FINAL REPORT

Demonstration of the Zero Emission Distributed Generation and Storage System

ESTCP Project EW-201346

MARCH 2018

Deborah Jelen
Electricore, Inc.

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Jelen, Deborah (Electricore, Inc.)
Odom, Sara (Electricore, Inc.)
Bisset, Steve (Terrajoule)

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27943 Smyth Drive, Ste 108
Valencia, CA 91355
USA

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The purpose of this project was to demonstrate the validated ability to convert, store and discharge renewable solar energy without fossil fuels or large-scale (chemical) battery energy storage. The proposed Distributed Generation and Storage (DGS) system - a cost-competitive alternative to traditional distributed generation systems was to demonstrate that renewable energy can be used for on-demand power generation as the primary power source for key facility nodes while also providing peak power mitigation.

Due to cost limitations to develop the technology by project partner, Terrajoule, the proposed demonstration was not able to complete the construction and installation of the project. In this report, please find a description of the proposed technology and demonstration, milestones achieved, project barriers, and potential for future use.

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ACRONYMS AND ABBREVIATIONS

ARNG	Army National Guard
Camp SLO	Camp San Luis Obispo, CA
CC DNI	Cosine-Corrected Direct Normal Irradiance
CPUC	California Public Utilities Commission
DGS	Distributed Generation and Storage
DNI	Direct Normal Irradiance
DoD	Department of Defense
EO	Executive Order
ESTCP	Environmental Security Technology Certification Program
HP	High Pressure
HTF	Heat Transfer Fluid
kW	Kilowatt
kWh	Kilowatt-hour
LCOE	Levelized Cost of Electricity
LP	Low Pressure
LPG	Liquefied Petroleum Gas
MW	Megawatt
MWh	Megawatt-hour
PCC	Point of Common Coupling
PG&E	Pacific Gas & Electric
P&ID	Piping and Instrumentation Diagram
USPFO	United States Property and Fiscal Office

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EXECUTIVE SUMMARY

Electricore and Terrajoule applied for Environmental Security Technology Certification Program (ESTCP) funding in 2012, with the assumption that full costs to develop the Terrajoule technology, prior to project construction and installation, would be provided by Terrajoule's venture capital investors. The funding for the non-recurring engineering (NRE) required prior to constructing the ESTCP installation was proposed as an in-kind contribution to the project. By 2014, the availability of USA venture capital for solar powered technology had completely disappeared, forcing the team to request a suspension of the project while seeking new venture capital funding sources in 2015. As of year-end 2017, Terrajoule had not secured the necessary funds and could not successfully complete the project design and installation.

In this report, please find a description of the proposed technology and demonstration, milestones achieved, project barriers, and potential for future use.

Activities completed under this project include the following:

- Site Survey
- Energy Audit
- Permitting, Site Approvals and Environmental Assessment
- Project Performance Objectives
- Demonstration Plan
- In-Progress Review Meeting
- Initial System Layout, Design, and Modeling

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1.0 INTRODUCTION

The purpose of this project was to demonstrate the validated ability to convert, store and discharge renewable solar energy without fossil fuels or large-scale (chemical) battery energy storage at Camp San Luis Obispo, California (Camp SLO). Terrajoule's Distributed Generation and Storage (DGS) system - a cost-competitive alternative to traditional distributed generation systems was to demonstrate that renewable energy can be used for on-demand power generation as the primary power source for key facility nodes while also providing peak power mitigation.

1.1 BACKGROUND

Current technologies for distributed generation and energy storage include the use of traditional natural gas or diesel-fueled generators or the installation of solar photovoltaic renewable energy paired with costly energy storage solutions such as battery banks.

The Department of Defense's (DoD) increased use of distributed generation provides installations the ability to generate their own power during peak load (and thus peak price) periods to mitigate demand surcharges from the local utility. Distributed generation also provides the DoD with increased energy security and reliability during grid failures due to natural or man-made events. This is currently met by either deploying traditional natural gas or diesel fueled generators or installing large-scale renewable energy. There are three major issues with this approach:

1. Diesel or natural gas generators can be installed and used as back-up power, but cannot be regularly run due to high cost of fuel and strict air pollution laws.
2. The supply of natural gas or diesel can be interrupted by either hostile or non-hostile causes, rendering the system inoperable and ineffective.
3. Large-scale renewable energy, notably solar, is inherently intermittent in nature and may not be available when needed without the added costs of grid scale energy storage (electrochemical or mechanical).

Terrajoule's DGS is unlike any other system available today in that it harnesses and stores solar energy which can be used to generate electrical power 24 hours per day. In addition, the power output can be adjusted according to load or to the variable price of electricity, much like an internal combustion generator. The DGS is a closed loop, clean power station that produces power when desired, without fuel or electric costs, demand charges, or peak rate increases. It can be connected to the grid, or operate completely standalone. The DGS is planned for deployment as modular power station units, ranging in generation capacity from 1 GWh/year (~115 kW average) to 5 GWh/year (~570 kW average). Any number of the modular units can be synchronized, to create centralized or distributed power generation systems of 10s or 100s of MW.

