ThermoHeart™ 25 kW_e High Performance Stirling Engine

Every day, all over the world, millions of dollars of valuable heat energy is wasted by being vented to the atmosphere. Sources of this wasted heat include drying and curing ovens, pollution control equipment, ceramic kilns, chemical manufacturing, petroleum refining and engine exhaust. While good technologies exist to create value from these heat streams at the largest scales (hundreds of kW to MW of power generation), there are few good options for waste heat recovery (WHR) power generation below 100kW. This situation leaves billions of dollars in clean electricity generation unrealized, resulting in unnecessary waste and pollution.

Cool Energy 25kW_e Product Development Overview:
One important solution to this challenge is Cool Energy's ThermoHeart™ Engine which converts low-temperature wasted heat into clean electricity. This engine has been developed by Cool Energy, Inc. of Boulder, CO and has demonstrated high conversion efficiency and operating reliability. The ThermoHeart Engine differs from other Stirling engines because it can use lower temperatures for its heat input (150 °C to 400 °C) than typical heat engines. Harnessing heat from this lower and largely untapped temperature range opens an entire new set of efficiency and renewable applications for power generation. The 25kW output power of the ThermoHeart Engine enables distributed renewable power systems in applications such as waste heat recovery, solar thermal electric, and biomass power. Testing is well underway on the 5th generation 25kW units, and has demonstrated nearly 30% thermal to electric conversion efficiency at 330°C. This remarkable efficiency level is the result of a historically novel engine design, common but carefully engineered materials of construction, and high-effectiveness internal heat exchangers.

The ThermoHeart® Engine – its applications and contributions to our energy needs: The primary market application for the ThermoHeart engine, due to its rapid payback time, is the recovery of wasted and exhaust heat to produce electricity. Application environments include commercial and industrial facilities, remote and military generators, and ship engines, all of which can benefit from using the ThermoHeart Engine for electricity production. Aside from providing cost savings and reducing emissions from using less fuel and power, other advantages of the ThermoHeart Engine include reducing the need to transport fuel to remote and military locations, a process that is often expensive and logistically difficult (and for the military, often dangerous). Among the additional applications for the ThermoHeart Engine are the use of **solar thermal, biomass, and geothermal sources** for powering homes and buildings.

Development of the ThermoHeart Engine began in 2006, and has been supported in part through grant awards from the US National Science Foundation, the Department of Energy, and the Environmental Protection Agency as well as contracts from the Department of Energy and Colorado Governor's Energy Office. Cool Energy has developed unique Stirling engines composed of high-surface-area heat exchangers, non-metallic self-lubricating piston/cylinder sets, and both metallic and non-metallic regenerators. The design approach employed by Cool Energy has emphasized reduced cost and high reliability to minimize the total cost of ownership and hence the cost of the energy produced. Designed initially for operations at lower temperatures (up to 300 °C) and moderate conversion efficiencies for waste heat recovery, the 5th generation engine design had its temperature range extended to 400°C for higher-temperature applications, including solar power. The fourth-generation prototype demonstrated an output of 3.1 kW_e at 315°C input temperature and 20 °C rejection temperature with conversion efficiencies of over 22%. One of the 4th-gen prototypes was sold to Schneider Electric and delivered in 2011. Two of the fourth-generation prototypes have been tested for reliability in Boulder, Colorado, where they have accumulated 9000 operating hours of power production between them. One of these units has now been installed successfully at a solar demonstration site in Nanjing, China. Two 5th generation 25kW ThermoHeart Engines are currently under test in Boulder, and results can be seen in the chart below and compared to other available methods of power generation at these temperatures.

