U.S. DEPARTMENT OF
**ENERGY**
Office of
**ENERGY EFFICIENCY & RENEWABLE ENERGY**

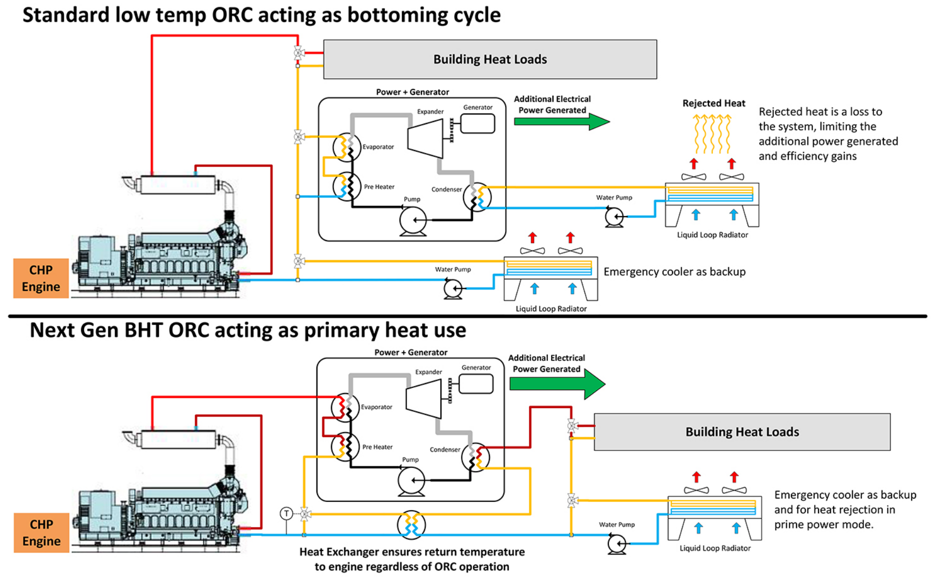
# Organic Rankine Cycle Integration and Optimization for High Efficiency CHP Genset Systems

Combined heat and power (CHP) systems provide both electricity and heat for their host facilities. CHP systems have mostly saturated the large industrial facility market, where economies of scale and the presence of needed technical staff make the deployment of large systems greater than 20 megawatt (MW) electrical capacity cost effective and practical. There remains, however, substantial room for growth of smaller CHP systems suited for small and mid-size manufacturing facilities.

In addition to manufacturing facility energy benefits, the needs of the modern electric grid are other potential drivers for further deployment of CHP systems. As intermittent renewable generation resources constitute a growing and increasingly significant portion of electricity generation, the need for dispatchable generation to maintain the stability of the grid grows. Many small and mid-size manufacturing facilities would be ideal hosts for flexible CHP systems that can provide needed grid services.

In order for CHP systems to be seamlessly integrated with the grid and provide more advanced grid services, further technical development is needed. For such CHP systems to be cost-effective and able to respond to changing grid conditions, they must be able to maintain high system efficiency at partial load conditions and have the ability to ramp up or down quickly.

This project seeks to enable a novel flexible CHP system concept by developing an Organic Rankine Cycle (ORC) system that can be integrated with a reciprocating engine to achieve total CHP system efficiencies of 85% or more at both its rated electrical capacity and at 50% capacity. To achieve this goal, the system will be capable of operating in higher temperatures and pressures than typical ORC systems.




Current Organic Rankine Cycle (ORC) systems operate at relatively low temperatures and are used as a bottoming cycle waste heat recovery solution (top figure). The ORC system being developed can operate at higher temperatures and can thus be the primary recipient of the heat from a reciprocating engine (bottom figure).
*Photo credit ElectraTherm.*

## Benefits for Our Industry and Our Nation

If successfully developed, the new ORC system with a higher temperature and pressure rating will allow a CHP system to generate more power and generate hotter water at the discharge, leading to a total CHP system efficiency of 85% or more. Such a high-efficiency CHP system would result in fuel and cost savings for industrial, commercial, and institutional facilities.

