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CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Organic Rankine Cycle (ORC) in a Textile Facility

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Gas Research and Development Program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with RD&D entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity
- Energy-Related Environmental Research
- Natural Gas-Related Transportation

Organic Rankine Cycle (ORC) in a Textile Facility is the final report for the Development and Demonstration of a Cost Effective, Packaged Approach to Industrial Gas Efficiency Using Organic Rankine Cycle Technology project (Grant Number PIR-14-024) conducted by Electric Power Research Institute. The information from this project contributes to the Energy Research and Development Division's Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

A majority of industrial facilities in California generate waste heat as part of their manufacturing processes. Much of this heat is rejected into the environment at varying temperatures above ambient levels. Currently, much of the heat is considered "low grade" which is difficult to capture and convert into other forms of useful energy. Organic Rankine Cycle technology is able to convert low temperature waste heat into electricity that increases overall plant efficiency and lowers operating costs with no net increase in criteria pollutants. However, the proposed Organic Rankine Cycle technology has not yet been proven to be viable with industrial applications (e.g., performance, financial return on investment, etc.). The purpose of this project was to demonstrate the feasibility of integrating an Organic Rankine Cycle system at an industrial facility, enabling the capture of low-temperature waste heat to produce electricity. If successful, the technology could be adopted by other industrial customers with low-temperature waste heat that is otherwise lost to the atmosphere.

Keywords: Waste heat to power, WHP, organic Rankine cycle, ORC, low grade heat, industrial facility

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Background

Many industrial customers have discovered and adopted strategies to capture and convert high-temperature (e.g., >800°F) waste heat streams into useful products such as steam or electricity through a combined heat and power system; however, it is more challenging to economically capture and utilize low grade waste heat (e.g., <500°F), which is typically rejected and lost to the environment. Organic Rankine Cycle (ORC) technology is able to capture and convert low grade waste heat to electricity. On-site generation of electricity from waste heat has the potential to reduce: 1) plant operating costs, 2) electricity demand, 3) emissions of criteria pollutants, and 4) greenhouse gases associated with the generation of electricity. These benefits help California to meet its renewable energy and climate goals.

Project Purpose and Approach

The purpose of this project was to:

- Demonstrate the design and operation of an ORC system to generate electricity on-site at an industrial facility.
- Advance industry understanding on best practices for design, integration, sizing, and installation of ORC systems to achieve cost-effective on-site electricity generation for industrial customers.

To evaluate the success of the project, the team planned to assess overall system performance in terms of reduction in annual energy use and CO2 emissions, translating into annual cost savings. These performance metrics would help evaluate the cost-effectiveness and beneficial impacts of ORC systems in industrial customer applications.

The project team spent considerable time and expense searching for and evaluating the potential fit of several candidate customer host sites, focusing mostly on industrial facilities with a consistent source of waste heat. The team evaluated waste heat availability on five customer candidate sites across three customers:

- American Apparel (two facilities)
- Sierra Aluminum (two facilities)
- Lekos Dye and Finishing (one facility) - selected host customer

The project team also carefully evaluated various ORC system suppliers including:

- Calnetix (100-125 kW): U.S.
- Verdicorp (100 kW): U.S.
- ElectraTherm (35-75 kW): U.S.
- Rank (20 kW): Spain
- Enogia (20 kW): France – selected supplier

Lekos, the selected host site, operates their plant 24 hours a day for six days a week. The boilers run continuously with the steam load varying throughout the day. As such, the project team was only able to take spot measurements and estimate average operating conditions, specifically boiler flue temperatures and flow rates. Spot check of flue gas temperatures and flow rates indicated that there was sufficient waste heat to produce at least 10 kW from the ORC system – and not much more. Therefore, during system design, the team did not anticipate the risk of overheating or the need to control the amount of waste heat that the boilers were delivering to the system.

The design, installation, and integration of the ORC system with the industrial plant was completed. However, during commissioning, the ORC system had to be shut down because the temperatures in the hot loop exceeded system tolerances. The project team identified a solution to control the amount of waste heat delivered to the hot loop, to be funded in a future phase of work. As a result, no data was collected over any meaningful period of time beyond commissioning due to the risk of damaging the ORC due to excessive heat.

Key Results

The ORC demonstration project introduced numerous complexities that were not anticipated nor budgeted for. It took considerably more time than expected to select a host customer due to several reasons including the first site ending operations and closing the facility (American Apparel). In addition, the top two ORC suppliers (Calnetix and Verdicorp) dropped out of consideration during waste heat evaluation at the preferred customer facility (Sierra Aluminum). The project was temporarily shut down due to the COVID-19 pandemic. Finally, the ORC system was damaged during initial start-up and required international shipment back to the supplier (Enogia in France) for repairs. These factors resulted in additional costs and schedule delays, which were not anticipated nor accounted for in the initial project schedule and budget estimates. Despite these challenges, the project team was able to complete installation, start-up, and commissioning of the ORC system at the selected customer site, Lekos Dye and Finishing, located in Rancho Dominguez, CA.

Enogia technicians traveled from France to Lekos for final inspection, start-up and commissioning which were completed November 6-7, 2022. During commissioning, the ORC generated 11.3 kW of electric power on boiler low-fire. During boiler high-fire, the hot loop unexpectantly overheated and, as a result, the project team had to suspend system operations. The project team concluded that the Hurst boiler, the primary source of heat, was operating on high fire (or close to operating maximum capacity) most of the time. There is much more captured waste heat from the Hurst steam boiler than projected. Given the likelihood of overheating the hot loop and risking damage to the ORC system again, the ORC is not able to run continuously until such time that a hot loop temperature control system is designed and installed. Therefore, data collected from this project is limited to that which was measured during start-up and commissioning, as reported by Enogia in its commissioning report. As a result, some project metrics were not able to be completed.

Further work is needed in order for the ORC to operate continuously. The project team recommends a future phase which would include design and installation of a robust flue gas diverter control system to regulate the amount of waste heat delivered to the hot loop. This would prevent overheating of the hot loop and allow the ORC to run continuously. If this approach is funded, the project team would like to collect data over a three-month period in order to document the performance, benefit, and value to Lekos as well as other potential industrial customers with available low-grade waste heat.

Knowledge Transfer and Next Steps

The project team completed the following technology transfer activities of the ORC demonstration project to various key stakeholders:

- Host site (Lekos) visits – various meetings with SoCalGas, a key stakeholder, were scheduled at the host site.
- Presentation to Larta Institute – Larta is a virtual accelerator that provides commercialization and tech-to-market assistance for startups and other developers of emerging technologies throughout the U.S.
- Outreach with other potential industrial customers – the project team reached out to various industrial customers who expressed an interest in ORC system technology. These customers include American Apparel in Garden Grove and Sierra Aluminum in Fontana.
- Past and present ORC manufacturers and service providers – the project team met with several ORC equipment suppliers and service providers during the project planning process.
- Project developers and engineers – the project team reached out to a number of engineers, contractors and developers of Combined Heat and Power projects.
- Natural gas and electric utilities and/or energy providers – in addition to SoCalGas, the project team reached out to Southern California Edison regarding the potential merits of ORC systems.

The project team recommends further research in order to document the value that the ORC system is providing to Lekos that, in turn, can help illustrate its potential value to other industrial customers.

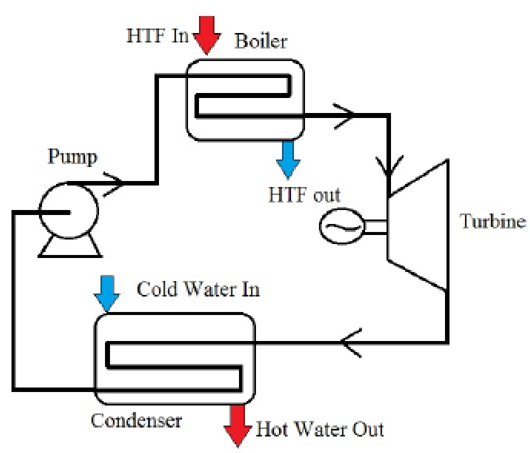
CHAPTER 1: Introduction

The majority of industrial facilities in California generate waste heat as part of their manufacturing processes. Many industrial customers have already discovered and adopted strategies to capture and convert high-temperature (e.g., >800°F) waste heat streams into useful products such as steam or electricity through a combined heat and power (CHP) system; however, it is more challenging to economically capture and utilize low grade waste heat (e.g., <500°F), which is typically rejected and lost to the environment.