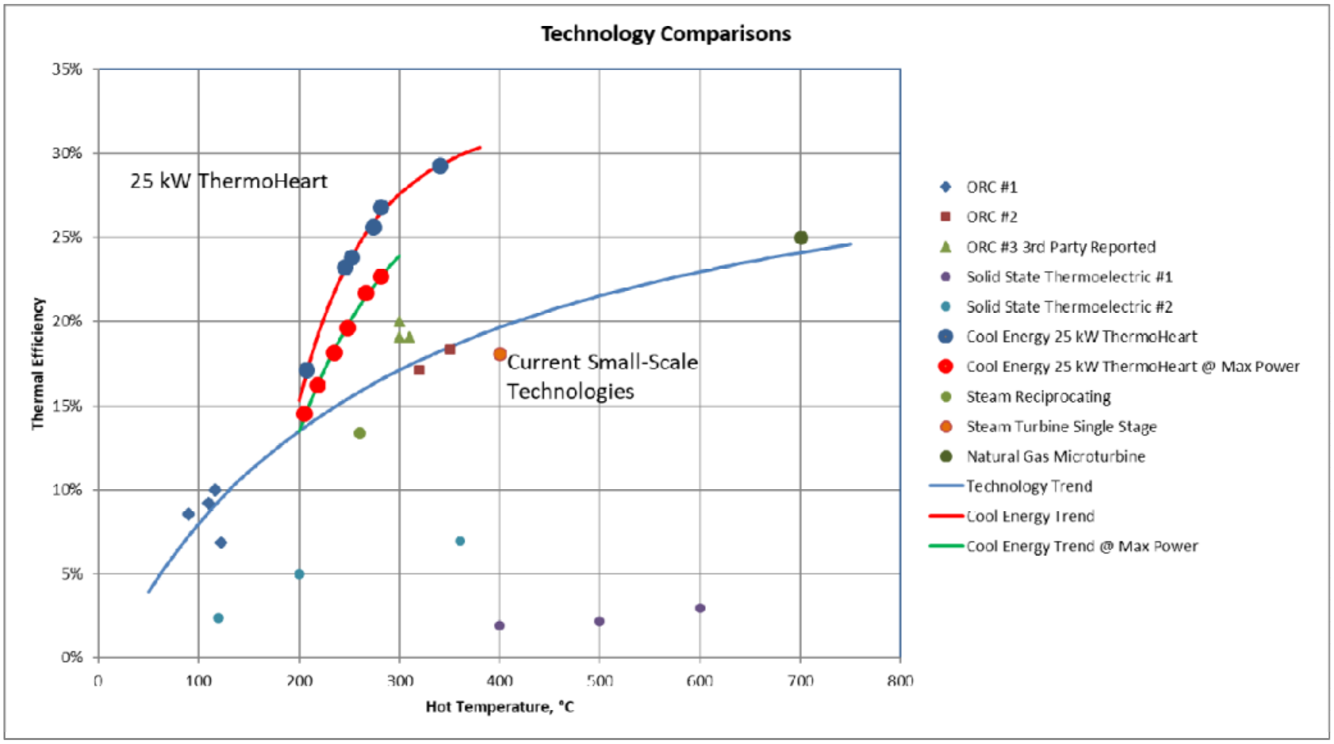

Figure 1) Chart of performance of generating technologies including the Gen 5 25kW ThermoHeart Engine, various organic Rankine cycle systems, solid state thermoelectric generators (TEGs), and steam and gas turbine systems. The blue line is the fit through all of the data except TEGs and the ThermoHeart Engine. The red line is the fit through the measured performance of the ThermoHeart Engine at maximum efficiency, and the green line is the measured ThermoHeart fit at max power.

Waste Heat Recovery applications for ThermoHeart® Engines[1]

The ThermoHeart® Engine can be used to recover low grade waste heat that has previously been uneconomical to recover, and boost operational efficiency of a power generator or process:

The ThermoHeart Engine can be used with any heat source in the engine's optimal input temperature range of 150-400 °C. Whereas cost-effective waste heat recovery solutions at higher temperatures (over 500 °C) already exist, the ThermoHeart Engine offers a solution for low grade waste heat recovery from commercial and industrial processes, from remote and military generators, and from large-scale propulsion engines. This approach increases the efficiency of operations and reduces fuel consumption.