1.2 OBJECTIVE OF THE DEMONSTRATION

The primary objective of this project was to demonstrate Terrajoule's cost competitive, zero emission distributed generation solution through the installation and operation of their innovative DGS system in Central California at Camp SLO. The project was to demonstrate the ability to convert, store and discharge renewable energy without the use of fossil fuels or large-scale chemical battery energy storage. This goal was to be accomplished by:

1. Demonstrating the conversion of solar energy to electrical power by concentrating solar energy to convert water to steam and then expanding the steam in a multi-stage reciprocating-piston steam engine system that drives electrical power generators;
2. Storing solar energy for later use by condensing solar-generated steam in a condenser/energy accumulator consisting of hot water in a pressure vessel, thus heating and further pressurizing the water (also known as a "steam accumulator"); and
3. Discharging the stored energy by using the thermal energy contained within the pressurized hot water to flash a portion of the water to steam, then expanding the steam in the reciprocating-piston steam engine that drives the electrical power generator.

A twelve (12) month demonstration was scheduled to cover a full solar cycle for solar collector performance characterization and to provide exposure to weather conditions that may reduce the ability to produce steam and store sufficient energy for generation. The data collected was to be analyzed to validate the storage and charge/discharge characteristics for the DGS.

1.3 REGULATORY DRIVERS

The DoD spends approximately $4 billion per year on facility energy consumption. This in turn helps to power and fuel over 500 military installations worldwide. These installations include over 500,000 buildings and structures, as well as, 160,000 non-tactical vehicles.[1]

The Department has three key installation energy goals:

1. Reduce energy usage and intensity,
2. Increase renewable onsite energy generation, and
3. Improve energy security.

The DoD Strategic Sustainability Performance Plan specifically calls out the following mandates:

- Executive Order (EO) 13514: Articulates both general and specific requirements to improve federal government efficiency through the development of a green economy and a decreased dependence on fossil fuels. The DoD Strategic Sustainability Performance Plan (the Plan) provides a coherent approach both for complying with multiple federal requirements for sustainability and for assuring the mission. The linkages between sustainability and the DoD mission are strong and direct. There are four key areas of intersection that form priorities for the Department:
    1. Energy and Reliance on Fossil Fuels
    2. Chemicals of Environmental Concern
    3. Water Resources Management
    4. Maintaining Readiness in the Face of Climate Change

[1] Department of Defense Annual Energy Management Report, Fiscal Year 2011

- Executive Orders 13423 & 13514: ‘‘Sustainability” and “sustainable’’ mean to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations of Americans. In January 2010, the Department released an aggressive target under EO 13514 for reducing direct greenhouse gas emissions from facilities and non-tactical fleet vehicles. These emissions are overwhelmingly due to direct energy use, especially electricity.

As of March 2018, there are significant developments in regulatory drivers outside the DoD that will influence the cost and environmental impact of the electricity available to many military installations:

- In California, Senate Bill SB 350, enacted in October 2015, directs utilities to generate at least 50% of electricity from renewable sources by 2030.
- In California, Senate Bill SB 338, the “Clean Peak” bill, was enacted in September 2017. Similar bills are pending in Massachusetts and Arizona. SB 338 acknowledges that it is not practical to reach the 50% SB 350 goal without developing substantial renewable sources in the peak demand hours of late afternoon, evening and night time.
- Meeting Clean Peak goals can only be achieved with large amounts of energy storage charged by renewable sources and dispatched on demand. The Terrajoule DSG technology is very well suited for this purpose.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

The DGS design is made up of three major subsystems: solar collectors, steam driven generator unit, and pressurized hot water energy storage.

1. Solar Collector: Solar concentrators generate steam while the sun is shining. A portion of the received energy is converted immediately to output power and the balance stored for later (night-time) use. For collectors, industry-standard RP-3 parabolic troughs, circulating oil Heat Transfer Fluid (HTF) through heat exchangers to produce steam at 45 bar absolute pressure and 257°C, are currently used for this purpose as these are a mature commodity product with proven reliability and performance. Figure 1 shows the prototype installed at the Oakdale, CA plant. As of May 2018, there are 2nd generation parabolic trough models in production with significantly reduced cost, such as the SkyTroughDSP manufactured by SkyFuel Inc. to a somewhat larger format than the RP-3 (7m vs. 6m aperture width).

Figure 1. Proposed Solar Collector

2. Steam Driven Generator Unit: The steam is converted to mechanical rotating shaft power via a modular steam engine, which is operated at constant, increased, or decreased output depending on load requirements. It is a multi-stage expansion system with 3 expansion stages, the first High Pressure (HP) stage consuming steam at up to 45 bar absolute / 257°C and exhausting into the pressurized hot water energy storage. Steam that flashes form the energy storage system on demand drives the 2nd and 3rd stages. The 3rd stage exhausts into a sub-atmospheric condenser at a minimum pressure of 0.1 bar and 46ºC. The commercial power station units will use steam engines manufactured by Spilling Technologies. Spilling has been manufacturing heavy-duty steam engines of this design for over 60 years. The engine drive shaft is used to drive a standard electric generator.

