STATE OF HAWAII

SOLAR WATER HEATING IMPACT ASSESSMENT

(1992 - 2011)

Prepared For:
Department of Business and Economic
Development and Tourism (DBEDT)
State of Hawaii

FINAL

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STATE OF HAWAII SOLAR WATER HEATING IMPACT ASSESSMENT (1977-2011)

1.0 EXECUTIVE SUMMARY:

This report reviews the number of solar water heating systems installed throughout the State of Hawaii since the state tax credit for solar systems was first implemented in 1977, and analyzes the savings in fossil fuels and electricity realized by their installation over the past 20 years from 1992 through 2011. The primary findings of this analysis are as follows:

- The total number of solar water heating systems installed since 1977 is 103,305.
- Based on an average 20 year life expectancy, the 74,018 total aggregate systems installed from 1992 through 2011 currently saves the State 152,847 MWh in electricity per year, which is sufficient to power 21,695 homes annually.
- This avoided electricity savings corresponds to an annual savings of 221,337 barrels of fuel oil that would have otherwise been required to generate this electricity, and a resulting reduction of 116,699 tons in annual avoided CO2 emissions.
- The total estimated value of the solar water installations that were installed cumulatively over the 20 year period from 1992 through 2011 is approximately $332 million.
- The estimated value of the State Tax Credits that were provided under the same period totaled approximately $116 million.
- There is a direct correlation between the number of solar water heating installations installed annually and the level of support from State and Federal credits.

2.0 SOLAR WATER HEATING IMPACT ASSESSMENT

From the inception of the State Tax Credit for solar water heating systems, the total number of solar systems that have been installed in the State of Hawaii from 1977 to 2011 was 103,305. These installations include those that were replaced over the years so the actual number of solar systems in service is lower.

Since solar water heating systems have a 20 year project life, the present impact of the solar heating systems that are installed and operating is conservatively estimated based on the systems that have been installed over the past 20 years from 1992 through 2011. Based on the methodology and basis for assessment analysis presented in the subsequent sections, the annual aggregate and cumulative impact of the installation of the solar water systems over the most current 20 year period is conservatively estimated and summarized in Table 1 below and in the Figures that follow:

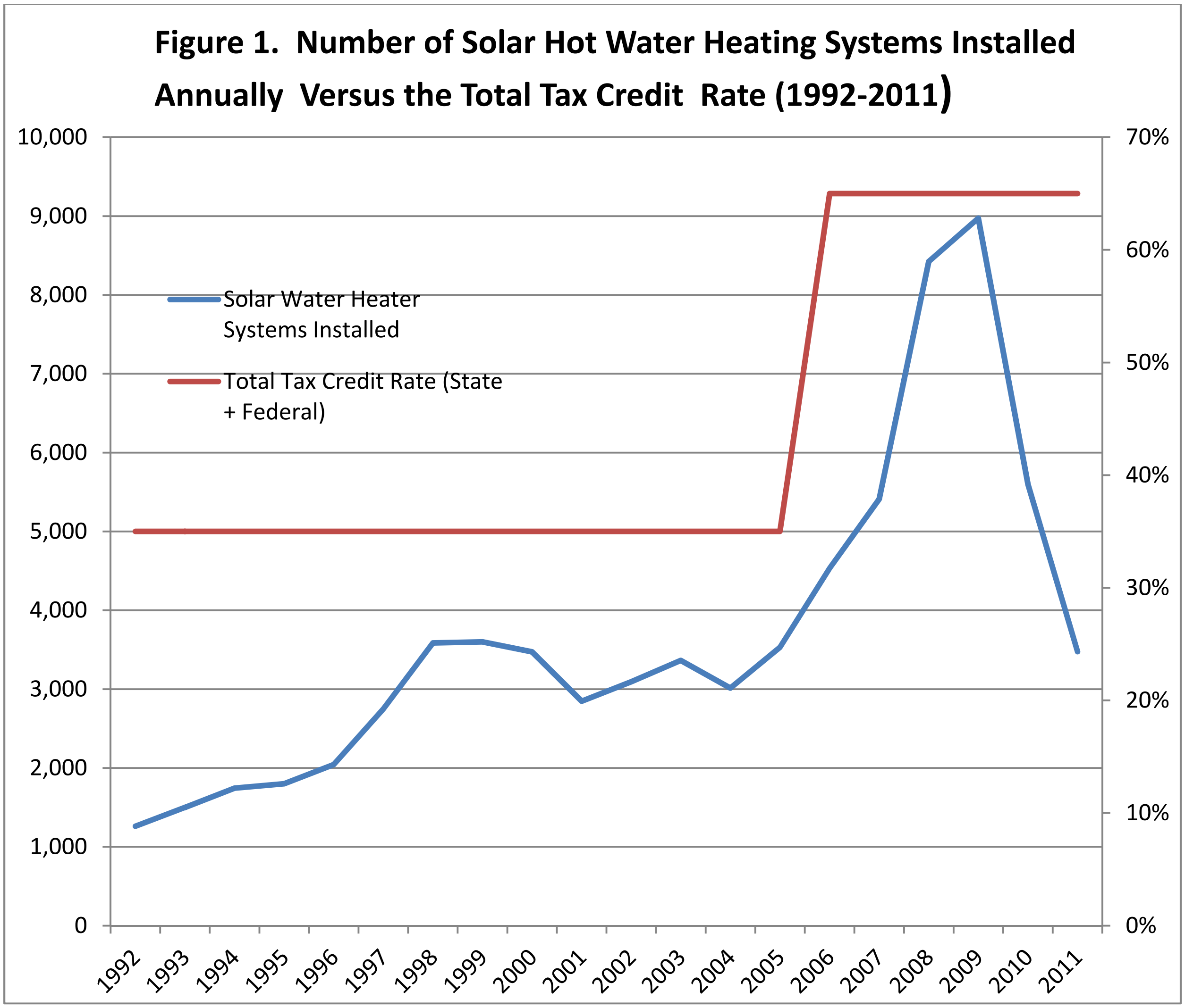
Table 1. Solar Water Heating System Impact Assessment (1992 - 2011)												
Year	Number of Solar Water Heating Systems Installed Statewide Per Year	Aggregate Number of Solar Water Heating Systems Installed Since 1992	Total Aggregate Annual MWh Savings at 2065 KWh/yr per System	Total Aggregate Fuel Oil savings at 9123 BTU/KWh heat rate (Barrels of oil Per Year)	Total Aggregate Avoided CO2 Emissions at 1527 lbs Co2/MWH (tons of Co2 Per Year)	TAX CREDIT LEVEL Total	State	Federal	Ave Solar Water Heating System Installed Cost ($ per system)	Basis	Estimated Total Annual Solar Water Heating Installed Cost ($)	Estimated Total Annual State Tax Credit ($)
1992	1,261	1261	2604	3771	1988	35%	35%	0%	$3,440	Actual Data	$4,337,840	$1,518,244
1993	1,500	2761	5701	8256	4353	35%	35%	0%	$3,440	From 1992	$5,160,000	$1,806,000
1994	1,744	4505	9303	13471	7103	35%	35%	0%	$3,440	From 1992	$5,999,360	$2,099,776
1995	1,800	6305	13020	18854	9941	35%	35%	0%	$3,440	From 1992	$6,192,000	$2,167,200
1996	2,043	8348	17239	24963	13162	35%	35%	0%	$3,440	From 1992	$7,027,920	$2,459,772
1997	2,750	11098	22917	33187	17497	35%	35%	0%	$3,440	From 1992	$9,460,000	$3,311,000
1998	3,586	14684	30322	43910	23151	35%	35%	0%	$3,440	From 1992	$12,335,840	$4,317,544
1999	3,599	18283	37754	54672	28825	35%	35%	0%	$3,440	From 1992	$12,380,560	$4,333,196
2000	3,473	21756	44926	65057	34301	35%	35%	0%	$3,440	From 1992	$11,947,120	$4,181,492
2001	2,846	24602	50803	73568	38788	35%	35%	0%	$3,440	From 1992	$9,790,240	$3,426,584
2002	3,094	27696	57192	82820	43666	35%	35%	0%	$3,440	From 1992	$10,643,360	$3,725,176
2003	3,363	31059	64137	92876	48968	35%	35%	0%	$3,440	From 1992	$11,568,720	$4,049,052
2004	3,014	34073	70361	101889	53720	35%	35%	0%	$3,440	From 1992	$10,368,160	$3,628,856
2005	3,531	37604	77652	112448	59288	35%	35%	0%	$3,440	From 1992	$12,146,640	$4,251,324
2006	4,534	42138	87015	126006	66436	65%	35%	30%	$5,250	Actual Data	$23,803,500	$8,331,225
2007	5,411	47549	98189	142187	74967	65%	35%	30%	$5,250	Actual Data	$28,407,750	$9,942,713
2008	8,424	55973	115584	167377	88249	65%	35%	30%	$5,250	Actual Data	$44,226,000	$15,479,100
2009	8,974	64947	134116	194212	102397	65%	35%	30%	$5,250	Actual Data	$47,113,500	$16,489,725
2010	5,597	70544	145673	210949	111222	65%	35%	30%	$6,600	Actual Data	$36,940,200	$12,929,070
2011	3,474	74018	152847	221337	116699	65%	35%	30%	$6,625	Actual Data	$23,015,250	$8,055,338
Totals Over the 20 Year Period (1992-2011):	74018	74018	1237356	1791810	944722						$332,863,960	$116,502,386

For the purpose of comparison with the latest available data on Hawaii total petroleum use and total electrical consumption in 2010, the 70,544 total solar water heating systems that were installed over the past 19 years from 1992 to 2010 saved an aggregate of 145,673 MWh per year in electricity. This amounted to an annual savings of 210,949 barrels of fuel oil that would have otherwise been required to generate this electricity, and a resulting reduction of 111,222 tons in avoided CO_2 emissions. Accordingly to Table F15: Total Petroleum Consumption Estimates, 2010, (Attachment 6) and the Hawaii Energy Statistics (Attachment 7), the State of Hawaii consumed a total of 12,610,000 barrels of oil to generate 10,013,000 MWh of electricity in 2010. The 70,544 total solar water heating systems that were in use in 2010 resulted in a 1.7% reduction in total fuel oil used for electricity and a 1.5% reduction in electrical consumption Statewide. The total aggregate electrical savings in 2010 from the installation of solar water heating systems was sufficient to displace the total annual electrical use of 20,677 homes, based on the average household electrical use of 7,045 kwh per year from the State of Hawaii Energy Data and Trends March 2011 Table 5.8 (Attachment 8).

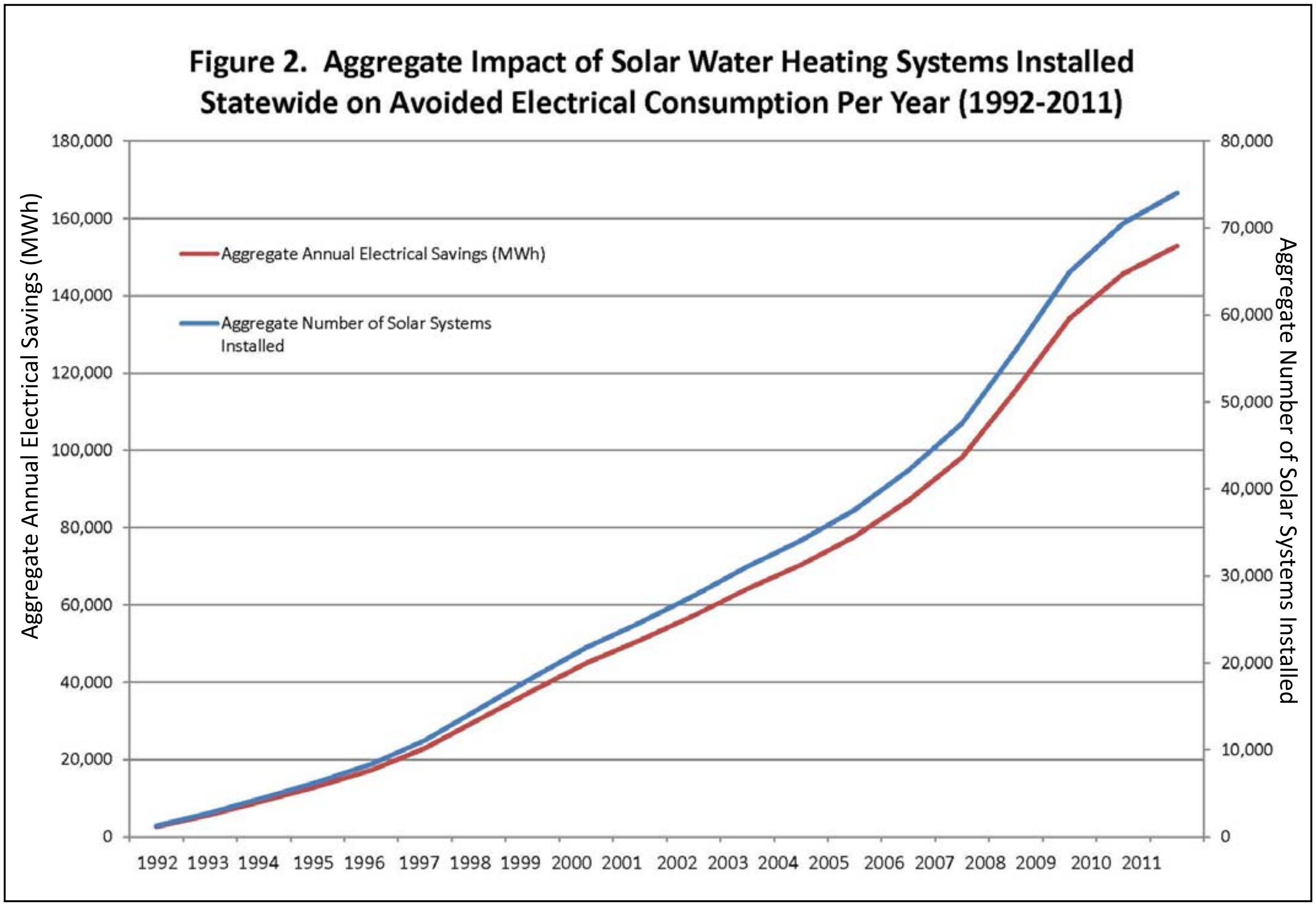
For the most recent year in 2011, the 74,018 total solar water heating systems that have been installed over the past 20 years saved an aggregate of 152,847 MWh per year in electricity. This amounted to an annual savings of 221,337 barrels of fuel oil that would have otherwise been required to generate this electricity, and a resulting reduction of 116,699 tons in avoided CO_2 emissions. Using the same State of Hawaii Energy Data and Trends data, the total aggregate electrical savings in 2011 from the installation of solar water heating systems was sufficient to displace the electricity used by 21,695 homes annually.

The total estimated value of the solar water installations that were installed cumulatively over the 20 year period from 1992 through 2011 is approximately $332 million, and the estimated value of the State Tax Credits that were provided totaled approximately $116 million.

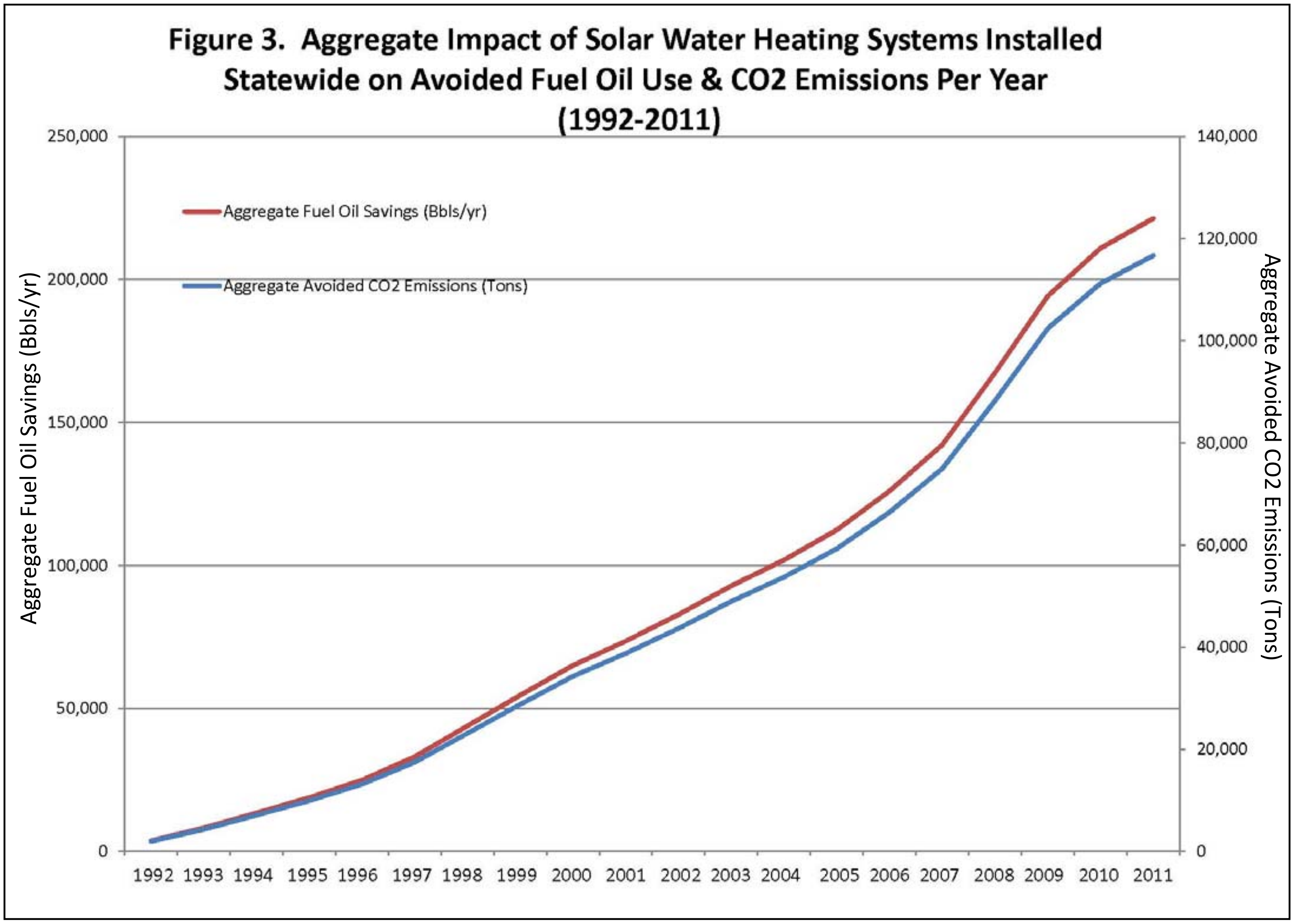
Figure 1 illustrates the number of solar water installations that have been installed annually from 1992 through 2011. There is a significant increase in the number of systems installed during the 2008 through 2010 timeframe which appears attributable to the reinstitution of the Federal tax credits in 2006.



The aggregate impact of the number of solar water installations that have been installed from 1992 through 2011 on avoided electrical use is shown in Figure 2. The cumulative to date savings resulting from the 74,018 total solar water heating systems installed between 1992 through 2011 totaled 1,237,356 MWh in electricity over this 20 year period.