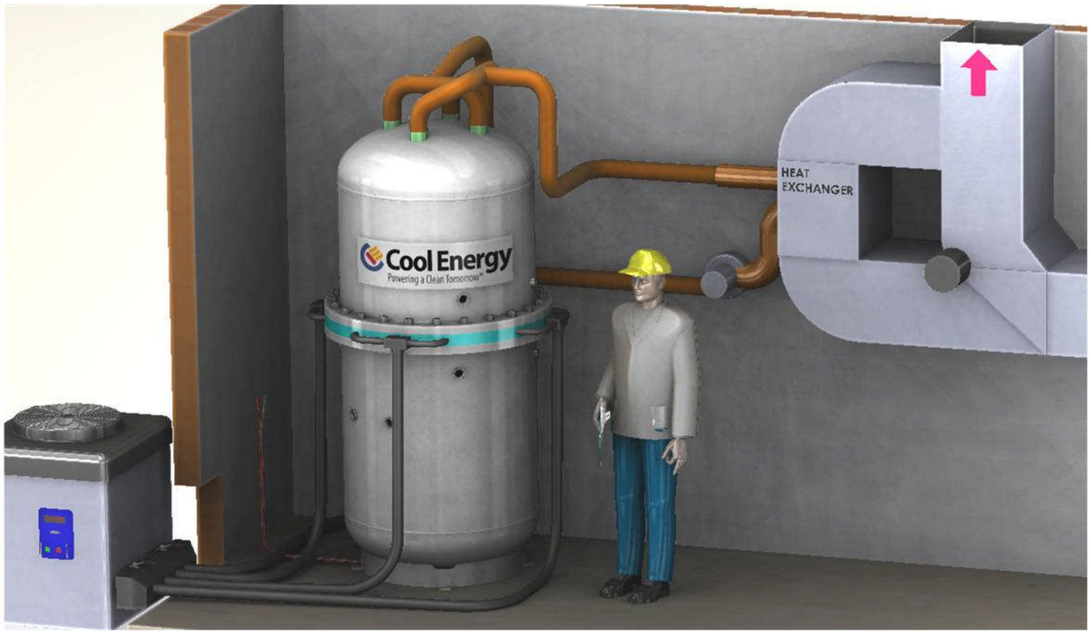

Figure 2) Rotary-drive 25 kW_e Stirling engine shown in an example waste heat recovery application. The source of hot gas flowing through the external heat exchanger could be a reciprocating engine exhaust stream, or waste from an industrial process or pollution control equipment. Gas temperatures up to 600°C can be used, even though the heat transfer fluid used to deliver thermal energy to the engine will not exceed 400°C.

The ThermoHeart Engine boosts the fuel efficiency of diesel generators by recovering waste heat

[1] Certain information about waste heat recovery presented in this section has been acquired from the website of the U.S. Department of Energy Intermountain Clean Energy Application Center – Waste Heat Recovery

The ThermoHeart Engine can boost the output of a diesel genset by up to 10% when recovering the waste heat the generator exhausts. In remote and military settings where fully burdened diesel fuel can cost up to $15/gal including transport costs, the payback period for the engine can be under one year. The reduced requirement for transport of fuel is a highly valuable benefit to the military, as a significant fraction of modern war-fighting casualties occurs during resupply missions of water and fuel.

An illustration of the ThermoHeart Engine configured to capture waste heat from a genset is included below.