Organic Rankine Cycle (ORC) technology is able to capture and convert low grade waste heat to electricity. ORC systems use organic working fluids, which change phases at much lower temperatures than water. More sophisticated heat capture methods can provide industrial and agricultural facilities with the ability to capture low-grade waste heat to drive an ORC system and produce electricity. On-site generation of electricity from waste heat has the potential of reducing 1) operating costs, 2) electricity demand, 3) criteria pollutants and 4) greenhouse gas emissions. However, the proposed ORC technology has not yet been extensively tested and proven in industrial applications in California to provide meaningful projections of performance and cost benefits such as payback time and return-on-investment.

ORC is a type of thermodynamic cycle. It is a variation of the Rankine cycle named for its use of an organic, high-molecular-mass fluid whose vaporization temperature is lower than that of water. The fluid, usually a type of refrigerant, allows heat recovery from lower-temperature sources such as biomass combustion, industrial waste heat, geothermal heat, solar ponds, etc. The low-temperature heat is converted into useful work that can itself be converted into electricity. Figure 1 illustrates a simple ORC system cycle.

Figure 1: Organic Rankine Cycle (ORC) System Cycle



Source: Researchgate - Sharma, Manish & Dev, Rahul. (2015). WORKING FLUID SELECTION FOR LOW TEMPERATURE ORGANIC RANKINE CYCLE.

The working principle of the Organic Rankine Cycle is the same as that of the Rankine cycle: the working fluid is pumped to a boiler/heat exchanger where it is heated, passed through an expansion device (turbine, screw, scroll, or other expander), and then through a condenser heat exchanger where it is finally re-condensed. The expander when coupled to a generator produces electricity. In the ideal cycle described by the engine's theoretical model, the expansion is isentropic (equal or constant entropy) and the evaporation and condensation processes are isobaric (equal or constant pressure).

The goals of this project were to:

- Demonstrate through proof-of-concept the design and operation of the ORC system to generate electricity on-site at an industrial facility. On-site generation of electricity will reduce the cost of electricity purchased from the utility grid, reduce electric demand on the grid, and reduce emissions of criteria pollutants and greenhouse gases associated with the generation of electricity for the grid.
- Advance industry understanding on best practices for design, integration, sizing, and installation of such systems to achieve cost-effective on-site electricity generation.

The purpose of this project was to test and demonstrate an innovative application of an integrated waste heat recovery system at an industrial host site (in this case, a textile plant) that captures low-grade waste heat to drive an ORC system. This application will advance the understanding of the technical and economic feasibility of this technology to cost effectively generate on-site electricity by recovering waste heat at industrial facilities. While this project was a proof of concept, the following benefits could help drive market adoption of ORC systems in California:

- Greater economic and environmental benefits through both recovery of wasted energy as well as clean generation through coordinated operation of clean energy components to support power and market systems, particularly during peak times when the grid is stressed or prices are high.
- Lower operating costs by capturing available waste heat and producing hot water to drive an ORC turbine and generate electricity without the need for additional natural gas. The project will help determine equipment configurations which could produce electricity at a lower cost than grid-purchased power. This project will also help validate methods to capture and use low-grade waste heat.
- No safety risk as ORC uses principles similar to a refrigeration cycle and steam generation at far lower temperatures and pressures than required for steam driven turbines, eliminating the need for certified operators and extensive maintenance procedures.
- Potential for additional employment in disadvantaged communities from widespread adoption of ORC systems, particularly those with a high concentration of industrial facilities.

To evaluate the success of the project, the team planned to assess overall system performance in terms of reduction in annual energy use and CO_2 emissions, translating into annual cost savings. These performance metrics would help evaluate the cost-effectiveness and beneficial impacts of ORC systems for industrial customers which produce low-grade waste heat (e.g., <500F).

CHAPTER 2: Project Approach

To demonstrate a proof of concept the project team structured the following project plan:

- Evaluate/Select Host Site
- Select ORC Supplier
- Complete Design, Prepare Construction Drawings
- Install and Commission ORC System
- Collect Performance Data
- Prepare Final Report

Evaluate/Select Host Site

The project team spent considerable time identifying and vetting several potential customer host sites beginning with the initial selection of American Apparel. The project team conducted detailed waste heat evaluations on three potential customers:

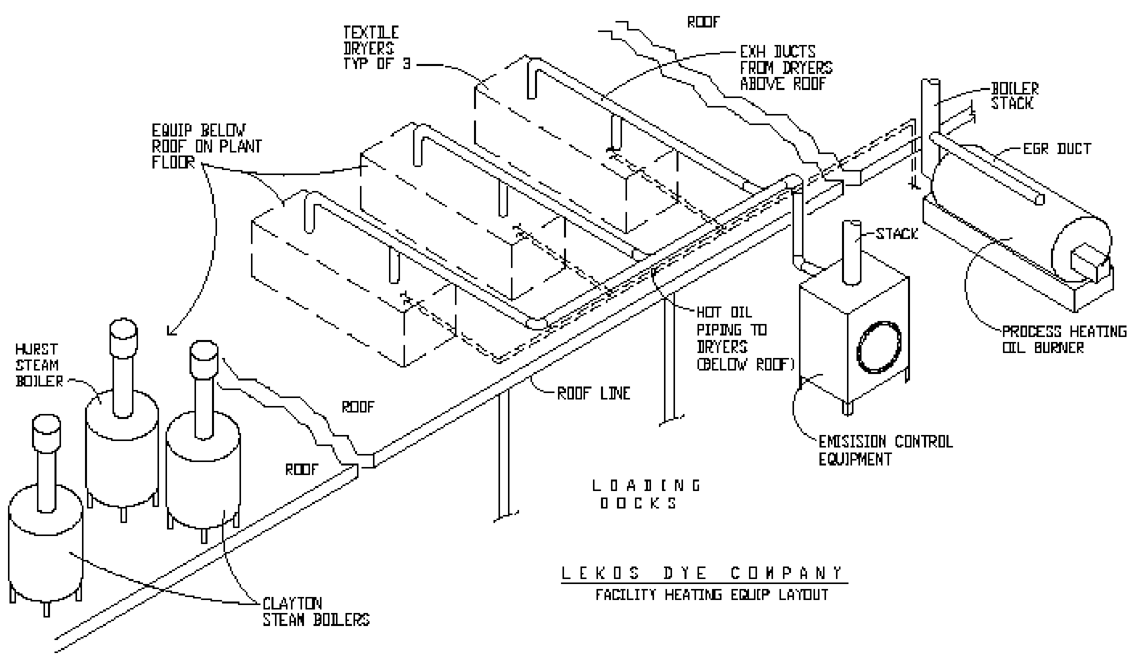
- **American Apparel:** conducted evaluations on two facilities in Hawthorne and Garden Grove. During this process, American Apparel filed for bankruptcy and was subsequently purchased by Gildan who began cutting costs. It was not clear whether the new owners would be interested in the project and/or relocate operations to another state. Consequently, the team elected to look elsewhere.
- **Lekos Dye and Finishing:** this customer was eager to serve as host customer right from the beginning. Lekos provides fabric dyeing services, using natural and synthetic fibers in open and tubular finishing, for a variety of clothing line customers. The company generally operates two to three working shifts per day, five days a week. The project team initially believed that there was adequate waste heat available from the dryers and boilers to drive a 100 kW ORC system. The customer signed a letter of intent regarding its willingness to contribute $50,000 to the project. Subsequently, however, spot temperature measurements of the dryers indicated that available waste heat was significantly less than predicted and not adequate to drive a 100 kW ORC system. Therefore, the project team began searching for another customer with higher waste heat potential.
- **Sierra Aluminum:** this customer was very interested in the technology/project and had plenty of waste heat from a process heater running continuously to drive a 100 kW ORC system, confirmed by two weeks of data logging.

In the midst of waste heat evaluation work at Sierra, our two primary 100 kW ORC suppliers suddenly dropped out of contention for various reasons (explained further in the next section of this report). Ultimately, Sierra Aluminum dropped out of the project because of concerns regarding the transfer of equipment title at the end of the project and, subsequently, lost patience altogether because of the lack of progress in identifying a suitable ORC supplier.