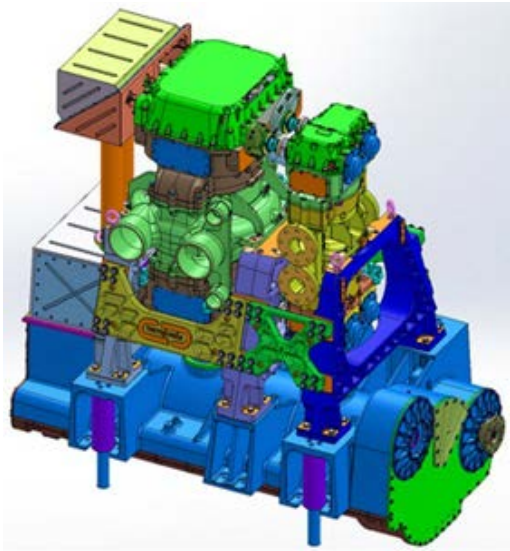

Figure 2. Generator Unit

3. Pressurized Hot Water Energy Storage: Energy storage is embedded in the system via pressurized hot water, stored in an insulated pressure vessel at operating temperatures between 127°C and 207°C (corresponding to pressures between 2.5 bar absolute and 18.25 bar absolute). The pressure vessel used is a commercially available 12,700 gallon vessel similar to a liquefied petroleum gas (LPG) storage tank (but containing only water and steam). Insulated with 36 inches of standard building insulation, the daily energy loss is less than 2% of stored energy. A single storage tank will store sufficient thermal energy that, converted by the engine system to electrical energy, provides over 500 kWh of electrical energy. Multiple tanks provide energy storage as required.

Figure 3. Proposed Pressurized Hot Water Energy Storage

Key components of the system design are provided in the diagrams below, as well as a system diagram showing main system components and energy flow.

