of this MOA. Any necessary additions, deletions or changes shall be made in writing and signed by the signatories to this MOA or their designated representatives.

The term of this MOA is coterminous with the term of the Interagency Agreement between the Department of Energy/Golden Field Office and the Naval Facilities Engineering Command.

This MOA will remain in effect until superseded or earlier terminated by written mutual agreement. Any party wishing to terminate this MOA shall submit a written notification to all the other parties with sufficient notice to prevent unreasonable disruption to the WTE demonstration project.

7. APPROVAL

The Parties hereby confirm this MEMORANDUM OF AGREEMENT and acknowledge their agreement by the following signatures.

Bobi Garrett

BOBI GARRETT
Deputy Laboratory Director
Alliance for Sustainable Energy, LLC
Managing and operating contractor for
National Renewable Energy Laboratory

DATE 10-Sep-2012

MICHAEL J. DOWLING
Deputy Director
Defense Commissary Agency

DATE August 10, 2012

ROBERT MANTZ, Ph.D.
Program Manager, Electrochemistry
U.S. Army Research Office
Army Research Laboratory

DATE 14 Aug 2012

JOHN P. OBUSEK, Sc.D.
Director
Natick Soldier Research Development and Engineering Center

DATE 9-7-12

Appendix B: High-Energy Densification Waste-to-Energy Conversion Interconnection Drawings

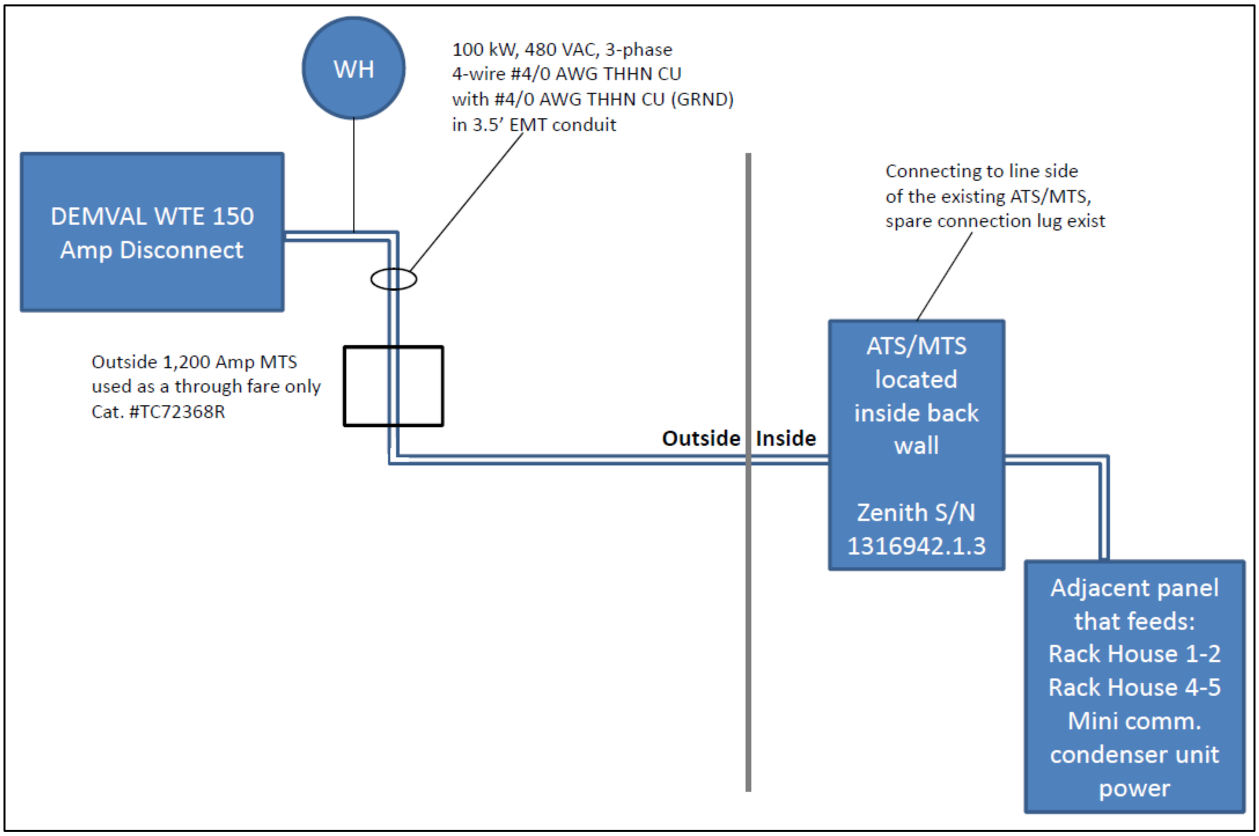

Figure AB-1. Defense Commissary Agency Engineering drawing showing interconnection panel