The project team searched for a smaller, 20 kW ORC system that was suited for Lekos who was still interested in the project. Available waste heat from both the American oil heater and new Hurst steam boiler at the Lekos site appeared to be a good fit for a 20 kW ORC system. Lekos Dye and Finishing is located at 3131 E. Harcourt Street, Rancho Dominguez, CA 90221.

Lekos had three large textile dryers, one heating boiler (with oil as heat transfer fluid) and three steam boilers, each with a potential for waste heat recovery. However, it was not feasible to install heat exchangers in the dryers as flue gas temperatures were less than 225 degrees F and exhaust from the dryers contained lint material that could clog up heat recovery coils. Two smaller steam boilers did not have sufficient capacity to justify installation of an expensive heat exchanger on the flue gas stack. On the other hand, there was sufficient waste heat from the American heating boiler and the newly acquired Hurst steam boiler to drive an ORC system. The schematic in Figure 2 shows the existing equipment layout and configuration prior to purchase and installation of the Hurst boiler.

Figure 2: Facility Heating Equipment Layout



Source: Occidental Analytical Group

Figure 2 shows one process heat boiler (American boiler) that circulated a thermal oil and three smaller steam boilers. During the project scoping exercise, Lekos made changes to its operation. The smaller boilers were relegated to standby operation, a new emission control system was installed and a new 550 HP Hurst boiler was ordered and subsequently installed close to the American boiler. The project team designed and installed heat recovery units for the American oil heater and Hurst steam boiler. All electricity generated by the ORC system was to be used by the facility.

Table 1 summarizes spot temperature measurements of the dryers and various boilers at Lekos collected by SoCalGas and the South Coast Air Quality Management District (SCAQMD).

Table 1: Spot Temperature Measurements

Lekos Dyeing & Finishing					
Spot Check by SoCalGas					
Boiler/Heater		**American Heating Boiler**		**Hurst Steam**	**Clayton Steam**
Measured		**Before EGR**	**After EGR**	**Boiler**	**Boiler**
Average Flow	cfm	3,262	2,470	1,215	2,060
Average Temperature	degF	469	449	327	250
Max Temperature	degF	472	453	329	256
SCAQMD Source Test Reports					
Measured		**EHWA Drying Oven**	**Hurst Steam Boiler**	**American Heating Boiler**	
Average flow	cfm	4860	1172	1818	
Average temperature	degF	276	314	N/A	

Previously, Lekos used the two smaller steam boilers to meet the plant steam load. The Hurst boiler is now being utilized as the primary steam source. Flow rate measurements between SoCalGas and SCAQMD differed by 24% for the American oil heater but were less than 5% for the Hurst steam boiler. Fluctuating demand for heat/steam is likely the cause of differing readings.

Select ORC Supplier

Calnetix

Calnetix, located in Cerritos, California, sells and services its Thermapower™ ORC systems under its subsidiary, Access Energy. Target markets include industrial, solar thermal, geothermal, incineration, oil and gas production and fuel cells. The Carefree Integrated Power Module™ (IPM) is the main component of the closed loop waste heat recovery system that utilizes heat input with temperatures of 180°F (82°C) or higher to generate up to 167 hp (125 kW) of electricity, and this feature differentiates Access Energy from all other waste heat recovery systems. The Access Energy system consists of a high-speed turbine expander and three proprietary technologies from Calnetix – a high-speed permanent magnet generator, low loss magnetic bearings, and power electronics – in one sealed unit. The Thermapower unit is controlled by an advanced programmable logic controller (PLC), with proprietary control algorithms. This allows for optimal heat utilization at widely different heat source conditions.

Magnetic bearings were chosen for this application because of their high reliability, long life, and ability to operate directly in the working fluid refrigerant without lubrication.

Calnetix was the team's top choice for this project. It had multiple units in the field and offered to sell a unit to the project team at a reasonable price. As the team was conducting waste heat evaluation at Sierra Aluminum, Calnetix decided suddenly to exit the North America market and concentrate exclusively on oil and gas markets in Asia. Therefore, the project team turned its attention to a backup supplier, Verdicorp.

Verdicorp

Verdicorp, located in Florida, offered an oil-free 100 kW ORC system with magnetic bearings. This supplier was attractive to the project team because the proposed system cost was much less than Calnetix. However, the big disadvantage was this supplier resembled a start-up with just a few units operating in the field. During waste heat evaluation with Sierra Aluminum, the company ran out of cash and was subsequently acquired by Multistack, a supplier of high efficiency chillers. The project team determined that Verdicorp was no longer a viable option for this project. The project team considered one last supplier in the 100 kW size class: ElectraTherm.

ElectraTherm

ElectraTherm, located in Flowery Branch, Georgia, manufacturers the BITZER POWER MODULE75 semi-hermetic twin screw expander/generator that can operate on low-quality heat as low as 70°C (158°F), a remarkably low temperature. The system is capable of generating up to 75 kW of electricity. ElectraTherm's patented ORC design represents a dramatic change from radial or axial turbine technologies, providing a more cost efficient, robust design with no shaft seal between the expander/generator combination, greatly enhancing reliability. However, the cost of the ElectraTherm system far exceeded the budget of the project and, thus, was dropped from consideration. The project team re-grouped and decided that it needed to search for a smaller, modular ORC system from a reputable supplier – U.S. or global.

Enogia and Rank

Two potential 20 kW ORC suppliers were identified, both in Europe: Enogia in France and Rank in Spain. Both companies produce smaller, 20 kW ORC systems and expressed interest in serving the needs of the ORC demonstration project. Enogia was ultimately selected as the preferred 20 kW ORC system supplier due to lower cost and greater field experience with multiple units operating in the field. Enogia featured a reliable, airtight, high-speed microturbine, offering the largest range of small ORC systems on the market, with modules rated from 10 kW to 180 kW. Enogia ORC systems can operate using waste heat as low as 70°C (158°F) and as high as 120°C (248°F). The working fluid of the Enogia ORC system is refrigerant R1233zd.

Finding customers with sufficient waste heat needed to operate an ORC system at or near full capacity of a 100 kW system was more difficult than anticipated because of technical, engineering, and cost issues. Smaller, 20 kW ORC systems will likely have greater appeal to a larger number of industrial customers in California.

Preliminary calculations from flue gas spot temperature measurements at Lekos suggested that waste heat from the American heating boiler and Hurst steam boiler could potentially produce 8-10 kW using an Enogia ENO-20LT ORC system, which is about 50% of its rated capacity. Continuous data logging could have more accurately verified the available waste heat over a period of time (e.g., one week) but that step was not taken due to schedule and budget constraints.

Proposed System Configuration:

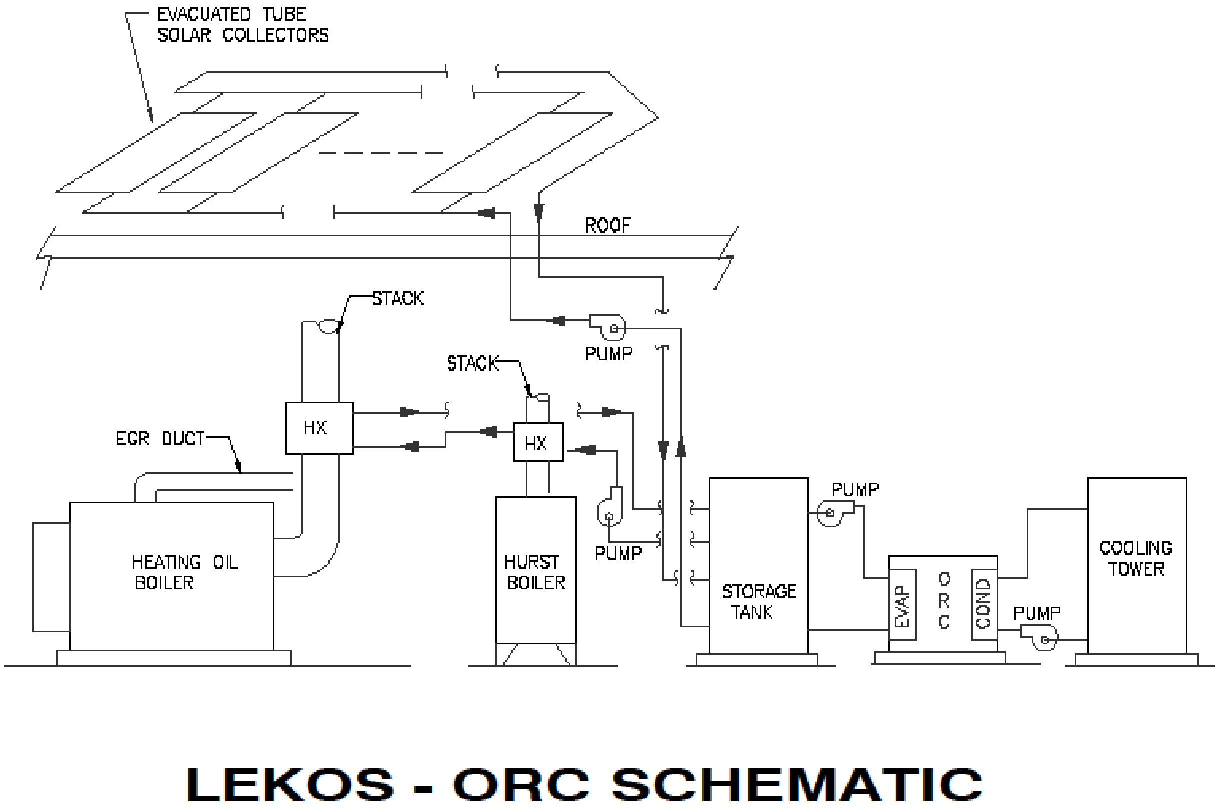
- Enogia 20 kW ORC system
- Heat exchangers in the American and Hurst boilers
- Cooling tower
- System integration, controls, electronics, electric intragrid interconnection
- Projected customer benefits: 10 kW electricity production 8 hours/day on average. Annual savings projection: 10 kW x 8 hours/day x 5 days/week x 50 weeks/year x $0.12/kWh = $2,400/year. (Note: company operations shut down two weeks each year for holidays.)
- System maintenance: to be determined