The aggregate impact of the number of solar water installations that have been installed from 1992 through 2011 on avoided fuel oil use and CO2 emissions is shown in Figure 3. The cumulative impact of the solar water heating systems has resulted in a total savings of 1,791,810 barrels of fuel oil that would have otherwise been required to generate this electricity, and a 944,722 ton reduction in avoided CO2 emissions over the entire period from 1992-2011.



Based on this assessment, the installation of solar water heating systems in Hawaii over the past 20 years has made a significant contribution in reducing electrical energy use and the amount of fuel oil imported to the State, while also lowering the amount of CO2 and other flue stack air emissions that would have otherwise been generated.

3.0 METHODOLOGY/BASIS FOR ASSESSMENTANALYSIS:

3.1 <u>Quantification of Solar Water Heating Systems Installations</u>:

The number of solar water heating system installations in the State of Hawaii for the period from 1992 through 2011 of 74,018 systems installed cumulatively over this period was derived from "Solar System Tax Credits Claimed (1977-2011)" (See Attachment 1). This data was derived and compiled from the following sources which are documented on page 2 of the report: the State of Hawaii Tax Reports, the Hawaii Solar Energy Association (HSEA), the electric utility companies (HECO, HELCO, MECO, and KIUC), Hawaii Energy, DBEDT, and the Military. The solar water installations tallied during this period reflect the number of systems that were documented to have received State and Federal tax credits and electric utility rebates. Since the life expectancy of a solar water heating system is 20 years (see Attachment 2 - Solar Water Heaters : ENERGY STAR), it is assumed all of the solar water systems installed over the past 20 years are still in service at this time. While some of these systems may have already been replaced, it is reasonable to assume that the majority of these systems have remained operational. In addition, some of the older solar water systems during the preceding period from 1977 through 1991 that total an additional 29,287 installations that are not included in this assessment also remain functional and would actually increase the impact of the solar system installed over the past 20 years if they were also counted. It is also assumed that all of these solar water heating systems were installed to displace the use of electrical water heaters since the electric utility company rebates provided a significant incentive for their installation.

3.2 Estimate of Avoided Electrical Use per Solar Water Heating System Installation:
The avoided electrical consumption per solar water heating system of 2,065 kwh per year per system is based on the analysis from Hawaii Energy - Technical Reference Manual No. 2011 Program Year 3 July 2011 to June 2012 (Excerpt pages 18-26 – Attachment 3). This analysis is based on the following which appear to be reasonable:

1. Average Hot Water Use Per Person: 13.3 Gallons per day
2. Average Occupants per Solar Water Heating System: 3.77
3. Final Water Heating Temperature: 130 degrees F
4. Initial Cold Water Supply Temperature: 75 degrees F
5. Electrical Resistance Heater COP: 0.90
6. Fraction of Water Heating Accomplished by Solar on an Annual Basis: 90%

The Hawaii Energy estimate of 2,065 kwh per year of electricity use avoided by installation of each solar water heating system is also consistent with an independent study, "Saying Mahalo to Solar Savings: A Billing Analysis of Solar Water Heaters in Hawaii," (Attachment 4) that was prepared in conjunction with the Hawaii Public Utilities Commission . This report calculated the savings of solar water heating installations in Hawaii using a statistical analysis of the utility bills before and after the solar water heating systems were installed in 6,302 homes in 2009 and 2010. According to their summary, " … Our impact estimate of 1,912 kWh is close to the current ex ante savings value of 2,066 kWh included in the Hawaii Energy PY2010 Technical

Reference Manual (TRM). Given that the savings estimates are so close, we did not recommend any change to the TRM value currently in use by the program…"

Based on these two reports, the avoided electrical consumption per solar water heating system of 2,065 kwh per year per system appears reasonable and is the basis for the electrical savings utilized in this assessment.

3.3 Estimate of Avoided Fossil Fuel and Carbon Dioxide Emissions:

The fossil fuel consumption and carbon dioxide emissions avoided from the savings in electricity due to the installation of the solar hot water heating systems is based on the heat rate of 9,123 Btu/kwh and a CO2 Emission Factor of 1,527 lb/Mwh for the average of all electrical power generation in the Hawaiian Islands. These figures were developed in the analysis from "Fuel and Carbon Dioxide Emissions Savings Calculation Methodology for Combined Heat and Power Systems, U.S. Environmental Protection Agency, Combined Heat and Power Partnership August 2012" (Attachment 5). A conversion factor of 150,000 Btu per gallon was used to convert from energy to residual fuel oil.

4.0 REFERENCES:

1. Solar System Tax Credits Claimed (1977-2011), Ron Richmond (Attachment 1)
2. Solar Water Heaters : ENERGY STAR, http://www.energystar.gov/index.cfm?c=solar_wheat.pr_savings_benefits (Attachment 2)
3. Hawaii Energy - Technical Reference Manual No. 2011 Program Year 3 July 2011 to June 2012 (Excerpt pages 18-26 – Attachment 3)
4. Saying Mahalo to Solar Savings: A Billing Analysis of Solar Water Heaters in Hawaii, Jenny Yaillen, Evergreen Economic/Chris Ann Dickerson, CAD Consulting/Wendy Takanishi and John Cole, Hawaii Public Utilities Commission (Attachment 4)
5. Fuel and Carbon Dioxide Emissions Savings Calculation Methodology for Combined Heat and Power Systems, U.S. Environmental Protection Agency, Combined Heat and Power Partnership August 2012 (Attachment 5)
6. Table F15: Total Petroleum Consumption Estimates, 2010, U.S. Energy Information Administration (Attachment 6)
7. Hawaii Energy Statistics http://energy.hawaii.gov/resources/dashboard-statistics (Attachment 7)
8. State of Hawaii Energy Data and Trends March 2011 Table 5.8 (Attachment 8)

ATTACHMENT 1

TAX CREDITS CLAIMED (1977-2011)

Effect of Incentives for Solar Water Heating Systems in Hawaii

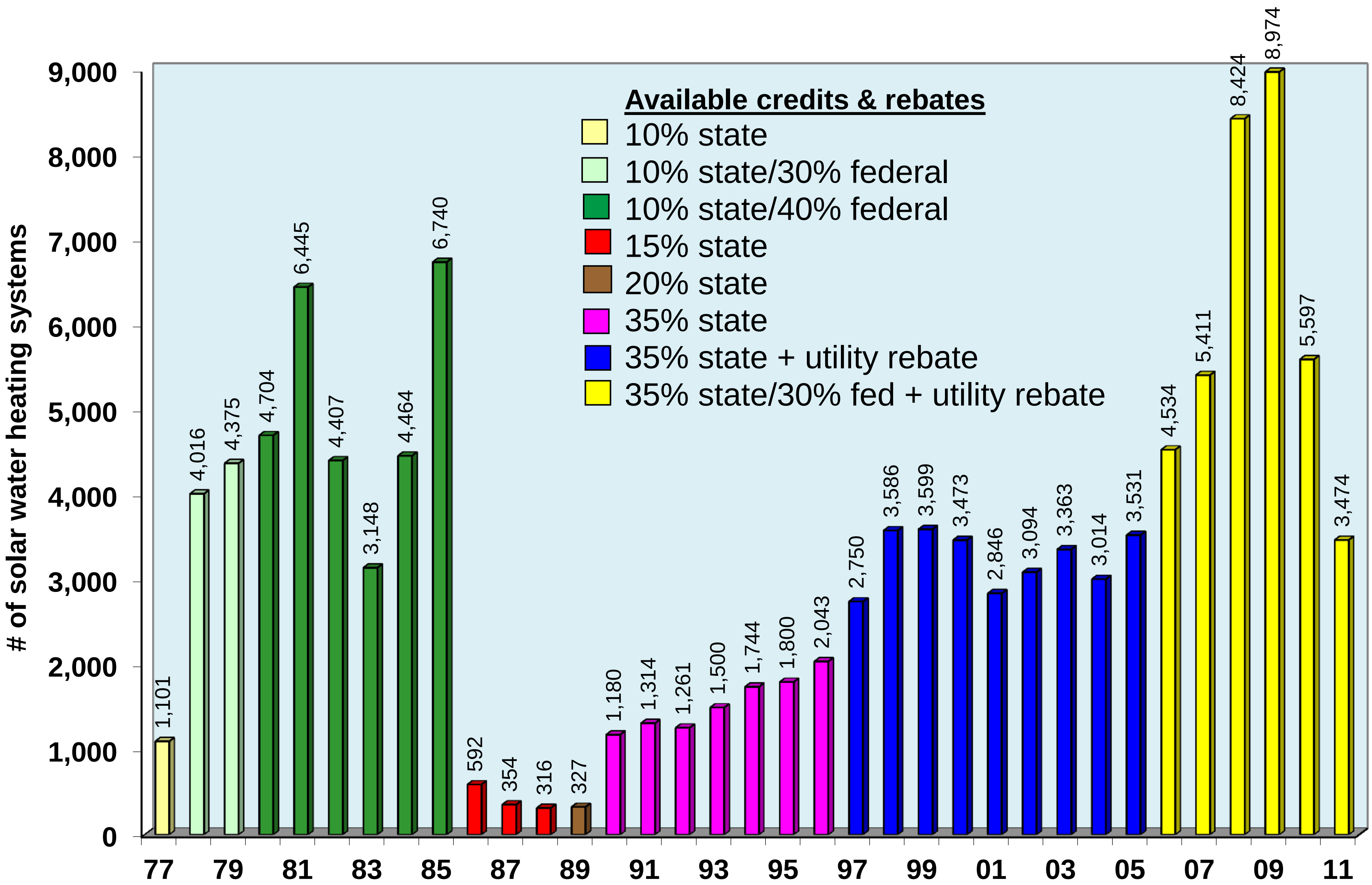


Chart '77-'11

Tax Credits Claimed 1977-2011

SOLAR SYSTEMS INSTALLED STATEWIDE and within the TRI-SERVICE AREA

YEAR	STATEWIDE	TAX CREDIT LEVEL Total	State	Fed.	AVER. COST	SOURCE
77	1,101	10%	10%	0%	$2,135	State Tax Report
78	4,016	40%	10%	30%	$2,907	State Tax Report
79	4,375	40%	10%	30%	$3,031	State Tax Report
80	4,704	50%	10%	40%	$3,346	State Tax Report
81	6,445	50%	10%	40%	$3,500	State Tax Report
82	4,407	50%	10%	40%	$3,659	State Tax Report
83	3,148	50%	10%	40%	$3,601	State Tax Report
84	4,464	50%	10%	40%	$3,519	State Tax Report
85	6,740	50%	10%	40%	$3,897	State Tax Report
86	592	15%	15%	0%	$2,230	State Tax Report
87	354	15%	15%	0%	$3,213	State Tax Report
88	316	15%	15%	0%	$3,142	State Tax Report
89	327	20%	20%	0%	$3,016	State Tax Report
90	1,180	35%	35%	0%	$3,751	State Tax Report
91	1,314	35%	35%	0%	n/a	State Tax Report
92	1,261	35%	35%	0%	$3,440	State Tax Report
93	1,500	35%	35%	0%	n/a	HSEA
94	1,744	35%	35%	0%	n/a	State Tax Report
95	1,800	35%	35%	0%	n/a	HSEA
96	2,043	35%	35%	0%	n/a	HSEA
97	2,750	35%	35%	0%	n/a	HECO, HELCO, MECO, KIUC
98	3,586	35%	35%	0%		HECO, HELCO, MECO, KIUC
99	3,599	35%	35%	0%		HECO, HELCO, MECO, KIUC
00	3,473	35%	35%	0%		HECO, HELCO, MECO, KIUC
01	2,846	35%	35%	0%		HECO, HELCO, MECO, KIUC
02	3,094	35%	35%	0%		HECO, HELCO, MECO, KIUC
03	3,363	35%	35%	0%		HECO, HELCO, MECO, KIUC
04	3,014	35%	35%	0%		HECO, HELCO, MECO, KIUC
05	3,531	35%	35%	0%		HECO, HELCO, MECO, KIUC
06	4,534	65%	35%	30%	$5,250	HECO, HELCO, MECO, KIUC
07	5,411	65%	35%	30%		HECO, HELCO, MECO, KIUC
08	8,424	65%	35%	30%		HECO, HELCO, MECO, KIUC
09	8,974	65%	35%	30%		HECO, HELCO, MECO, KIUC
10	5,597	65%	35%	30%	$6,600	HEP, KIUC, DBEDT, Military
11	3,474	65%	35%	30%	$6,625	HEP, KIUC, DBEDT, Military
TOTAL	103,305					

Note: 1. Residential electric customers were eligible for rebates if they replaced their existing solar hot water systems with program systems. These systems are referred to as "burnout replacements".
2. HECO, HELCO, MECO began tracking burnout replacements in 1996.
3. System counts listed here have not been adjusted reflect burnout replacements.
4. Accordingly, total number of installed systems are overstated.

YEAR	Rebated Retrofit Systems Oahu	Hawaii	Maui	Kauai	New SFD	Total	Private Sector New SFD Total	Variance	Adjusted	Military SFD Actus	Forest City	Total	Total New SFD
10	2,586	547	523	80	1,861	5,597	1,859	458	**1,401**	340	120	**460**	**1,861**
11	2,397	543	534	?		3,474	1,669	442	**1,227**	553	215	**768**	**1,995**

Tax Credits Claimed 1977-2011

ATTACHMENT 2

PY11 - HAWAII ENERGY TECHNICAL REFERENCE MANUAL NO. 2011 (PAGES 18-26)
SECTION 8. (REEM) RESIDENTIAL ENERGY EFFICIENCY MEASURES

8 (REEM) Residential Energy Efficiency Measures

8.1 High Efficiency Water Heating

8.1.1 Solar Water Heater

Measure ID: See Table 7.3

Version Date & Revision History
Draft date: February 24, 2010
Effective date: July 1, 2010
End date: TBD

Referenced Documents:
- Energy and Peak Demand Impact Evaluation Report of the 2005-2007 Demand Management Programs – (KEMA 2005-07)
- Econorthwest TRM Review – 6/23/10
- Evergreen TRM Review – 2/23/12

TRM Review Actions:
- 6/23/10 Rec. # 6 – For PY 2010, adjust claimed demand savings based on participant data from all service territories covered. Adjust Demand Savings based on participant data weighted average of KEMA results across all counties. Change from 0.50 to 0.46 kW. non-military – Adopted and incorporated into PY2010-1 TRM.
- 6/23/10 Rec. # 7 - For PY 2010, include a discussion of shell losses in the savings analysis and supporting documentation. Discussion included in PY2010-1 TRM.
- 10/5/11 – Currently Under Review.

Major Changes:
- Eliminated Military figure as no foreseeable military retrofit applications will be received.
- Demand change to weighted average from KEMA 2008. 0.46 kW
- Changed individual water usage from 13.3035 to 13.3

Measure Description:
Replacement of Electric Resistance Water Heater with a Solar Water Heater designed for a 90% Solar Fraction. The new Solar Water Heating systems most often include an upgrade of the hot water storage tank sized at 80 or 120 gallons.

Systems must comply with Hawaii Energy Solar Standards and Specifications which call out:
- Panel Ratings
- System Sizing
- Installation orientation de-rating factors
- Hardware and mounting systems

Shell Losses:
The increase in size from a 40 or 60 gallon to an 80 or 120 gallon standard electric resistance water heater would in and of itself increase the “shell” losses of the system. These shell losses are the result of a larger surface area exposing the warm water to the cooler environment and thus more heat lost to the environment through conduction through the tank. Engineering calculations by Econorthwest puts this at a 1% increase in losses. This is further reduced by 90% as the solar water system provides that fraction of the annual water heating requirements.

Baseline Efficiencies:
Baseline usage is a 0.9 COP Electric Resistance Water Heater. The baseline water heater energy consumption is by a single 4.0kW electric resistance element that is controlled thermostatically on/off controller based of tank finish temperature set point. The tank standby loss differences between baseline and high efficiency case are assumed to be negligible.

Demand Baseline has been determined by field measurements by KEMA 2005-07 report. The energy baseline also comes from the KEMA 2005-07 report and is supported by engineering calculations shown in this TRM.

Building Types	Demand Baseline(kW)	Energy Baseline (kWh)
Residential	0.57	2,733

High Efficiency:
Solar Water Heater designed for a 90% Solar Fraction. The Solar Systems use solar thermal energy to heat the water 90% of the time and continue to utilize electricity to operate the circulation pump and provide heating through a 4.0 kW electric resistance element when needed.

Solar Contractors do not favor Photo-Voltaic powered DC circulation pumps as they have proven less reliable in the field than an AC powered circulation pump.

The electric resistance elements in the high efficiency case do not have load control timers on them.

The energy is the design energy of a 90% solar fraction system with circulation pump usage as metered by KEMA 2008.

The on peak demand is the metered demand found by KEMA 2008.

Building Types	Demand High Efficiency (kW)	Energy High Efficiency (kWh)	Circ. Pump %
Residential	0.07	379	28%

Energy Savings:

Solar Water Heater Gross Savings before operational adjustments:

Building Types	Demand Savings (kW)	Energy Savings (kWh)
Residential	0.46	2,354

Operational Factor	Adjustment Factor
Solar Fraction Performance (sfp)	0.94
Persistence Factor (pf)	0.93
Demand Coincidence Factor (cf)	1.0

Solar Water Heater Net Savings after operational adjustments:

Building Types	Demand Savings (kW)	Energy Savings (kWh)
Residential	0.46	2,065

Savings Algorithms

Solar Water Heater - Non-Military Single Family Home

Energy per Day (BTU) = (Gallons per Day) x (lbs. per Gal.) x (Temp Rise) x (Energy to Raise Water Temp)

Hot Water needed per Person		13.3	Gallons per Day per Person	HE
Average Occupants	x	3.77	Persons	KEMA 2008
Household Hot Water Usage		50.141	Gallons per Day	
Mass of Water Conversion		8.34	lbs/gal	
Finish Temperature of Water		130	deg. F Finish Temp	
Initial Temperature of Water	-	75	deg. F Initial Temp	
Temperature Rise		55	deg. F Temperature Rise	
Energy to Raise Water Temp		1.0	BTU / deg. F / lbs.	
Energy per Day (BTU) Needed in Tank		23,000	BTU/Day	
Energy per Day (BTU) Needed in Tank		23,000	BTU/Day	
BTU to kWh Energy Conversion	÷	3,412	kWh / BTU	
Energy per Day (kWh)		6.7	kWh / Day	
Days per Month	x	30.4	Days per Month	
Energy (kWh) per Month		205	kWh / Month	
Days per Year	x	365	Days per Year	
Energy (kWh) Needed in Tank to Heat Water per Year		2,459	kWh / Year	
Elec. Res. Water Heater Efficiency	÷	0.90	COP	
Base SERWH Energy Usage per Year at the Meter		2,732	kWh / Year	KEMA 2008 - HECO
Design Annual Solar Fraction		90%	Water Heated by Solar System	Program Design
		10%	Water Heated by Remaining Backup Element	
Energy Usage per Year at the Meter		2,732	kWh / Year	
	x	10%	Water Heated by Remaining Backup Element	
Back Up Element Energy Used at Meter		273	kWh / Year	
Circulation Pump Energy		0.082	kW	KEMA 2008
Pump Hours of Operation	x	1,292	Hours per Year	KEMA 2008
Pump Energy used per Year		106	kWh / Year	
Back Up Element Energy Used at Meter		273	kWh / Year	72%
Pump Energy used per Year	+	106	kWh / Year	28%
Design Solar System Energy Usage		379	kWh / Year	
Base SERWH Energy Usage per Year at the Meter		2,732	kWh / Year	
Design Solar System Energy Usage	-	379	kWh / Year	
Design Solar System Energy Savings		2,353	kWh / Year	
Design Solar System Energy Savings		2,353	kWh / Year	
Performance Factor		0.94	pf	HE
Persistance Factor	x	0.93	pf	KEMA 2008
		2,065	kWh / Year	KEMA 2008
Residential Solar Water Heater Energy Savings		**2,065**	**kWh / Year Savings**	
Base SERWH Element Power Consumption		4.0	kW	
Coincidence Factor	x	0.143	cf	8.6 Minutes per hour
Base SERWH On Peak Demand		0.57	kW On Peak	KEMA 2008
Base SERWH On Peak Demand	-	0.57	kW On Peak	
Solar System Metered on Peak Demand	-	0.11	kW On Peak	KEMA 2008
		0.46	kW On Peak	
Residential Solar Water Heater Demand Savings		**0.46**	**kW Savings**	

Operating Hours
See Table above.