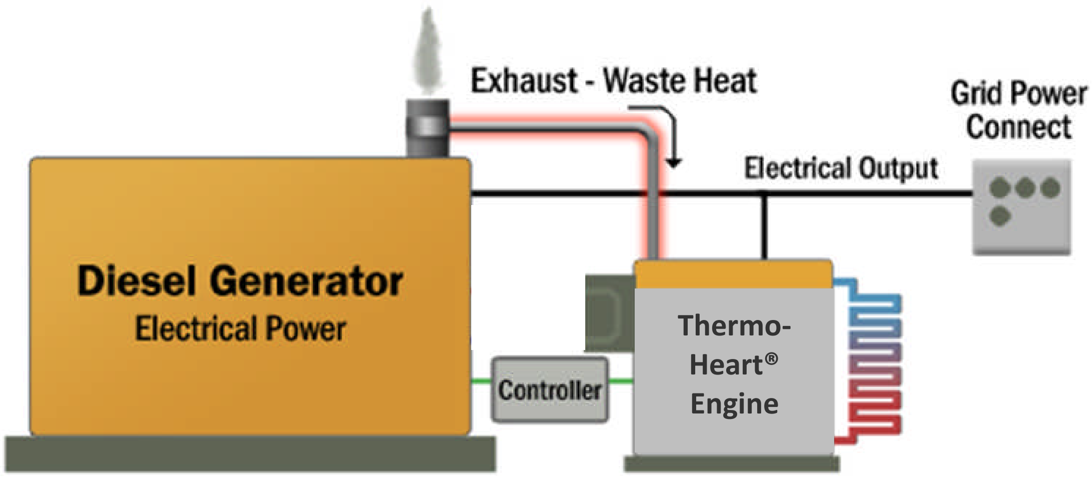

Fig 3) ThermoHeart® Engine configured to recover genset exhaust waste heat

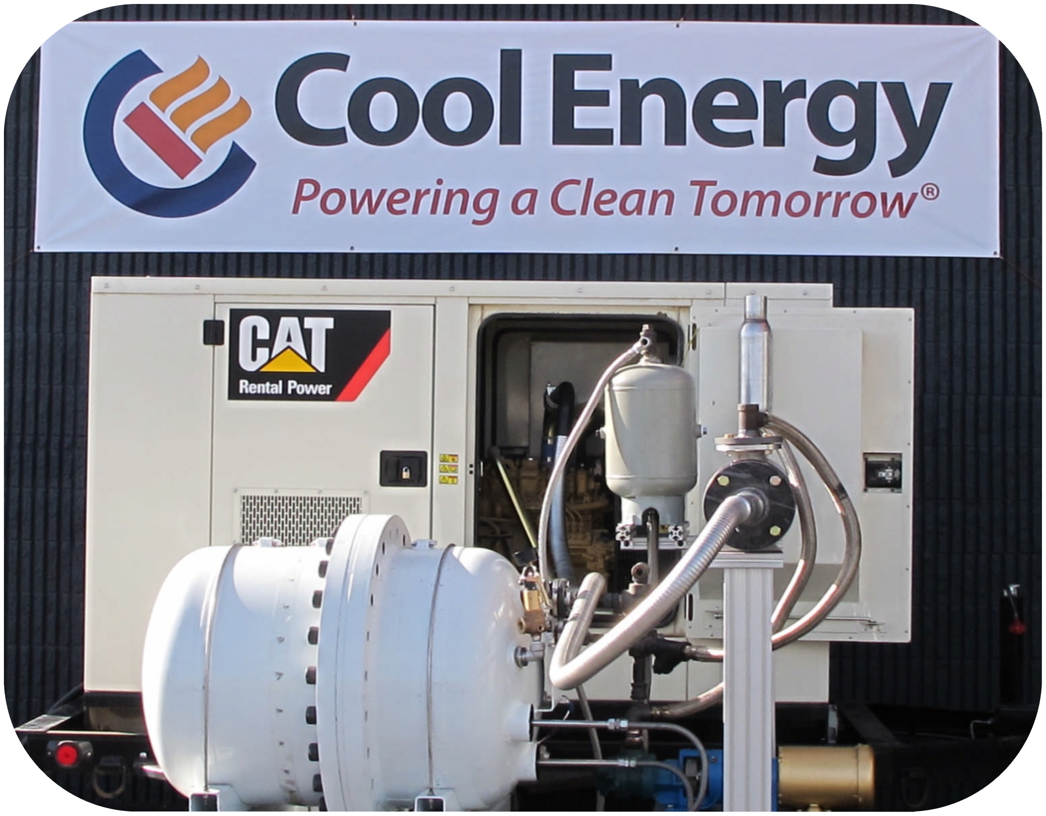

Fig 4) 3 kW_e ThermoHeart® Engine boosting genset output by up to 7%.