Complete Design, Prepare Construction Drawings

Project design was a challenge due to space limitations and continuous plant modifications by Lekos plant operations personnel. This required the project team to modify the equipment layout on multiple occasions. The project team also had to provide adequate structural support to the heat recovery coils for each boiler flue stack, which were close to the building outside wall. Therefore structural platforms had to be designed to support the high weight stainless steel heat recovery coils.

The design team specified a single 3” hot water pipe loop that branched out to each heat recovery coil, powered by a 5 HP 3500 RPM pump that is applicable for high temperature water. An expansion tank was designed with nitrogen in order to maintain fluid level and pressures since the temperature and pressure were high. The ORC cold loop required a cooling tower to reject the heat, powered by a 3 HP pump. The schematic design of the system is shown in Figure 3 below.

Figure 3: ORC Schematic



Source: Occidental Analytical Group

The schematic incorporates two elements in the design that were eliminated due to cost and other considerations. The first is a 1,000-gallon storage tank, which was going to be difficult to install as the plant engineer reserved whatever available space for future use. The second was a solar thermal system if needed to permit operation of the system during low steam demand and during weekend shutdown. Again, due to cost considerations, both options were eliminated. Design work and construction drawings are included in Appendix A.

The proposed deployment plan provided a roadmap to ensure that system design, permitting, construction and commissioning activities proceeded in a smooth, straightforward manner with no surprises and managed expectations. Elements of the deployment plan were as follows:

A. Ensure SoCalGas/Customer Acceptance of Proposed Project Configuration
B. Preliminary Selection of ORC System (e.g., Enogia ENO-20LT), UL (Underwriter Laboratories)/CSA Certification
C. Verification of Waste Heat Availability
D. Provide Preliminary Engineering Configuration, Bill of Materials, Cost, etc.
E. Apply for Electric Utility Interconnection – This was not done as electricity generation was low compared to site demand
F. Complete Engineering Design and Construction Drawings
G. Solicit Construction Bids, Pending Final Permits
H. Obtain Permit from L.A. County Building and Safety Department

I. Select Contractor, Schedule Work
J. Commission System and Collect Data for up to 12 Months
K. Customer Acceptance or System Removal
L. Final Report

A brief description of the plan for each step is described below:

A. Customer Acceptance of Proposed Project Configuration: ensure that SoCalGas and Lekos understand: 1) the proposed scope of work, 2) potential use of the ORC system manufactured in Europe, 3) performance expectations, 4) customer benefits, and 5) project risks.

B. Preliminary Selection of ORC System (e.g., Enogia ENO-20LT): the Enogia ENO-20LT generates up to 20 kW net electricity output, which should be suitable for the target customer, Lekos. Another important consideration is that the Enogia ORC system must achieve UL/CSA certification prior to installation at Lekos. Note that UL/CSA certification, led by CSA Group a standards organization, was not pursued. This step will be completed in the next phase of work, pending funding availability (discussed further in this report).

C. Verification of Waste Heat Availability: install data logging equipment to verify the waste heat potential for all combustion sources and suitability of the Enogia 20 kW ORC system and/or whether a solar thermal system is needed to provide supplemental heat so that the ORC system can operate at maximum system capacity. Ultimately the project team did not have the time and budget to complete this critical task. This step will be completed in the next phase of work, pending funding availability (discussed further in this report).

D. Preliminary Engineering Configuration: prepare a preliminary system design that includes a P&ID (Piping and Instrumentation Drawing), Bill of Materials and estimated installation cost.

E. Electric Utility Interconnection: use the preliminary engineering drawings as a basis for applying for an interconnection agreement on behalf of the customer with SCE. This step will be completed in the next phase of work, pending funding availability (discussed further in this report).

F. Engineering Design and Construction Drawings: construction drawings were prepared to request proposals for structural, mechanical, electrical and controls work.

G. Construction Bids, Pending Final Permits: issue a competitive Request for Proposal and solicit construction bids from qualified general contractors. Final selection of a general contractor will be based on criteria developed by the project team, with input from the customer.

H. Selection of Contractor, Schedule Work: the project team will make a final selection on the winning General Contractor and establish a construction schedule in harmony with the customer in order to minimize disruption to operations and ensure a smooth integration process.

I. System Commissioning, Collection of Data: the ORC system will be commissioned for start-up to ensure that everything is working as designed, the equipment is meeting performance specifications and the customer is satisfied. Data will be collected for several months to monitor overall system performance and serve as a basis for the final report. As discussed previously, the ORC system was successfully commissioned but could not run continuously because of overheating of the hot loop. System control upgrades are required which will be completed in the next phase of work, pending funding availability (discussed further in this report).

J. Customer Acceptance or System Removal: at the end of the project term, the customer will have the option of either keeping the equipment, or ask the project team to remove and restore the site to its previous condition. The latter scenario could be expected if system performance did not meet expectations and/or the customer was not satisfied at all with the ORC system. The customer chose to retain the equipment and interested in the next phase of work, provided that additional funding is secured to enable the ORC system to run continuously.

K. Final Report: a final report will be prepared, summarizing the history of this project, challenges and lessons learned, findings, conclusions, and recommendations.

Figure 3 provides a schematic on how the ORC system is integrated with the Hurst steam boiler and American oil heater (that was subsequently retired from service). The solar array was added as a possible addition to the project if additional thermal heat was required at a later date.

Install and Commission ORC System

The project team contracted Maintech Resources to install the ORC system per construction drawings and specifications. Construction work was completed in September 2019. Initial system commissioning was attempted in November 2019 with the benefit of on-site Enogia technicians who traveled to the U.S. earlier but system testing was terminated because of damage to the ORC system caused by: 1) excessive water temperatures in the hot loop, which damaged the ORC turbine wheel and bearings, and 2) small particles of dirt (likely from the iron pipe), which plugged the ORC internal heat exchanger.

The ORC equipment was disconnected and shipped to Enogia in France for repairs (post COVID) in late 2021. Enogia completed necessary repairs and shipped the ORC system back to Lekos in June 2022. Testing, start-up and commissioning were completed early November 2022.

Collect Performance Data

Minimum operating temperature to start the Enogia ORC system is about 175° Fahrenheit (79° Celsius) and the maximum allowed temperature of the hot loop is about 250° Fahrenheit (121° Celsius). Enogia also verified that the project team could start the system with a hot side water flow rate of 35-40 gallons per minute (gpm) instead of the designed flow rate of 100 gpm. The project design team deferred decisions, due to schedule and budget issues, on whether to: 1) upgrade the hot side pump from 5.0 HP to 7.5 HP, 2) replace pressure restricting valves with lower pressure options, or 3) both in order to achieve the target flow rate of 100 gpm.