Loadshape
TBD

Freeridership/Spillover Factors
TBD

Persistence
The persistence factor has been found to be 0.93 based in the KEMA 2005-07 report that found 7% of the systems not operational.

Lifetime
15 years

Measure Costs and Incentive Levels

Table 1 – SWH Measure Costs and Incentive Levels

Description	Unit Incentive	Incremental Cost
Non-Military	$ 750	$6,600

Component Costs and Lifetimes Used in Computing O&M Savings
TBD

Reference Tables
None

8.1.2 Solar Water Heating Loan Interest Buydown (LIB)

Measure ID: See Table 7.3

Version Date & Revision History
Draft date: May 22, 2011
Effective date: November 1, 2011
End date: TBD

Referenced Documents:

- Energy and Peak Demand Impact Evaluation Report of the 2005-2007 Demand Management Programs – (KEMA 2005-07)
- Econorthwest TRM Review – 6/23/10
- Evergreen TRM Review – 2/23/12

TRM Review Actions:

- 6/23/10 Rec. # 6 – For PY 2010, adjust claimed demand savings based on participant data from all service territories covered. Adjust Demand Savings based on participant data weighted average of KEMA results across all counties. Change from 0.50 to 0.46 kW. non-military – Adopted and incorporated into PY2010-1 TRM.
- 6/23/10 Rec. # 7 - For PY 2010, include a discussion of shell losses in the savings analysis and supporting documentation. Discussion included in PY2010-1 TRM.
- 10/5/11 – Currently Under Review.

Major Changes:

- Eliminated Military figure as no foreseeable military retrofit applications will be received.
- Demand change to weighted average from KEMA 2008. 0.46 kW
- Changed individual water usage from 13.3035 to 13.3

Measure Description:
The Solar Water Heating Loan Interest Buydown Program offers eligible borrowers an interest buy down of $1,000 (with a minimum loan of $5,000) toward the financing of a solar water heating system from a participating lender – see www.hawaiienergy.com for a list of participating lenders.

Replacement of Electric Resistance Water Heater with a Solar Water Heater designed for a 90% Solar Fraction. The new Solar Water Heating systems most often include an upgrade of the hot water storage tank sized at 80 or 120 gallons.

Systems must comply with Hawaii Energy Solar Standards and Specifications which call out:

- Panel Ratings
- System Sizing
- Installation orientation de-rating factors
- Hardware and mounting systems

Shell Losses:
The increase in size from a 40 or 60 gallon to an 80 or 120 gallon standard electric resistance water heater would in and of itself increase the "shell" losses of the system. These shell losses are the result of a larger surface area exposing the warm water to the cooler environment and thus more heat lost to the environment through conduction through the tank. Engineering calculations by Econorthwest puts this at a 1% increase in losses. This is further reduced by 90% as the solar water system provides that fraction of the annual water heating requirements.

Baseline Efficiencies:
Baseline usage is a 0.9 COP Electric Resistance Water Heater. The baseline water heater energy consumption is by a single 4.0 kW electric resistance element that is controlled thermostatically on/off

controller based of tank finish temperature set point. The tank standby loss differences between baseline and high efficiency case are assumed to be negligible.

Demand Baseline has been determined by field measurements by KEMA 2005-07 report. The energy baseline also comes from the KEMA 2005-07 report and is supported by engineering calculations shown in this TRM.

Building Types	Demand Baseline(kW)	Energy Baseline (kWh)
Residential	0.57	2,733

High Efficiency:
Solar Water Heater designed for a 90% Solar Fraction. The Solar Systems use solar thermal energy to heat the water 90% of the time and continue to utilize electricity to operate the circulation pump and provide heating through a 4.0 kW electric resistance element when needed.

Solar Contractors do not favor Photo-Voltaic powered DC circulation pumps as they have proven less reliable in the field than an AC powered circulation pump.

The electric resistance elements in the high efficiency case do not have load control timers on them.

The energy is the design energy of a 90% solar fraction system with circulation pump usage as metered by KEMA 2008.

The on peak demand is the metered demand found by KEMA 2008.

Building Types	Demand High Efficiency (kW)	Energy High Efficiency (kWh)	Circ. Pump %
Residential	0.07	379	28%

Energy Savings:

Solar Water Heater Gross Savings before operational adjustments:

Building Types	Demand Savings (kW)	Energy Savings (kWh)
Residential	0.46	2,354

Operational Factor	Adjustment Factor
Solar Fraction Performance (sfp)	0.94
Persistence Factor (pf)	0.93
Demand Coincidence Factor (cf)	1.0

Solar Water Heater Net Savings after operational adjustments:

Building Types	Demand Savings (kW)	Energy Savings (kWh)
Residential	0.46	2,065

Savings Algorithms

Solar Water Heater - Non-Military Single Family Home

Energy per Day (BTU) = (Gallons per Day) x (lbs. per Gal.) x (Temp Rise) x (Energy to Raise Water Temp)

Hot Water needed per Person		13.3	Gallons per Day per Person	HE
Average Occupants	x	3.77	Persons	KEMA 2008
Household Hot Water Usage		50.141	Gallons per Day	
Mass of Water Conversion		8.34	lbs/gal	
Finish Temperature of Water		130	deg. F Finish Temp	
Initial Temperature of Water	-	75	deg. F Initial Temp	
Temperature Rise		55	deg. F Temperature Rise	
Energy to Raise Water Temp		1.0	BTU / deg. F / lbs.	
Energy per Day (BTU) Needed in Tank		23,000	BTU/Day	
Energy per Day (BTU) Needed in Tank		23,000	BTU/Day	
BTU to kWh Energy Conversion	÷	3,412	kWh / BTU	
Energy per Day (kWh)		6.7	kWh / Day	
Days per Month	x	30.4	Days per Month	
Energy (kWh) per Month		205	kWh / Month	
Days per Year	x	365	Days per Year	
Energy (kWh) Needed in Tank to Heat Water per Year		2,459	kWh / Year	
Elec. Res. Water Heater Efficiency	÷	0.90	COP	
Base SERWH Energy Usage per Year at the Meter		2,732	kWh / Year	KEMA 2008 - HECO
Design Annual Solar Fraction		90%	Water Heated by Solar System	Program Design
		10%	Water Heated by Remaining Backup Element	
Energy Usage per Year at the Meter		2,732	kWh / Year	
	x	10%	Water Heated by Remaining Backup Element	
Back Up Element Energy Used at Meter		273	kWh / Year	
Circulation Pump Energy		0.082	kW	KEMA 2008
Pump Hours of Operation	x	1,292	Hours per Year	KEMA 2008
Pump Energy used per Year		106	kWh / Year	
Back Up Element Energy Used at Meter		273	kWh / Year	72%
Pump Energy used per Year	+	106	kWh / Year	28%
Design Solar System Energy Usage		379	kWh / Year	
Base SERWH Energy Usage per Year at the Meter		2,732	kWh / Year	
Design Solar System Energy Usage	-	379	kWh / Year	
Design Solar System Energy Savings		2,353	kWh / Year	
Design Solar System Energy Savings		2,353	kWh / Year	
Performance Factor		0.94	pf	HE
Persistance Factor	x	0.93	pf	KEMA 2008
		2,065	kWh / Year	KEMA 2008
Residential Solar Water Heater Energy Savings		**2,065**	**kWh / Year Savings**	

Operating Hours
See Table above.

Loadshape
TBD

Freeridership/Spillover Factors
TBD

Persistence
The persistence factor has been found to be 0.93 based in the KEMA 2005-07 report that found 7% of the systems not operational.

Lifetime
15 years

Measure Costs and Incentive Levels
Hawaii Energy will be allowed to claim credit for the fraction of the energy and demand savings and total resource benefits that is proportional to the share of customer incentive cost paid with PBFA funds.

The following distribution is provided for energy and demand impacts:

PBFA (Public Benefit Fee Administrator)	25%
ARRA (American Recovery and Reinvestment Act)	75%

Energy Savings	2065 kWh/year
Demand Savings	0.46 kW

Pre-Bonus Period (11/1/10 - 3/21/11)			PBF				ARRA			
	Unit Incentive	Incremental Cost	Unit Incentive	% Contribution	Energy Savings (kWh/year)	Demand Savings (kW)	Unit Incentive	% Contribution	Energy Savings (kWh/year)	Demand Savings (kW)
Military	$ 1,000	$ 4,400	$ 250	25%	516	0.12	$ 750	75%	1549	0.35
Non-Military	$ 1,000	$ 6,600	$ 250	25%	516	0.12	$ 750	75%	1549	0.35

Bonus Period (3/22/11 - 6/30/11)			PBF				ARRA			
	Unit Incentive	Incremental Cost	Unit Incentive	% Contribution	Energy Savings (kWh/year)	Demand Savings (kW)	Unit Incentive	% Contribution	Energy Savings (kWh/year)	Demand Savings (kW)
Military	$ 1,750	$ 4,400	$ 250	14%	295	0.07	$ 1,500	86%	1770	0.39
Non-Military	$ 1,750	$ 6,600	$ 250	14%	295	0.07	$ 1,500	86%	1770	0.39

Component Costs and Lifetimes Used in Computing O&M Savings
TBD

Reference Tables
None

8.1.3 Solar Water Heater Energy Hero Gift Packs

Measure ID:

Version Date & Revision History
Draft date: October 4, 2011
Effective date: July 1, 2011
End date: June 30, 2012

Referenced Documents:
- Energy and Peak Demand Impact Evaluation Report of the 2005-2007
- Demand Management Programs – KEMA (KEMA 2005-07)
- Econorthwest TRM Review – 6/23/10
- Energy and Peak Demand Impact Evaluation Report of the 2005-2007 Demand Management Programs – (KEMA 2005-07)
- Evergreen TRM Review – 2/23/12

TRM Review Actions:
- 10/5/11 – Currently Under Review.

Major Changes:
- 11/22/11 – LED algorithm updated. See section 8.2.2 for changes.
- 11/22/11 – Akamai Power Strip kWh savings updated based on NYSERDA Measure Characterization for Advanced Power Strips.
- 11/22/11 – Updated content in headings *Description*, *Base Case*, *High Efficiency Case*, and *Energy Savings* in regard to LED lamps to match section 8.2.2.
- 11/29/11 – Low Flow Shower Head algorithm updated – previously claiming only 50% of total energy savings due to inaccurately calculating hot and cold water mix. Also updated *Energy Savings* table as necessary.
- 4/17/12 – Updated CFL and LED algorithms to refer to CFL and LED sections in TRM to ensure accuracy. Updated energy savings numbers to be consistent with EMV revisions.
- 8/1/12 – Updated Low Flow Shower Head algorithm to reduce demand savings from 40% to 20% as per EM&V review (Feb. 2012)

Description:
Potential gift pack components:
- Compact Fluorescent Lamp
- Akamai Power Strip
- LED Lamp
- Low Flow Shower Head

Base Case
- 60 W incandescent lamps
- Standard power strip or no power strip
- 25% 60W incandescent, 25% 40W incandescent, 25% 23W CFLs and 25% 13W CFLs (See LED TRM)
- Low Flow Shower Head rated at 2.5 gpm

High Efficiency Case
- 15W CFLs
- Akamai Power Strip
- 50% 7W LED Lamp and 50% 12.5W LED Lamp
- Low Flow Shower Head rated at 1.5 gpm

ATTACHMENT 3

ENERGY STAR - SAVE MONEY AND MORE WITH ENERGY STAR QUALIFIED SOLAR WATER HEATERS

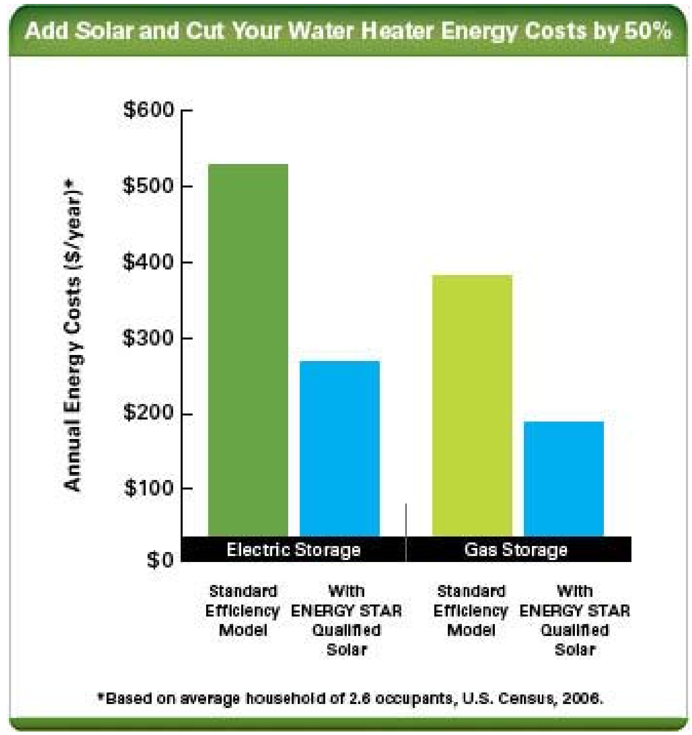
Save Money and More with ENERGY STAR Qualified Solar Water Heaters

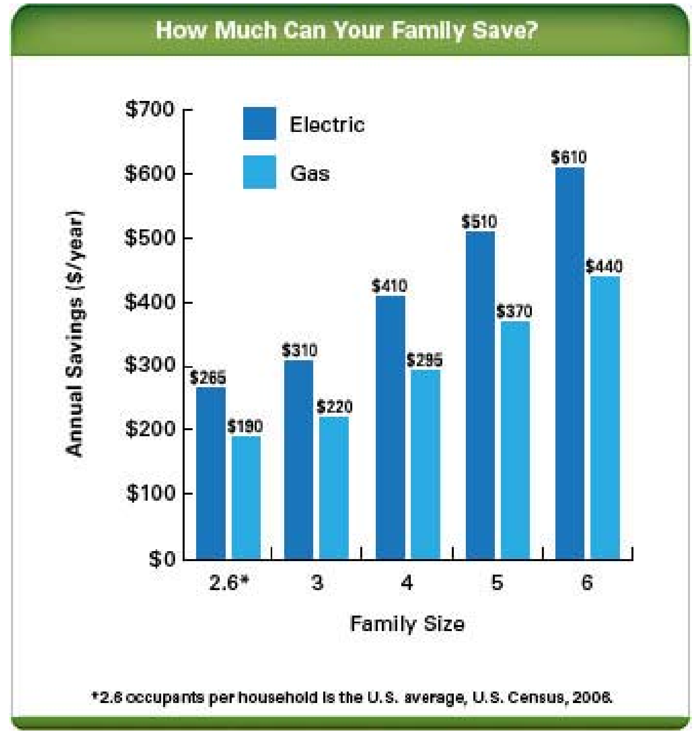
An ENERGY STAR qualified solar water heating system can cut your annual hot water costs in half, and is generally designed for use with an electric or gas back-up water heater. Demonstrate your environmental leadership by voting with your wallet for renewable energy solutions. Purchase an ENERGY STAR qualified solar water heater for your home and enjoy these benefits:

Save money. By using sunshine to heat or preheat your water, you can cut your water heating bill in half. This means you can save $190 annually if you combine solar with a backup gas-storage water heater instead of using the gas water heater alone. If you have an electric tank water heater for back-up, you'll save about $250 each year on electricity bills. Large families with greater hot water needs can save even more.

Invest in a better environment. Water heated by the sun just feels better. The purchase of a solar system can take about 10 years to pay for itself, but by taking advantage of Federal tax credits you can recoup the price premium more quickly. In the meantime, your investment will pay dividends for the environment. ENERGY STAR qualified solar water heaters can cut your carbon dioxide emissions in half. Installing a qualified solar water heater will reduce the load of your electric water heater by almost 2,500 kWh per year, preventing 4,000 pounds of carbon dioxide from entering the atmosphere annually. This is the equivalent of not driving your car for four months every year!

Long lifetime. The average life expectancy of qualified solar water heating systems is 20 years, much longer than standard gas or electric storage water heaters.




How Much Can Your Family Save?
Electric
Gas
Annual Savings ($/year)
$700
$600
$500
$400
$300
$200
$100
$0
$265
$190
$310
$220
$410
$295
$510
$370
$610
$440
2.6*
3
4
5
6
Family Size
*2.6 occupants per household is the U.S. average, U.S. Census, 2006.

ATTACHMENT 4

SAYING MAHALO TO SOLAR SAVINGS: A BILLING ANALYSIS OF SOLAR WATER HEATERS IN HAWAII

Saying Mahalo to Solar Savings: A Billing Analysis of Solar Water Heaters in Hawaii

Jenny Yaillen, Evergreen Economics
Chris Ann Dickerson, CAD Consulting
Wendy Takanish and John Cole, Hawaii Public Utilities Commission

ABSTRACT

Over the last several years, the market share for solar water heaters has steadily increased in the state of Hawaii. The Hawaiian government mandated that all new homes have solar water heaters installed, and the state offers incentives to homeowners who opt to purchase solar water heaters for their existing homes. The evaluation of savings and market conditions associated with this equipment is important as other markets consider the energy savings potential of solar water heating technology. This paper provides the results of a billing analysis used to estimate savings of residential solar water heaters in the state of Hawaii and feedback from consumers and contractors on the remaining potential.

The billing analysis was conducted with a monthly panel data regression model using utility billing data and program tracking data for 2,457 customers who installed solar water heaters during program year 2009, estimating changes in household electricity consumption between the pre- and post-installation periods.

The results of this paper are significant because they help provide an updated savings value for solar water heaters in Hawaii and give a current assessment of market conditions. While Hawaii's climate is unique, these savings and market findings can assist other regions in tapping solar water heater potential in their markets. These results will be of interest to other states with sunny climates that have a high solar energy potential.

Introduction, Background, and Summary of Findings

This paper presents the results of a solar water heater billing analysis conducted as part of a larger evaluation of Hawaii Energy's conservation and efficiency programs. The analysis focused on the residential installation of solar water heaters for the program year 2009 (PY2009) and 2010 (PY2010).[1] This paper also presents some findings on the condition of the market for solar water heaters in Hawaii.