Other Useful Information about ThermoHeart® Engines

More about Stirling engines

Cool Energy has developed the ThermoHeart® Engine which is a heat engine based on the Stirling cycle (invented in the early 1800's by Robert Stirling) and for which no internal combustion is required. The Stirling engine operates by expansion and compression of air or other gas (called the working fluid), at different temperature levels such that there is a net conversion of heat energy to mechanical work. The ThermoHeart Engine uses nitrogen as the working fluid and is driven by relatively low temperatures (150 °C-400 °C). The mechanical work produced by the working fluid is transferred through pistons and connecting rods to a mechanism that drives a rotary generator built inside the engine, which ultimately creates electrical power.

The ThermoHeart® Engine is efficient and simple in its operation

The ThermoHeart target operating temperature range enables materials to be used in the engine components that minimize thermal losses and reduce weight and cost relative to typical engines operating at high temperatures. Advantages the Stirling engine has over organic Rankine cycle machines include excellent part load performance, a wide operating temperature range not constrained by temperature restrictions of the working fluid, and high performance at both constant and variable rates of waste heat production.

The ThermoHeart Engine is quiet

Because the ThermoHeart Engine operates at a relatively low speed (600 rpm), has no internal combustion or explosions and is fully balanced, the engine is quiet and low in vibration. The metal housing adds acoustic and thermal insulation.

Reliability of the ThermoHeart Engine

The ThermoHeart Engine is designed for a 20,000-hour service interval – 3 years at 80% operating time. The design lifetime of the engine is targeted at 180,000 operating hours. There is no internal lubrication required as all bearings are sealed and the moving seals are self-lubricating. Two 3kW units have been evaluated for reliability on a continuous-operation test stand. One would operate continuously, while the other was torn down and the key components were measured to determine wear rate and estimate component lifetime. One engine has 6000 hours of run-time (180,000,000 revolutions), while the other has 2800 hours of run-time.