Because of the projected high CHP system efficiency at part load conditions, the new ORC technology would also contribute to the development of flexible CHP systems that could be used to provide needed grid services, such as additional generating capacity during times of peak demand and voltage regulation. Having such flexible CHP systems could provide significant financial benefits to the host facility, but also to the grid system operator and all ratepayers. According to a 2018 manufacturing sector analysis conducted for the U.S. Department of Energy, widespread deployment of flexible CHP systems that are able to provide grid services could result in annual financial benefits of approximately $1.4 billion in the state of California alone. These savings consist of lower industrial site energy costs, reduced grid operating costs, and capacity value of the new electric generators.

## Applications in Our Nation's Industry

A CHP system consisting of a high-efficiency reciprocating engine and the developed ORC system will be suitable for many small and mid-size manufacturing facilities with both electrical and thermal loads. Because of the higher temperature of the rejected heat from the ORC system, it is suitable for most space heating applications. This increases the number of potential host sites when compared to typical ORC systems.

Flexible CHP systems that can provide grid services are expected to be financially attractive investments in markets with high penetration of intermittent renewable resources, such as California, Texas, and several Midwestern states.

## Project Description

This project seeks to develop an ORC system that operates in higher temperature and pressure ranges, which will allow the waste heat leaving the system to be utilized for a wider range of applications, including space heating and cooling. To achieve this goal, the project team will explore different variants of a high pressure expander and feed pump, heat exchanger alternatives, and new working fluids. The ORC system will be designed to match a reciprocating engine with a 1 MW capacity or more. The project goal is to be able develop a CHP system with electricity generation efficiency of 45% or greater and total system efficiency of 85% or greater at rated electrical capacity, and electricity generation efficiency of 30% or greater and total system efficiency of 85% or greater at 50% of rated electrical capacity.

### Barriers

- Need for a highly optimized heat recovery system to achieve 85% total CHP system efficiency at 50% of rated electrical capacity
- Upgrading all ORC system components to be able to operate in higher temperatures and pressures
- Increasing ORC condensing temperature high enough to be compatible with existing hydronic heating systems
- Identification of new working fluids that achieve desired system performance and have very low global warming potential

### Pathways

ORC systems are a proven technology to utilize low-temperature waste heat to generate electricity. In a typical system configuration with a reciprocating engine, ORC is used as a bottoming cycle and the highest temperature leaving the condenser is in the range of 120°F. In order for the waste heat to be used for facility heating and cooling applications, the waste heat leaving the ORC should be approximately 185°F. The project team will explore different variants of a high pressure expander and feed pump, heat exchanger alternatives, and new working fluids to achieve this goal.

The new high pressure expander solution will build on screw compressor technologies developed by BITZER, the parent company of ElectraTherm and world's largest independent manufacturer of refrigeration compressors. The project team will utilize two tools developed by ElectraTherm to model and evaluate different types of hardware and ORC system configurations, reducing the time and effort needed for system development and testing.

Two ORC system prototypes will be constructed. The first prototype will be able to run at the targeted temperature and pressure conditions, and data from the initial prototype will be used to validate the ability of the system models to predict cycle performance in the new operating range. Once the system model is validated, it can be used to find optimal system components for the second prototype. The second prototype will be evaluated in a test cell to confirm that the reciprocating engine and ORC system combination will achieve project goals for efficiency.

### Milestones

This three-year project began in late 2018.

- Design and construction of an initial prototype ORC system capable of operating at higher temperatures and pressures (2019)
- Update and validation of thermodynamic system model based on prototype test data (2020)
- Design and construction of a new ORC system prototype capable of meeting project goals (2020)
- Operation and performance validation of the new ORC system (2021)
- Completion of techno-economic and technology to market analyses (2021)

## Technology Transition

If the new ORC system is successfully demonstrated, ElectraTherm will reach out to reciprocating engine manufacturers to educate them about the technology. In this marketing effort, ElectraTherm will rely heavily on its parent company BITZER's well-known global name and market presence. The highly efficient and flexible CHP systems being enabled by incorporating the ORC system will be suitable for many commercial, institutional, and small and mid-size manufacturing facilities with both electrical and thermal loads. If the system can provide an attractive return on investment, there is much room for growth for such CHP systems in the 1-20 MW capacity range.

## Project Partners

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