

ELECTRATHERM DOE CHP ENERGY PORTFOLIO REVIEW

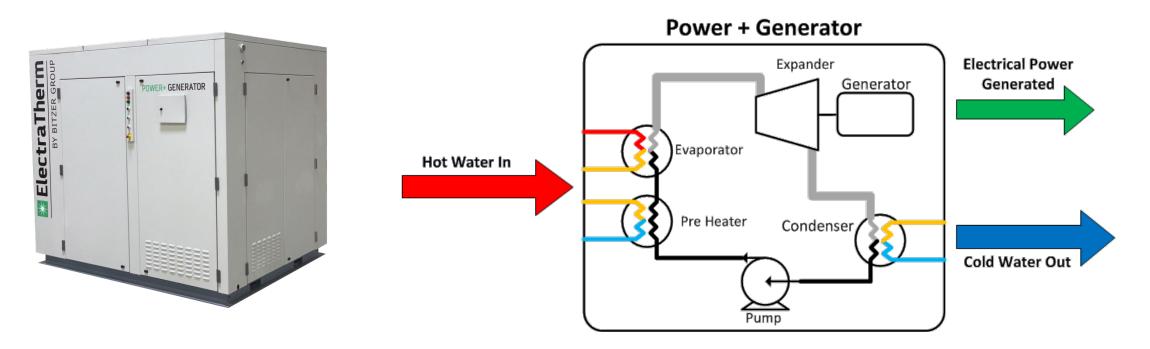
Southwest Research Institute, June 7-9th 2022

Tom Brokaw / Kevin Kirkeby

ElectraTherm

BACKGROUND - ORC

Similar to Steam Cycle with a Lower Temperature Working Fluid



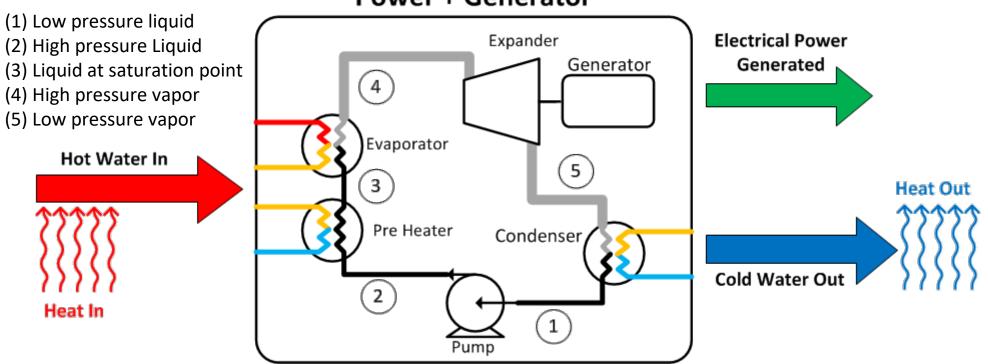
ElectraTherm

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The Organic Rankine Cycle (ORC) is a thermodynamic cycle which uses an organic fluid to convert low-temperature heat into mechanical work. That mechanical work is converted into electricity.

BACKGROUND - ORC

Similar to Steam Cycle with a Lower Temperature Working Fluid



Power + Generator

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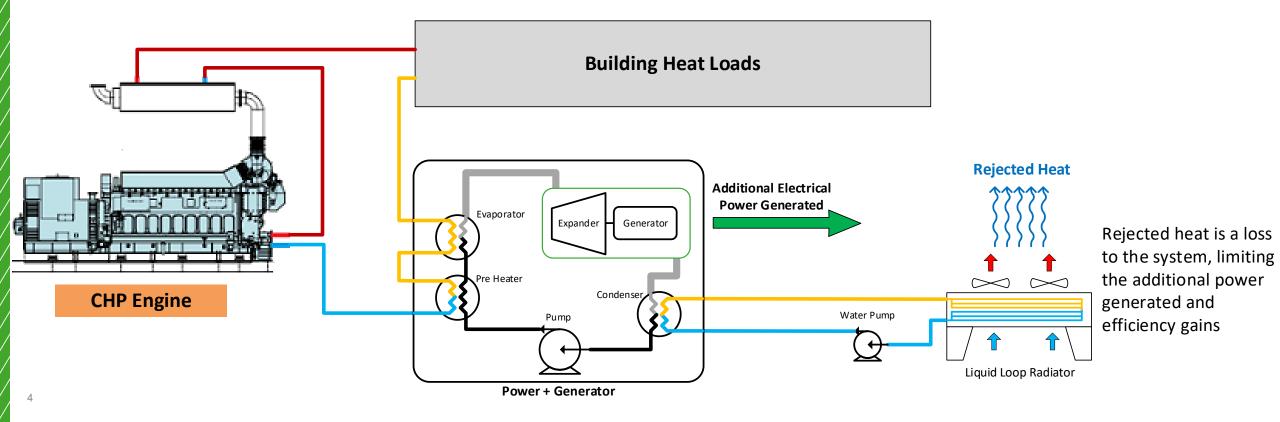
BACKGROUND - CHP

