Home Generator Benchmarking Program

Residential Natural Gas Fired Electrical Generator and MicroCHP

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Introduction

Over the past ten years, the United States' average electrical losses from transmission and distribution were 6%. In 2012 this meant a loss of 210 terawatt-hours nationally, equating to an estimated loss of $23.2 trillion[1]. Today, American households are increasingly choosing electrical space heating over other methods, which exacerbates these transmission losses.

Satisfying these heating requirements without relying on electricity transmitted via the grid could:

1. Reduce electrical losses by up to 39 terrawatt-hours/year.
2. Save up to $4.41 trillion/year.
3. Reduce carbon emissions.

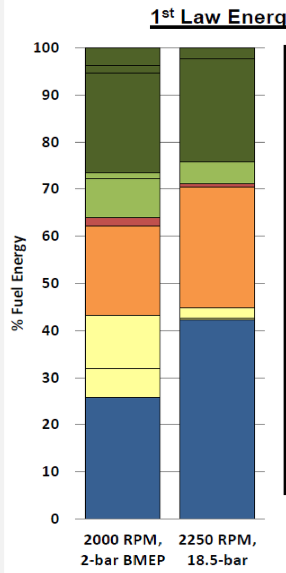
A viable way to cut back transmission losses would be to generate electricity at the residential site. However, the low efficiency of residential generators leads to poor economics compared to grid sourced electricity.

Micro combined heat and power (micro-CHP), a technology commercially available in Germany, Japan and briefly in the U.S., provides an economic solution. Micro-CHP uses a conventional natural gas fired generator to generate electricity, then utilizes the heat from the exhaust gases for water and space heating. This utilization of otherwise wasted energy greatly increases efficiency.

Recent data suggests that, excluding space heating, the typical American home requires nominally 1 kW of electrical power[3]. A micro-CHP generator sized to supply this electrical demand would also provide 3-4 kW of thermal energy. Enough to satisfy a large portion of a home's space and water heating demands.

To quantify the potential for micro-CHP uses, commercially relevant residential natural gas powered generators will be benchmarked. Previously unavailable thermal efficiency, exergy efficiency, lifetime and levelized cost of energy data will be collected and disseminated.

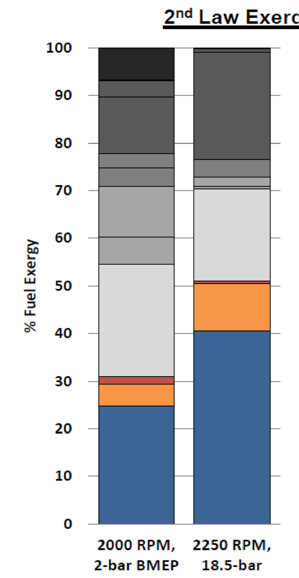
1st Law Energy Balance



% Fuel Energy	2000 RPM, 2 bar	Peak BTE
Qo - Piping	3.9 %	0 %
Qo - Turbocharger	1.6 %	2.4 %
Qo - Engine	21.1 % *	21.8 % *
Q - Intercooler	1.2 %	4.7 %
Q - EGR Cooler	8.2 %	0 %
Q - Oil	0 % *	0 % *
Q - Engine Coolant	0 % *	0 % *
Incomplete Combustion	1.8 %	0.6 %
Exhaust	19.2 %	25.7 %
Friction Work	11.2 %	2.1 %
Pumping Work	6.0 %	0.4 %
Brake Work	25.9 %	42.3 %
Total Fuel (kW)	25.2 kW	156.9 kW