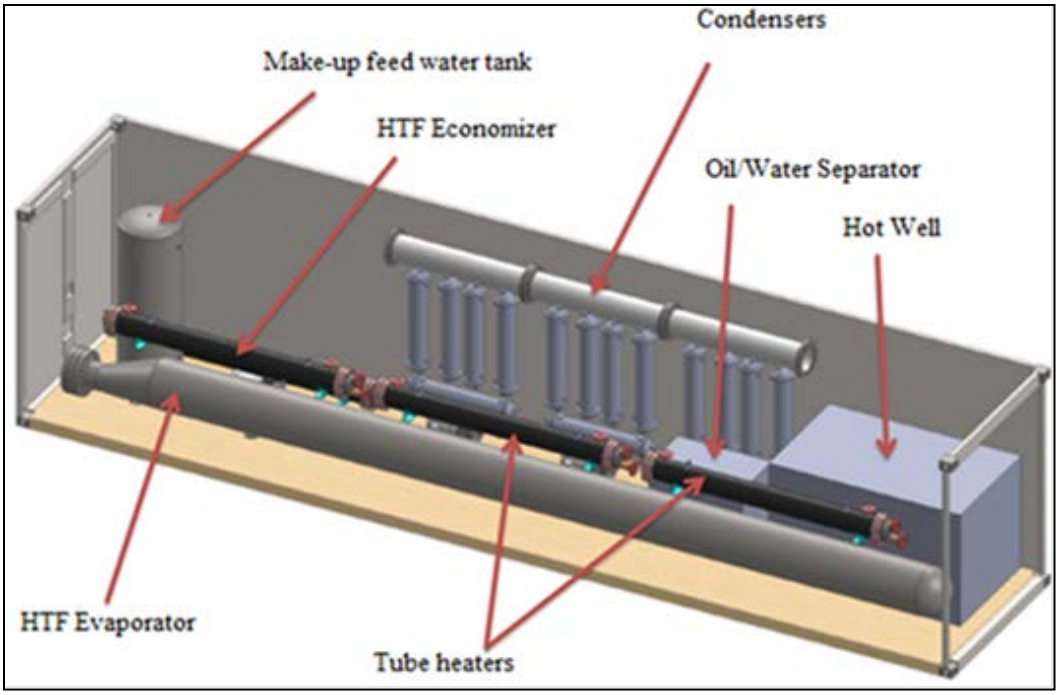

Figure 4. Proposed Balance of Plant Container

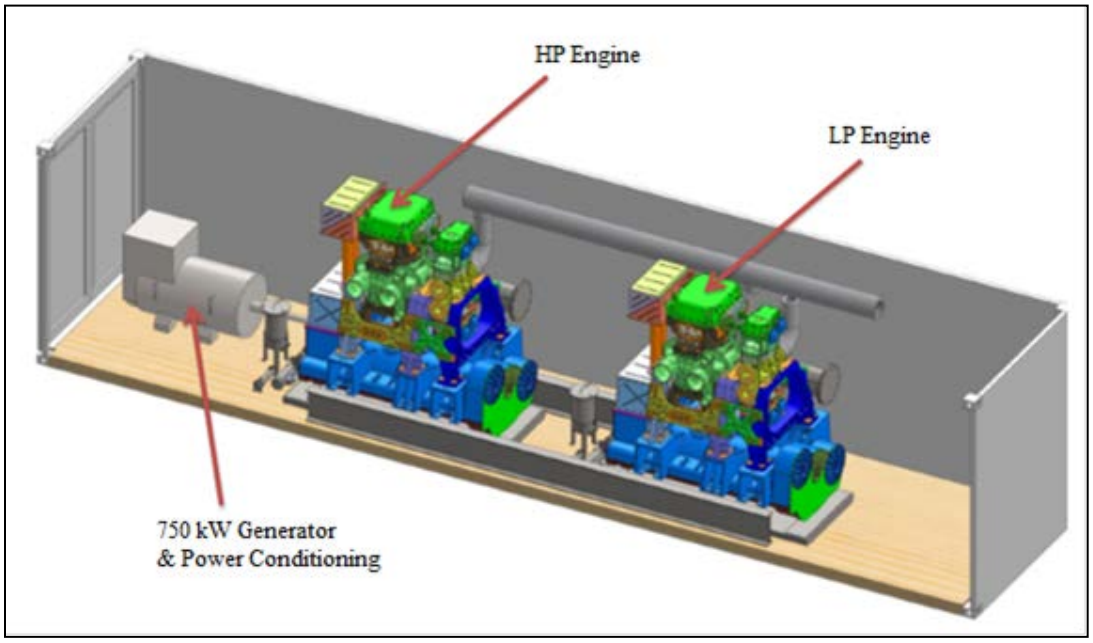

Figure 5. Proposed Engine Container

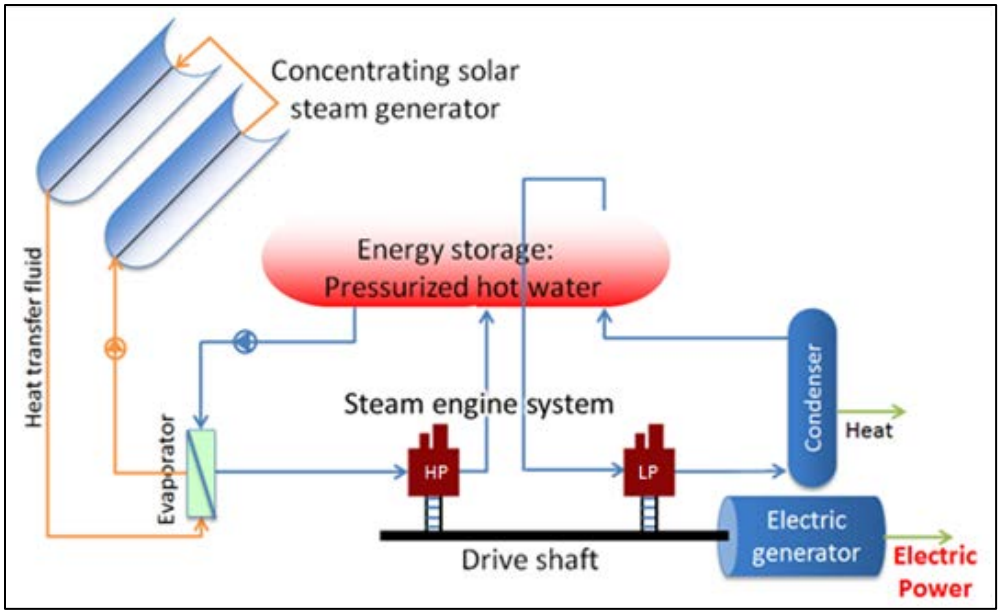

Figure 6. System Diagram Featuring Energy Pathway

One of the many values added by the proposed project was the ability to use renewable energy for on-demand power generation as primary power to key nodes with peak power mitigation by: a) demonstrating that the system, when configured as a grid-connected distributed energy generation system, can continue to generate power in the event of disruption of power from the grid; b) demonstrating that the power generated by the system in the event of grid disruption can be controlled to match the variable power needs of the key node to which it is connected, by a combination of solar energy (if available) converted to electrical power in real time, and stored thermal energy converted to electrical power at a rate that is controllable to meet the demand; and c) demonstrating that when connected to a grid that is currently operational, the system's power output can be controlled so as to increase the rate of conversion of stored thermal energy to electrical power such that a short-term increase in the facility's consumption of electrical power is offset, thus mitigating the assessment of peak demand charges by the electrical utility.

2.2 TECHNOLOGY DEVELOPMENT

Prior to the initiation of the ESTCP-supported Camp SLO project, Terrajoule built a prototype near Oakdale, California, which successfully proved the concept and verified that the performance model was fundamentally correct. The Oakdale prototype was intended as a proof of concept, and was not engineered to be replicable or maintainable for long-term use. The Camp SLO project was engineered to serve as the pilot project for a replicable commercial power station product that would operate reliably over its 25-year operational life.