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ElectraTherm ORC commonly used as a Bottoming Cycle

- // CHP generated more heat than the building needs
- // Extra power generated for the site
- // Return temperature guaranteed for engine
- // Rejected heat is lost



BACKGROUND - CHP

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ElectraTherm ORC used as a Bottoming Cycle // ORC runs when building is not using all the heat // Extra power generated, no extra engine cooling needed





BACKGROUND – CHP + ORC

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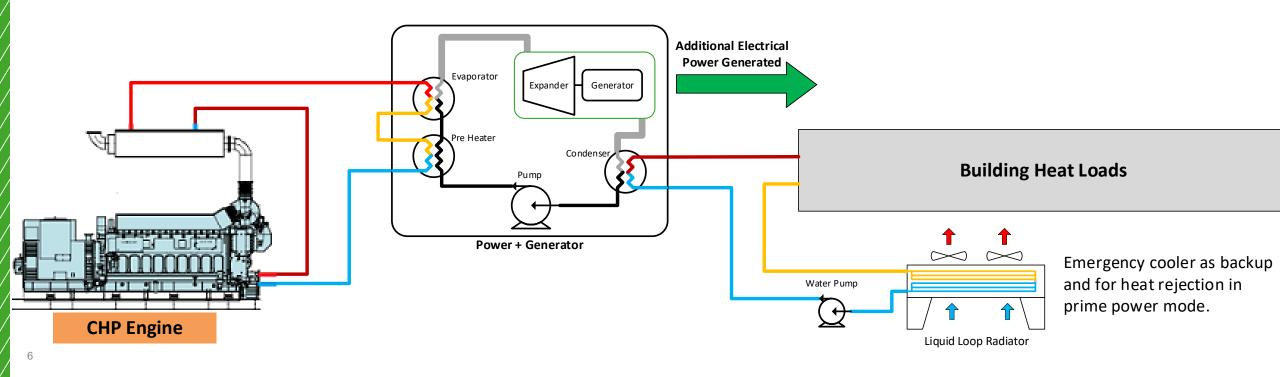
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ElectraTherm High Temp ORC – Flexible CHP

// Higher temperature ORC – primary heat from the Engine

- // Extra power generated for the site
- // Cold side of the ORC elevated to be useful for the building

// Potenial for additional power generation when building heat demand is low



BACKGROUND – EXPANDER

Maximum temperature determined by ORC Maximum Allowable Working Pressure

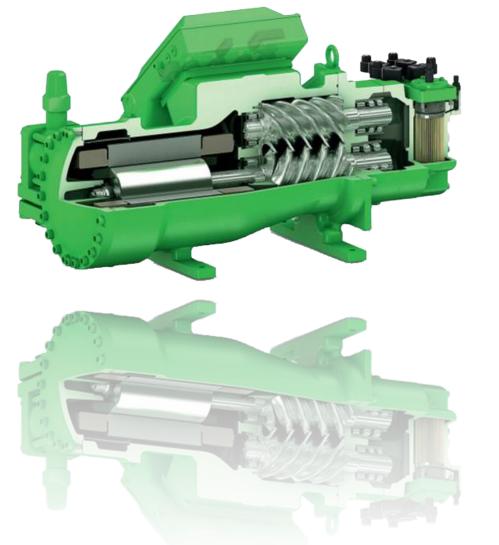
M.A.W.P set by the pressure rating of the expander.