* Insufficient oil and coolant data to separate ambient heat losses from block

2nd Law Exergy Balance



% Fuel Exergy	2000 RPM, 2 bar	Peak BTE
I – Mixing & valve loss	6.8 %	0 %
I - ΔP - Intercooler	0 %	0.1 %
I - ΔP - EGR Cooler	0 %	0 %
I - Q - Intercooler	0.1 %	0.8 %
I - Q - EGR Cooler	3.4 %	0 %
I - Q - Engine	11.9 %	22.4 %
I - Qo - Turbocharger	3.0 %	3.8 %
I - Qo - Piping	3.9 %	0 %
I - Friction Work	10.7 %	2.0 %
I - Pumping Work	5.7 %	0.4 %
I – Combustion Irreversibility	23.6 %	19.5 %
Qx – Coolant, Oil	0 % *	0 % *
Incomplete Combustion	1.5 %	0.5 %
Exhaust	4.7 %	9.9 %
Brake Work	24.7 %	40.6 %
Total Fuel (kW)	26.4 kW	163.5 kW

* Insufficient oil and coolant data to determine exergy transferred to these streams that could be recoverable

Figure 2 Sample 1st and 2nd law analysis of energy distributions for GM 1.9-L diesel at road load and peak efficiency.

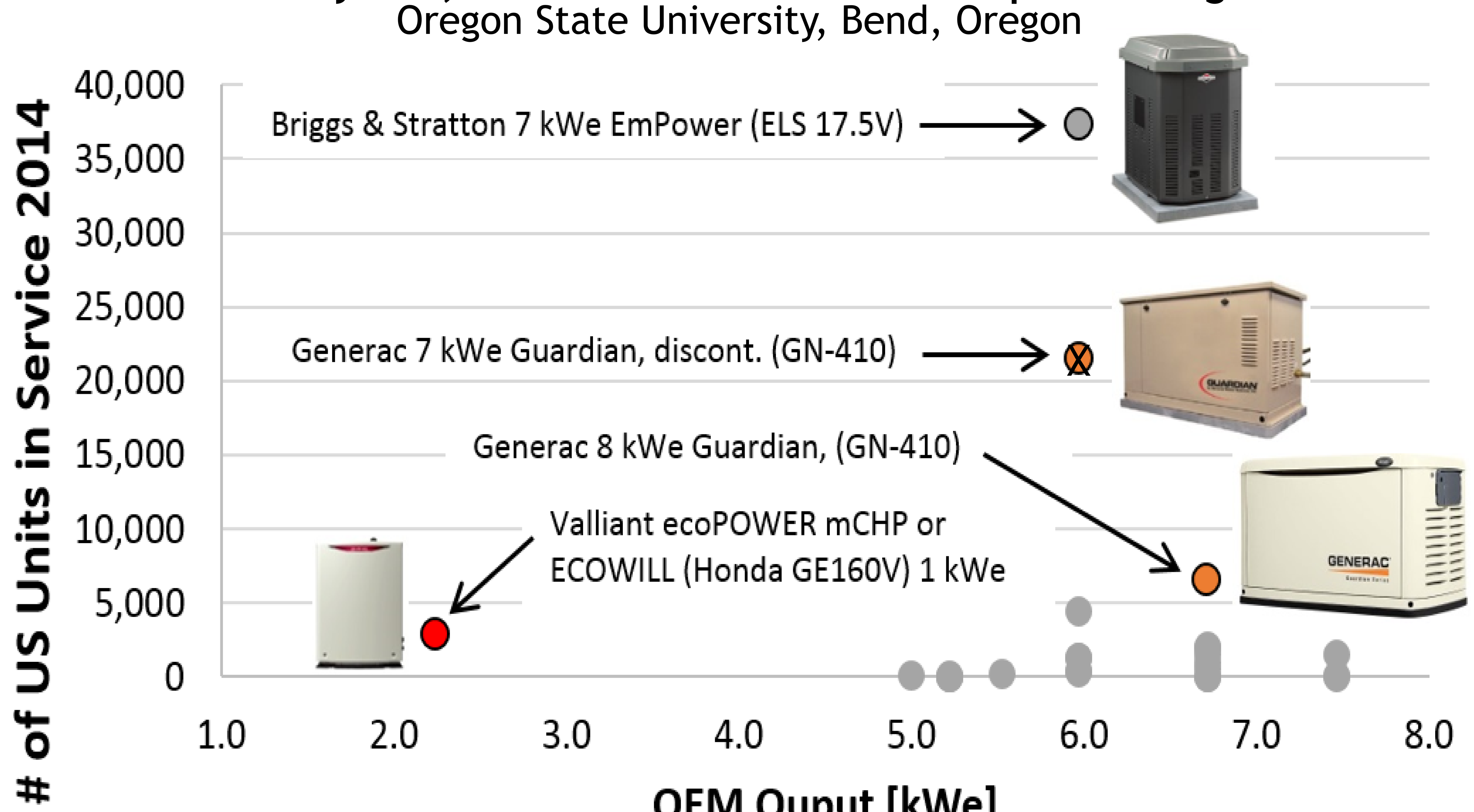


Figure 1 U.S. 2014 popular generator models by population.

Generator Selection

To select representative generators, a residential generator market database was purchased from a market research firm that included information such as current population, electrical output, and fuel type. Information from this database is visualized in Figure 1.

Important highlights include:

1. Only a single natural gas powered, <1 kWe genset in the U.S.
2. The Briggs & Stratton EmPower and Generac Guardian are the most popular US units.

After research into both units the Generac Guardian (Figure 3) was chosen over the Briggs & Stratton EmPower due to the following reasons:

- Higher brake thermal efficiency