A key requirement for reliable long-term operation was the development of mass-producible HP and LP steam engines. Terrajoule embarked on a multi-million-dollar development in collaboration with Roush Industries of Michigan. As with the prototype engines, the designs were based on the proven Skinner Universal Unaflow engines from the 1900s, but were modified to incorporate modern techniques for piston engine design and manufacture. The designs benefitted from lessons learned from the engines used in the Oakdale prototype.

By the time in 2014 when further venture capital funding had become unavailable, the steam engine designs were complete and in the final review stage prior to tooling, fabrication and testing.

During the extensive design review process, both internal and independent, several modifications were made to ensure long-term reliability, maintainability and manufacturability. Terrajoule completed an evaluation of fatigue criteria for the crankshaft and piston rods based on recommendations from independent due diligence. The piston rod was determined to be marginal at the current size and the decision was taken to increase the size from 38 mm diameter to 44 m diameter. This meant that ten parts, associated with pistons and piston rods for low pressure engines LP1 and LP2, had to be redesigned to accommodate a larger piston rod design. The high pressure engine design was revised to increase the number of common parts in order to reduce cost.

The system layout was designed such that system components would be contained in a shed rather than separate containers, in response to tank size. This design choice gave more freedom for maintenance and better insulation. Additional components in the shed included the engines and balance of plant, for increased access and lower cost. All items would be transportable by container.

A complete thermodynamic and mechanical model of the Camp SLO system was completed based on the P&ID. The modeling and P&ID allowed Terrajoule to optimize the balance of plant components and provide a more accurate picture of electrical output and cost savings for Camp SLO.

2.2.1 ONGOING TECHNOLOGY DEVELOPMENT

It is worthwhile summarizing the significant developments that have occurred since further venture capital funding became unavailable in 2014. These developments have been made with significant investments of time and expertise by key Terrajoule partners, and by primarily unfunded time of key Terrajoule personnel. Here are the major developments:

- While the steam engine design phase was essentially complete, the remaining cost to tool, fabricate, equip a test facility and test the engines required further multi-million dollar funding. Funding for such breakthrough energy technologies was readily available in 2008 but impossible to find in 2014 (and 2018). Therefore we sought a solution that used off-the-shelf engines that had long-term reliability proven over decades of operation.

  There is one remaining manufacturer of heavy-duty steam engines, Spilling Technologies of Hamburg, Germany. Terrajoule had originally considered their engines unsuitable for two reasons:

  a) They were designed for operation with exhaust pressures above atmospheric pressure, so could not achieve the required efficiencies that could be reached with condensing sub-atmospheric exhaust;

  b) The engines were too expensive.

  Working with Spilling experts, both of these issues were resolved:

a) Instead of using a two-stage compound piston engine for the LP engine, we can use a hybrid approach with the first stage using a Spilling piston engine and the second stage using a single-stage saturated steam turbine with sub-atmospheric condensing exhaust. Such turbines are readily available. This hybrid provides the required efficiency using off-the-shelf hardware with decades of performance and reliability data.

b) The cost issue is commercial, not technical, in that the Spilling Company produces for specialty applications with low annual unit volume. We have made arrangements with Spilling to license the engine designs for manufacture at a lower cost facility capable of higher production volumes, such as Roush Industries in Michigan.

- The parabolic trough represents about half the cost of the system. Our key supplier for the Camp SLO project, SkyFuel, Inc., remains the best source for parabolic trough solar collectors. SkyFuel has been acquired by a larger company with low cost manufacturing capability. The new owner has funded the development of a second generation parabolic trough, the SkyTroughDSP. As a result, the solar collectors will be available in high volume at approximately half the cost of the pilot Camp SLO price, enabling the Terrajoule to maintain its competitive cost advantages while the costs of competing technologies decline (e.g. PV solar panels combined with batteries).

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Advantages

- Performance Advantages: The DGS system was to have been able to generate and store energy, as well as distribute load-matching power 24 hours a day, only using solar energy as a resource.
- Cost Advantages: In year-round operation of a 200kW-rated system, the team expected to deliver a Levelized Cost of Electricity (LCOE) less than $0.09/kWh amortized over a 25-year minimum system lifetime. The team currently expects that in production volume of 100 MW per year, a unit that generates 5 GWh/year, with peak power of 2 MW and storage capacity of 12 MWh-e, will deliver an LCoE of less than $0.05/kWh.

Limitations

- Performance Limitations: At this time, there are no widespread technological or other limitations to deployment within areas of high direct normal irradiance (DNI).
- Cost Limitations: Military and DoD installations have different cost/payback profiles in comparison with those of large commercial users, as DoD can't take advantage of the same incentives and rebates that commercial users have access to.
- Investment Limitations: Availability of venture capital investment for solar technology limited the ability of the team to develop the proposed design. USA investment funding for new solar power hardware development was reduced to zero by 2014 for the following reasons (in the opinion of Terrajoule): The limited partners who supply funds to the venture capital firms cut off all funding for solar hardware, because the venture capital firms had delivered highly negative returns across the solar hardware sector, with dozens of solar startups having been shut down without achieving commercial viability.