The ORC system generated 11.3 kW when the Hurst boiler was operating on low-fire, where the boiler is operating at the minimum input when demand is reduced. The hot loop over-heated when the boiler was operating on high-fire (during maximum plant heat load) and, as such, the ORC had to be shut down as the project team had no means to control the amount of waste heat delivered to the hot loop. As such, the project team was not able to collect operating data over an extended period of time. The project team recommended design and installation of a new, automated hot loop temperature control system. However, there was no remaining budget and so the team had to close out the project. The project team will continue to work with the customer to obtain funding for system modifications so that the ORC system can operate continuously.

Prepare Final Report

The project team prepared and submitted a final report for this project.

CHAPTER 3: Results

Supporting project milestones, metrics and outcomes are summarized in Table 2 below:

Table 2: Key Tasks/Milestones

Key Task/ Milestone	Metric	Outcome
Select host customer site	Customer host selected	Complete. Carefully screened five customer facility sites before selecting Lekos Dye & Finishing
Select ORC system supplier	ORC system selected	Complete. Calnetix and Verticorp dropped out of project; selected Enogia 20 kW ORC system
ORC system design	Construction drawings	Complete
Control system design	Project team approval	Complete. However, need auto control system to prevent over-heating of hot loop
Installation & commissioning	Successful start-up and system commissioning	Complete. ORC system damaged during initial start-up; after repairs, completed final start-up and commissioning. ORC system produced 11.3 kW but not able to run continuously.
Data monitoring	Data acquisition system (DAS) functional. Calculated energy and operating cost savings, reduced emissions	Incomplete. DAS is functional but ORC system is not operating continuously. Energy, operating cost savings, and reduced emissions are estimates.
Evaluate benefits	Determine cost-effectiveness and overall impact	Incomplete due to lack of performance data since ORC system cannot operate continuously.

The project team completed system design, installation, start-up and commissioning of the ORC system at Lekos. However, during the first round of commissioning, the hot loop overheated during initial start-up and that consequently damaged the ORC turbine and bearings. In addition, particulates inside the carbon steel pipe eventually made their way into the ORC system and clogged the evaporator coil. A decision was made to shut down and repair the ORC system. However, scheduled repairs were delayed by almost two years due to the Covid pandemic and ocean shipping logistical issues.

The ORC system was disconnected, packaged in shipping crates and shipped to Enogia in France for repairs in Q4-2021. Repairs were completed in the first half of 2022 and the equipment was shipped back to Lekos in June 2022. In August-September, 2022, the project team completed mechanical and electrical connections and completed pre-commissioning work with Enogia participating remotely. Upon recommendations of Enogia, the project team also selected, designed and installed a pipe filter in the hot loop in order to trap debris to eliminate the risk of clogging up the ORC evaporator.

It should also be mentioned that Lekos retired the American oil heater in Q1-2022, thus removing a second source of waste heat for this project. The ORC system is now relying on only one source of waste heat from the newer Hurst steam boiler. It was initially unclear to the project team whether the waste heat from the Hurst boiler would be sufficient to reach the baseline target electric power production of 10-12 kW. We know now that the Hurst boiler is able to provide sufficient waste heat to produce greater than 11 kW of power.

System start-up and commissioning work, with Enogia technicians on-site, was completed from November 6-7, 2022. The ORC system was able to produce 11.3 kW electricity for a short period of time with the boiler on low-fire. When the boiler was on high-fire, the temperature of the hot loop exceeded ORC system tolerances and the system had to be shut down. Waste heat captured from the Hurst team boiler and delivered to the hot loop was higher than expected. The project team realized that a modulating diverter system was needed for the Hurst boiler flue gas to control the amount of waste heat delivered to the hot loop that would enable the ORC system to run continuously. For safety purposes, the ORC was shut down after successful commissioning until such time as a modulated diverter could be installed to avoid damage to the ORC.

Data Collection

The Enogia ORC system produced 11.3 kW of electricity for a short duration while the Hurst boiler was on low-fire. Additional data is planned to be collected in the future after a suitable hot loop temperature control system is designed and installed so that the ORC system can operate continuously.

Enogia prepared and delivered a system commissioning report which concluded that the ORC system is functional. All ORC components were checked (pump, sensors, turbine, electrical components, actuator) and did not show any fault or default. The Enogia team installed remote sensing and control capabilities. The ORC system was started and electrical production of about 12 kWe was recorded. Enogia also recommends that the cold loop piping be reversed to achieve counter-flow heat exchange to help optimize system performance. Finally, Enogia recommends that the ORC system not run continuously until a hot loop temperature control system is designed, installed and tested.

Recommended Next Steps:

- Design and install a means to monitor and control the amount of waste heat delivered to the hot loop that enables the ORC system to operate continuously. For instance:
  - Hot loop radiator
  - Automated, modulating boiler stack diverter system, controlled by the hot loop water temperature

- Reverse the cold loop pipe connections to achieve counterflow heat exchange for optimal performance and effectiveness (per Enogia).
- Implement a water treatment control system/schedule for cold and hot loops (e.g., rust-inhibitor).

System Start-Up and Commissioning

During initial start-up in Q4-2019, the ORC system was subjected to excessive temperatures from the hot loop that exceeded tolerances. Enogia remotely determined that the ORC system suffered damage and needed repairs. Higher than expected hot loop temperatures damaged the turbine and particulates from the hot loop pipe plugged the system evaporator. After Covid, the project team regrouped and a decision was made to remove and ship the ORC system to Enogia headquarters in France for repairs Q4-2021 rather than fly technicians to California with limited number of spare parts. Here are details on what happened:

- Disconnected ORC equipment at Lekos:
    - ORC system:
        - West Coast Piping Services disconnected four spool pieces (flange connectors) from the ORC system, two for the 'hot loop' and two for the condenser loop. Installed temporary steel pipe supports to keep existing pipelines safe. Installed four 3" carbon steel blind flanges to cap off the valves and four new PN16 blind flanges for the ORC system to protect the connectors during shipping.
        - Berokoff Electrical disconnected electric power cables, conduit and conductors from the Power Conditioner unit.
    - ORC power conditioner: Berokoff Electrical disconnected all electric power cables, conduit and conductors, carefully labeling everything for reinstallation at a later date.
- Transported equipment to shipper: Lekos maintenance crew, with assistance from the mechanical and electrical contractors, carefully and skillfully hoisted the ORC system and power conditioner boxes via forklift onto a flatbed truck for transportation to D&S Export and Packing in Santa Fe Springs, California, on September 20, 2021.
- Prepared equipment for shipping: D&S removed the two pieces of equipment from the flatbed truck and fabricated shipping containers for both, verifying physical dimensions and the weight of each for loading onto the shipping vessel.
- Shipped ORC equipment to Enogia headquarters in France: Enogia shipper picked up the two shipping crates from D&S Export and Packing on October 11, 2021, and loaded them onto a shipping vessel in the Port of Long Beach. The equipment finally arrived at Enogia headquarters on January 28, 2022.
- Retirement of American oil heater: During the first half of 2022, Lekos retired and removed the American oil heater from service, leaving only one waste heat source for

the ORC system, the Hurst steam boiler. The project team was concerned that the waste heat from the Hurst boiler would be inadequate to meet the target electricity production rate of 10-12 kW. As it turned out, it was more than adequate.