- Perceived quality (higher cost and longer warranty)
- Overall support from the manufacturer.

The 2 kWe generator identified in Figure 1 is the Honda/Climate Energy freewatt™ which is the state-of-the-art micro-CHP unit in the U.S. and was sold from 2002-2007.

Methodology

Three generators will be selected that best represent both the U.S. residential generator fleet and the state of the art of global micro-CHP generators.

Testing will be done at three independent laboratories:

1. Oregon State University's Energy Systems Laboratory in Bend, Oregon.
2. Oak Ridge National Laboratory in Oak Ridge, Tennessee
3. Intertek Carnot Testing Laboratory in San Antonio, Texas

The gensets will be tested in two modes:

1. With the ICE and motor connected. Data collected in this mode will include:
   - Fuel consumption
   - Electrical power output
   - emissions
2. With the ICE coupled to a dynamometer. Data collected in this mode will include:
   - Output torque (brake thermal efficiency)
   - Fuel flow
   - emissions

These data will be used to conduct a 1st and 2nd law analysis such as the example in Figure 2 to the left.

Results

To date, two generators have been procured and are undergoing testing.

Figure 4Generac Guardian being instrumented on the test stand at Intertek-Carnot Testing Laboratory in San Antonio, TX.

The Generac Guardian 7 kWe genset (Fig. 4) is currently undergoing testing at Intertek- Carnot Testing Laboratory.

Also, a new Climate Energy freewatt™ was procured and is undergoing testing at Oregon State's Energy Systems Laboratory (Figure 5).