Source: Defense Commissary Agency

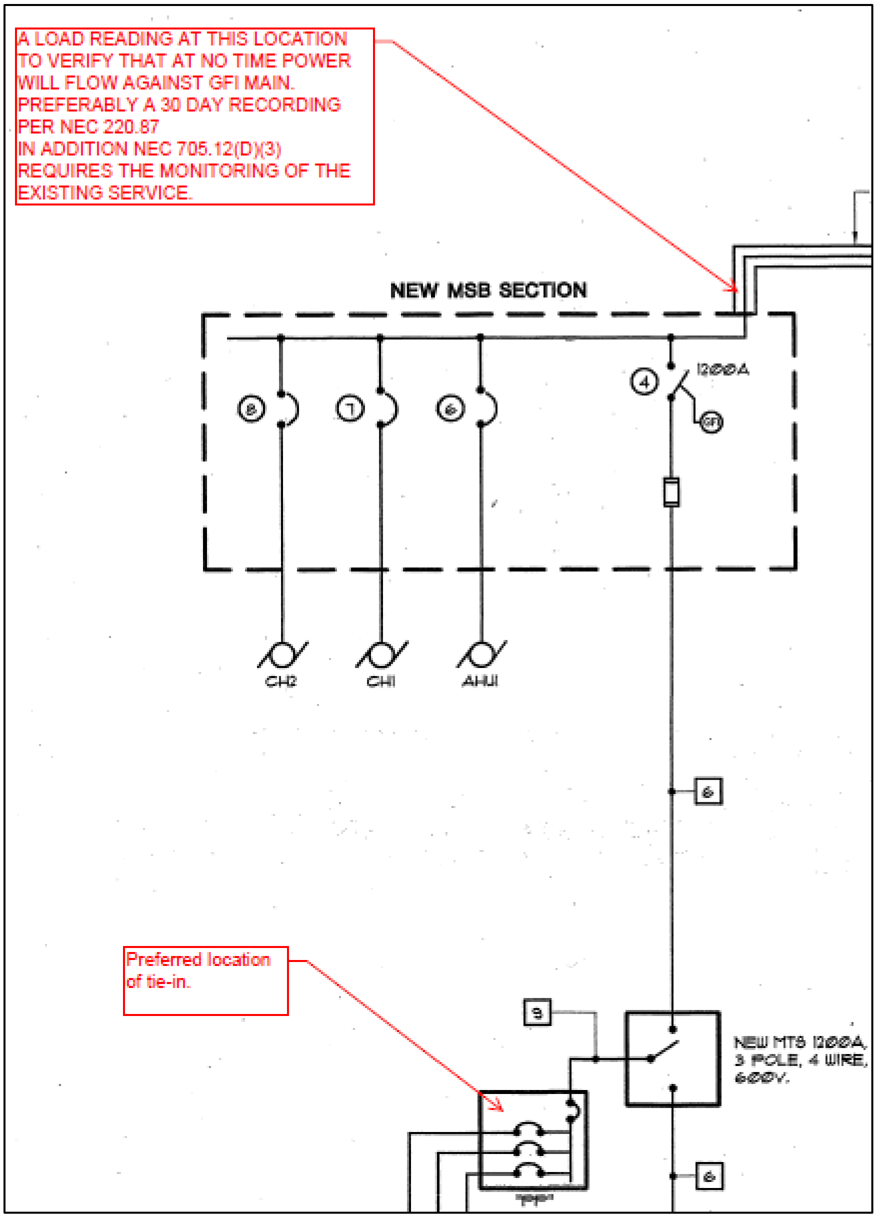

Figure AB-2. Portion of the commissary electrical system proposed for interconnection (with CPC comments)

Source: Defense Commissary Agency

Appendix C: Options to Improve the Commercial Viability of High-Energy Densification Waste-to-Energy Conversion

Ash Issues

High-energy densification waste-to-energy conversion (HEDWEC) technology developers would need to address cardboard gasification issues to increase its commercial readiness for retail and grocery store applications. As reported in Section 4, the feedstock for HEDWEC contained about 3.78% inert materials, which results in ash. This ash level is higher than historically successful feedstocks, such as walnut shells or a high-quality pulpwood feed. The ash level is, however, below the range expected for many residue feeds, as shown in Table 13.

