EXECUTIVE SUMMARY

Waste Gasification System for Fixed Installation On-site Distributed Generation

ESTCP Project EW-201334

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ACRONYMS AND ABBREVIATIONS

ARFVTP	Alternative and Renewable Fuel and Vehicle Technology Program
CEC	California Energy Commission
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
FHL	Fort Hunter Liggett
MSW	Municipal Solid Waste
MTPD	Metric Ton (tonne) Per Day
SERDP	Strategic Environmental Research and Development Program
SNEP	Specific Net Electricity Production
Tonne	Metric Ton

ACKNOWLEDGMENTS

The SE project team thanks the DoD for its crucial funding and support via the Environmental Security Technology Certification Program (ESTCP). This partnership with the DoD enabled the SE project team to design, build, and commission a first-of-a-kind FastOx® gasification system to demonstrate utilization of waste as an alternative energy resource. The US Army and Fort Hunter Liggett (FHL) has created the ideal testing ground for the system and both were excellent partners and contributors to this project.

The SE project team also thanks the California Energy Commission (CEC) for its co-funding via the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP). The CEC was instrumental in developing the demonstration plant and the production capability of renewable Fischer-Tropsch liquid fuels from clean synthesis gas.

The ESTCP and CEC's participation has greatly increased the speed at which the SE project team could develop its first plant and has helped leverage additional commercialization developments, including renewable electricity and renewable hydrogen production from waste at the current location and for future plants.

The SE project team also thanks its entire hard working and innovative team of engineers, business development managers, administrative professionals, consultants and vendors who have worked diligently to develop and implement this first commercial demonstration project.

The SE project team would finally like to acknowledge and thank the many individuals who provided guidance and direct assistance in bringing this technology and project to fruition. These include, but are not limited to:

- Todd Dirmeyer, CEM – former FHL Engineering Chief/Energy Manager
- Greg Vallery, PE, CEM – former FHL Director Public Works
- Glenn Woodson – Resource Efficiency Manager, FHL DPW
- Dr. Jim Galvin, PhD – former Program Manager, Energy & Water, SERDP-ESTCP
- Tim Tetreault, PMP, CEM – Program Manager, Energy & Water, ESTCP

1.0 INTRODUCTION

Sierra Energy (SE) in partnership with the Department of Defense's (DoD) Environmental Security Technology Certification Program (ESTCP) and the California Energy Commission (CEC), installed and demonstrated a commercial scale gasification plant at Fort Hunter Liggett (FHL) in Monterey County, California. This system is designed to convert municipal solid waste (MSW) and waste wood generated on base into electricity and ultra-low sulfur clean, renewable Fischer-Tropsch Liquid fuels.

The plant is the pilot of SE's patented FastOx® gasification thermochemical conversion process, which breaks waste down at the molecular level without burning. The system utilizes the injection of concentrated oxygen and steam to convert the waste into raw syngas. The syngas generated by the FastOx gasifier, consisting mostly of H_2 and CO, is sent through a gas cleaning isle where impurities such as particulate matter, acidic compounds, and other unwanted organic compounds are reduced to acceptable levels. The clean syngas is then sent to a low-pressure header, from which it can flow to a generator to produce electricity or a separate subsystem to produce liquid fuels.

By utilizing this technology to produce baseload renewable sustainable energy, this DoD installation will gain additional self-sufficiency and reduced vulnerability by operating independent of the civilian power grid. The data collected during the completed and future operations will allow for cost savings calculations and for project managers to interpret the avoided costs of landfilling wastes and procuring energy, as well as environmental impacts.

SE is currently in the early operations and demonstration phase. This final report will discuss all significant activity and outcomes that have occurred during the project to this point.

2.0 OBJECTIVES

This project tests the hypothesis that the demonstration plant at FHL will prove that the FastOx gasification system is a robust, net-energy-producing, and cost-efficient way to eliminate waste by converting it to baseload electricity, in comparison to the existing practice of hauling waste to landfill and electricity being pulled from the local utility.

Military readiness is compromised when an installation experiences power failure. The DoD's current strategy of obtaining energy from fragile commercial energy grids involves inherent risks. Commercial energy grids are susceptible to service interruptions resulting from natural disasters and competition for resources. Though solar energy is a viable source of energy during the day, it does not adequately supply nighttime energy needs. Available options do not provide the resiliency required for the security of installations [1].

A key driver of this project was President Obama's 2007 Executive Order 13423 [2] that strengthens federal environmental and energy management. This includes provisions to increase renewable energy and landfill diversion and reduce greenhouse gas emissions. Federal agencies were directed "to improve the energy efficiency and reduce greenhouse gas emissions through reduction of energy intensity by (i) 3% annually through the end of fiscal year 2015, or (ii) 30% by the end of fiscal year 2015 relative to the baseline of the agency's energy use in fiscal year 2003" [2]. The DoD developed a program to address this order that involved inter-agency partnerships to "speed innovative energy and conservation technologies from laboratories to military end users" [4], culminating in programs such as ESTCP that are providing funding for this demonstration.