The Hawaiian market for solar energy efficiency equipment is somewhat different from the rest of the country. To start, Hawaii's climate and abundance of sunshine make it an ideal locale for the success of a measure like solar water heaters. In addition, the high energy prices that Hawaiian consumers face provide even more reason to invest in a technology like solar water heating.

Interest in solar water heating and renewable energy as a whole has a long history in Hawaii. As early as 1976, Hawaii provided energy tax credits for residents and businesses that purchased and installed renewable energy systems, including solar water heaters. In 1996 a

[1] Hawaii Energy's program year runs from July 1 to June 30. For example, program year 2009 refers to program activities undertaken between July 1, 2009 and June 30, 2010.

rebate was made available through the public benefit fund of Hawaii Energy Efficiency Programs. The public benefits fund was originally collected and administered by Hawaii Electric Company (HECO) and Maui Electric Company (MECO). Since 2009, the energy efficiency programs and rebates have been administered through Hawaii Energy. Rebates for solar water heaters are currently funded by the public benefits fee paid into by ratepayers along with some funding from the American Recovery and Reinvestment Act (ARRA).

Hawaii Energy is a third-party organization that implements conservation and energy efficiency programs throughout Hawaii. They operate a portfolio of programs that cover the residential and commercial sectors, with some programs targeted specifically toward new construction and residential low-income customers. The solar water heater program is currently a part of their residential program offerings. The last time these programs were evaluated was in 2008 when KEMA, Inc. conducted an impact evaluation of the 2005-2007 program cycle of the residential and commercial portfolio.

Our analysis focused on the solar water heater program since coming under the control of Hawaii Energy in 2009. Total solar water heater program participation for PY2009 and PY2010 is shown in Table 1. In our final model, participants from PY2010 are used as a control group to determine the savings realized by PY2009 participants, as the PY2010 participants had not yet installed the solar water heater in 2009 (the year used for the billing analysis). Including the PY2010 customers in the sample provides an additional control for external influences (e.g., economic conditions, household and structural changes) that may impact energy use.

Table 1. Solar Water Heater Participants

Program Year	Number of Participants
2009	3,607
2010	2,695
Total	6,302

The annual savings estimate for solar water heaters found as a result of this analysis is shown below in Table 2, along with a 95 percent confidence interval. Our impact estimate of 1,912 kWh is close to the current *ex ante* savings value of 2,066 kWh included in the Hawaii Energy PY2010 Technical Reference Manual (TRM).[2] Given that the savings estimates are so close, we did not recommend any change to the TRM value currently in use by the program.

Table 2. Savings Estimate and 95% Confidence Interval

Annual Savings (kWh)	95 % Conf. Interval LOWER BOUND	95 % Conf. Interval UPPER BOUND	Current TRM Value (kWh)
1,912	1,714	2,111	2,066

Source: Analysis by Evergreen Economics of data provided by Hawaii Energy

[2] The PY2010 TRM savings value of 2,066 kWh is based on the 2008 evaluation by KEMA Inc. of the 2005-2007 Hawaii demand side management programs, which included a solar hot water heater metering study.

Billing Regression

For the billing regression, we developed a fixed effects billing regression model using monthly panel data to estimate changes in household electricity consumption between the baseline ("pre") and post-measure-installation periods. The billing regression model relates normalized monthly electricity consumption by household by month to:

1. An indicator variable for the months in which the solar water heater was installed
2. Monthly dummy variables to control for external factors[3]
3. Interaction terms between the indicator for solar water heater installation and monthly dummy variables

Interactions between the first two independent variables were examined and ultimately included in the model. The final model was estimated using the linear values of the dependent and independent variables.[4] While a number of different specifications were explored, the final fixed effects model was specified as follows:

$$kWh_{it} = \beta_0 + \beta_1 SWH_{it} + \beta_2 Month_{it} + \beta_3 Month_{it} * SWH_{it} + e_{it}$$

Where:

kWh = Normalized monthly electricity consumption for each month (in kWh)

SWH = Indicator variable for post-period solar water heater installation period

$Month$ = Indicator variables for each month excluding December

$Month * SWH$ = Interaction terms between indicator for post-period solar water heater installation and monthly indicators

i = Index for household (i = 1,..., n)

t =Index for monthly time period (t=1,2,..., T)

$[\beta_0, ..., \beta_3,]$= Coefficients to be estimated in the model

$[e]$= Error term assummed normally distributed

Data Used in Analysis

Monthly electricity billing data and information related to the timing of solar water heater installation were provided by Hawaii Energy for participants in program years 2009 and 2010. Utility billing data were provided from April 2008 to July 2011.

Weather or temperature data were not included in this analysis since water heater use is not greatly affected by daily outdoor temperature and temperatures are relatively constant throughout the year in Hawaii. However, monthly indicator variables were included in the final

[3] December was excluded to avoid perfect collinearity between independent variables.
[4] As opposed to the alternative of first transforming the dependent variable and/or the independent variables by the natural log function.

model specification to capture any seasonal or monthly effects that may exist. Variables included in the billing regression model are defined below in

Table 3.

Table 3. Description of Model Variables

Variable	Description
kWh	Normalized monthly electricity consumption by month (calculated by scaling usage from number of meter read days to the average number of days per month)
SWH	Indicator variable for months after solar water heater installation (equals 1 if in post-installation period; else equals 0)
Month (January, February, March, etc.)	A vector of indicator variables for month of year (equals 1 if observation falls in that month; else equals 0)
Month_SWH (Jan_SWH, Feb_SWH, Mar_SWH, etc.)	A vector of indicator variables for month of year and solar water heater installation (equals 1 if in post-installation period and observation falls in that month; else equals 0)

Data screens were employed to ensure that only participants within a reasonable consumption range were included in the analysis. This data screen was based on monthly kWh usage and participants were selected for analysis if their monthly usage fell between 50 and 3,000 kWh. The effect of implementing this screen on the data is shown in Table 4 below.

Table 4. Summary of Data Screens

Program Year	Total Participants	Participants with Billing Data	Participants Meeting kWh Criteria
2009	3,607	3,606	2,457
2010	2,695	2,693	1,951
Total	6,302	6,299	4,408

Source: Analysis by Evergreen Economics of data provided by Hawaii Energy

This data screen was used in the final model presented in this paper. Column four of Table 4 shows the number of individual participants included in the final model. Pre- and post-installation data were included for all 2,457 PY2009 participants shown in this table. The 1,951 participants from PY2010 were included as a control group, and as such only their pre-installation billing data were included in the analysis.

Billing Model Estimation Results

The results from the billing regression model are shown below in Table 5. All of the estimated coefficients are of the expected sign (either negative or positive) and the primary variable of interest (SWH) is statistically significant at the 5 percent level. About half of the monthly indicator variables are statistically significant at the 5 percent level as well. The coefficients on monthly indicators and interaction terms show that kWh usage varies by month, with February, March, April, and May showing statistically significant lower usage per month, on average, than December (the omitted variable).

The coefficient of interest with respect to solar water heater energy savings is β_1 (the coefficient on the post-installation indicator). This coefficient is negative, indicating that, after accounting for monthly variations in electricity usage and holding all else constant, participants experienced an estimated base decrease of 159.37 kWh per month after installation of a solar water heater. This translates to an annual savings of 1,912 kWh due to the solar water heater installation.

Note that this result captures all changes in usage in the post period and attributes them to the solar water heater installation. To the extent that there are external influences that are reducing energy use outside the program and are not controlled for in our model, then the savings estimates derived from the model will overstate the actual energy savings of the solar water heaters.

Table 5. Regression Results

Variable	Coefficient	Std. Error	t-statistic	p-value
(β_0) Constant	845.62	4.56	185.59	0.00
(β_1) SWH	-159.37	8.43	-18.90	0.00
(β_2) January	13.14	6.56	2.00	0.05
(β_2) February	-27.05	6.79	-3.98	0.00
(β_2) March	-33.46	6.63	-5.04	0.00
(β_2) April	-39.69	6.86	-5.78	0.00
(β_2) May	-33.50	7.04	-4.76	0.00
(β_2) June	-7.60	6.23	-1.22	0.22
(β_2) July	-1.12	6.24	-0.18	0.86
(β_2) August	11.26	6.32	1.78	0.08
(β_2) September	7.61	6.31	1.21	0.23
(β_2) October	1.69	6.38	0.27	0.79
(β_2) November	4.93	6.57	0.75	0.45
(β_3) January_SWH	8.37	11.77	0.71	0.48
(β_3) February_SWH	-6.30	12.06	-0.52	0.60
(β_3) March_SWH	4.81	11.45	0.42	0.68
(β_3) April_SWH	-7.80	11.82	-0.66	0.51
(β_3) May_SWH	5.20	11.82	0.44	0.66
(β_3) June_SWH	-10.30	11.17	-0.92	0.36
(β_3) July_SWH	-1.37	11.28	-0.12	0.90
(β_3) August_SWH	-2.33	12.51	-0.19	0.85
(β_3) September_SWH	-0.16	12.25	-0.01	0.99
(β_3) October_SWH	6.43	12.26	0.52	0.60
(β_3) November_SWH	4.54	12.31	0.37	0.71

Source: Analysis by Evergreen Economics of data provided by Hawaii Energy

The coefficient on SWH (β_1) in Table 5 above was used to calculate the annual savings attributable to solar water heaters. The data used in the model was on a monthly basis, so the coefficient estimate of -159.37 indicates that an average of 159.37 kWh in savings were realized in each month that a solar water heater was installed. To get an annual savings value, this number was simply multiplied by 12. The formula used to calculate annual savings is shown below:

Estimated change in annual energy use due to Solar Water Heater = Coefficient on SWH * 12

Table 6 below shows the estimated annual savings for solar water heaters installed by PY2009 participants along with a 95 percent confidence interval and the existing savings value in Hawaii Energy's PY2010 Technical Reference Manual (TRM).

Table 6. Billing Regression Savings Estimate and 95% Confidence Interval

Annual Savings (kWh)	95 % Conf. Interval LOWER BOUND	95 % Conf. Interval UPPER BOUND	2010 TRM Savings (kWh)
1,912	1,714	2,111	2,066

Source: Analysis by Evergreen Economics of data provided by Hawaii Energy

Comparison to Existing Savings Values

These billing regression results are slightly lower than, although generally consistent with, the savings value calculated in the PY2010 TRM. The TRM value for solar water heater savings is 2,066 kWh annually and assumes an average household occupancy of 3.77 people. The average household occupancy reported by the surveyed PY2009 participants was 3.53, which is slightly lower than that assumed by the TRM. A lower occupancy is generally associated with less hot water use and consequently these households may see slightly smaller annual savings than the TRM suggests.

In addition, the annual kWh consumption of the sample households is lower than the average found in earlier solar water heater impact evaluations. The average annual base consumption in the model data was 10,147 kWh, whereas the annual base consumption found in the 2001-03 Impact Evaluation prepared by KEMA was 11,096 kWh. The kWh savings reported by KEMA for solar water heaters in that report was 2,201 kWh. The small difference in occupancy and base consumption between these groups may explain some of the difference in savings found by our analysis. Despite these differences, the TRM savings value of 2,066 kWh does fall within the 95 percent confidence interval of our estimated savings, indicating that our analysis confirms the existing value for solar water heaters.

Solar Water Heater Market Findings

The solar water heating market provides considerable opportunity for energy savings in Hawaii. Based on the findings in this analysis, installed residential solar water heaters can save the average Hawaii household nearly 20 percent on their annual electric bill, which is equivalent to about \$500 to \$700 annually, depending on the electricity rate for each island.[5] The expected lifetime of a solar water heater is 15 years, and the savings will persist over that time. These savings have been significant enough that the Hawaii State Senate passed SB no. 644, which requires all new single-family residences constructed after January 1, 2010 to include a solar water heater system. Despite this requirement for new residential homes, there is still a large market for retrofitting solar water heaters in existing homes. The current estimates are that roughly 75 percent of homes in Hawaii do not have a solar water heater system.

The Hawaii Energy solar water heater program recently transitioned its focus to retrofitted solar water heating systems in order to comply with the new Senate Bill that mandated solar water heating on all new homes. The retrofit market often consists of those customers that

[5] Average residential electricity rates in Hawaii for 2010 varied from \$0.2547 on Oahu to \$0.3711 on Lanai.

are the most difficult and costly to serve and, as a result, the incentive program is even more vital to installations of solar water heaters for this market segment. The incremental cost of a solar water heater is listed as $6,600 in the PY2010 TRM and has a rebate amount of $750. The additional electricity cost savings provided by the solar water heater adds an extra incentive for retrofit customers.

At the end of 2009 there was a significant rush of solar water heater installations by new construction builders and customers in order to take advantage of the rebate before the expiration date. There was also an initial boost in install rates at the beginning of the 2010 program year, and again at the end of calendar year 2010. In March 2011, Hawaii Energy was approved to use ARRA funding to double the cash rebate amount for solar water heater systems, which resulted in 800 systems being sold in one month and completely exhausting the additional approved funds.

The current solar water heater program is strong, and interviews with solar water heater contractors reveal that they see it as a reliable technology, which requires little more than routine maintenance. To assist in this routine maintenance, Hawaii Energy has started offering a rebate for solar water heater tune-ups in PY2011 at a cost of $250 to participants after a $50 rebate. In addition to contractor satisfaction with the equipment, participant surveys revealed that 97 percent of PY2009 participants and 96 percent of PY2010 participants were "somewhat satisfied" or "very satisfied" with their solar water heater purchase. Together these two results indicate that solar water heaters have a positive market presence in Hawaii.

Summary and Conclusions

Using a billing regression model and a sample of 2009 and 2010 solar water heater participants, we estimated annual savings from this measure of 1,912 kWh. This generally confirms the savings value of 2,066 kWh in use by Hawaii Energy for PY2010, as that value lies within the 95 percent confidence interval of our savings estimate. The slight difference may be explained by lower occupancy rates and/or lower household energy consumption in our analysis sample relative to the values found in previous impact evaluations. For these reasons, we did not recommend any changes to the current *ex ante* value of 2,066 kWh used by Hawaii Energy for solar water heaters.

The market for solar water heaters in Hawaii now relies heavily on retrofitting water heating systems in existing homes due to the recent legislation requiring solar water heaters in all new construction projects. Our research found that there is still considerable potential in the retrofit market, and that incentives can be a substantial driver toward replacement. Additionally, interviews with contractors revealed that solar water heaters are a reliable technology that requires little maintenance and surveys of participants revealed high satisfaction rates with the installed equipment.

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ATTACHMENT 5

EPA COMBINED HEAT AND POWER PARTNERSHIP
FUEL AND CARBON DIOXIDE EMISSIONS SAVINGS CALCULATION METHODOLOGY
FOR COMBINED HEAT AND POWER SYSTEMS, AUGUST 2012

Fuel and Carbon Dioxide Emissions Savings Calculation Methodology for Combined Heat and Power Systems

U.S. Environmental Protection Agency

Combined Heat and Power Partnership

August 2012

The U.S. Environmental Protection Agency (EPA) CHP Partnership is a voluntary program that seeks to reduce the environmental impact of power generation by promoting the use of CHP. The CHP Partnership works closely with energy users, the CHP industry, state and local governments, and other stakeholders to support the development of new CHP projects and promote their energy, environmental, and economic benefits.

The CHP Partnership provides resources about CHP technologies, incentives, emissions profiles, and other information on its website at www.epa.gov/chp. For more information, contact the CHP Partnership Helpline at chp@epa.gov or (703) 373-8108.

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1.0 Introduction

Amid growing concerns about energy security, energy prices, economic competitiveness, and climate change, combined heat and power (CHP) has been recognized for its significant benefits and the part it can play in efficiently meeting society's growing energy demands while reducing environmental impacts. Policy makers, project developers, end users, and other CHP stakeholders often need to quantify the fuel and carbon dioxide (CO_2) emissions savings of CHP projects compared to conventional separate heat and power (SHP) in order to estimate projects' actual emissions reductions. An appropriate quantification of the energy and CO_2 emissions savings from CHP plays a critical role in defining its value proposition. At this time, there is no established methodology to quantify and make this estimation.

Summary of Key Points

- To calculate the fuel and CO_2 emissions savings of a CHP system, both electric and thermal outputs of the CHP system must be accounted for.
- The CHP system's thermal output displaces the fuel normally consumed in and emissions emitted from on-site thermal generation in a boiler or other equipment, and the power output displaces the fuel consumed and emissions from grid electricity.
- To quantify the fuel and CO_2 emissions savings of a CHP system, the fuel use of and emissions released from the CHP system are subtracted from the fuel use and emissions that would normally occur without the system (i.e., using SHP).
- A key factor in estimating the fuel and CO_2 emissions savings for CHP is determining the heat rate and emissions factor of the displaced grid electricity. EPA's Emissions & Generation Resource Integrated Database (eGRID) is the recommended source for these factors. See Appendix B for information about these inputs.

This paper provides the EPA Combined Heat and Power Partnership's (the Partnership) recommended methodology for calculating fuel and CO_2 emissions savings from CHP compared to SHP.[1] This methodology recognizes the multiple outputs of CHP systems and compares the fuel use and emissions of the CHP system to the fuel use and emissions that would have normally occurred in providing energy services through SHP.

Although the methodology recommended in this paper is useful for the specific purposes mentioned above, it is not intended as a substitute methodology for organizations quantifying and reporting GHG inventories. EPA recommends that organizations use accepted GHG protocols, such as the World Resources Institute's Greenhouse Gas Protocol[2] or The Climate Registry's General Reporting Protocol[3], when calculating and reporting a company's carbon footprint.

However, the CO_2 emissions savings amounts estimated using the methodology recommended in this paper can be reported as supplemental information in an organization's public disclosure of its GHG inventory in order to help inform stakeholders of the emissions benefits of CHP and to highlight the organization's commitment to energy-efficient and climate-friendly technologies.

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[1] CHP can also reduce emissions of methane and nitrous oxide along with other air pollutants. Although methane and nitrous oxide are not discussed in this paper they are accounted for in the CHP Emissions Calculator. The CHP Emissions Calculator is available at: http://www.epa.gov/chp/basic/calculator.html.

[2] The Greenhouse Gas Protocol is available at: http://www.ghgprotocol.org/.

[3] The Climate Registry General Reporting Protocol is available at: http://www.theclimateregistry.org/resources/protocols/general-reporting-protocol/.

The paper is organized as follows:

- Section 2 introduces CHP and explains the basis for fuel and CO_2 emissions savings from CHP compared to SHP.
- Section 3 presents a methodology for calculating the fuel and CO_2 emissions savings from CHP.
- Appendix A presents a sample calculation of fuel and CO_2 emissions savings using the EPA CHP Emissions Calculator.[4]
- Appendix B explains the use of EPA's Emissions & Generation Resource Integrated Database (eGRID) as a source for two important variables in the calculation of fuel and CO_2 emissions savings from displaced grid electricity: displaced grid electricity heat rate[5] and CO_2 emissions factors. It also describes how to select values for these variables.

[4] The EPA CHP Emissions Calculator is available at: http://www.epa.gov/chp/basic/calculator.html.
[5] Heat rate is the ratio of fuel energy input as heat (Btu) per unit of net power output (kWh).