Table 13. Ash Levels for Various Biomass Samples

Biomass Sample	Ash %
Refuse-derived fuel, Tacoma	26.13
Wood, yard waste	20.37
Bark	9.37
Almond hulls	5.78
Shredded currency	5.47
Peanut hulls	5.89
Urban wood waste	2.50
Furniture waste	3.61
Mixed paper waste	8.33
Paper	6.0
Orange peel and seeds	4.55

The ash content of the broken pallets was not reported. Assuming an ash content of 5% for the pallets, the ash content is estimated below.

Table 14. Ash Content for Various Components of Commissary Feedstock

Component	Wt %, dry	Ash %
Dry cardboard	69	2.1
Pallets	15	5.0
Waxed cardboard	8	3.5
Dehydrated organics	8	1.7
Sample average		**2.6**

The ash content should still be reasonable and not cause gasifier problems. The ash removal system does need to be designed to handle a higher level of ash. The reported formation of clinkers is likely related to ash composition and higher operating temperatures (as discussed in Section 4), not ash level. Ash composition analysis was not performed, so definitive comments cannot be made. However, literature values for ash composition of paper/cardboard show widely varying ranges of silica and alkaline materials, such as calcium and potassium. The phase diagrams for silicon-calcium-potassium systems are very complex, and it is well known that these mixtures may result in very low ash sintering/fusion temperatures and contribute to clinker formation. If the actual sintering problem is alkali related, there are additives (e.g., magnesia) that can be added to the feed to raise the sintering temperature.

If gasifier performance relative to earlier feedstocks, such as walnut shells, had remained constant, then char yield should have only increased by 2%-3%. Instead it has increased by a factor of four, from 4% to about 16%. This issue was believed to be caused by complications from increased briquette size, as discussed in Section 4. Potential fixes might involve smaller diameter briquettes with lower specific gravity (less densification).

Material Flow

The material flow through the HEDWEC system created issues in two primary ways. First, the briquettes did not flow through the gasifier in the same way as biomass feedstocks previously used in similar systems. This, and the different constituents of the feedstock, created instability and high temperatures. To mitigate high temperatures, the feed rate into the gasifier was lowered. The side effect of this was lowered production of syngas, which resulted in a lower volume of fuel available for the engines and lower power generation.

The second issue associated with the flow of feedstocks was the formation of clinkers, which was attributed to a relatively low melting point of the ash contained in the cardboard. The residence time of materials in the gasifier was decreased by increasing mechanical agitation to move material through more rapidly. This placed additional mechanical stresses on components' welds and resulted in repeated weld failures. Modifying the briquetting process to improve gas flow through the gasifier is likely to reduce the frequency of mechanical shaking required. That, along with changes in shaker welding, should improve shaker operation.

Emissions Controls

The sulfur mitigation system was a prototype system and created issues due to pressure buildup in the system, which affected operations of the internal combustion engines. Community Power Corporation (CPC) designed a new system for sulfur mitigation, using four drums instead of two, in its plans for the next version of HEDWEC. This will allow for higher throughput of syngas through the sulfur mitigation system. CPC also has more heavily insulated containers and more precise heating of the sulfur mitigation system to help reduce the condensation in the system that was experienced during HEDWEC testing.

Appendix D: Biomass/Waste-to-Energy Industry Assessment

An overview of sector barriers to gasification development and commercialization is examined below. The discussion begins with an analysis of technology barriers that must be overcome to achieve successful technology pathways leading to the commercialization of biomass conversion and feedstock technologies. Next, an examination of institutional barriers is presented that encompasses the underlying policies, regulations, market development, and education needed to ensure the success of gasification applications, such as combined heat and power (CHP).

Technology Barriers

Biomass is a very desirable fuel and feedstock because it is renewable, sustainable, and clean (generally does not contain many pollutant-forming species, such as sulfur, nitrogen, and heavy metals). Biomass is also widely available throughout the world and amenable to conversion to a wide variety of useful forms. However, biomass, more so than virtually any other fuel or energy source, varies considerably in its elemental composition, energy content, and physical characteristics. Biomass includes woody and herbaceous materials and residues, as well as the biogenic fraction of waste materials, such as municipal solid waste, cardboard, paper, and food wastes. It also contains species, such as alkali metals that, while not considered pollutants, often cause mechanical problems in conversion systems, such as deposition and corrosion of heat transfer surfaces and mechanical system internals. As such, it presents considerable technical challenges at virtually all phases of conversion to useful energy forms and products. These technical challenges were evaluated by the U.S. Department of Energy (DOE) as part of development of a biopower technical strategy,[9] and are reproduced below.