- ORC System Diagnostics and Repairs: Repairs were more extensive than expected, based on the results of system diagnostics.
    - ORC turbine/bearings were damaged and had to be replaced due to excessive heat exposure (hot loop temperature reaching 140°C in some cases).
    - Evaporator was found to be plugged with black particles (rubber or otherwise), which would impact system performance and potentially result in component failure in due time. The evaporator system supplier was able to successfully wash out the debris at a much lower cost, thus avoiding the need to replace another expensive component.
    - Enogia took the opportunity to replace/upgrade numerous sensors, controls and the PLC in order to improve reliability and system durability.
    - Enogia technicians reassembled the ORC system and operated the unit for a total of 14 hours in the lab at full capacity, producing 20 kW of continuous power.
- Shipment Back to Lekos: Enogia repackaged the ORC system and power controller in shipping crates and air freighted both to the U.S. The equipment arrived at Lekos on June 13, 2022.
- Customer Site Inspection: West Coast Piping Services visited Lekos on July 11, 2022, to plan for reinstallation that was scheduled for July 14, 2022. During the site visit, a discussion ensued on the need to filter the hot water inlet pipe in order to prevent debris from entering the ORC system once connected to the piping. Representatives from West Coast Piping Services recommended that the team install a pipe strainer to trap unwanted debris. It was agreed that West Coast Piping Services would provide a spec sheet and cost estimate for this additional work, which they provided later in the day. It was also agreed during this site visit that the piping system should be flushed before connecting to the ORC system on July 14, 2022.
- Attempted Reinstallation of ORC Equipment on July 14, 2022: West Coast Piping Services arrived on site on July 14, 2022, at 6:00 a.m. It was quickly discovered that Lekos maintenance personnel had already removed the shipping crate of the power conditioner and set it in place. West Coast Piping Services removed the shipping crate of the ORC system and, with the help of Lekos maintenance personnel and a forklift operator, set the ORC system in its place on the concrete pad. West Coast Piping Services then removed the four blank flanges on the customer piping system and discovered black sediment that had accumulated at the end of the pipe. West Coast Piping Services said this material was likely rust from the black iron pipe and that it could be the substance that plugged up the ORC evaporator. For this reason, the project team stopped work and reinstalled the blank flanges until the black sediment problem was solved. It was important to resolve the particulate problem, flush out the pipes and add a rust inhibitor before reconnecting the piping to the ORC system. West

Coast Piping Services also recommended that the project team order new steel gaskets for the flange connectors.

- Resolution of Black Sediment: Based on the nature of the particulates that were discovered during installation, West Coast Piping Services recommended that the project team use a pipe filter instead of a pipe strainer and provided a price quote, ranging from $8,000 to $12,000 depending on piping configuration. This recommendation was approved and the project team moved forward with implementation.
- Final connection of ORC system: West Coast Piping Services returned to Lekos in September, flushed the hot loop and condenser loops to remove sediment and other unwanted particles, installed a 3” Keckley pipe filter/strainer to the hot loop and reconnected the ORC system to the hot loop and condenser loop pipes – total of four flange connections.
- Berokoff Electrical reinstalled all electrical and data control system connections.
- Precommissioning Test: Project team completed system precommissioning with Enogia on a video call by connecting a laptop to the ORC system. TeamViewer software provided Enogia with remote system access. These tests verified proper installation of:
  - The particle/pipe filter on the hot loop
  - A 3-way valve and by-pass on the hot loop
  - Wiring connections to the ORC electrical cabinet
  - Wiring connections to the Yaskawa inverter cabinet
  - Pressure and temperature sensors

  Enogia also conducted a test to ensure that the battery back-up power supply was working properly. The power supply was found to be working properly and the fuse was removed after completion of the test. One issue that was discovered during pre-commissioning: the MainsPro (protection relay) correctly displays the voltage of the three-phase power. However, the LEDs blink red instead of being fixed and green. This is probably due to a phase inversion and Enogia will fix this during commissioning.
- Plan for water treatment: the project team also met with eo-parisi, a water treatment contractor about installation of water treatment system for the hot loop and condenser loop. Eo-parisi indicated that water was the best working fluid for both the hot loop and condenser loop provided that it be treated with a rust inhibitor. A glycol mixture is not recommended for this application. The pipe filter should catch most of the particulates in the pipe. Eo-parisi submitted an estimate for this work:
  - ProMinent Fluid Controls SlimFlex5 Controller SF5: $3,250
  - 2 pumps inhibitor & biocide: $1,082
  - 2 secondary containment tanks inhibitor & biocide: $1,024
  - Installation: $3,150
  - Service: $350 per month

The project team forwarded this estimate to Mr. Daniel Lee of Lekos who indicated that Lekos will take care of water treatment for the two loops and said that he will discuss the estimate and proposed scope of work with Eo-parisi. According to Enogia, all elements of the ORC system, including pressure sensors, temperature sensors, and auxiliaries are working properly. The system was now ready for recommissioning.

- System Recommissioning: Enogia technicians traveled to Lekos the week of October 31, 2022, inspected the ORC system and completed all pre-commissioning testing November 4, 2022. System start-up and commissioning work was scheduled for and completed November 6-7, 2022. Enogia's commissioning report is included in the appendix. Summary of work performed/completed:
  - Phase-inversion electrical problem repaired on-site prior to start-up.
  - Verified that all mechanical and electrical connections to the ORC system, including installation of a pipe filter, were completed properly and in a satisfactory manner.
  - Inspected and verifyied operation of hot and cold loops. Enogia technicians recommended reversing of cold loop piping connections (e.g., inlet and outlet) to achieve counterflow of heat in order to maximize heat transfer effectiveness.
  - Completed system start-up and commissioning November 6-7, 2022. System produced 11.3 kW electricity with the boiler on low-fire.

  When the boiler was on high-fire, the temperature of the hot loop exceeded ORC system tolerances and the system had to be shut down. The waste heat from the Hurst team boiler was clearly much higher than expected. The project team recommended design and installation of an automated modulating diverter controller to modulate the amount of waste heat delivered to the hot loop, thus enabling the ORC system to run continuously. After system re-commissioning, the ORC system was shut down until such time as a modulated diverter can be installed to avoid damage to the ORC system.

Technology Transfer

The project team completed the following technology transfer activities of the ORC demonstration project to various key stakeholders:

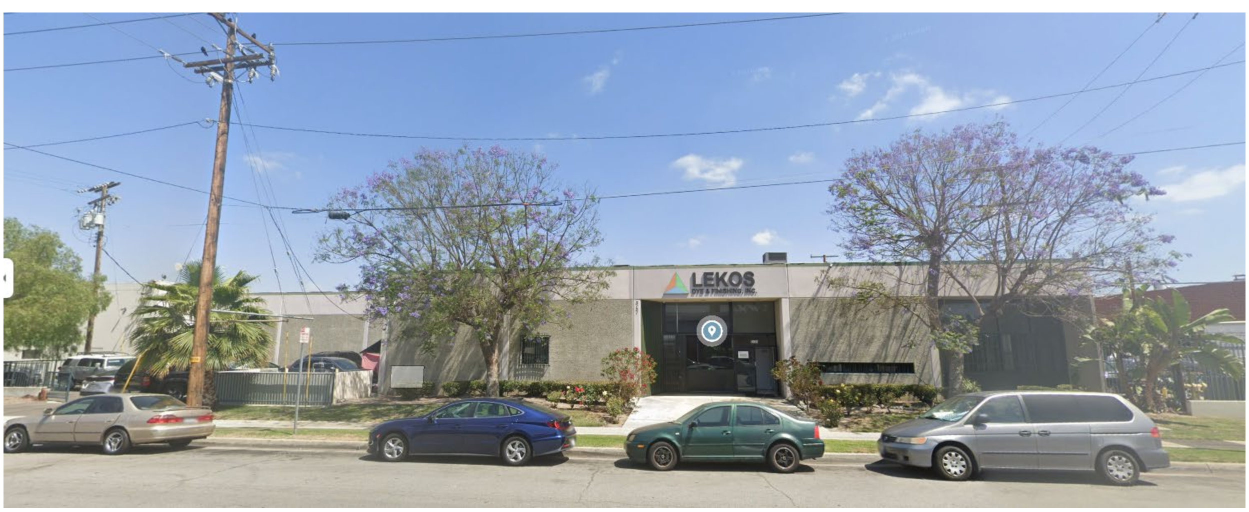
- Host site (Lekos) visits – various meetings with SoCalGas, a key stakeholder, were scheduled at the host site. SoCalGas project engineers had a chance to meet with plant operators, were provided with a plant tour, inspected key equipment components and provided input on the design and installation of the ORC system throughout the project period. SoCalGas is an advocate of this emerging technology and can help arrange visits with other prospective customers and stakeholders once the system is up and running.
- Presentation to Larta Institute – Larta is a virtual accelerator that provides commercialization and tech-to-market assistance for startups and other developers of emerging technologies throughout the U.S. Larta was provided with an overview of the technology and the demonstration project at Lekos. In the future, Larta could help

schedule host site visits for prospective customers and speak about the merits of ORC systems at various conferences and industry events once the system is operational.