2.0 What Is CHP?

Combined heat and power (CHP) is a highly efficient method of providing power and useful thermal energy (heating or cooling) at the point of use with a single fuel source. By employing waste heat recovery technology to capture a significant portion of the heat created as a by-product of fuel use, CHP systems typically achieve total system efficiencies of 60 to 80 percent. An industrial or commercial entity can use CHP to produce electricity and thermal energy instead of obtaining electricity from the grid and producing thermal energy in an on-site furnace or boiler. In this way, CHP can provide significant energy efficiency, cost savings, and environmental benefits compared to the combination of grid-supplied electricity and on-site boiler use (referred to as separate heat and power or SHP).

CHP plays important roles both in efficiently meeting U.S. energy needs and in reducing the environmental impact of power generation. Currently, CHP systems represent approximately 8 percent of the electric generating capacity in the United States.[6] Benefits of CHP include:

- **Efficiency benefits:** CHP requires less fuel than SHP to produce a given energy output, and because electricity is generated at the point of use, transmission and distribution losses that occur when electricity travels over power lines from central power plants are displaced.
- **Reliability benefits:** CHP can be designed to provide high-quality electricity and thermal energy on site without relying on the electric grid, decreasing the impact of outages and improving power quality for sensitive equipment.
- **Environmental benefits:** Because less fuel is burned to produce each unit of energy output, CHP reduces emissions of greenhouse gases (GHG) and other air pollutants.
- **Economic benefits:** Because of its efficiency benefits, CHP can help facilities save money on energy. Also, CHP can provide a hedge against fluctuations in electricity costs.

In the most common type of CHP system, known as a topping cycle (see Figure 1), fuel is used by a prime mover[7] to drive a generator to produce electricity, and the otherwise-wasted heat from the prime mover is recovered to provide useful thermal energy. Examples of the two most common topping cycle CHP configurations are:

- A reciprocating engine or gas turbine burns fuel to generate electricity and a heat recovery unit captures heat from the exhaust and cooling system. The recovered heat is converted into useful thermal energy, usually in the form of steam or hot water.
- A steam turbine uses high-pressure steam from a fired boiler to drive a generator producing electricity. Low-pressure steam extracted from or exiting the steam turbine is used for industrial processes, space heating or cooling, domestic hot water, or for other purposes.

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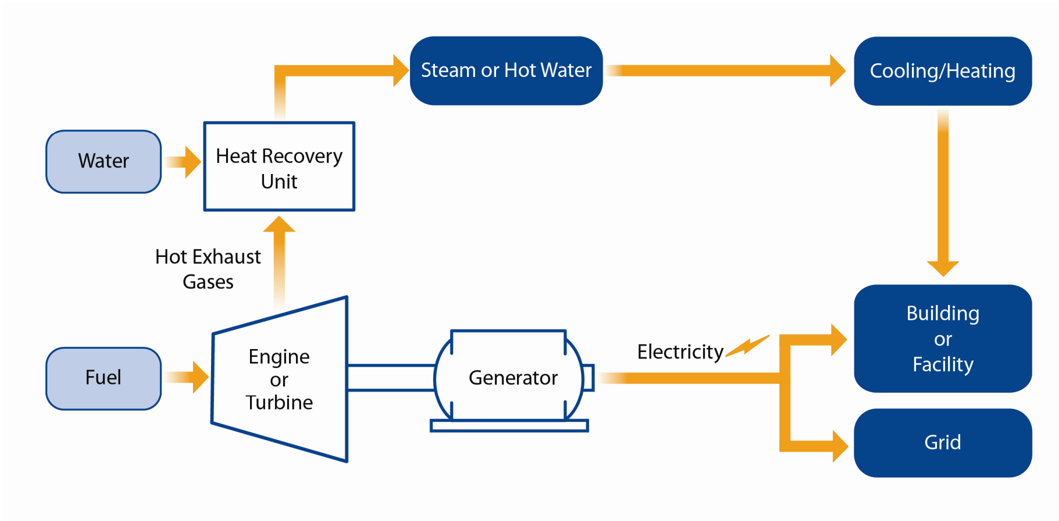
[6] *CHP Installation Database* developed by ICF International for Oak Ridge National Laboratory and the U.S. DOE; 2012. Available at http://www.eea-inc.com/chpdata/index.html.
[7] Prime movers are the devices (e.g., reciprocating engine, gas turbine, microturbine, steam turbine) that convert fuels to electrical energy via a generator.

Figure 1: Typical Reciprocating Engine/Gas Turbine CHP Configuration (Topping Cycle)



In another type of CHP system, known as a bottoming cycle, fuel is used for the purpose of providing thermal energy in an industrial process, such as a furnace, and heat from the process that would otherwise be wasted is used to generate power.

2.1 How CHP Systems Save Fuel and Reduce CO_2 Emissions

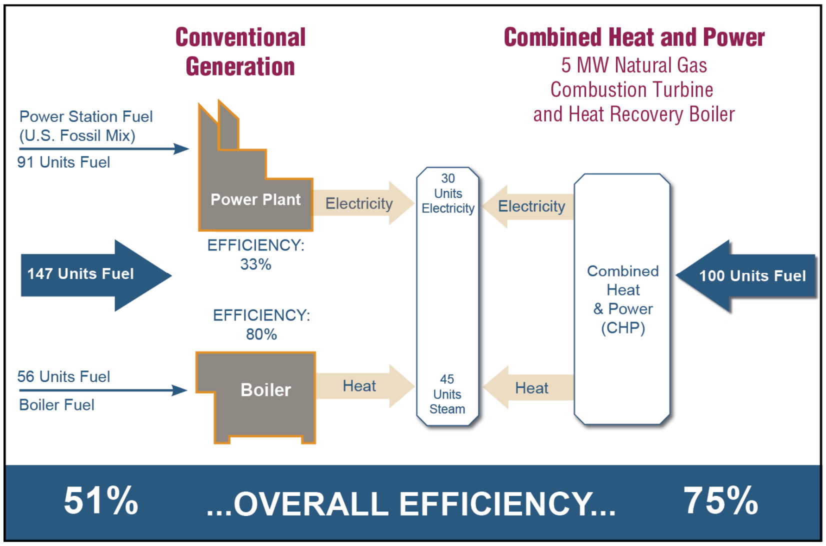
CHP's efficiency benefits result in reduced primary energy[8] use and thus lower CO_2 emissions.

Figure 2 shows the efficiency advantage of CHP compared to SHP.[9] CHP systems typically achieve total system efficiencies of 60 to 80 percent compared to about 45 to 55 percent for SHP. As shown in Figure 2, CHP systems not only reduce the amount of total fuel required to provide electricity and thermal energy, but also shift where that fuel is used. Installing a CHP system on site will generally increase the amount of fuel that is used at the site, because additional fuel is required to operate the CHP system compared to the equipment that otherwise would have been used on site to produce needed thermal energy.

In the example shown in Figure 2, the on-site fuel use increases from 56 units in the SHP case to 100 units in the CHP case. However, despite this increase in on-site fuel use, the total fuel used to provide the facility with the required electrical and thermal energy drops from 147 units in the SHP case, to 100 units in the CHP case, a 32 percent decrease in the amount of total fuel used.

[8] Primary energy is the fuel that is consumed to create heat and/or electricity.
[9] Like Figure 1, Figures 2 and 3 illustrate the most common CHP configuration known as the topping cycle. See section 2.0 for more information.

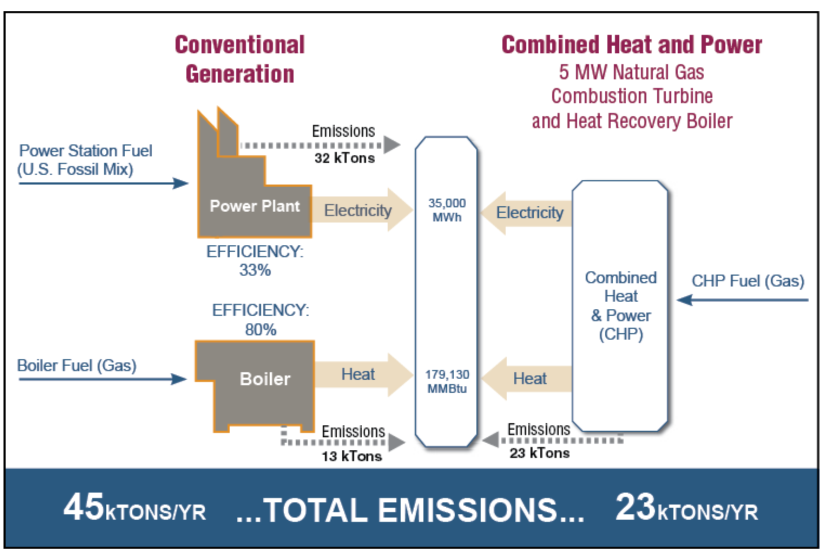
Figure 2: Energy Efficiency - CHP Versus Separate Heat and Power (SHP) Production (Topping Cycle)



Note: *Conventional power plant delivered efficiency of 33% (higher heating value [HHV]) is based on eGRID 2012 (2009 data) and reflects the national average all fossil generating efficiency of 35.6% and 7% transmission and distribution losses. eGRID provides information on emissions and fuel resource mix for individual power plants, generating companies, states, and subregions of the power grid. eGRID is available at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.*

Using less fuel to provide the same amount of energy reduces CO_2 and other emissions. Figure 3 shows the annual CO_2 emissions savings of a natural gas combustion turbine CHP system compared to SHP. In this case, the CHP system produces about half the annual CO_2 emissions of SHP while providing the same amount of energy to the user.

Figure 3: CO_2 Emissions - CHP Versus Separate Heat and Power (SHP) Production (Topping Cycle)



Note: *Emissions savings are based on the efficiencies included in Figure 2 for SHP and a 5 MW gas turbine CHP system and 7,000 annual operating hours. Power plant CO_2 emissions are based on eGRID 2012 national all fossil generation average (2009 data).*

3.0 Calculating Fuel and CO_2 Emissions Savings from CHP

To calculate the fuel or CO_2 emissions savings of a CHP system, both outputs of the CHP system—thermal energy and electricity—must be accounted for. The CHP system's thermal output typically displaces the fuel otherwise consumed in an on-site boiler, and the electric output displaces fuel consumed at central station power plants.[10] Moreover, the CHP system's electric output also displaces fuel consumed to produce electricity lost during transmission and distribution.

The displaced fuel use and CO_2 emissions associated with the operation of a CHP system can be determined by:

a. Calculating the fuel use and emissions from displaced separate heat and power (SHP) (i.e., grid-supplied electricity and on-site thermal generation such as a boiler)
b. Calculating the fuel use and emissions from CHP
c. Subtracting (b) from (a)

Equation 1 presents the recommended approach for calculating the fuel savings of a CHP system. Equation 2 presents the recommended approach for calculating CO_2 emissions savings of a CHP system.

Note: Sections 3.1 and 3.2 present the approaches for calculating the individual terms found in Equations 1 and 2. Appendix A presents a sample calculation of CO_2 savings using the EPA CHP Emissions Calculator which uses the methodology and equations outlined in this section.

Equation 1: Calculating Fuel Savings from CHP

$$F_S = (F_T + F_G) - F_{CHP}$$

where:

F_S = Total Fuel Savings (Btu)
F_T = Fuel Use from Displaced On-site Thermal Production (Btu)
F_G = Fuel Use from Displaced Grid Electricity (Btu)
F_{CHP} = Fuel Used by the CHP System (Btu)

Step 1: Calculate F_T and F_G using Equation 3 (page 8) and Equation 6 (page 10), respectively.

Step 2: Calculate F_{CHP} through direct measurement or using Equations 8 (page 11), 9 (page 11) or 10 (page 12).

Step 3: Calculate F_S.

[10] The thermal output from CHP can also be used to produce cooling in an absorption or adsorption chiller. Accounting for cooling introduces complexities that are not addressed in the methodology presented in this paper. However, the CHP Emissions Calculator does account for cooling.

Equation 2: Calculating CO_2 Savings from CHP

$$C_S = (C_T + C_G) - C_{CHP}$$

where:

C_S = Total CO_2 Emissions Savings (lbs CO_2)
C_T = CO_2 Emissions from Displaced On-site Thermal Production (lbs CO_2)
C_G = CO_2 Emissions from Displaced Grid Electricity (lbs CO_2)
C_{CHP} = CO_2 Emissions from the CHP System (lbs CO_2)

Step 1: Calculate C_T and C_G using Equation 4 (page 8) and Equation 7 (page 10), respectively.

Step 2: Calculate C_{CHP} using Equation 11 (page 12).

Step 3: Calculate C_S.

Note on using Equations 1 and 2 for bottoming cycle CHP systems: In the case of bottoming cycle CHP, also known as waste heat to power, power is generated on site from the hot exhaust of a furnace or kiln with no additional fuel requirement. Therefore, the fuel use and CO_2 emissions for both the CHP system and displaced thermal energy (F_{CHP}, C_{CHP}, F_T, and C_T) are all zero.

3.1 Fuel Use and CO_2 Emissions from Displaced On-site Thermal Production and Displaced Grid Electricity

3.1.1 Fuel Use and CO_2 Emissions from Displaced On-site Thermal Production

The thermal energy produced by a CHP system displaces combustion of some or all of the fuel that would otherwise be consumed for on-site production of thermal energy.[11] The fuel and CO_2 emissions savings associated with this displaced fuel consumption can be calculated using the thermal output of the CHP system and reasonable assumptions about the efficiency characteristics of the equipment that would otherwise have been used to produce the thermal energy being produced by the CHP system. Equation 3 presents the approach for calculating the fuel use from displaced on-site thermal production. Equation 4 presents the approach for calculating the CO_2 emissions from displaced on-site thermal production. Table 1 lists selected fuel-specific CO_2 emissions factors for use in Equation 4.

[11] In certain circumstances, CHP systems are designed so that supplemental on-site thermal energy production is sometimes utilized.

Equation 3: Calculating Fuel Use from Displaced On-site Thermal Production

$F_T = CHP_T / \eta_T$

where:

F_T = Fuel Use from Displaced On-site Thermal Production (Btu)
CHP_T = CHP System Thermal Output (Btu)
η_T = Estimated Efficiency of the Thermal Equipment (percentage in decimal form)

Step 1: Measure or estimate CHP_T.

Step 2: Select η_T (e.g., 80% efficiency for a natural gas-fired boiler, 75% for a biomass-fired boiler).

Step 3: Calculate F_T.

Equation 4: Calculating CO_2 Emissions from Displaced On-site Thermal Production

$C_T = F_T * EF_F * (1x10^{-6})$

where:

C_T = CO_2 Emissions from Displaced On-site Thermal Production (lbs CO_2)
F_T = Thermal Fuel Savings (Btu)
EF_F = Fuel Specific CO_2 Emission Factor (lbs CO_2 /MMBtu)
$1x10^{-6}$ = Conversion factor from Btu to MMBtu

Step 1: Calculate F_T using Equation 3.

Step 2: Select the appropriate EF_F from Table 1.

Step 3: Calculate C_T.

Table 1: Selected Fuel-Specific Energy and CO_2 Emissions Factors

Fuel Type	Energy Density	CO_2 Emissions Factor, lb/MMBtu
Natural Gas	1,028 Btu/scf	116.9
Distillate Fuel Oil #2	138,000 Btu/gallon	163.1
Residual Fuel Oil #6	150,000 Btu/gallon	165.6
Coal (Anthracite)	12,545 Btu/lb	228.3
Coal (Bituminous)	12,465 Btu/lb	205.9
Coal (Subbituminous)	8,625 Btu/lb	213.9
Coal (Lignite)	7,105 Btu/lb	212.5
Coal (Mixed-Industrial Sector)*	11,175 Btu/lb	207.1

* This is the default value for coal used in the CHP Emissions Calculator. Users can also manually enter specific factors for type of coal used, if known.

Source: 40 CFR Part 98, Mandatory Greenhouse Gas Reporting, Table C-1: Default CO_2; Emission Factors and High Heat Values for Various Types of Fuel. Available at: http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=1e922da1c1055b070807782d1366f3d1&rgn=div9&view=text&node=40:21.0.1.1.3.3.1.10.18&idno=40.

3.1.2 *Fuel Use and CO_2 Emissions from Displaced Grid Electricity*

Grid electricity savings associated with on-site CHP include the grid electricity displaced by the CHP output and related transmission and distribution losses.

When electricity is transmitted over power lines, some of the electricity is lost. The amount delivered to users[12] is therefore less than the amount generated at central station power plants, usually by an average of about 6 to 9 percent.[13,14] Consequently, generating 1 MWh of electricity on site means that more than 1 MWh of electricity no longer needs to be generated at central station power plants.[15] Fuel and CO_2 emissions savings from displaced grid electricity should therefore be based on the corresponding amount of displaced grid electricity generated and not on the amount of grid electricity delivered (and consumed).

Equation 5 presents the approach for calculating the displaced grid electricity from CHP. Once the displaced grid electricity from CHP is determined, the fuel use (Equation 6) and CO_2 emissions (Equation 7) from displaced grid electricity can be calculated.

Note: Key factors needed to calculate the fuel use and CO_2 emissions from displaced grid electricity are the heat rate and CO_2 emissions factor for the grid electricity displaced. EPA's Emissions & Generation Resource Integrated Database (eGRID) is the recommended source for these factors. CHP fuel and CO_2 emissions savings calculations should be based on the heat rates and emissions factors of the eGRID subregion where the CHP system is located, utilizing the eGRID all fossil or non-baseload emissions factors as appropriate. See Appendix B for information about using eGRID.

Equation 5: Calculating Displaced Grid Electricity from CHP

$$E_G = CHP_E \ / \ (1-L_{T\&D})$$

where:

E_G = Displaced Grid Electricity from CHP (kWh)
CHP_E = CHP System Electricity Output (kWh)
$L_{T\&D}$ = Transmission and Distribution Losses (percentage in decimal form)

Step 1: Measure or estimate CHP_E.

Step 2: Select $L_{T\&D}$. (Use the eGRID transmission and distribution loss value for the appropriate U.S. interconnect power grid*)

Step 3: Calculate E_G.

* eGRID lists the estimated transmission and distribution loss for each of the five U.S. interconnect power grids (i.e., Eastern, Western, ERCOT, Alaska, and Hawaii). (eGRID Technical Support Document: http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2012_year09_TechnicalSupportDocument.pdf).

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[12] For clarity, the amount of electricity generated by a central station power plant is referred to as "generated" electricity and the amount of electricity consumed by a facility supplied by the grid is referred to as "delivered" electricity.
[13] EPA eGRID Technical Support Document. April 2012. http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2012_year09_TechnicalSupportDocument.pdf
[14] DOE Energy Information Administration. State Electricity Profiles. http://205.254.135.24/cneaf/electricity/st_profiles/e_profiles_sum.html
[15] For example, assume a consumer without CHP requires 1.0 MWh of electricity each year and T&D losses equal 8%. The delivered electricity is 1.0 MWh/yr, and the generated electricity is 1.087 MWh/yr (= 1/(1-0.08)).

Equation 6: Calculating Fuel Use from Displaced Grid Electricity

$F_G = E_G * HR_G$

where:

F_G = Fuel Use from Displaced Grid Electricity (Btu)
E_G = Displaced Grid Electricity from CHP (kWh)
HR_G = Grid Electricity Heat Rate (Btu/kWh) for the appropriate subregion

Step 1: Determine E_G using Equation 5.