The DoD's 2011 Strategic Sustainability Performance Plan sets goals for renewables in the military. The targets of this plan are directly addressed by this project by diverting MSW and waste wood from landfills [3]. The primary objective of the project is to help facilitate FHL's mission of a net-zero waste facility.

3.0 TECHNICAL APPROACH

To test the hypothesis stated above, the existing FHL waste and energy operations were measured to provide a baseline. The project equipment was then designed, shipped and installed on-site. The final phase was to test the full plant via operational campaigns according to the demonstration plan. Data acquisition tools and instruments are used throughout the system to ensure adequate data is collected for each objective and phase. Through detailed analysis of operations data, the impact of the FastOx process was compared to the baseline and conclusions made, ultimately analyzing the potential operational benefits of this renewable energy technology for federal entities.

The project was divided into several test phases and related milestones, and these objectives were further broken down and organized by tasks. Tasks were completed by the project team and managed by SE. This team also established phases based on performance objectives reached. Major tasks in this demonstration project are described below.

- Engineering – All major equipment and engineering tasks were divided between the assembled project team comprised of Sierra Energy, various sub-contractors and outside laboratories. The project manager maintained a responsibility matrix to ensure the completion of tasks on parallel tracks. The core technology design was the first stage of the project, running in parallel with site-specific engineering prior to construction.
- Permitting – This task included air, water, waste, building, and facility use permitting. The onsite Fire Department also performed several quarterly inspections and the project team coordinated with the California Occupational Safety and Health Administration (Cal/OSHA), and separately with the Monterey Country Department of Health, to ensure regulatory compliance.
- Construction and Installation – This task included site preparation by the local contractors, off-site fabrication of containerized equipment modules, and the delivery and installation of all equipment and utilities connections.
- Operations during Commissioning – There were four phases to this commissioning process. Site Acceptance Testing confirmed that the equipment and subsystems arrived per the original mechanical design specifications. Independent subsystem testing in the middle of its operating envelope was followed by performance qualification to verify that equipment was functioning across an expanded operating envelope. The final phase was full system testing of the lower and upper limits, and performance testing that verified that all subsystems were working in line during full plant operations.
- Operations during Demonstration – SE followed a test schedule that included several operating campaigns. This leads into ongoing testing at the facility beyond the original project timeframe and is the final stage of the demonstration portion of the project.
- Transfer of Equipment – When the FastOx® gasification testing phase is completed and the system is optimized and proven beneficial, the plant will continue to be operated by SE staff in collaboration with FHL.

Performance Objectives were established to guide the project and measure the potential benefits of the technology as a renewable energy source. The following is a summary of each performance objective and a description of success criteria.

- Peak Specific Renewable Electricity Generation – A performance objective of 700 kWh net export per tonne of waste into gasifier was determined as the baseline expectation for operations on post-recycling residual waste in California.
- Specific Operating Cost – This performance objective was to confirm system operation can achieve unlevelized cost parity with, or be less expensive than, the existing average electricity procurement cost at FHL ($0.176/kWhe in FY18).
- Environmental Benefit – This performance object was to compare the specific emissions of the project to those of "mixed fossil fuel energy production," to validate the environmental benefits of using syngas fuels. The aim was not only to meet the specific emissions of fossil fuels but see significant reductions in each.

- System Turndown – At the reduced 1/10th capacity operations, the Specific Net Electricity Production (SNEP) will not drop by more than 25% from the designed value (of 700 kWh/tonne).
- Landfill Diversion Percentage – At full operations, a minimum goal was set at 75% landfill diversion.
- Total Mass of Material Gasified – This performance objective was to see an inimum of 275 tonnes of material being converted in the FastOx gasifier, to ensure the system was evaluated with satisfactory sample size.
- System Uptime – To exceed 75% online and available status.
- Seasonal Operations Robustness – To have no major, operationally-disruptive qualitative affects observed.
- Odor and Noise – To receive no complaints for either odor or noise.

The objectives were further divided into test groups so that the metrics related to specific success criteria could be collected and analyzed. For each test group, independent, dependent, and controlled variables were defined. The operating parameters and campaign goals were designed for system optimization and to meet the success criteria for the performance objectives.

4.0 RESULTS AND DISCUSSION

SE completed the design, permitting, fabrication, installation, commissioning and demonstration of a first-of-its-kind oxygen-blown waste gasification system. This technology platform when developed further will provide various DoD entities and managers the ability to diversify their waste disposal and energy procurement portfolios, while subsequently increasing energy resiliency, decreasing environmental footprint, and decreasing overall levelized costs. The SE team produced syngas at FHL during the demonstration campaigns and expects to produce electricity and liquid fuels in 2020. SE plans to work with the U.S. Army to ensure that power production can continue for at least 10 years after steady state operations begins, and ideally for the 25-year expected life of the equipment.

Quality assurance and quality control procedures were in place during all operations and included confirmation of instrumentation calibration such as gas analyzers and flow meters, data cleansing and statistical analysis and working with independent approved laboratories.