Technical challenges and barriers to developing and deploying small-scale biotechnology systems are shown in Table 15. The top priorities were identified as fuel and feedstock quality, cost, and availability; finding users for cogenerated waste heat; and the lack of demonstrated, cost-effective, small-scale gasifiers.

- **Waste heat utilization**. The most critical barrier is the difficulty in finding users for cogenerated heat in close proximity to the source. Finding a use for waste heat is needed to justify the implementation of more efficient CHP systems. The infrastructure for utilizing (transporting) heat may also be lacking, and it may be difficult to integrate waste heat with existing systems.
- **Fuel quality and handling**. The high cost and uncertain availability of biomass feedstocks are challenging for small-scale, as well as large-scale users. There is still significant uncertainty about how to handle biomass feedstocks (preprocess, store, convey), and how to ensure that a consistent quality of supply is maintainable year-round.
- **Small-scale gasification**. Gasification systems for use at smaller scales are not yet commercially available. While this technology has significant potential, new scalable designs will be needed to integrate with the unique requirements of small-scale power. Emissions data for operating gasifiers is lacking, which creates concerns for environmental compliance and permitting. In addition, current synthesis gas cleanup technologies are insufficient, particularly with regard to

[9] *Biopower Technical Strategy Workshop Summary Report.* Washington, D.C.: U.S. Department of Energy, Energy Efficiency & Renewable Energy, 2010. www1.eere.energy.gov/bioenergy/pdfs/biopower_workshop_report_december_2010.pdf.

organics, which limits prediction of system performance and operation and may also impact emissions.

- **Technology development/demonstration at small scale**. The lack of continuously operating demonstration plants for new technologies in the United States, especially for smaller-scale systems, increases the technical risk of new systems. There is also limited experience with moderately sized gas turbines, which might be utilized in these applications. Limited understanding of ash content and production of aerosols that cause corrosion is another technical issue that requires resolution.
- **Fuel flexibility**. Small systems are typically developed for one feed or one class of feed with a small range of physical and chemical properties. While there is good understanding of the requirement to tailor certain physical properties (e.g., size, density, angle of repose, etc.) to ensure correct feeding and gasifier operation, there is less understanding of other physical properties, such as permeability and ash content, that may impact gasifier operating characteristics, including effective oxygen/biomass stoichiometry and slagging behavior. Strategies are needed to further evaluate the impact of densification on feed properties and gasifier behavior, to evaluate the possible use of additives to control fouling/slagging, and to develop simple real-time, online measurements methods to permit measurements of contaminants as part of flexible fuel operations (e.g., near infrared analysis of ash composition).
- **Waste use and discharge**. Reduction of water usage and wastewater discharge is a challenge for small-scale biopower systems. One issue is that the lower-cost generating options use comparatively high amounts of water. Strategies are needed for water reuse and overall reduction in water requirements.
- **Environmental controls**. A priority challenge is the need for cost-effective air emission controls to meet ever-increasing regulatory emission limits, particularly for new systems (e.g., gasification). The high cost of pollution abatement and controls and the need to meet increasingly stringent (and potentially uncertain) standards make it more difficult to justify investment in small-scale power.

Table 15. Technical Barriers and Challenges for Smaller-Scale Systems[a]