Step 2: Select HR_G for the appropriate subregion. (See Appendix B for information about appropriate values and eGRID as a source for grid electricity heat rates.)

Step 3: Calculate F_G.

Equation 7: Calculating CO_2 Emissions from Displaced Grid Electricity

$C_G = E_G * EF_G$

where:

C_G = CO_2 Emissions from Displaced Grid Electricity (lbs CO_2)
E_G = Displaced Grid Electricity from CHP (kWh)
EF_G = Grid Electricity Emissions Factor (lbs CO_2 /kWh) for the appropriate subregion

Step 1: Determine E_G using Equation 5.

Step 2: Select EF_G for the appropriate subregion. (See Appendix B for information about appropriate values and eGRID as a source for grid electricity CO_2 emission factors).

Step 3: Calculate C_G.

3.2 Fuel Use and CO_2 Emissions of the CHP System

The energy content of the fuel consumed by the CHP system (F_{CHP} in Equation 1) can be determined through several methods. Direct measurement (option 1) produces the most accurate results, but if direct measurement is not an option the Partnership recommends the use of options 2, 3, or 4.

1) Direct measurement of the higher heating value (HHV) of the fuel consumed (typically in $MMBtu_{HHV}$). No calculation required.

2) Converting the fuel volume into an energy value (Btu equivalent) using a fuel-specific energy density using Equation 8.

3) Converting the fuel weight into an energy value (Btu equivalent) using a fuel-specific energy density (mass basis) using Equation 9.

4) Applying the electrical efficiency of the CHP system to the CHP system's electric output using Equation 10.

Equation 8: Calculating Energy Content of the Fuel Used by CHP from the Fuel Volume

F_{CHP} = $V_F * ED_F$

where:

F_{CHP} = Fuel Used by the CHP System (Btu)
V_F = Volume of CHP Fuel Used (cubic foot, gallon, etc.)
ED_F = Energy Density of CHP Fuel (Btu/cubic foot, Btu/gallon, etc.)

Step 1: Measure or estimate V_F.

Step 2: Select the appropriate value of ED_F. (See Table 1 on page 8)

Step 3: Calculate F_{CHP}.

Equation 9: Calculating Energy Content of the Fuel Used by CHP from the Fuel Weight

F_{CHP} = $W_F * ED_F$

where:

F_{CHP} = Fuel Used by the CHP System (Btu)
W_F = Weight of CHP Fuel Used (lbs)
ED_F = Energy Density of CHP Fuel – Mass Basis (Btu/lb)

Step 1: Measure or estimate W_F.

Step 2: Select the appropriate ED_F. In order to be used here, the values in Table 1 (page 8) must be converted to a mass basis using the fuel-specific density.

Step 3: Calculate F_{CHP}.

Equation 10: Calculating Energy Content of the Fuel Used by CHP from the CHP Electric Output

F_{CHP} = $(CHP_E / EE_{CHP}) * 3412$

where:

F_{CHP} = Fuel Used by the CHP System (Btu)
CHP_E = CHP System Electricity Output (kWh)
EE_{CHP} = Electrical Efficiency of the CHP System (percentage in decimal form)
3412 = Conversion factor between kWh and Btu

Step 1: Measure or estimate CHP_E.

Step 2: Determine EE_{CHP}. (This value should account for parasitic losses, and is usually available in a product specification sheet provided by the manufacturer of the equipment.)

Step 3: Calculate F_{CHP}.

The CO_2 emissions from the CHP system are a function of the type and amount of fuel consumed. CO_2 emissions rates are commonly presented as pounds of emissions per million Btu of fuel input (lb/MMBtu). Table 1 on page 8 lists common fuel-specific CO_2 emissions factors. Equation 11 presents the approach for calculating CO_2 emissions from a CHP system (C_{CHP} in Equation 2).

Equation 11: Calculating CO_2 Emissions from the CHP System

C_{CHP} = $F_{CHP} * EF_F$

where:

C_{CHP} = CO_2 Emissions from the CHP System (lbs CO_2)
F_{CHP} = Fuel Used by the CHP System (Btu)
EF_F = Fuel Specific Emissions Factor (lbs CO_2 /MMBtu)

Step 1: Measure or calculate F_{CHP} using Equations 8 (page 11), 9 (page 11), or 10 (page 12).

Step 2: Select the appropriate EF_F from Table 1 on page 8.

Step 3: Calculate C_{CHP} the CO_2 emissions from the CHP system.

Appendix A: EPA CHP Emissions Calculator Example Calculation

The Partnership developed the EPA CHP Emissions Calculator to help users calculate the fuel and CO_2 emissions reductions achieved by CHP compared to SHP.[16] The default values in the Calculator are based on the guidelines in this paper. However, users can also input selected CHP system characteristics and emissions factors for CHP fuel, displaced thermal fuel, and displaced grid electricity.

The EPA CHP Emissions Calculator is available at: http://www.epa.gov/chp/basic/calculator.html.

The following example shows how a user would operate the CHP Emissions Calculator to determine the fuel and CO_2 savings achieved by a CHP system. The example system is a 5 MW natural gas-fired combustion turbine and heat recovery boiler CHP system that provides heating for an industrial process at a facility in Pennsylvania. The CHP system is displacing thermal energy provided by an existing natural gas boiler and grid electricity in the RFC East subregion (the eGRID subregion that includes Pennsylvania).[17]

Calculator Input

The following figures show the calculator inputs that are needed to evaluate this system. Figure 4 shows the Calculator inputs related to the CHP system itself. For this example, the Calculator default values were used for the electric efficiency and the power-to-heat ratio of the CHP system.

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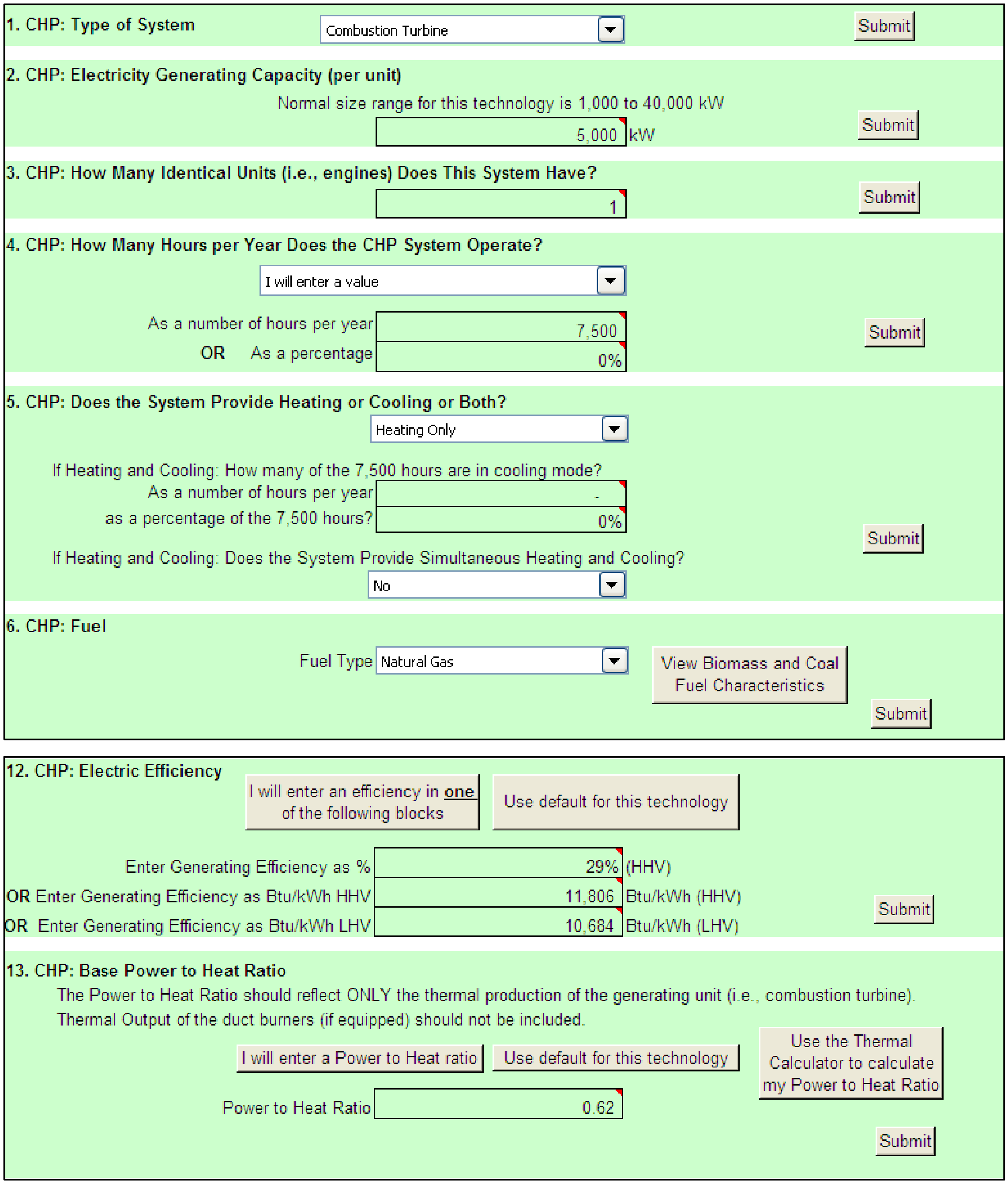
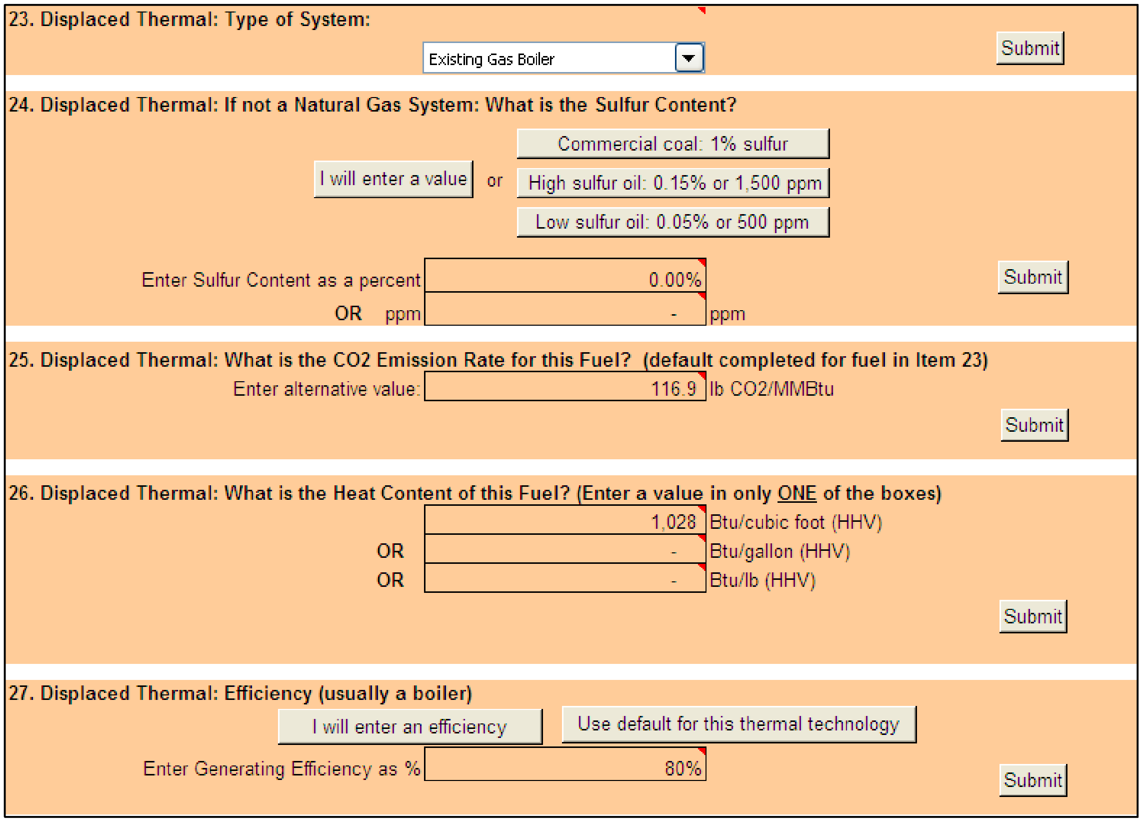
[16] The CHP Emissions Calculator also accounts for methane (CH4), nitrogen oxides (NOx), nitrous oxide (N2O), and sulfur dioxide (SO2).
[17] Information about eGRID subregions is contained in Appendix B.

Figure 4: CHP Emissions Calculator – CHP System Characteristics



After entering the information about the CHP system to be evaluated, information is entered related to the displaced on-site thermal energy production (i.e., the thermal energy produced by the CHP system that replaces thermal energy formerly produced by an on-site boiler). Information about the thermal equipment and fuel provides the basis for calculating the displaced thermal fuel use and CO_2 emissions. Figure 5 shows the Calculator inputs related to the displaced thermal energy.

Figure 5: CHP Emissions Calculator – Displaced Thermal Energy



The equations for calculating fuel use and CO_2 emissions from displaced on-site thermal energy production are:

Fuel Use from Displaced On-site Thermal Energy Production (Equation 3):

$$F_T = CHP_T / \eta_T$$
$$257{,}964 \text{ MMBtu/yr} = 206{,}371 \text{ MMBtu/yr} / 80\%$$

where:

F_T = Fuel Use from Displaced On-site Thermal Production (Btu)
CHP_T = CHP System Thermal Output (Btu)
η_T = Thermal Equipment Efficiency (%)

CO_2 Emissions from Displaced On-site Thermal Production (Equation 4):

$$C_T = F_T * EF_F$$
$$30{,}155{,}992 \text{ lbs } CO_2 = 257{,}964 \text{ MMBtu/yr} * 116.9 \text{ lb } CO_2\text{/MMBtu}$$

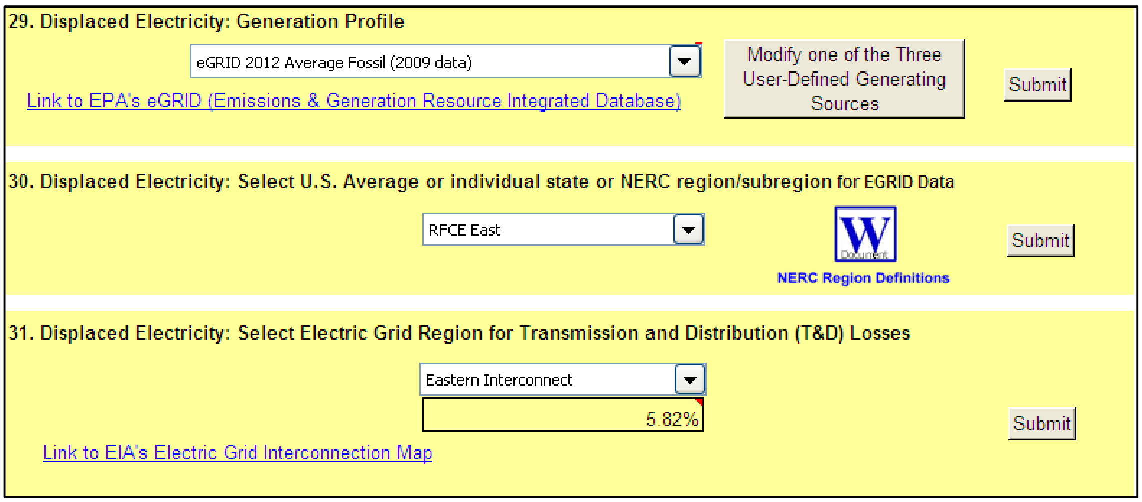
where:

C_T = CO_2 emissions from displaced on-site thermal production (lbs CO_2)
F_T = Thermal Fuel Savings (Btu)
EF_F = Fuel Specific Emissions Factor (lbs CO_2/MMBtu)

The CHP Emissions Calculator inputs related to the displaced grid electricity are shown in Figure 6 below. eGRID emissions rates include: Total Output Emissions Rate, Fossil Fuel Output Emissions

Rate, and Non-Baseload Output Emissions Rate. The Partnership recommends using the Fossil Fuel Output Emissions Rate because it most accurately reflects the emissions of generation displaced by CHP(see eGRID information in Appendix B). The Partnership also recommends using the rate for the RFC East eGRID subregion which includes eastern Pennsylvania where this system is located. For transmission and distribution (T&D) losses, the Partnership recommends using the eGRID value for grid losses from the appropriate U.S. interconnect power grid. There are five U.S. interconnect power grids (Eastern, Western, ERCOT, Alaska, and Hawaii), and the appropriate grid for this example is the Eastern grid, with an average T&D losses of 5.82%.

Figure 6: CHP Emissions Calculator – Displaced Electricity



The total fuel use and CO_2 emissions of displaced grid electricity are calculated using the following equations:

Displaced Grid Electricity from CHP (Equation 5):

$$E_G = CHP_E \; / \; (1 - L_{T\&D})$$

$$39{,}817.4 \text{ MWh/year} = 37{,}500 \text{ MWh/year} / (1 - 5.82\%)$$

where:

E_G = Displaced Grid Electricity from CHP (kWh)
CHP_E = CHP System Electricity Output (kWh)
$L_{T\&D}$ = Transmission and Distribution Losses (%)

Fuel Use from Displaced Grid Electricity (Equation 6):

$$F_G = E_G * HR_G$$

$$380{,}909 \text{ MMBtu/year} = 39{,}817.4 \text{ MWh/year} * 9{,}566 \text{ Btu/kWh} / 1000$$

where:

F_G = Fuel Use from Displaced Grid Electricity (Btu)
E_G = Displaced Grid Electricity from CHP (kWh)
HR_G = Grid Electricity Heat Rate (Btu/kWh)

CO_2 Emissions from Displaced Grid Electricity (Equation 7):

$$C_G = E_G * EF_G$$

$$67{,}211{,}771{,}200 \text{ lbs } CO_2 = 39{,}817.4 \text{ MWh/year} * 1{,}688 \text{ lb } CO_2\text{/kWh} * 1000$$

where:

C_G = CO_2 Emissions from Displaced Grid Electricity (lbs)
E_G = Displaced Grid Electricity from CHP (kWh)
EF_G = Grid Electricity Emissions Factor (CO_2 lb/kWh)

Calculator Results

Once the user has entered all of the information on the Inputs page of the Calculator and clicked the "Go to Results" button the Results page is displayed. Figure 7 illustrates the results for this example, which shows that the CHP system reduces overall fuel consumption by 196,018 MMBtu/year and CO_2 emissions by 22,794 tons/year.

Figure 7: CHP Emissions Calculator – Fuel and Emissions Savings Results

CHP Results

CHP
EPA COMBINED HEAT AND POWER PARTNERSHIP

The results generated by the CHP Emissions Calculator are intended for eductional and outreach purposes only; it is not designed for use in developing emission inventories or preparing air permit applications.