- Outreach with other potential industrial customers – the project team has, as part of the project planning process, already reached out to various industrial customers who expressed an interest in ORC system technology. These customers include American Apparel in Garden Grove and Sierra Aluminum in Fontana. Both customers were enthusiastic about participating in the demonstration project but, for various reasons, Lekos was chosen as the preferred host site for this project. We plan to resume outreach with these industrial customers, along with their peers once the system is operational.
- Past and present ORC manufacturers and service providers – the project team met with several ORC equipment suppliers and service providers during the project planning process.
- Project developers and engineers – the project team reached out to a number of engineers, contractors and developers of combined heat and power (CHP) projects who were interested in the ORC demonstration project.
- Natural gas and electric utilities and/or energy providers – in addition to SoCalGas, the project team reached out to SCE regarding the potential merits of ORC systems. SCE was very interested in participating as a project sponsor but chose not to do so given that SoCalGas had already committed funding and there was insufficient time to add another funding stakeholders. SCE helped the project team to better understand grid interconnection requirements and offered a streamlined process to review the interconnection plan for the ORC demonstration project. EPRI shared lessons learned from this project with our member utilities around the United States and globally to disseminate information about the ORC demonstration project including project background, selection of ORC system and host site, issues and challenges, system performance and recommendations for how this technology can achieve widespread deployment.

Figures 4-14 are pictures of the demonstration site and ORC components.

Figure 4: Lekos Dye and Finishing, Compton, CA



Source: Google

Figure 5: Installed 20 kW Enogia ORC system and Amcot cooling tower

Source: EPRI

Figure 6: Hurst steam boiler and flue gas heat exchanger

Source: Berokoff Energy Solutions, Inc.

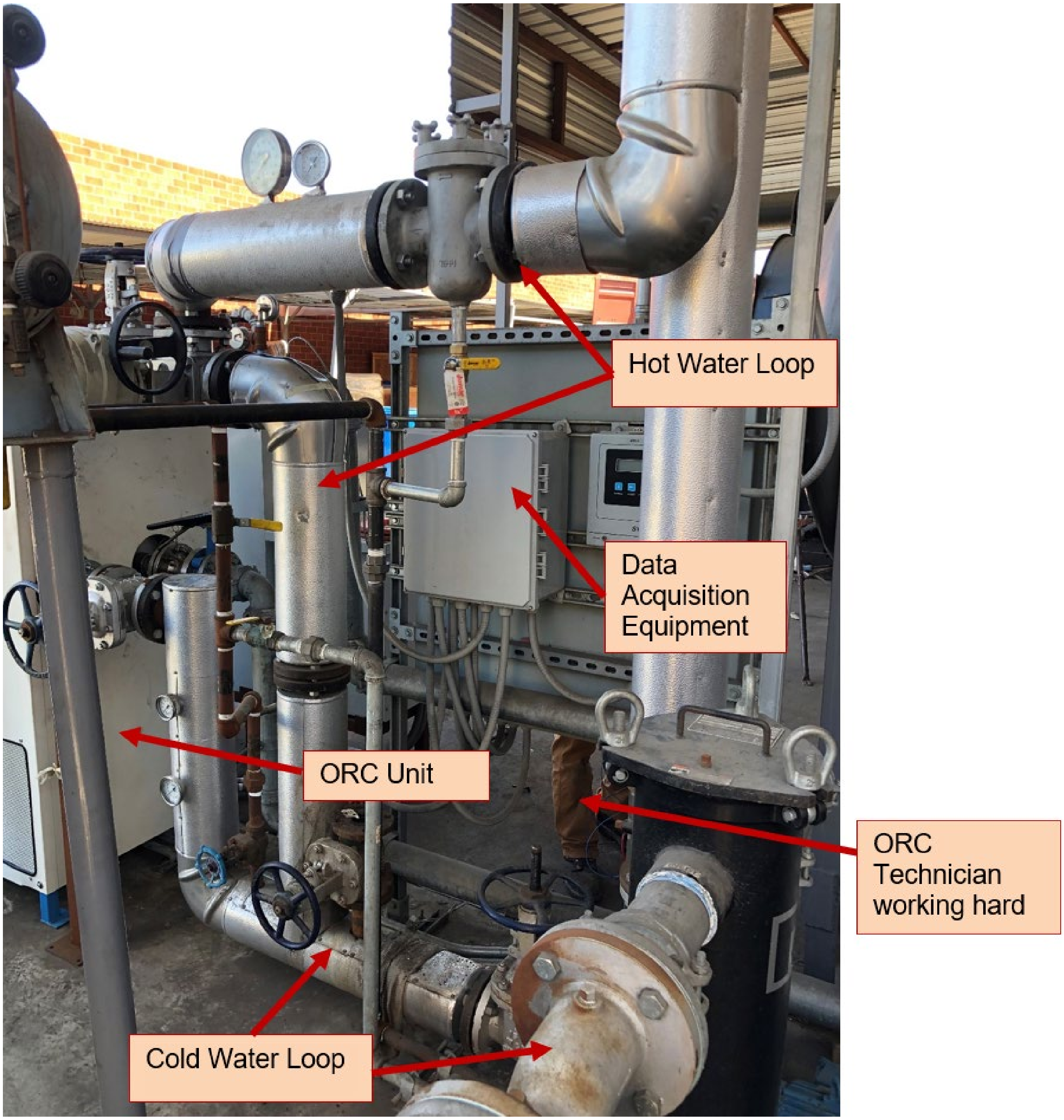
Figure 7: Originally installed American oil heater and flue gas heat exchanger (removed early 2022)

Source: Berokoff Energy Solutions, Inc.

Figure 8: Piping to and from the cooling tower to the ORC system (cold loop)

Source: Berokoff Energy Solutions, Inc.

Figure 9: ORC system piping (hot loop, pipe strainer, cold loop)

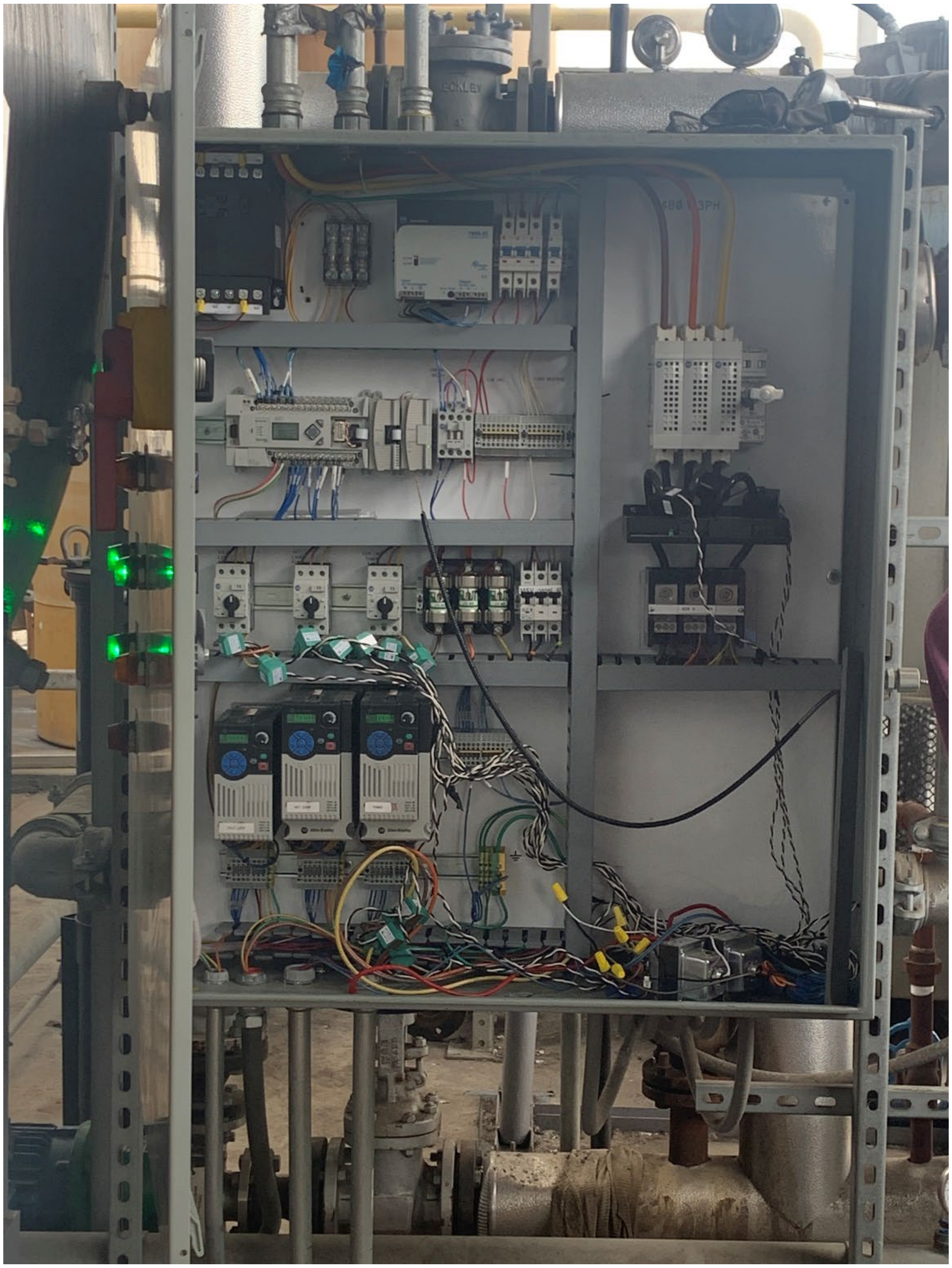


Source: Berokoff Energy Solutions, Inc.