> The primary reason for that was that Chinese solar panel manufacturers delivered quality product at lower prices. The primary reason for that was that the Chinese government created incentives and demand for massive investment in solar technology at large scale. The Chinese simply invested more in both product design and manufacturing technology, and implemented at a much larger scale, moving rapidly down the manufacturing volume curve. Other factors such as currency manipulation, labor costs, and lack of pollution controls were secondary, with the primary factor being public policy enabling PV production at a massive scale.

This has left the United States without an innovation path for new solar technology, yet new innovations are available for development, and are necessary, especially in the area of renewable power that is dispatchable to meet demand 24 hours per day.

Terrajoule continues to pursue funding to commercialize its technology, and expects to procure that funding overseas. Successful deployment of new technology on a significant scale depends on funding for these phases:

- Research
- Development
- Demonstration
- Deployment at large scale

Research is well funded through various agencies, universities and labs. Deployment at large scale is very well funded via private investment in power projects such as utility-scale solar PV and wind farms, but only for technologies that are mature and "bankable." There is no funding for "risk capital" investment in technology innovation from these sources.

Funding for the Development phase was traditionally provided by venture capital, but that has disappeared due to the losses incurred across-the-board by venture capital in solar hardware. There is some funding for the Demonstration phase, the ESTCP program being an excellent example, but it is limited to demonstration projects for incremental innovation, since there is no Development funding for breakthrough innovation.

To the extent that public funding is available for Development, e.g. ARPA-E, the nature of the process is highly prescriptive and tends to fund only developments along accepted pathways that are determined top-down, for example the DOE's SunShot program to invest in high temperature large-scale Concentrating Solar Power. These are worthwhile investments but provide no significant funding for the breakthroughs that can occur when alternate innovations are funded.

CONCLUSION: There were no technology or cost barriers that blocked this technology. The technology can fulfill a unique and critical role in the USA's secure energy future. The barrier was entirely the availability of funding for the Development stage. If that funding had been adequate, then ESTCP's funding of the Demonstration stage would have been highly effective.

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3.0 PERFORMANCE OBJECTIVES

A summary of the proposed technology and economic performance objectives are listed below. Given that the demonstration was not completed, there are no results to be reported.

Table 1. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
Peak power output (grid connected mode and island mode)	kW	Meter readings of power output, DNI readings, data date/ time stamps	300kW
Continuous power output during a 24hr period with ending stored energy exceeding initial stored state (grid connected mode and island mode)	kWh	Meter readings of power output, DNI readings, data date/ time stamps, energy storage readings	2400kWh over 24 hour period
Load following characteristics (grid connected mode and island mode)	kW	Meter readings of power output, DNI readings, data date/ time stamps	Output matches power demand
Peak power output of system during interruptions in sunlight (grid connected mode and island mode)	kW	Meter readings of power output, DNI readings, data date/ time stamps	300kW
Energy production over demonstration period	MWh	Meter readings of power output, DNI readings, data date/ time stamps	566 MWh produced over 1-year demonstration period
Greenhouse gas emissions avoided over demonstration period	Tons of CO_2	Estimated release of GHG emissions	440 tons of CO_2 emissions avoided over 1-year demonstration period
Payback	Years	Terrajoule costs, external financial assumptions	9 years
Levelized cost of electricity (LCOE)	cents/kWh	Terrajoule costs, external financial assumptions	6.4 cents / kWh
Internal rate of return (IRR)	%	Terrajoule costs, external financial assumptions	10%
Qualitative Performance Objectives			
System maintenance	Time intervals, man hours, costs	Scheduled and unscheduled maintenance events	Maintenance cost is less than that of a similar system
User/Site Satisfaction	Feedback from Camp SLO personnel	Maintenance and management personnel interviews	Feedback showing level of satisfaction and areas for improvement

Testing was scheduled to be conducted under the following conditions:

- Ambient conditions between 0°C (32°F) and 35°C (95°F).
- Average hourly wind speed less than 10m/s (22.3 mph).
- Peak gusting wind speed below 35m/s (78 mph).
- Mirrors are clean.

4.0 FACILITY/SITE DESCRIPTION

The DGS system was slated to be installed at Camp SLO; the base spans more than 5,400 acres along the coast of Central California.

The demonstration site is a motor pool lot next to the United States Property and Fiscal Office (USPFO) warehouse on the north-east section of Camp SLO. From a technical, environmental and logistical stand-point, it would have been more than adequate for the project. It is in close proximity to a road, power distribution, large warehouse building, and has no significant environmental impact concerns for installation. In addition, the site already has a flat compacted surface with an existing fence, reducing additional site preparation prior to the installation.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

Camp SLO has 400 personnel in the Permanent Party and trains approximately 100,000 soldiers annually. The camp provides a full spectrum of support for live and constructive training in support of professional development, individual and company level collective training for the Army National Guard (ARNG) and all other armed forces units. Camp SLO also enables sustained conduct of operations in support of Federal and State emergencies.

Below is a proposed drawing of the demonstration site, with the approximate area of system components overlaying the motor pool. The site is approximately ¾ acre.