Annual Emissions Analysis

	CHP System	Displaced Electricity Production	Displaced Thermal Production	Emissions/Fuel Reduction	Percent Reduction
NO_x (tons/year)	20.35	27.80	12.90	20.35	50%
SO_2 (tons/year)	0.13	167.11	0.08	167.05	100%
CO_2 (tons/year)	25,885	33,601	15,078	22,794	47%
CH_4 (tons/year)	0.488	0.965	0.284	0.761	61%
N_2O (tons/year)	0.049	0.538	0.028	0.517	91%
Total GHGs (CO_2e tons/year)	25,910	33,788	15,093	22,970	47%
Carbon (metric tons/year)	6,400	8,308	3,728	5,636	47%
Fuel Consumption (MMBtu/year)	442,855	380,909	257,964	196,018	31%
Number of Cars Removed				3,991	

This CHP project will reduce emissions of Greenhouse Gases (CO2e) by 22,970 tons per year

This is equal to 5,636 metric tons of carbon equivalent (MTCE) per year

This reduction is equal to removing the carbon emissions of 3,991 cars

The equations for the relationship for total fuel savings and CO_2 savings are as follows:

Total Fuel Savings from CHP (Equation 1):

$$F_S = (F_T + F_G) - F_{CHP}$$

196,018 MMBtu/year = (257,964 MMBtu/year + 380,909 MMBtu/year) – 442,855 MMBtu/year

where:

F_S = Total Fuel Savings
F_T = Fuel Use from Displaced On-site Thermal Production
F_G = Fuel Use from Displaced Grid Electricity
F_{CHP} = Fuel Used by the CHP System

Total CO_2 Savings from CHP (Equation 2):

$$C_S = (C_T + C_G) - C_{CHP}$$

22,794 lbs CO_2 = (15,078 lbs + 33,601 lbs) – 25,885 lbs

where:

C_S = Total CO_2 Emissions Savings
C_T = CO_2 Emissions from Displaced On-site Thermal Production
C_G = CO_2 Emissions from Displaced Grid Electricity
C_{CHP} = CO_2 Emissions from the CHP System

Figure 8 shows the outputs of the CHP system in more detail, and Figure 9 shows the emissions rates for the CHP system as well as those from the displaced thermal production and displaced electricity generation.

Figure 8: CHP Emissions Calculator, CHP Outputs

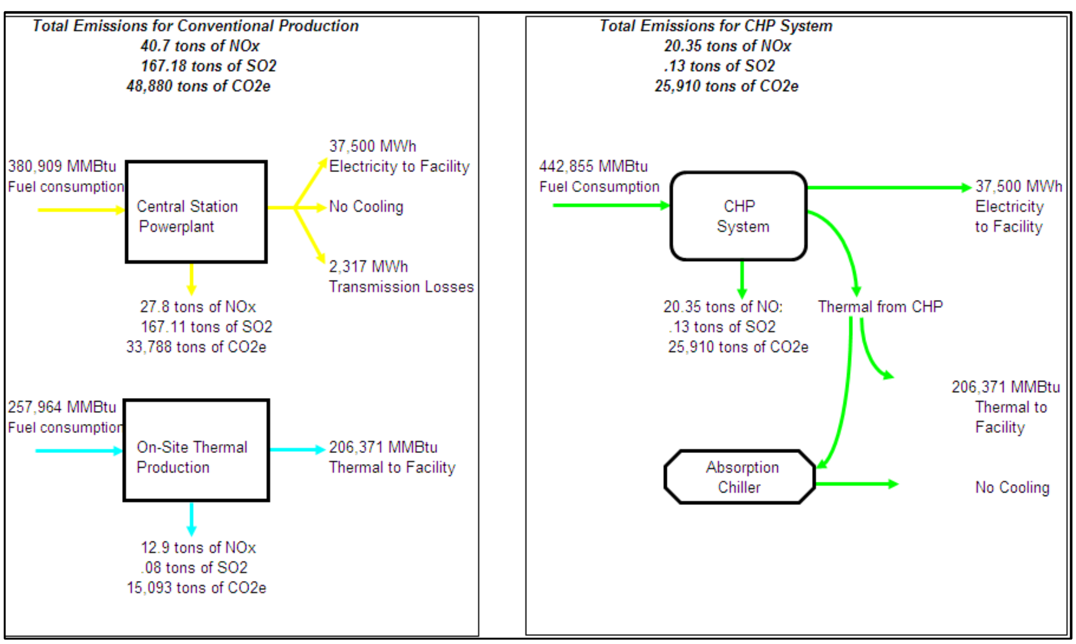
CHP Technology:	Combustion Turbine	
Fuel:	Natural Gas	
Unit Capacity:	5,000	kW
Number of Units:	1	
Total CHP Capacity:	5,000	kW
Operation:	7,500	hours per year
Heat Rate:	11,809	Btu/kWh HHV
CHP Fuel Consumption:	442,855	MMBtu/year
Duct Burner Fuel Consumption:	-	MMBtu/year
Total Fuel Consumption:	**442,855**	**MMBtu/year**
Total CHP Generation:	**37,500**	**MWh/year**
Useful CHP Thermal Output:	206,371	MMBtu/year for thermal applications (non-cooling)
	-	MMBtu/year for electric applications (cooling and electric heating)
	206,371	**MMBtu/year Total**
Displaced On-Site Production for Thermal (non-cooling) Applications:		Existing Gas Boiler
	0.10	lb/MMBtu NOx
	0.00%	sulfur content
Displaced Electric Service (cooling and electric heating):		
	There is no displaced cooling service	
Displaced Electricity Profile:	eGRID 2012 Average Fossil (2009 data)	
Egrid State:	RFCE East	
Distribution Losses:	6%	
Displaced Electricity Production:	37,500	MWh/year CHP generation
	-	MWh/year Displaced Electric Demand (cooling)
	-	MWh/year Displaced Electric Demand (electric heating)
	2,317	MWh/year Transmission Losses
	39,817	**MWh/year Total**

Figure 9: CHP Emissions Calculator, Emissions Rates

Annual Analysis for CHP	CHP System: Combustion Turbine			Total Emissions from CHP System
NO_x (tons/year)	20.35	-		20.35
SO_2 (tons/year)	0.13	-		0.13
CO_2 (tons/year)	25,885	-		25,885
CH_4 (tons/year)	0.488	-		0.488
N_2O (tons/year)	0.049	-		0.049
Total GHGs (CO_2e tons/year)	25,910	-		25,910
Carbon (metric tons/year)	6,400	-		6,400
Fuel Consumption (MMBtu/year)	442,855	-		442,855

Annual Analysis for Displaced Production for Thermal (non-cooling) Applications				Total Displaced Emissions from Thermal Production
NO_x (tons/year)				12.90
SO_2 (tons/year)				0.08
CO_2 (tons/year)				15,078
CH_4 (tons/year)				0.284
N_2O (tons/year)				0.028
Total GHGs (CO_2e tons/year)				15,093
Carbon (metric tons/year)				3,728
Fuel Consumption (MMBtu/year)				257,964

Annual Analysis for Displaced Electricity Production	Displaced CHP Electricity Generation	Displaced Electricity for Cooling	Displaced Electricity for Heating	Transmission Losses	Total Displaced Emissions from Electricity Generation
NO_x (tons/year)	26.18	-	-	1.62	27.80
SO_2 (tons/year)	157.38	-	-	9.73	167.11
CO_2 (tons/year)	31,645	-	-	1,955.56	33,601
CH_4 (tons/year)	0.908	-	-	0.056	0.965
N_2O (tons/year)	0.506	-	-	0.031	0.538
Total GHGs (CO_2e tons/year)	31,821	-	-	1,966	33,788
Carbon (metric tons/year)	7,825	-	-	484	8,308
Fuel Consumption (MMBtu/year)	358,740	-	-	22,169	380,909



Appendix B: Displaced Grid Electricity Fuel Use and CO_2 Emissions

The displaced fuel use and CO_2 emissions associated with the operation of a CHP system can be determined by:

a. Calculating the fuel use and emissions from displaced separate heat and power (SHP) (i.e., grid-supplied electricity and on-site thermal generation such as a boiler)
b. Calculating the fuel use and emissions from CHP
c. Subtracting (b) from (a)

The challenge of calculating the fuel use and emissions associated with displaced grid electricity stems from the fact that grid electricity is generated by a large number of sources with different fuels and different heat rates. The sources that are reasonably expected to be displaced must therefore be determined in order to estimate the displaced fuel use and emissions.

Section 3.1.1 of this paper presents the Partnership's recommended methodology for calculating the fuel use and emissions from displaced thermal generation, and section 3.1.2 presents the recommended methodology for calculating the fuel use and emissions from displaced grid electricity. Section 3.2 presents the recommended methodology for calculating the fuel use and emissions from CHP.

This appendix complements the methodology provided in section 3.1.2 by:

- Discussing use of EPA's Emissions & Generation Resource Integrated Database (eGRID) as a resource for the grid electricity heat rate (HR_G) and the grid electricity emissions factor (EF_G) needed to calculate the fuel and CO_2 emissions associated with displaced grid electricity from CHP.

- Explaining why, when calculating fuel and CO_2 emissions savings associated with CHP, the Partnership recommends using the following factors:
    - the eGRID all fossil emissions factor and heat rate for the eGRID subregion where the CHP system is located for baseload CHP (i.e., greater than 6,500 annual operating hours), and
    - the eGRID non-baseload emissions factor and heat rate for the eGRID subregion where the CHP system is located for CHP systems with relatively low annual capacity factors (i.e., less than 6,500 annual operating hours) and with most generation occurring during periods of high system demand.

B.1 EPA's Emissions & Generation Resource Integrated Database (eGRID)

Background

EPA's eGRID[18] is a comprehensive and widely-used resource[19] for information about electricity-generating plants that provide power to the electric grid and report data to the U.S. government. eGRID provides data on:

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[18] EPA has generated and published detailed information on electricity generation and emissions since 1998. The most recent edition of eGRID, eGRID2012 version 1.0, was released in 2012 and contains data collected in 2009. More information is available at. http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

- Generation (MWh)
- Fuel use
- Plant heat rate
- Resource mix (e.g., coal, gas nuclear, wind, solar)
- Emissions associated with power generation in the United States

In order to enhance the usability of this data, eGRID separates and organizes it into useful levels of aggregation, as follows:

- Plant
- State
- Electric generating company (EGC)
- Power control area (PCA)
- eGRID subregion
- North American Electric Reliability Corporation (NERC) region
- U.S. total

Note:

- eGRID consists of historic sets of recent data; it does not include projections of the operating characteristics of generating units in the future.
- The generation data and related data categories provided by eGRID are based on generated electricity, not consumed (i.e., delivered) electricity and therefore do not include the impact of transmission and distribution (T&D) losses (see Section 3.1.2 and Equation 5 for more information on T&D losses).

Aggregation Level – eGRID subregion

EPA defines eGRID subregions based on NERC regions and PCAs. There are 26 eGRID subregions (see Figure B-1) in eGRID2012, and each consists of one PCA or a portion of a PCA. eGRID subregions generally represent sections of the grid that have similar resource mix and emissions characteristics.

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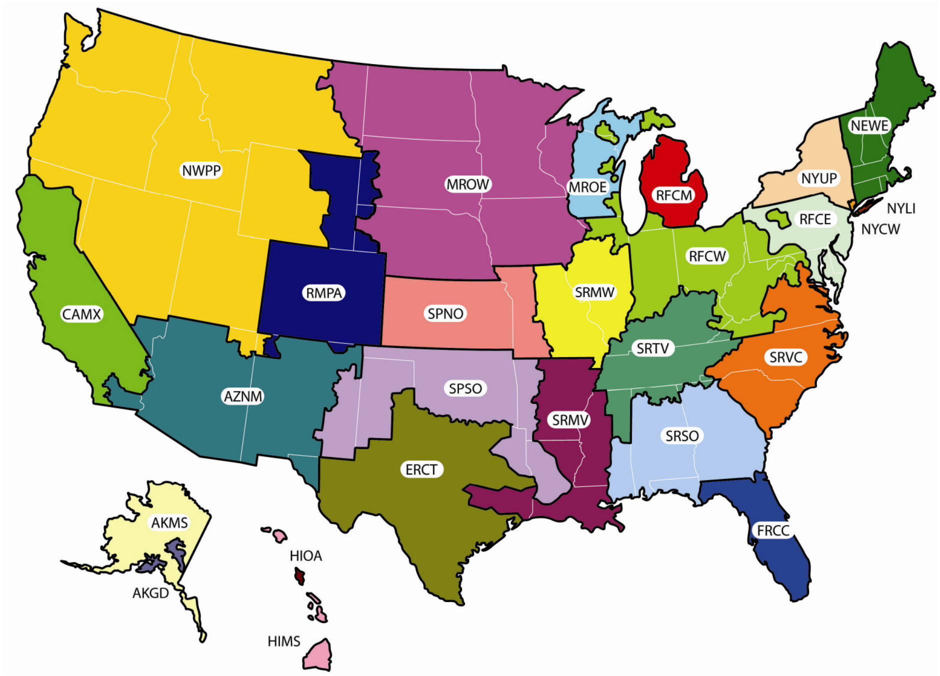
[19] According to the eGRID Technical Support Document, more than 40 tools, applications, and programs (public and private) rely on eGRID data.

Figure B-1: eGRID Subregion Map[20]



Emissions and Heat Rate Data

eGRID presents the heat rate of each listed plant, and emissions data aggregated by fuel type and by generation source category (e.g., all fossil fuels). eGRID also presents emissions data for several pollutants—carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2), methane (CH_4), nitrous oxide (N_2O) and mercury (Hg)—in the form of emissions rates on an output basis (lb/MWh) and on a fuel input basis (lb/MMBtu).

Notes on Terminology. For the sake of clarity and consistency, eGRID emission rates (lb/MWh) are referred to in this appendix as *emissions factors*. Also note that, because this document addresses how to calculate avoided CO_2 emissions, all subsequent references to eGRID emissions data in this appendix refer to CO_2 emissions only.

Three types of generation rates provided in eGRID are discussed in this appendix[21]:

- **Total Output**
  The Total Output rates are based on data for all power generation regardless of energy source (i.e., fossil, nuclear, hydro, and renewables) within a defined region or subregion. One CO_2 emissions factor (lb/MWh) and one heat rate (Btu/kWh) value are associated with the category for each NERC region and eGRID subregion.

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[20] Many of the boundaries shown on this map are approximate because they are based on company location rather than on strict geographical boundaries.
[21] In addition to the three eGRID generation categories listed here, eGRID also includes an "annual combustion output" category. This category is not discussed in this appendix since it was primarily developed to estimate NO_X and SO_2 emissions from combustion generating units that are dispatched to respond to marginal increases in electricity demand, and thus not applicable to CO2 calculations involving CHP.

- **Fossil Fuel Output**
  The Fossil Fuel Output rates are based on data for power generation from fossil fuel-fired plants within a defined region or subregion. One CO_2 emission factor (lb/MWh) and one heat rate (Btu/kWh) value are associated with the category for each NERC region and eGRID subregion. EPA characterizes this emissions factor as "a rough estimate to determine how much emissions could be avoided if energy efficiency and/or renewable energy displaces fossil fuel generation."[22] The EPA CHP Partnership's CHP Emissions Calculator uses the emissions factor and heat rate from this category to determine emissions and fuel use from displaced grid electricity when evaluating CHP systems.[23]

  eGRID also provides emissions factors by specific fossil fuel type (i.e., for coal-, natural gas-, and oil-fired generating plants). These emissions factors are useful in assessing the different impacts of fossil fuels, but they are rarely used to evaluate the relationship between CHP and displaced grid electricity emissions.

- **Non-baseload Output**
  The Non-baseload Output rates are based on data for power generation from combustion generating units within a defined region or subregion that do not serve as baseload units. One CO_2 emissions factor (lb/MWh) and one heat rate (Btu/kWh) value are associated with the category for each NERC region and eGRID subregion. The term "baseload" refers to those plants that supply electricity to the grid even when demand for electricity is relatively low. Baseload plants are usually brought online to provide electricity to the grid regardless of the level of demand, and they generally operate continuously except when undergoing routine or unscheduled maintenance. EPA developed the non-baseload output emissions factors to estimate emissions reductions from energy efficiency projects and certain types of clean energy projects based on the emissions from generating units that are dispatched to respond to marginal increases in electricity demand.[24] eGRID calculates the non-baseload factors by weighting each plant's emissions and generation according to its capacity factor. The generation and emissions from plants that operate most of the time, (that is, baseloaded plants with annual capacity factors greater than 0.8) are excluded. All the generation and emissions from fuel-based plants that operate infrequently during the year (for example, peaking units with capacity factors less than 0.2) are included. A portion of the emissions and generation from the remaining fuel-based plants (i.e., those with capacity factors between 0.2 and 0.8) are included, with higher portions used for plants with lower capacity factors and lower portions used for plants with higher capacity factors.

Table B-1 provides the all generation, all fossil, and non-baseload emissions factors from eGRID.

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[22] "EPA eGRID Technical Support Document. April 2012. http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2012_year09_TechnicalSupportDocument.pdf
[23] The CHP Emissions Calculator is available at: http://www.epa.gov/chp/basic/calculator.html
[24] Rothschild, S. and Diem, A., "Guidance on the Use of eGRID Output Emissions Rates", http://www.epa.gov/ttn/chief/conference/ei18/session5/rothschild.pdf

Table B-1: eGRID 2012 CO_2 Emission Factors and Heat Rates by NERC Region and eGRID Subregion (2009 year data)

	All Generation		All Fossil Average		Non-Baseload	
NERC Region and Subregions	Heat Rate (Btu/kWh)	CO2 Emission Factor (lb/MWh)	Heat Rate (Btu/kWh)	CO2 Emission Factor (lb/MWh)	Heat Rate (Btu/kWh)	CO2 Emission Factor (lb/MWh)
Alaska Systems Coordinating Council	8,203	1,126	10,235	1,405	9,820	1,348
ASCC Alaska Grid	9,445	1,281	10,321	1,400	9,740	1,321
ASCC Miscellaneous	3,340	521	9,375	1,463	9,416	1,469
Florida Reliability Coordinating Council	7,708	1,177	8,964	1,366	8,464	1,301
FRCC All	7,708	1,177	8,964	1,366	8,464	1,301
Hawaiian Islands Coordinating Council	9,123	1,527	9,587	1,603	9,508	1,620
HICC Miscellaneous	8,434	1,352	10,242	1,725	9,851	1,616
HICC Oahu	9,383	1,593	9,383	1,567	9,396	1,621
Midwest Reliability Organization	7,940	1,624	10,735	2,231	9,900	2,063
MRO East	8,001	1,592	10,038	2,078	9,152	1,868
MRO West	7,931	1,629	10,853	2,257	10,120	2,115
Northeast Power Coordinating Council	4,771	654	8,746	1,183	8,549	1,210
NPCC Long Island	10,139	1,348	10,139	1,260	10,644	1,337
NPCC New England	5,463	728	8,687	1,137	8,201	1,157
NPCC NYC/Westchester	4,967	611	8,467	1,001	9,278	1,118
NPCC Upstate NY	3,150	498	8,684	1,404	8,246	1,347
Reliability First Corporation	6,964	1,370	9,930	1,963	9,463	1,879
RFC East	5,299	947	9,566	1,688	9,052	1,629
RFC Michigan	8,484	1,659	10,024	2,002	9,134	1,835
RFC West	7,500	1,521	10,038	2,048	9,811	2,002
Southeast Reliability Corporation	6,739	1,247	9,681	1,840	8,859	1,671
SERC Midwest	8,401	1,750	10,364	2,162	10,511	2,193
SERC Mississippi Valley	6,633	1,002	9,174	1,432	7,768	1,202
SERC South	7,316	1,326	9,399	1,776	8,713	1,622
SERC Tennessee Valley	6,916	1,358	10,002	1,988	9,697	1,921
SERC Virginia/Carolina	5,522	1,036	9,687	1,877	8,717	1,677
Southwest Power Pool	9,034	1,668	10,274	1,912	9,130	1,693
SPP North	9,014	1,816	10,997	2,215	10,661	2,148
SPP South	9,043	1,599	9,971	1,784	8,506	1,514
Texas Regional Entity	7,199	1,182	8,758	1,441	7,026	1,155
TRE All	7,199	1,182	8,758	1,441	7,026	1,155
Western Electricity Coordinating Council	5,774	953	9,186	1,541	7,407	1,249
WECC California	5,230	659	8,056	1,043	7,498	994
WECC Northwest	4,505	819	9,651	1,793	7,580	1,405
WECC Rockies	9,567	1,825	10,561	2,018	9,203	1,757
WECC Southwest	6,968	1,191	9,333	1,601	6,907	1,188

B.2 Selecting the Appropriate eGRID Aggregation Level

As explained in Section B.1, eGRID data is aggregated in many ways (e.g., plant, state, EGC, eGRID subregion). However, when selecting the appropriate grid electricity emissions factor (EF_G) and heat rate (HR_G) required by Equations 6 and 7 in Section 3.1.2, the aggregation level should reflect the nature of the electricity supply to the site where the CHP system is located. The Partnership therefore recommends using the eGRID emissions factor and heat rate for the eGRID subregion where the CHP system is located. The Partnership bases this recommendation on the following factors[25]:

- In general, eGRID subregions represent sections of the grid that have similar resource mix and emissions characteristics, operate as an integrated entity, and support most of the demand in the subregion with power generated within the subregion.
- Using the state aggregation level may not be appropriate, because emissions factors and heat rates for this level often omit generation that is imported into the state or generation that is exported to other states, and therefore may less accurately reflect the fuel use and emissions impacts of generation displaced by a specific CHP system than the eGRID subregion aggregation level." The EGC level likely omits an even greater amount of imports and exports than the state level, and, therefore, also may not be appropriate for the same reasons as for the state level.
- Emissions factors and heat rates for the NERC region or U.S. average aggregation levels do not reflect significant regional variations in the emissions from generation, and therefore do not accurately reflect the fuel use and emissions impacts of generation displaced by a specific CHP system.