Waste Heat Utilization	
High priority	Lack of customer for waste heat generated by CHP in close proximity to the source
Medium priority	Difficult integration of adsorption/absorption chillers with CHP
Lower priority	Lack of infrastructure for using heat from CHP
Fuel Quality and Handling	
High priority	High cost and availability of biomass feedstock
Medium priority	Feedstock handling (conditioning, preprocessing, collection, conveyance to boiler)
Lower priority	Inconsistent quality of fuel supply Ability to identify/understand fuel type and treatment needed (wet/dry, chips/grinding) Lack of feedstock standardization
Small-Scale Gasification	
High priority	Lack of cost-effective small gasifiers
Medium priority	Lack of good emissions data for gasification systems Inefficient gasification clean up, particularly for organics
Lower priority	Concerns over impact of syngas quality on internal combustion engines, boilers, and pipelines Lack of reliable, cost-effective system for syngas clean up Tar and particulate control technologies do not scale down easily or cost-effectively
Technology Development/Demonstration at Small Scale	
High priority	Lack of continuously operating demonstration plants for new technologies in the U.S. Ash and aerosol issues, including slagging and fouling Lack of experience with moderate-sized gas turbines
Medium priority	Uncertainty of overall system availability and impact on profitability Need for new “clean” high-efficiency technologies for CHP applications (e.g., low nitrogen oxide and sulfur oxide, pre-vaporized liquid biofuel combustion) Lack of cost-effective downstream unit operations for anaerobic digestion Lack of cost-effective, scaled-down reactor designs Lack of technological flexibility to adjust to natural fuel quality
Lower priority	Insufficient data/understanding of combusting, gasifying, and feeding lignin residuals from ethanol facilities and the difference from raw biomass (e.g., particle size increase contaminants)
Water Use and Discharge	

Medium priority	Reduction of water usage and wastewater discharge Excessive water use with low-cost generating options	
Lower priority	"Mining the Pressate" (e.g., nitrogen) Handling effluent remediation (e.g., to a wastewater treatment plant for reuse)	
Environmental Controls		
High priority	Economic air emission controls to meet ever increasing regulatory emission limits	
Lower priority	Lack of emission controls to meet requirements in non-attainment areas	

[a] Unless otherwise noted, barriers and priority activities are generally associated with CHP applications.

Institutional Barriers

The commercial development of renewable energy technologies can be impeded by barriers that do not involve technical aspects of a given technology. Technological progress that improves performance or increases system efficiencies can open doors to deployment; however, market issues ultimately depend on overcoming the institutional challenges these technologies will face. It can be far more difficult to put into place the necessary institutional mechanisms that will drive these commercial efforts. The keys to the successful implementation of energy technologies, and in particular, biopower technologies, are overcoming issues that can be categorized as the following:

- Regulatory
- Financial
- Infrastructural
- Perceptual.

These categories were first developed in *The Potential of Renewable Energy: An Interlaboratory White Paper*, by INEEL et al, prepared for DOE in March 1990.

Additional non-technical barriers identified by DOE in 2010 include:

- Policy
- Risk management
- Scalability.

Regulatory

Through the regulatory process, governments direct activities in the broader societal interest. Regulations usually pertain to two broad issues: (1) markets, and (2) health, safety, and environmental protection. Regulatory factors can create technology development opportunities that would not exist in unregulated environments. Within the United States, for example, the passage of the Public Utilities Regulatory Policy Act (PURPA) in 1978 required electric utilities to buy power from independent power producers and was designed to encourage small-scale electric power production from renewables, cogeneration, and energy conservation. This law has been considered by some analysts to be "the single most important spur to creation of a commercial renewable power market ... ."[10] During the 1980s, biomass power capacity rapidly expanded as a result of laws mandating that utilities purchase power from suppliers under contracts based on avoided power generation costs (as specified under PURPA). These contractual prices were substantially higher than current wholesale power prices, and permitted biomass projects to be financed and operated at a profit.

In the 1990s, changes in the electric power industry due to massive restructuring resulted in lower avoided costs, and as present contracts are concluded, this biomass generation could be at risk. The closing of high-cost power plants and the introduction of high-efficiency natural gas facilities are also putting considerable downward pressure on electricity prices.

Although this situation presents challenges, the restructuring of the power industry is also providing new opportunities for biopower. Markets are developing for "green power," where electricity from selected generation sources can be sold at higher prices (typically 1-2 cents per kilowatt-hour). Through consumer choice, green markets offer opportunities to expand the use and future development of renewable technologies. Increased biopower is also being encouraged through renewable portfolio standards and other incentives established by state regulatory agencies.[11] These standards require utilities to provide certain percentages of power, typically 5%-10%, from renewable sources. Despite this progress, state and market incentives for biopower only exist in certain states, and federal, state, and municipal policies and definitions with regard to green power and qualifying biopower technologies (e.g., some states and municipalities only include landfill gas) need to be harmonized to create a robust portfolio standard. This could lead to increased acceptance of biopower and the resulting grassroots demand for increased deployment.