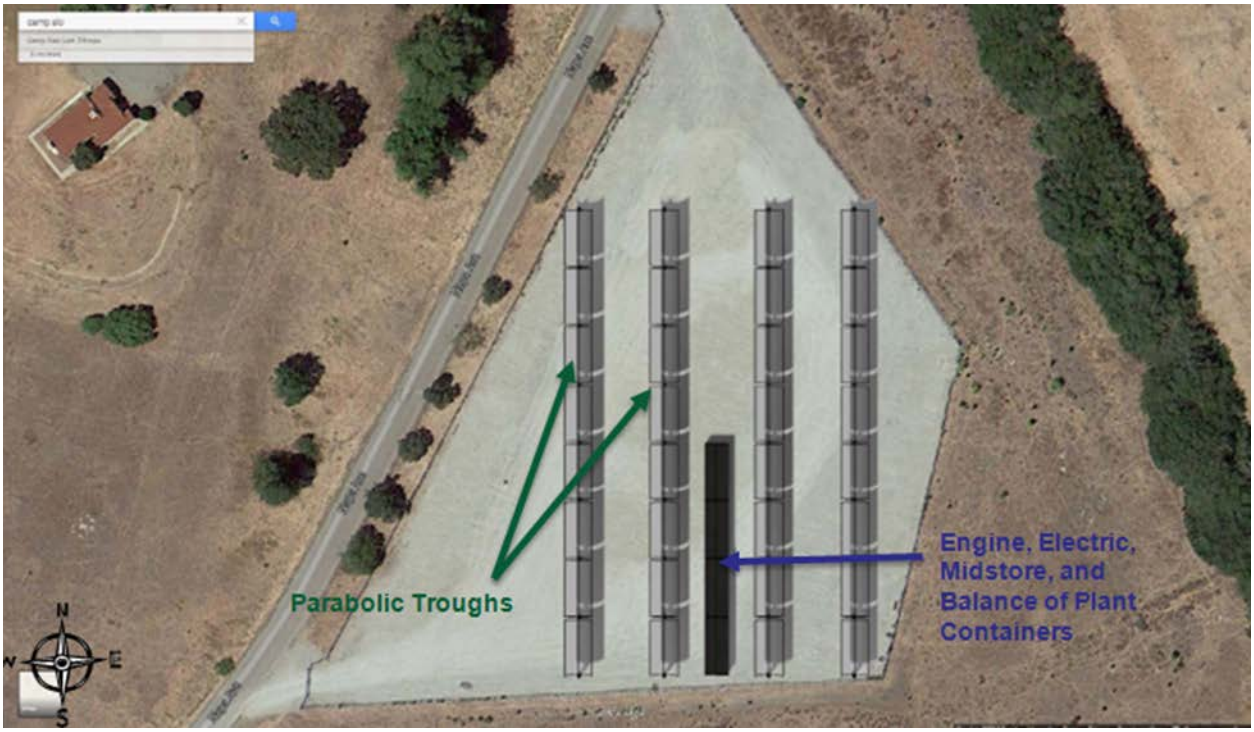

Figure 7. Bird's Eye View of Demonstration Site with System Overlay

4.2 FACILITY/SITE CONDITIONS

The following criteria was evaluated when determining a site for the demonstration:

- Geographic Criteria: This site is located in an area with high DNI, which is characteristic of the American Southwest. The site has an unimpeded east west view in order for the solar collectors to track the sun for all potential hours of daylight. There is a small hill overlooking the site to the west. However, the hill will only be a factor in the final hour of the day, in which irradiance from the sun will be of lower quality than in the morning and mid-day.
- Facility Criteria: The warehouse next to the motor pool could use waste heat from the DGS system's cooling requirements to provide domestic hot water and space heating as an added benefit to this project.
- Facility Representativeness: The selected site represents a number of similar sites found common in many DoD installations that could benefit from Terrajoule's technology solution.

Because the project was scheduled to take place in Pacific Gas & Electric (PG&E) territory, the DGS system would have been required to comply with the Rule 21 tariff. Rule 21 is a set of regulations determined by the California Public Utilities Commission (CPUC) concerning interconnection, operation, and metering requirements for distributed generation to be connected to a utility's electric system. The system would also need to comply with IEEE 1547.

5.0 TEST DESIGN

The planned demonstration was to have provided data analysis and evaluations from three (3) different sources including:

1. ERDC-CERL would provide an independent data analysis and "DoD Assessment" of the technology, including:
   a. Interpretations of system performance and relevance to DoD installation power needs
   b. Applicability at DoD installations based on geography, economics and mission.
2. Terrajoule engineers would review the data collected and provide company economics.
3. Electricore would provide an un-biased assessment of the system performance and document any issues/concerns that may arise during the program.

Electricore, ESTCP and additional project team members planned to monitor the system performance via an online monitoring service program.

5.1 CONCEPTUAL TEST DESIGN

A summary of the proposed conceptual test design is provided in the table below.