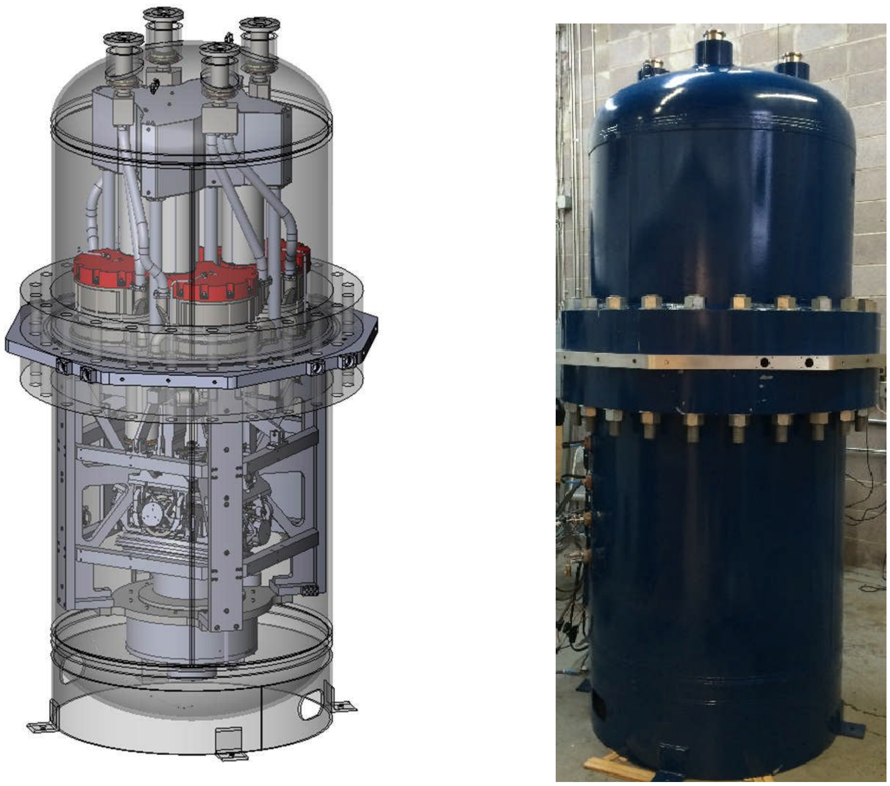

Fig 5) left: CAD of 25kW ThermoHeart® Engine. Right: photograph of engine fully assembled. The penetrations in the upper pressure vessel are the thermal heat transfer oil inlets and outlets. The heat rejection fluid is circulated through the center aluminum plate.

Fig 6) left: Top view of 25kW ThermoHeart® Engine. Right: photograph of engine under test.

25 kW$_e$ ThermoHeart Engine specifications

Operating speed: 550 RPM

Engine weight: 8700 lbs

Engine dimensions: 52" dia. x 105" tall

Lifetime: 180,000 hours, with service interval every 20,000 hours

Operating Ambient Temperatures: -40C to 80C

Output Voltage: Inverted to 360 to 480 V-ac, depending on local grid requirements

Operating parameters: see table below

Expected Operating Parameters for a Cool Energy 25 kW$_e$, 400°C ThermoHeart® Engine with a 20°C rejection environment. Lower rejection temperatures will produce higher powers and efficiencies. The chart below is for an engine charged with nitrogen at 580 psi. Lower charge pressures will produce less power, but at certain conditions will deliver higher conversion efficiencies.

Hot Side Inlet Temp, °C	Oil Flow Rate, L/min	Hot Side Outlet Temp, °C	Input Heat Rate Required, W	Rejection Heat Rate Required, W	Gross Generator Output Power, W	Generator Gross Thermal to Electrical Conversion Efficiency
150	115	131	53,891	51,654	2,237	4.2%
150	170	137	54,110	51,732	2,378	4.4%
150	250	141	54,252	51,783	2,468	4.5%
150	380	144	54,356	51,821	2,535	4.7%
200	115	180	60,482	52,731	7,751	12.8%
200	170	186	60,690	52,668	8,022	13.2%
200	250	191	60,829	52,628	8,202	13.5%
200	380	194	60,930	52,599	8,330	13.7%
250	115	229	67,066	54,321	12,745	19.0%
250	170	235	67,272	54,214	13,058	19.4%
250	250	240	67,406	54,147	13,259	19.7%
250	380	243	67,502	54,099	13,404	19.9%
300	115	277	73,658	56,400	17,258	23.4%
300	170	285	73,849	56,274	17,575	23.8%
300	250	290	73,980	56,200	17,780	24.0%
300	380	293	74,074	56,148	17,926	24.2%
350	115	326	80,223	58,864	21,359	26.6%
350	170	334	80,422	58,747	21,675	27.0%
350	250	339	80,552	58,673	21,879	27.2%
350	380	343	80,645	58,620	22,025	27.3%
400	115	376	86,675	61,675	25,000	28.8%
400	170	384	85,723	60,723	25,000	29.2%
400	250	389	85,133	60,133	25,000	29.4%
400	380	393	84,723	59,723	25,000	29.5%

About Cool Energy, Inc.:
Cool Energy is a privately held corporation, based in Boulder, Colorado.

To date, Cool Energy has been backed primarily by angel and venture capital investment and has received several SBIR grants from the National Science Foundation, the Department of Energy, and the Environmental Protection Agency. Cool Energy is a certified B Corporation. Cool Energy is currently raising its Series C round of capital for the purposes of beginning volume manufacturing.

For more information about the company, please contact Sam Weaver, CEO at spweaver@coolenergy.com or 303-442-2121.

Solar Impulse Foundation presents the ThermoHeart Engine top honors for ambitious for-profit environmental solutions