Conversion to Semi-Hermetic Expander

// Integrated generator

// No shaft seal needed

// Higher case pressure rating = Higher temperature ORC circuit



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BACKGROUND – CONTROLS FLEXIBILITY

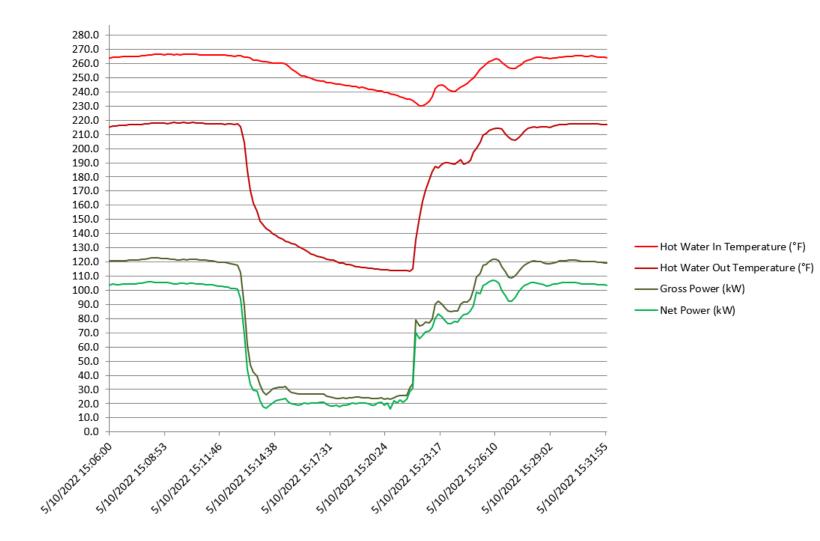
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Automatic controls allow for load following

- // New expander has much
 faster response controls
 tuning / improvement
- // ORC can stay connected through large changes in temperature and flow
- // Allows for uninterrupted transitions between heating, prime power, or different load conditions

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Budget Period 1 Summary

- ✓ New working fluid chemical compatibility study
- ✓ High temperature ORC design complete
- ✓ Prototype unit running at a commercial test site
- ✓ Thermodynamic Model Validated

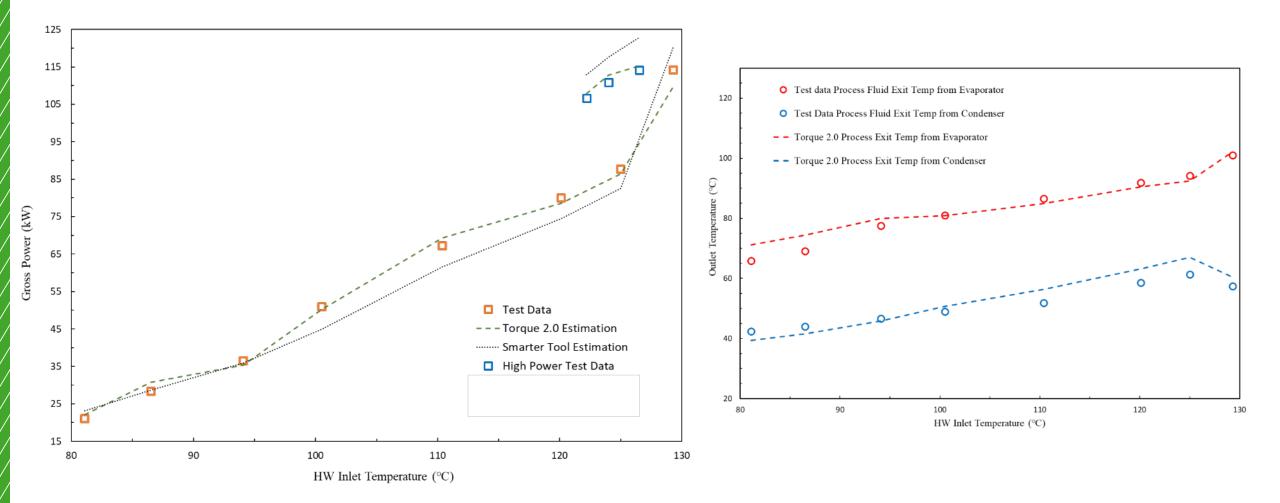








ACCOMPLISHMENTS – THERMODYNAMIC MODEL VALIDATION



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MODELING SOFTWARE UPDATE

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Estimating Software

- // Quick calculation of power output based on heat source conditions
- // Full heat balance provided
- // Water (CHP) or air on OCR
 cold side