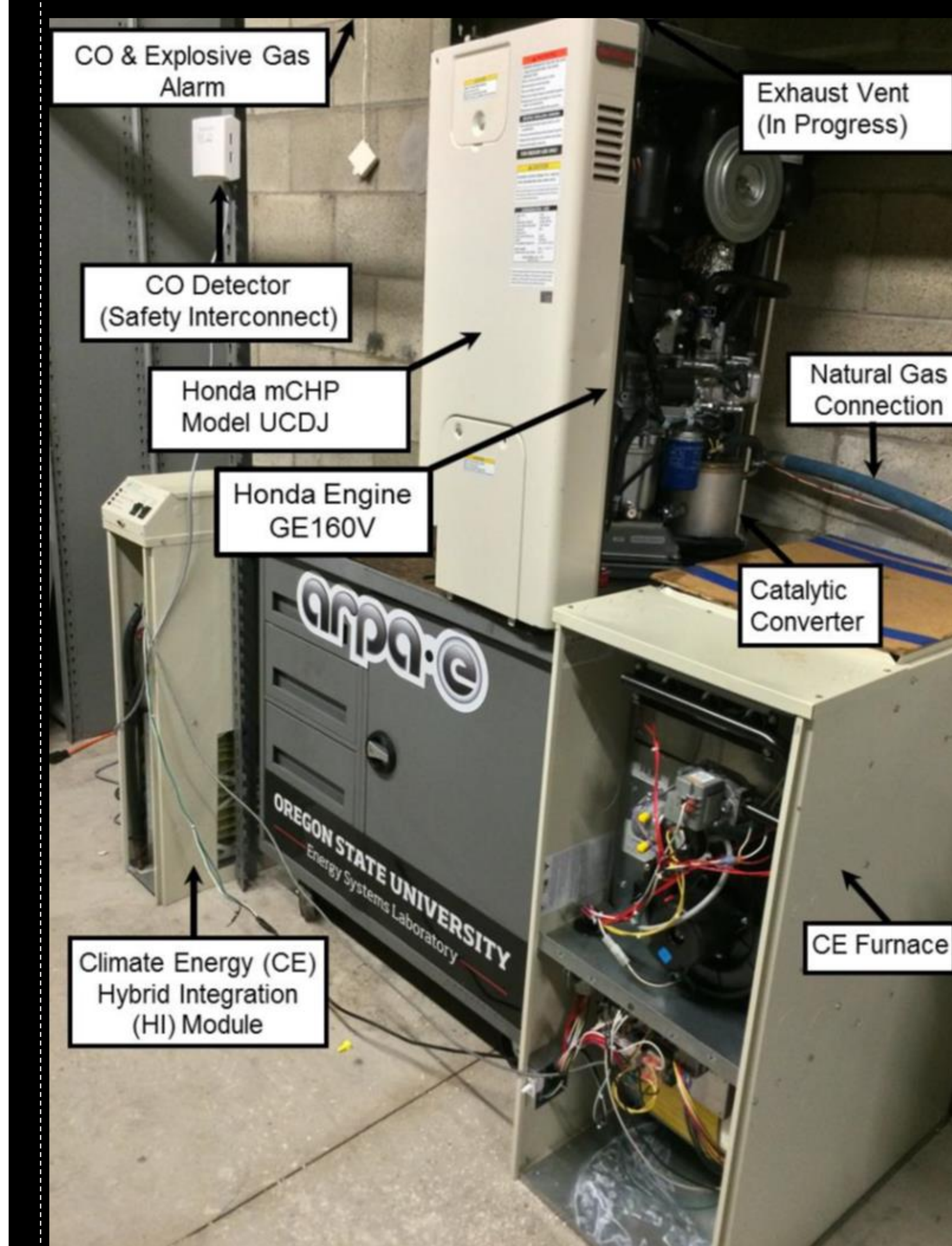


Figure 5 Climate Energy freewatt™ installed at OSU's Energy Systems Laboratory.

Future Work

Round robin testing will begin on the Climate Energy freewatt™ after it has been successfully installed at the Energy Systems Laboratory.

Once testing of the Generac Guardian is completed at Intertek-Carnot Emission services the generator will be shipped to OSU's Energy System Laboratory where a lifetime analysis and levelized cost of energy analysis will be conducted.

Acknowledgments

arpa·e

Oak Ridge National Laboratory

Intertek

Oregon State UNIVERSITY

Literature Cited

1. U.S. Energy Information Administration, Independent Statistics & Analysis. (2014, May 1). *State Electricity Profiles* (edition) [online]. Available: http://www.eia.gov/electricity/state/
2. U.S. Energy Information Administration, Independent Statistics & Analysis. (2014, September 25). *Everywhere but Northeast, fewer homes choose natural gas as heating fuel* [online]. Available: http://www.eia.gov/todayinenergy/detail.cfm?id=18131
3. G. Conzelmann. (2014, April). *Electricity Load Profiles and Load Management* [Powerpoint Presentation].