In the United States today, there exists a very dynamic environment that involves the regulation of emissions. The regulations that control the release of oxides of sulfur (SO_x) and nitrogen (NO_x) are rapidly tightening under a variety of cap and trading schemes now being proposed for pollutants, particularly for NO_x. These regulations may work as a potential boon to biopower because biopower technologies, such as cofiring, improve utilities' emissions profiles in SO_x and NO_x. However, in some instances, the U.S. Environmental Protection Agency regulations and policies discourage existing coal plants from cofiring by opening them up to new source reviews if they modify their existing plants to accept biomass. There is a need to reduce regulatory uncertainty related to new source reviews and emissions. This is a critical issue because there are more than 200 companies outside the wood products and food industries that generate biopower in the United States. Where power producers have access to very low-cost biomass supplies, cofiring is an attractive option for power companies to save fuel costs and earn emissions credits.

In the future, the potential regulation of greenhouse gas emissions may result in a particular advantage for the carbon dioxide neutral biopower technology.

Financial

Financial constraints pertain to the availability and cost of a project and to the overall financial attractiveness of renewable energy technologies. Capital markets generally perceive the deployment of emerging technologies as involving more risk than established technologies. The higher the risk, the

[10] Silverman, M. and Worthman, S. "The Future of Renewable Energy Industries." *The Electricity Journal,* March 1995.
[11] For more information, see the Database of State Incentives for Renewables & Efficiency: www.dsireusa.org/.

higher the rate of return demanded on capital, thus impacting the rate of investment in these new, emerging technologies.

Tax incentives for renewable energy technologies have been passed by Congress to promote the deployment of renewable energy generation. Federal incentives include the Modified Accelerated Cost-Recovery System for certain property, the business energy investment tax credit, the renewable electricity production tax credit, and interconnection standards for small generators.

Infrastructural

Infrastructure is a general term for the entire energy service production and delivery system. It involves decisions made by a broad range of players, including consumers; energy service providers such as utilities; fuel suppliers; and others. The nature of the biomass technology requires the need for infrastructure for the supply of feedstocks and for distributing products.

Unlike fossil fuels, such as coal and natural gas, which have a highly developed and sophisticated infrastructure in the United States via railroad transportation and pipelines, a similar infrastructure does not currently exist for biofuels.

At this time, the biomass supplies are dominated by low-cost residue streams. The residue stream consists of materials derived from self-generated residues by industries that process biomass for fiber or food uses (such as paper mills, lumber mills, sugar mills, etc.) or other economic activities (agriculture, urban construction and demolition, rate of waste generation, etc.). The quality, quantity, and cost of these resources continually vary in response to economic growth rates, discount factors, and regulation, (e.g., the regulation of landfill activity and policies toward recycling).

Another problem associated with the technology infrastructure concerns the 50-mile supply radius for the economic collection and transportation of fuel. In the future, the development of new technology that allows for the conversion of biomass into a liquid may allow for the feedstock to be transported more cost-effectively at greater distances. In the meantime, small modular systems are being looked at for distributed applications. The systems are less than 5 megawatts and can be transported directly to the feedstock production site.

Perceptual

There is a lack of familiarity with biomass power technologies by the public, government, and industry decision-makers. Many people still do not know what the term “biomass” means, let alone understand some of the benefits and new technology developments associated with biomass. In addition, some environmental groups do not view biomass as a “green” technology. Awareness of biomass tends to be associated with liquid fuels, wood stoves, and concerns over emissions with the combustion of wood than with biomass as an alternative energy technology. Less is known by the public and others about the low emissions, high efficiency, and environmental benefits offered with state-of-the-art biomass power systems. There are also concerns related to harvesting of trees as well as the need for sustainable supply. These unfavorable perceptions translate into financial costs and risks to any biomass project. Only with considerable education efforts and demonstration that environmental concerns are being accounted for can the risks of nonacceptance be overcome.

WTE systems also suffer from a link in some people’s minds to the waste incinerators used in previous decades. While modern WTE systems include multiple advanced technologies to control emissions, the connection to previous, environmentally questionable solid-waste incinerators is a barrier to many WTE projects in the United States and elsewhere.[12]

Additional Barriers

Nontechnical barriers identified by DOE in the areas of policy, risk management, and economics as reported are given below.

Policy

Policy issues are generally related to a lack of uniform legislation to support deployment of small-scale biomass power plants. A key issue is uncertainty over carbon legislation and production incentives (renewable energy credits). A key barrier is the shortage of consistent regulations for small-scale biomass systems. Large regulatory risks when combined with financial risk can stifle innovation, as well as investment.