Units Metric Imperial	Cooling Method Water Radiator	ElectraTher BY BITZER GR	Automatic
	Inputs	Power+ Evaluation	Average Estimated Outputs 2.1.0.1
0 % GLY 65 - 132 °C	132.0 C • Hot Water In Temperature		64.0 kWe P+ Gross Power Output 52.9 kWe P+ Net Power Output
3 - 23 L/s	20.0 L/s Thot Water Flow Rate	System Type Grid	1499 kW Thermal Power Into P+
[4500 kw Thermal Pow Available	Image: Type L Image: 60 Hz Type M 50 Hz	3001 kW Remaining Thermal Power
[0 kW Additional T Power	hermal O Type I O Type H	1441 kW Thermal Power Rejected 113.2 C Hot Water Exit Temperature
12 - 65 °C	55.9 C Cold Water 1 Temperature		85.0 C Cold Water Exit Temperature
6 - 26 L/s	12.0 L/s Cold Water Flow Rate	Working Fluid R245fa 🔻	1.6 kWe Estimated Load from Cold Water Pump
0 % GLY		Calculate Optimize	51.3 Estimated System Net Power Output
Reset Estim	ate assumes pure water (0% propylene glycol b	y volume.) Tom Brokaw	
132.0 C 20.0 L/s	Evaporator	Generator Generated 64.0 kWe	Thermal Power Rejected 1441 kW
3001 kW 113.2 C	Pump	85.0 C 12.0 L/s 55.9 C	Water Source For Condensers
24.04	Power + Genera	tor	

MODELING SOFTWARE UPDATE

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Gas Module

- // Allows for: Air, Natural Gas Exhaust, Steam, and Custom Fluid
- // Evaluation of parallel
 and series operation
- // Defines requirements for interface heat exchanger
- // Water (CHP) or air on OCR cold side

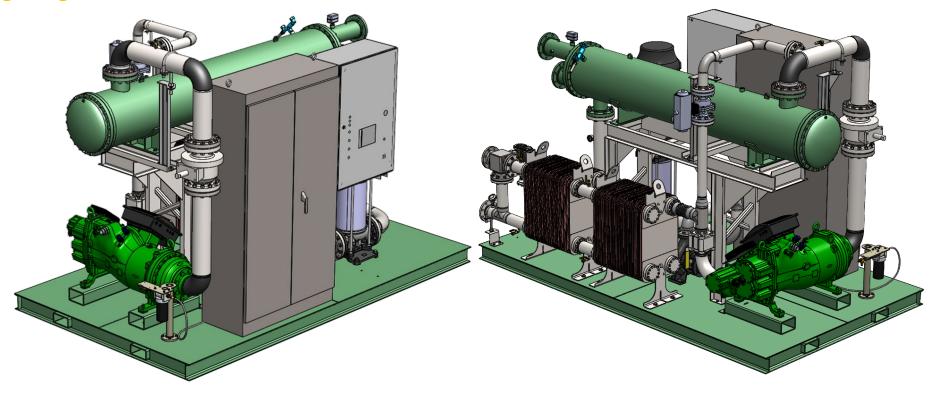
🖪 Gas Module	- 🗆 ×
Gas Type Natural Gas Exhaust V 3876 kw	cuits 2 Machines 2 System Net per Machine V 2.1.0.0 al Flow Flow per circuit 144.7 kWe 105.0 kW 08 Apr 2022
Density 0.38 kg/m^3 22.0 m^3/sec	100, gpm 254.0 gpm Evaporator Evaporator 1938 kW 109.1 F System Type 254.0 Thermal Power Rejected 1766 kW System Type 254.0 Thermal Power Rejected 1766 kW
Series 6000 ▼ Grid 164.1 C ● 60 Hz ○ 50 Hz	1.1 kWe Pump 26.0 L/s Water Pump Type M 11.8 C 79.8 F F Type H Power + Generator
Units Metric Imperial Cooling Method Water Radiator Calculate	Stage Two
Cooling Load Calculation Automatic Manual	
Inputs To Stage One Machine	
70 - 1200 °C 500.0 C Gas Temperature Record History? 22.000 m^3/sec Gas Flow Rate ✓ Unlimited Thermal Power? 0 KW Thermal Power 0 % GLY 70 - 150 °C 132.2 C Het Water Intel Temperature 95.1 - 364.5 gpm 254.0 gpm HW Flow Rate 0 % GLY 70 - 150 °C 132.2 C Het Water Intel Temperature 95.1 - 364.5 gpm 254.0 Optimize HW Flow? 0.9 C Temperature Los Through connection Manual Automatic 2 Number of Circuits ✓ Auto CW In 53.6 - 176 °F 79.8 F Cold Water Inlet Temperature 9 - 26 L/s 26.0 L/s CW Flow Rate per Machine 0 % GLY 33.8 - 113 °F 60.0 F Anthom Air Temperature	Gross 135.9 kWe Net 108.0 kWe 108.0 kWe
Average Estimated Total Outputs 289.3 KWe Total Gross Power Output 256.2 KWe Total Net Power Output 3876 KW Total Thermal Power Into P+ Series	□ Stage Four
3532 kW Total Thermal Power Rejected 101.8 C ORC Side Hot Water Exit Temperature 2.3 kWe Estimated Total Load from Hot Water Pump 8.6 kWe Estimated Total Load from Cold Water Pump 35.3 kWe Estimated Total Load from Radiator Fans	Show History Hide History
210.0 kWe Estimated Total System Net Power Output	Reset