Figure 10: Heat exchanger from the American oil heater flue gas after the unit was retired and removed from service in early 2022

Source: Berokoff Energy Solutions, Inc.

Figure 11: Data control panel

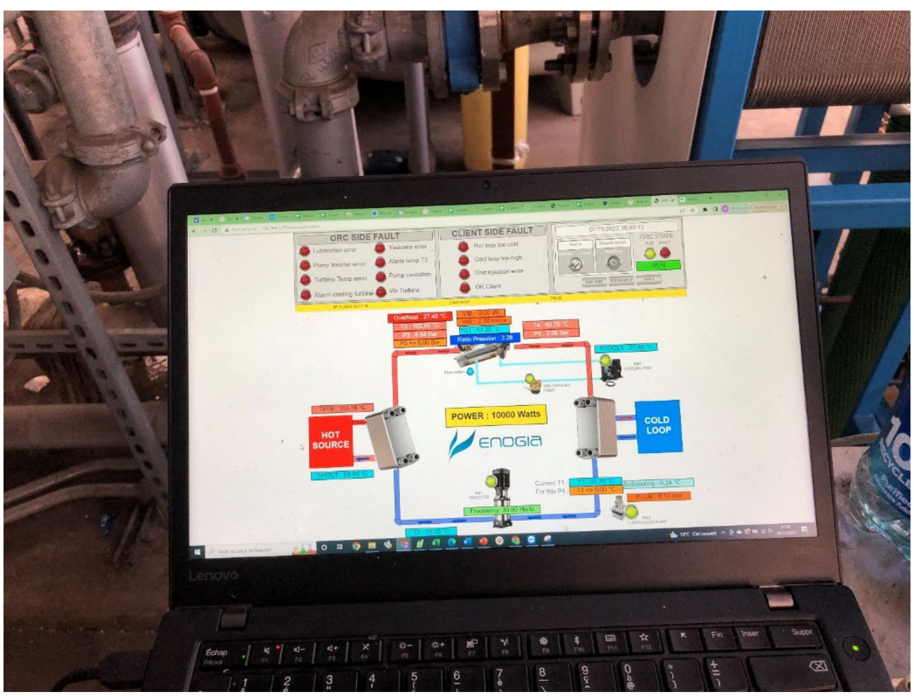


Source: EPRI

Figure 12: ORC pre-commissioning system test

Source: Berokoff Energy Solutions, Inc.

Figure 13: ORC monitoring system software (snapshot taken during start-up)



Source: Berokoff Energy Solutions, Inc.

Figure 14: ORC system during commissioning

Source: EPRI

CHAPTER 4: Conclusion

The project team was able to meet the primary project goal of demonstrating the design and operation of an ORC system to generate electricity on-site at an industrial facility. This included selection of a host site and ORC supplier, design, installation and commissioning of the ORC system. There were many lessons learned regarding best practices for design, integration, sizing, and installation to achieve cost-effective on-site electricity generation. However, the ORC system could not operate continuously under the original parameters and the project team was not able to collect and summarize performance data over a period of time. As a result, some project metrics were not able to be evaluated such as overall system performance, reduction in annual energy use/CO_2 emissions and annual cost savings. It is the author's hope that additional funding could be secured sometime in the near future to complete all remaining tasks of this project to evaluate the cost-effectiveness and beneficial impacts of small, modular ORC systems for industrial customers which produce low-grade waste heat. Future scope of work should include design and installation of a control system that can modulate the amount of waste heat delivered to the hot loop and, thus, enable the ORC system to run continuously.

This project was particularly challenged by the difficulty of finding a suitable host customer, qualified ORC system supplier, damage to the ORC system during initial start-up and of course COVID-19. These factors caused considerable delays and additional expenses to the project.

Here is a summary of key lessons learned and conclusions for consideration by other potential industrial customers:

- ORC technology offers an innovative means to capture/utilize low-grade waste heat from industrial customers.
- There are a limited number of small (<100 kW) ORC suppliers in the United States. The project team selected a suitable 20 kW ORC technology from Enogia, located in France.
- ORC technology can operate on low-grade waste heat/hot water as low as 175F.
- ORC technology can capture and utilize waste heat from numerous industrial customers with boilers/furnaces where flue gas temperatures are in the 275 – 500F range.
- ORC system cost and installation is challenging. State/utility incentives would likely be needed to help drive adoption.
- The addition of solar thermal panels could help improve system economics by supplying additional thermal heat. A technoeconomic analysis is needed to help evaluate the feasibility of this hybrid system option.
- The use of high-temperature, non-corrosive pipe materials could eliminate the risk of iron pipe sediment damaging the ORC blade wheel and evaporator.

- It is critical to maintain strict temperature controls of the hot loop in order to avoid damaging the ORC equipment. Controls must also enable the ORC system to operate continuously.
- Clear start-up and shutdown procedures are needed to ensure smooth operation, minimize equipment maintenance costs and optimize system durability.

Recommended Additional Research

The project team recommends further research in order to document the value that the ORC system is providing to Lekos that, in turn, can help illustrate its potential value to other industrial customers. Additional funding is needed from the customer (Lekos) and/or project sponsor (SoCalGas) to complete the following activities:

1. Design and install a hot loop temperature control system. Perform system testing to verify operation.
2. Reverse the cold condenser pipe connections (per recommendations of Enogia) in order to improve overall system performance.
3. Inspect/upgrade the existing data acquisition system.
4. Re-start the ORC system with Enogia assisting remotely, ensure proper operation of hot loop temperature control system, complete testing and full commissioning.
5. Provide a detailed system operations manual for the customer including system layout, alerts, start-up/shut-down procedures, recommended maintenance, etc.
6. Collect data, monitor performance for 3-6 months.
7. Obtain UL (Underwriter Laboratories)/CSA certification
8. Complete system performance assessment, waste heat collected, electricity produced, customer benefits, determination on whether a solar thermal system with a hot water storage tank (potential new project opportunity) could help optimize performance and electricity production of the ORC system.
9. Showcase project, schedule tours (via customer and SoCalGas), share performance results and determine potential value and benefit to other industrial customers with available low-level waste heat.
10. Summarize results in report.

References

Calnetix/Access Energy 125 kW ORC system website: http://www.access-energy.com/

Electratherm 75 kW ORC system website: https://electratherm.com/power-module-75/

Verticorp business/technology slide deck: https://vdocument.in/verdicorp-organic-rankine-cycle-turbine-introduction-verdicorp-inc1.html?page=1

Technoeconomic analysis of small, modular ORC systems/technologies, published by MDPI, January 2017, https://www.mdpi.com/1996-1073/10/4/413

Enogia ORC system website: https://enogia.com/en/orc-3/

Rank ORC system website: https://www.rank-orc.com/

American Apparel bankruptcy notice: https://www.reuters.com/article/us-bankruptcy-american apparel-idUSKBN1390GX

Sierra Aluminum website: https://www.samuel.com/our-businesses/sierra-aluminum

Lekos Dye and Finishing website: http://lekosdye.com/

Project Deliverables

Project deliverables are as follows:

- System Design Report
- Deployment Plan Report
- Engineering Drawings
- Enogia Commissioning Report