Risk Management

It is often challenging to make the business case for small-scale systems and clear financial hurdles, which creates high risk and makes investment in these systems less appealing. Business models, a long-term outlook, and market data for biopower systems, particularly on a small scale, are inadequate, which reduces attractiveness as an investment. Adequate price supports for "green" electricity, which could reduce risk, are lacking. A contributing factor is the lack of investors who understand and appreciate the benefits of CHP for small scale applications. Return on investment for an energy project is often viewed differently than other projects (e.g., higher risk factors) and may be harder to justify, especially if energy prices are low.

System Economics

The limiting and high cost structure for small-scale systems was identified as one of the most important barriers. In most utility markets, small-scale CHP may have much lower cost-effectiveness than large utilities. Capital expenses and operating costs may also be higher per megawatt.

[12] The Clean Air Act of 1970 and subsequent amendments in 1990 established a regulatory framework that has resulted in significantly lower air emissions from modern combustion-based WTE facilities than their predecessors.

Appendix E: Small-Scale Waste-to-Energy Case Study

In assessing the state of the small-scale gasification industry, NREL became aware of another technology provider that had conducted recent demonstrations, MSW Power. MSW Power has developed a system called the Green Energy Machine (GEM) and shared analyses of GEM's performance in recent demonstrations. GEM operates similarly to HEDWEC, but instead of using the syngas to fire an internal combustion engine, it feeds the syngas into a diesel engine to offset diesel fuel consumption.

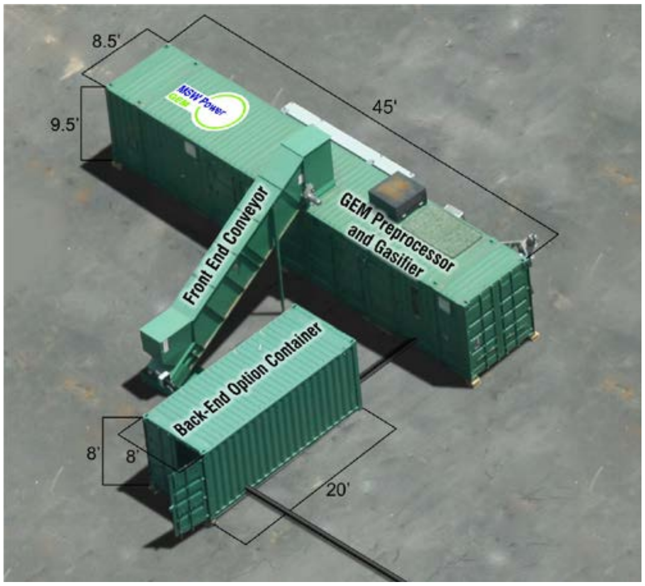

Figure AE-1. Aerial view of GEM system

Source: MSW Power

Demonstration History

The GEM case study included the following demonstrations:

- Edwards Air Force Base system in operation from June 20, 2012 to Sept. 22, 2012
- Second generation GEM operating in Plymouth, Massachusetts, Dec. 3, 2012 to June 22, 2013.

Table 16 is a summary of GEM performance expectations developed after the completion of recent field tests. Table 17 provides the actual GEM performance results observed during these field tests.

Table 16. Expected GEM Performance

Parameter	Expected Performance
Run time (annual)	7,488
Waste processed (tons/day)	3
Electricity generated (kWh gross)	90-100
Heat generated (MBtu/hr) with genset	.614
Heat generated (MBtu/hr) with boiler	1.2
Ash disposed (%)	5.6

Source: MSW Power

Table 17. Summary of Operating History of GEM Systems

Parameter	Combined Performance Data
Run time (hours)	5,444
Waste processed (tons)	525
Electricity generated (kWh)	167 k
Heat generated (MBtu)	676.9 M
Ash disposed (%)	5.6

Source: MSW Power

Feedstock Used

Table 18 provides an overview of the feedstock used during various stages of testing for GEM.