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Budget Period 2 Summary

- ✓ Next Generation ORC design complete
- Next Gen ORC Construction complete
- Engine Configuration and BOP design complete
- Successful modeling of CHP ORC system capable of meeting program goals



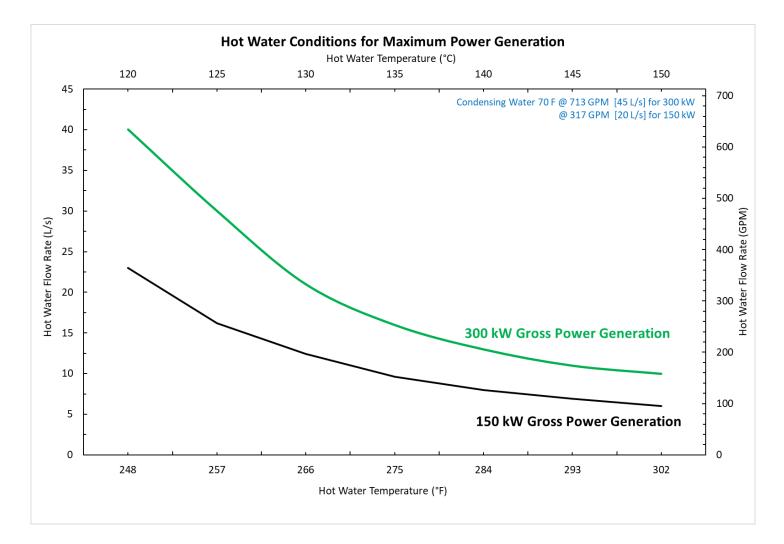
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Budget Period 2 Summary