Although the plant was still in early demonstrations, data was collected from the campaign's steady state FastOx operations on waste wood to syngas. While a major goal is to operate the system at a steady state and to generate electricity, the electrical generator was yet to be operated, so there was not enough empirical data to validate the success criteria relative to actual operations and electricity metrics. In the absence of empirical data, the team used computer simulated data to estimate potential electricity generation, as follows. When 10 metric tons per day of waste wood feedstock with 20% moisture is introduced into the FastOx gasifier, the computer simulation model created on Aspen Plus predicts a net electric power output of 674 kWhe/tonne.

One coproduct of the system is a stone material composed of inorganic materials that is tapped out of the bottom of the gasifier vessel. This is a salable product and typically a revenue source. A sample of this vitrified stone from waste wood gasification was collected after one of the operating campaigns and sent to an independing lab for analysis for the presence of metals and EPA non-hazardous waste confirmation testing. The results confirmed its determination as "non-hazardous" meaning the coproduct can be reused or sold and does not require disposal at a hazardous waste landfill.

The following table summarizes the results to date (obtained during the ESTCP project) for each performance objective.

Performance Objective	**Summary of Results**
Peak Specific Renewable Electricity Generation	Current calculations using preliminary plant operating data shows an expected specific net export of 674 kWh_e/tonne, with the goal of 700 kWh_e/tonne at a minimum. This is expected to increase with optimization of the plant and process.
Specific Operating Cost	Current calculations for a repeat 10 Metric Tons (tonnes) Per Day (MTPD) project show an unlevelized Operating Cost of \$0.005/kWh_e.
Environmental Benefit	Without operations on the syngas genset, the manufacturer's own conservative emissions profile guarantees must be used as a placeholder. CO < 5.93 g/kWh_e, NO_x at 2.80 g/kWh_e and Non-Methane Hydrocarbons < 1.12 g/kWh_e.
System Turndown	Calculations extrapolated from initial operations at 2.3 MTPD capacity, shown the SNEP should not drop more than 19.7% at 10:1 (1.0 MTPD) operations.
Landfill Diversion Percentage	Unable to validate on MSW feed materials due to absence of operating data with MSW, but on wood waste is in the 95–99%wt. landfill diversion range.
Total Mass of Material Gasified	7.5 tonnes of materials gasified in early operations. At 5 MTPD (50% throughput capacity), will require 54 days of operations to reach success criteria of 275 tonnes.
System Uptime	Insufficient data to evaluate given limited operations beyond commissioning.
Seasonal Operations Robustness	Initial environment-related equipment failures have been resolved. However, increased waste material moisture content will lower overall operating efficiency. This can be mitigated with a dryer that reutilizes waste-heat from the system.
Odor and Noise	No complaints to-date and would likely not be an issue for most semi-industrial DoD installation settings, especially with mitigation measures readily available.

A simple cost model for the FastOx gasification facility was also completed. The cost included leveraged funds from stakeholders, including SE and FHL. Based on this costing analysis, a repeat project without cost-rework and redesign would be economical. The following costing elements were considered: permitting, site preparation, installation, consumables, operations and maintenance, hardware, and salvage value. These factors were further assessed through a Life Cycle Cost Assessment, which compares the baseline case that uses the civilian electrical utility provider and waste disposal service providers versus the FastOx gasifier system case. The study determined that the FastOx® gasification system provides the lower overall cost – indicating that it is the preferred solution – with net savings of \$3.2 million over the conventional baseline approach over the 20-year analysis period.

5.0 IMPLICATIONS FOR FUTURE RESEARCH AND BENEFITS

ESTCP funding has enabled SE to build and demonstrate its first commercial demonstration scale FastOx gasification plant in California. The project also moves the gasification industry forward in terms of deployed system references, knowledge and operating data. In addition to the project-specific objectives, SE and the project team have produced several ancillary studies as a result of this plant. A Life Cycle Analysis and Techno Economic Analysis report was generated in collaboration with the project team's university partners (UCD Davis), a potential new Low Carbon Fuel Standard (LCFS) pathway was developed, and several public and private research entities have communicated with SE on future studies.

SE and the project team will continue to collect and evaluate the operations data to further prove and optimize the technology in a commercial capacity.

Future applications for the DoD include operations at both domestic and foreign operating bases. Given the inherent scalability of the FastOx gasification platform, systems can be applied at a wide range of existing installations serving diverse populations. There are considerable benefits to adopting the FastOx technology as a deployable solution for overseas missions, to supplement existing electricity generators and offset diesel and JP-8 requirements. This technology implementation in foreign territories would also help mitigate the need for convoys to transport waste, resulting in further reduction of risk during missions [1].

6.0 REFERENCES

[1] C. Hammock, *Keynote: Energy Programs of the Army, presented at the Defense Energy Summit,* Austin, TX, 2013.

[2] Office of the President, *Executive Order (EO) 13423: Strengthening Federal Environmental, Energy, and Transportation Managements,* Federal Register, 2007.

[3] DoD Senior Sustainability Officer and Under Secretary of Defense, *Department of Defense Strategic Sustainability Performance Plan,* 2011.

[4] "Memorandum of Understanding between U.S. Department of Energy and U.S. Department of Defense," 22 July 2010. [Online]. Available: http://energy.gov/sites/prod/files/edg/media/Enhance-Energy-Security-MOU.pdf.