Table 18. Feedstock Testing Summary[a]

Incoming Composition						Calorimetric Value (pellets at 10% moisture)	
Waste Source	**Paper/Cardboard**	**Plastic**	**Food**	**Other**	**Moisture Content**	**Btu/lb**	**Bulk Density (lbs/ft^3)**
R&D testing	42%	16%	44%	0%	22%	8,990	32
Coffee roaster	28%	21%	50%	1%	15%	11,190	33
State college	41%	29%	27%	3%	31%	8,133	27
State prison	23%	22%	46%	9%	52%	9,572	27
Car manufacturer	33%	28%	31%	4%	27%	8,854	29
Edwards AFB	29%	18%	30%	23%	47%	9,178	30

Source: MSW Power

[a] The values presented are averages. Variations occur with every batch of waste. Lowest moisture content received was 5%, and the highest was 66%. Lowest higher heating value was 6,500 and the highest was 11,190 (as shown).

Return on Investment Examples

Table 19 provides the economic opportunities projected by MSW Power. These projections have not been validated by NREL.

Table 19. Sample Return on Investment Calculations for the GEM with a Diesel Engine[a]

Investment = $1.1 M	**Scenario 1**		**Scenario 2**	
	Unit Price	**Average Annual Savings**	**Unit Price**	**Average Annual Savings**
Electricity (kWh)	$0.27	$141K	$0.14	$80K
Heat (MBtu)	$15	$74K	$10	$54K
Waste disposal (tons)	$125	$109K	$80	$76K
Other net savings (Costs)		($54K)		($76K)
Total		**$269K**		**$134K**

Source: MSW Power

[a] This is based on a modified diesel genset scenario only. The "other net savings" include maintenance, consumables, and diesel fuel costs.

Appendix F: Potential Waste-to-Energy Technology Providers

Table 20. Partial List of WTE Technology Providers

Company	Contact	Technology	Notes
AlternNRG-Westinghouse Plasma Corp.	Mark A. Wright 770-696-7698 wrightm@westinghouse-plasma.com	Plasma arc gasification	• Biomass facility operating in Pennsylvania • WTE facilities operating in Japan and India
Biomass Energy Systems, Inc. (BESI)	Tony Calenda 100 Overlook Center 2nd Floor Princeton, NJ 08540 321-795-3107 tony.calenda@biomassenergysystems.net	Rotary kiln gasification	• Operating a 100 TPD unit in South Korea, fueled by industrial waste (mainly fabric, wood, plastic, packaging materials)
International Environmental Solutions (IES)	Karen Bertram 714-372-2272 karenbertram@wastetopower.com	Horizontal auger-fed gasification	• Operating 30 TPD unit in Mecca, CA • Finalist for LA County WTE projects
Organic Energy Gasification	Jan d'Ailly 32 Academy Crescent Waterloo, Ontario, N2L 5H7 519-884-9170 jadilly@organicenergy.ca	Low-temperature gasification	• WTE facilities operating in Ontario, Canada, since 2001 • 25 TPD and 50 TPD modules • 94.9% conversion claim • Performance guarantee offered • $7-$9 million turnkey installation and $700K-$900K O&M costs estimated
Plasma Power LLC	James Juranitch 730 W. McNabb Rd Ft. Lauderdale, FL 33309 262-443-9100 Jjuranitch@plasmapowerllc.com	Plasma arc gasification	• 250 TPD WTE facility operating in Iowa • 20 TPD WTE facility in planning stages in Florida • WTE facilities operating in Europe and Asia • Capital cost of $19 million and O&M costs of $237K estimated

Company	Contact	Technology	Notes
Princeton Environmental	Peter Tien 14-58 154th St Whitestone, NY 11357 718-767-7271 peter.tien@princetonenvironmental.com	Gasification	• 30-60 TPD WTE facilities operating in Japan • 30 years of experience in this field • Capital cost of $8 million and O&M cost of $200K estimated
Pyrogenesis	Tom Whitton 1744 William St, Ste 200 Montreal, Quebec H3J 1R4 514-937-0002 twhitton@pyrogenesis.com	Plasma arc gasification	• 10.5 TPD unit operating at Hurlburt Air Field, Florida • Capital cost $9 million, O&M unknown
Recycling Solutions Technology	Steve Jones 31 East 12th St Cincinnati, OH 45202 513-241-2228 steve@jaap-orr.com	Rotary kiln gasification	• 300 TPD unit operating in Inez, Kentucky • Capital cost $8-10 million, O&M unknown
Rockwell - Intellergy	Richard Noling 1400 Hall Ave. Richmond, CA 94804 510-837-6200 Rick_Noling@gmail.com	Rotary gasifier, steam reformer	• No WTE facility in operation • Claim of 60% hydrogen content in syngas • 30 TPD and 75 TPD size units • $8 million capital cost and $500K O&M costs estimated