✓ Next Generation ORC design complete

Projected output curves based on Thermodynamic system model



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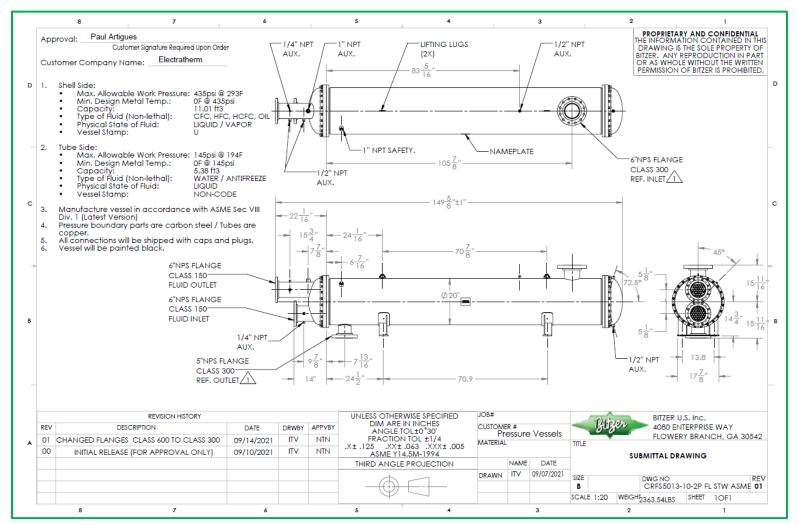
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Budget Period 2 Summary

✓ Next Generation ORC design complete

Shell and Tube Condenser

- // Lower pressure drop on the working fluid side
- // Less subcooling
- // Simplified piping design



ACCOMPLISHMENTS – MODELING OF CHP – ORC SYSTEM **ElectraTherm**

CHP Test Case

- // 10MW Cogeneration Unit
- // Meets DOE Targets for Electrical Efficiency
- // Does not meet targets for total CHP Efficiency
- // Sufficient heat in the exhaust that can be used with Next Gen ORC

JMS 920 GS-N.L							
% of Rated Output		Energy input (LHV)	Electrical output				
100%	kW	22,703	10,377				
	Efficiency		45.7%				
50%	kW	12,315	5,189				
	Efficiency		42.1%				

Cogeneration Unit	
JMS 920 GS-N.L	
no special Grid Code	
920	
J920 FleXtra	
Electrical output	10377 kW el.
Thermal output	6088 kW

ACCOMPLISHMENTS – MODELING OF CHP – ORC SYSTEM **ElectraTherm**

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CHP Test Case

- // 4.3MW of heat available in the Exhaust
- // Maximum ORC Power when building heat is
 not needed
- // Lower power but usable heat when the building needs it

Thermal energy balance

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Energy input	kW	22.703
CAC Charged air cooler (Intercooler)	kW	3.713
Lube oil	kW	1.176
Jacket water	kW	1.199
Exhaust gas cooled to 180 °C	kW	3.036
Exhaust gas cooled to 100 °C	kW	4.383
Surface heat	kW	369
Exhaust gas data		
Exhaust gas temperature at full load	°C [8]	355
Exhaust gas temperature at bmep= 18 [bar]	°C	~ 395
Exhaust gas temperature at bmep= 12 [bar]	°C	~ 432
Exhaust gas mass flow rate, wet	kg/h	56.463
Exhaust gas mass flow rate, dry	kg/h	52.994
Exhaust gas volume, wet	Nm³/h	44.591
Exhaust gas volume, dry	Nm³/h	40.275
Max.admissible exhaust back pressure after engine	mbar	60

HWT In (C)	HWF (L/s)	HWT Out (C)	Heat Extracted (kW)	CWT In (C)	CWF (L/s)	CWT Out (C)	Heat Rejected (kW)	Gross (kW)
150	40	125	4000	32	55	47	3450	300
		127.5	3547	55		70	3180	232
		128.1	3447	60		74	3104	216
		129.5	3241	68		85	2927	194

ACCOMPLISHMENTS – MODELING OF CHP – ORC SYSTEM **ElectraTherm**

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CHP Test Case

- // Combining the power and heat rejected by the ORC
- // DOE targets are now met for Electric efficiency and CHP efficiency
- // Potential to have added flexibility and power output when the building does not need all the heat

% of Rated Output		Energy input (LHV)	Electrical output	CAC HT & CAC LT	Lube oil	Jacket water	Total recoverable thermal	Total CHP Efficiency
100%	Engine kW	22,703	10,377	3,713	1,176	1,199	6,088	
	ORC kW		232			·	3,180	
	Efficiency		45.7%				40.8%	86.5%
50%	Engine kW	12,315	5,189	1,261	1,011	837	3,109	
	ORC kW		160				2,192	
	Efficiency		43.4%				43.0%	86.5%



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Any Questions?

Tom Brokaw

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www.electratherm.com