Table 2. Test Design

Hypothesis	Dependent Variable(s)	Independent Variable(s)	Test Design (reference General Conditions for Testing in Section 4.2)	Test Phases
Peak power output	Power Output (kW)	CC DNI (W/m²), Ambient temperature (°C), LP Engine output (kW)	Pyrheliometer operation and data collection, System operation, Collection of power output data from PCC, Time stamp of data	Pretest mirror clean, weather station check and system operation, System operation and test, Data collection, analysis
Continuous power output during a 24hr period	Energy Output (kWh)	CC DNI (W/m²), Ambient temperature (°C), LP Engine output (kW)	Pyrheliometer operation and data collection, System operation, collection of power output data from PCC, minimum instantaneous power output set for 50kW.	Pretest mirror clean, weather station check and system operation, System operation and test, Data collection, analysis
Load following characteristics	Power Output (kW)	CC DNI (W/m²), Ambient temperature (°C), LP Engine output (kW)	Pyrheliometer operation, System operation, collection of power output data from PCC, system manipulation to provide change in electrical power output, time stamp of data	Pretest mirror clean, weather station check and system operation, System operation and test, Data collection, analysis
Peak power output of system during interruptions in sunlight	Power Output (kW)	CC DNI (W/m²), Ambient temperature (°C), LP Engine output (kW)	Pyrheliometer operation, System operation, collection of power output data from PCC, system manipulated to simulate interruption in sunlight, time stamp of data	Pretest mirror clean, weather station check and system operation, System operation and test, Data collection, analysis
Energy production over demonstration period	Energy Output (MWh)	CC DNI (W/m²), Ambient temperature (°C), LP Engine output (kW)	Pyrheliometer operation and data collection, System operation, Collection of power output data from PCC, Time stamp of data	System operation and test, Data collection, analysis
Greenhouse gas emissions avoided over demonstration period	Tons of CO_2	Power output (kW), grid energy CO_2 output	Collection of power output data from PCC, Data comparison to traditional fossil fuel energy production	System operation and test, Data collection, analysis
Payback, LCOE, and IRR	Energy Output (MWh), system cost ($)	Energy output (MWh), system cost ($), maintenance cost ($), cost of fuel ($), cost of capital ($), life of system (years), discount rate (%)	Cost analysis	Data collection, analysis
System maintenance	Maintenance required (hours), maintenance interval (months), maintenance cost ($)		Maintenance performed as per Terrajoule's maintenance schedule	System operation and test, Data collection, analysis
User/site satisfaction			Survey provided to site manager and base staff	System operation and test, Feedback collection, analysis

6.0 POTENTIAL FOR USE

The proposed technology has broad applications for DoD use. The use of thermo-mechanical systems and the ability to operate without grid power make the technology a candidate for any DoD site with adequate space to install the system. The selected site represents a number of similar sites found common in many DoD installations that could benefit from Terrajoule's technology solution.

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7.0 IMPLEMENTATION ISSUES

As the team was unable to complete the installation and demonstration, implementation issues were limited to the planning stage. Future implementations should include:

- Potential regulations:
  - Rule 21 is a set of regulations determined by the California Public Utilities Commission (CPUC) concerning interconnection, operation, and metering requirements for distributed generation to be connected to a utility's electric system.
  - The system would also need to comply with IEEE 1547
- Permits:
  - DoD permit requirements vary by location. Though none were planned for this demonstration, future host sites will need to provide guidance to necessary permits.
- End-user concerns, reservations, and decision-making factors:
  - Physical location near electrical interconnect will ease installation.
  - Physical location near occupied buildings will provide a location for use of waste heat from the DGS system's cooling requirements to provide domestic hot water and space heating.
  - Site selection in an area with adequate DNI is necessary. A site has an unimpeded east west view in order for the solar collectors to track the sun for all potential hours of daylight is important to maximize performance. Note that exceptionally high DNI is not required to meet economic constraints. For example, most locations in the California Central Valley are suitable. Siting is not restricted to locations with exceptionally high DNI such as Blythe or Daggett, California, or Tucson, Arizona. Any site with an annual DNI of 1800 kWh per square meter or more (5 kWh per square meter per day average) is a good candidate.
- Relevant procurement issues
  - None experienced during this project.

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8.0 REFERENCES

There are no outside references utilized in this report.

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APPENDIX A POINTS OF CONTACT

Point of Contact Name	Organization Name Address	Phone Email	Role in Project
Deborah Jelen	Electricore, Inc.	(661) 607-8319 jelen@electricore.org	Executive Director / Principal Investigator
Steve Bisset	Terrajoule	(650) 269-0494 steve@terrajoulecorp.com	Co - Principal Investigator
Gregory Malley	California National Guard	(916) 854-3162 greg.malley@us.army.mil	CA National Guard Representative
Nicholas Josefik	US Army CERL	(217) 373-4436 Nicholas.M.Josefik@usace.army.mil	ERDC-CERL Representative
Rick Tidball	ICF International	(206) 801-2846 ext. 26 rick.tidball@icfi.com	ESTCP Technical Advisor
Maj. Brian Wintzer	Camp San Luis Obispo	(805) 594-6599 brian.n.wintzer.mil@mail.mil	Camp SLO Director of Public Works
Nathan Parks	Camp San Luis Obispo	(805) 782-6793 nathan.m.parks.nfg@mail.mil	Camp SLO Environmental Representative