In summary, in the absence of nationally consistent and complete utility-specific import and export data, the eGRID subregion level heat rates and emissions factors most accurately characterize the generation that is displaced by CHP systems.

B.3 Selecting the Appropriate eGRID Emissions and Heat Rate Category

When selecting the eGRID emissions and heat rate category, it is important to select the category that contains central station generators representative of those that are displaced by CHP systems. At first glance, each of the eGRID categories mentioned above (i.e., total output, fossil fuel output, and non-baseload) may seem like reasonable choices for HR_G in Equation 6 and EF_G in Equation 7 of Section 3.1.2; however the Partnership recommends using the following factors:

- the eGRID fossil fuel output emissions factor and heat rate for the eGRID subregion where the CHP system is located for baseload CHP (i.e., greater than 6,500 annual operating hours), and
- the eGRID non-baseload emissions factor and heat rate for the eGRID subregion where the CHP system is located for CHP systems with relatively low annual capacity factors (i.e., less than 6,500 annual operating hours) and with most generation occurring during periods of high system demand.

This section provides a detailed rationale for this recommendation.

Estimating the energy and emissions displaced by CHP requires an estimate of the nature of generation displaced by the use of power produced by the CHP system. Accurate estimates can be made using a

[25] Rothschild, S. et al., "The Value of eGRID and eGRIDweb to GHG Inventories", http://www.epa.gov/cleanenergy/documents/egridzips/The_Value_of_eGRID_Dec_2009.pdf

power system dispatch model to determine how emissions for generation in a specific eGRID subregion are impacted by the shift in the system demand curve and generation mix resulting from the addition of CHP systems. However, these models are complex and costly to run.

As stated previously, eGRID provides two rates that can be used to estimate the mix of generation that is displaced by the use of clean energy technologies such as CHP: the fossil fuel output rates and the non-baseload output rates. Use of the total output rates is not appropriate since it includes a substantial amount of baseload generation that is not offset by CHP projects.

The following load duration curve analysis demonstrates why CHP typically displaces fossil-fuel fired power generation, and explains appropriate uses of the fossil fuel and non-baseload emissions factors and heat rates.

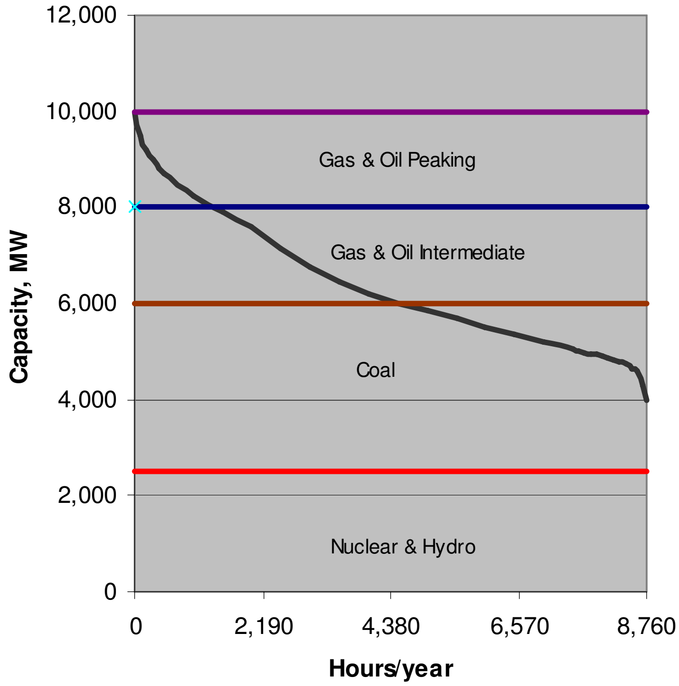
Load Duration Curve Analysis

Using eGRID data, which accurately characterizes the emissions associated with generation in a given region or subregion, a relatively simple load duration curve analysis can be used to show the impact of CHP additions. The load duration curve analysis presented here first introduces a typical load duration curve, and then shows how the addition of CHP affects the resources dispatched.

Demand for electricity varies widely over the year, and different types and sizes of generators are used to meet the varying load as it occurs. A load duration curve represents the electric demand in MW for a specific region or subregion for each of the 8,760 hours in the year.

Figure B-2 below presents a load duration curve for a hypothetical PCA. The shape of the curve is typical of electric load duration curves. Demand in MW is indicated on the vertical axis and the hours of the year are indicated on the horizontal axis. Hourly demand levels are ordered from highest to lowest. In this example, the graph shows that the highest hourly electric demand is 10,000 MW and the demand for the next highest hour is about 9,800 MW. The minimum demand is 4,000 MW, meaning that every hour of the year had at least this much demand. The area under the curve represents the total generation for the year. The zones defined by horizontal lines represent a typical generating mix and dispatch order. In a competitive electric market, the generators are dispatched based on their bid price into the market (typically a function of the variable costs of generation, fuel, other consumable items, and operation and maintenance costs). Generators with low variable costs will be dispatched first, and will therefore operate many hours per year (i.e., serve as baseload generators).

Figure B-2: Hypothetical Power System Load Duration Curve and Dispatch Order



Generators are dispatched in order of operating cost – lowest to highest:

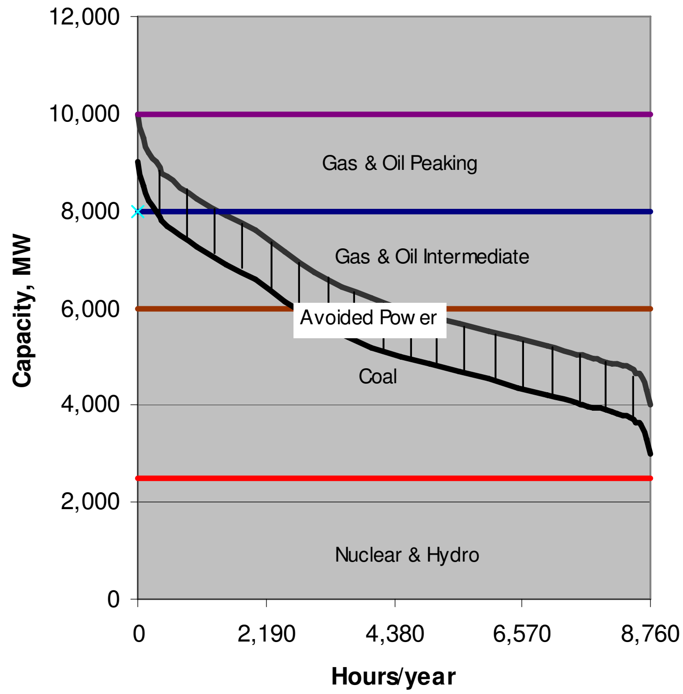
- The lowest-cost generators (nuclear and hydroelectric) operate whenever they are available. This is illustrated in Figure B-2, which shows that these generators operate continuously over the entire year.

- Coal generation is typically the next-lowest operating cost source of power. While coal plants largely serve as baseload plants, there are periods in which coal power must be scaled back or turned off during periods of low demand. This is indicated in Figure B-2 as the area above the curve and below the 'Coal' zone line. Also, some coal capacity—generally older, less efficient systems—are often used as intermediate sources.

- Natural gas and oil-fired systems typically have the highest operating costs, and therefore operate the fewest number of hours. The generators with the very highest operating costs are typically only used to meet peaking loads. Natural gas combined cycle plants have lower costs and are typically used for intermediate loads (and, in some cases, for baseload generation).

Figure B-3 illustrates the effect of baseload CHP capacity that avoids 1,000 MW of central power generation in the aforementioned hypothetical PCA. For simplicity, it is assumed that the CHP system operates for the entire year even though CHP systems may be offline for two or more weeks a year for planned or unplanned maintenance.

Figure B-3: Marginal Displaced Generation due to 1,000 MW of CHP



A review of Figure B-3 indicates the following:

- Because the CHP capacity operates continuously, the load duration curve shifts downward to reflect the 1,000 MW reduction in demand for all hours of the year.

- Compared to the base case (the top curve), the additional CHP capacity displaces an equal amount of generation each hour that it runs, shifting the load curve down while it runs. The CHP system therefore displaces power from the last unit of generation that would have been dispatched in each of these hours.

- Depending on the hour, the displaced generator could be a coal, oil, or gas steam unit, a combined cycle generator, a central station peaking turbine, or a reciprocating engine peaking unit.

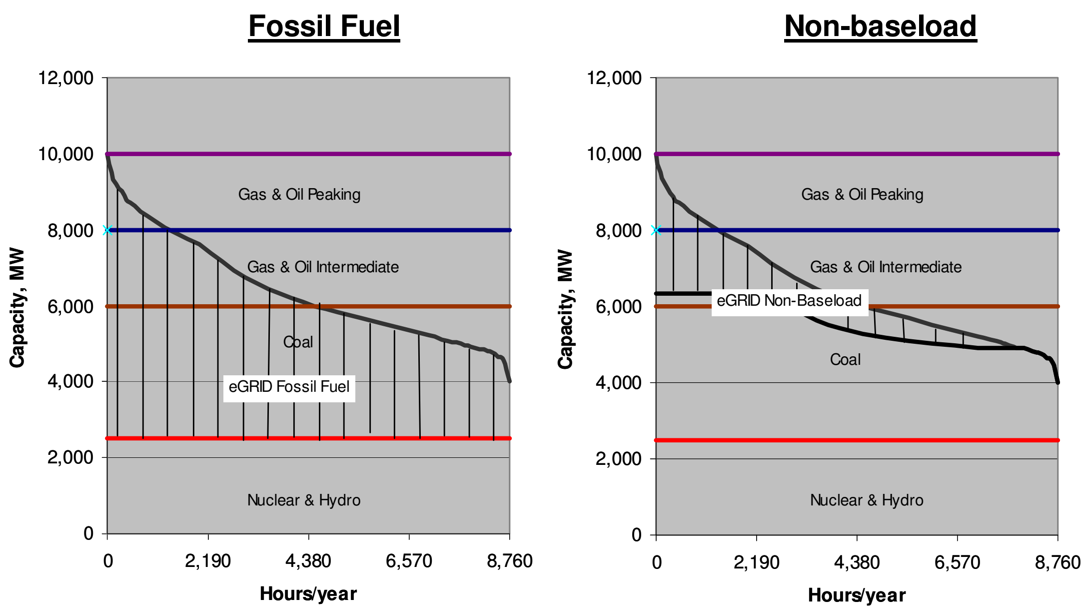
- Generators with a lower dispatch order, such as nuclear, hydro, and certain renewables, are unaffected. These resources operate whenever they are available so are unaffected by changes in power demand that result from CHP additions.

- The generation (and corresponding emissions) displaced with CHP is therefore the fossil plant output represented by the hash-marked area—a mix of mostly baseload and intermediate generation with some peaking generation.

From Figure B-3, we see that CHP additions typically displace fossil fuel-fired power generation. Therefore, the choice of which eGRID emission factor and heat rate to use for fuel and emissions savings calculations depends on whether the CHP system in question operates as a baseload or non-baseload system. As mentioned previously, CHP is mostly a baseload resource since it operates most of the year, so in most cases the eGRID fossil fuel emissions factor and heat rate should be used. For those CHP systems with relatively low annual capacity factors as well as with most generation occurring during periods of high system demand, the most appropriate estimate of displaced generation is represented by the eGRID non-baseload emission factor and heat rate.

The graphs in Figure B-4 show the eGRID fossil fuel and non-baseload rates mapped onto the hypothetical load duration curve. The difference between the two categories is largely in the amount of coal-fired power that is included. The all fossil category includes a greater share of coal power whereas the non-baseload category does not include coal-fired generators that do not operate during periods of low demand. The eGRID plant data shows that 65.7 percent of the generation in the all fossil average generation is coal-fired while only 47.7 percent of the generation in the non-baseload measure is coal-fired.

Figure B-4: eGRID Fossil Fuel and Non-baseload Rates Mapped onto Hypothetical Load Curve



Note: Non-baseload share cannot be mapped exactly onto the load duration curve. An approximation is shown.

B.5 Conclusion

When calculating the fuel and CO_2 emissions savings associated with CHP, the Partnership recommends using the eGRID emissions factors and heat rates for the eGRID subregion where the CHP system is located. Although not as accurate as a detailed dispatch analysis, a comparison of the displaced generation from baseload CHP (Figure B-3) to the all fossil and non-baseload areas (Figure B-4) suggests that the fossil fuel emission factor and heat rate are reasonable estimates for the calculation of displaced emissions and fuel for a baseload CHP system (i.e., greater than 6,500 annual operating hours). Similarly, for non-baseload CHP systems with relatively low annual capacity factors (i.e., less than 6,500 annual operating hours) and with a relatively high generation contribution during periods of high system demand, the most appropriate estimate of displaced generation is represented by the non-baseload emission factor and heat rate.

ATTACHMENT 6

U.S. ENERGY INFORMATION ADMINISTRATION, STATE ENERGY DATA SYSTEM
TABLE F15: TOTAL PETROLEUM CONSUMPTION ESTIMATE, 2010

Table F15: Total Petroleum Consumption Estimates, 2010

State	Residential	Commercial	Industrial	Transportation	Electric Power	Total	Residential	Commercial	Industrial	Transportation	Electric Power	Total
	Thousand Barrels						Trillion Btu					
Alabama	2,359	1,878	14,361	85,957	215	104,769	9.3	9.6	84.5	463.0	1.3	567.6
Alaska	1,717	2,305	7,095	36,904	795	48,815	9.7	13.0	42.0	207.3	4.8	276.8
Arizona	1,196	1,691	10,061	85,556	117	98,622	4.6	9.1	59.5	459.7	0.7	533.6
Arkansas	1,593	1,133	9,313	52,437	75	64,550	6.1	5.9	52.5	284.7	0.4	349.7
California	8,582	6,891	72,878	562,679	2,242	653,272	33.5	35.5	422.8	3,064.0	13.5	3,569.3
Colorado	3,241	1,580	10,768	76,774	37	92,400	12.5	8.2	58.8	415.0	0.2	494.6
Connecticut	13,292	3,096	2,368	44,243	764	63,762	74.4	16.5	11.9	235.9	4.8	343.4
Delaware	1,634	525	2,783	12,505	104	17,551	7.5	2.5	16.8	66.6	0.6	94.0
Dist. of Col.	219	413	114	2,796	434	3,976	1.3	2.3	0.6	14.8	2.5	21.5
Florida	2,434	6,947	21,620	283,048	16,019	330,068	9.5	35.3	126.7	1,534.4	98.2	1,804.1
Georgia	3,364	2,238	16,173	178,712	212	200,697	13.0	11.1	93.4	972.5	1.2	1,091.3
Hawaii	239	817	3,670	24,144	12,610	41,481	0.9	3.7	21.8	134.0	78.2	238.6
Idaho	1,185	679	5,183	23,762	(s)	30,809	4.9	3.4	31.0	128.7	(s)	168.0
Illinois	6,779	2,266	48,800	178,628	204	236,677	26.3	11.3	264.7	965.7	1.2	1,269.3
Indiana	4,887	1,987	25,693	111,909	256	144,732	19.5	10.0	149.5	607.4	1.5	787.9
Iowa	4,817	3,558	19,315	55,705	317	83,712	18.9	18.0	89.7	301.3	1.9	429.8
Kansas	2,337	815	28,953	44,771	296	77,172	9.0	3.7	135.3	243.2	1.8	393.0
Kentucky	2,881	715	26,543	84,762	4,378	119,281	11.5	3.5	142.8	460.3	26.3	644.3
Louisiana	735	1,281	238,100	115,945	5,621	361,683	2.8	6.9	1,256.4	646.1	33.9	1,946.2
Maine	6,901	3,883	2,845	22,960	413	37,001	37.0	20.4	17.1	124.1	2.6	201.1
Maryland	5,699	3,297	6,700	81,113	650	97,459	29.1	17.5	40.1	434.0	3.9	524.5
Massachusetts	16,808	6,938	3,358	84,328	468	111,900	94.5	39.5	18.4	450.3	2.9	605.7
Michigan	9,911	2,039	13,989	134,118	593	160,650	39.5	10.5	81.4	715.6	3.6	850.6
Minnesota	6,291	2,413	21,940	86,649	64	117,357	26.6	12.4	126.9	467.1	0.4	633.3
Mississippi	2,031	1,197	13,148	62,452	137	78,966	7.8	5.8	77.8	339.8	0.9	432.1
Missouri	4,967	1,558	15,119	105,102	254	126,999	19.2	7.2	83.6	565.7	1.5	677.2
Montana	2,082	437	8,332	19,147	1,154	31,154	8.2	2.0	49.6	104.4	7.0	171.1
Nebraska	2,215	518	6,440	32,117	57	41,348	8.6	2.6	35.8	174.8	0.3	222.1
Nevada	743	576	5,681	38,324	25	45,349	3.1	3.0	33.1	206.8	0.1	246.0
New Hampshire	5,457	2,245	1,964	20,051	116	29,833	27.4	11.5	11.9	106.4	0.7	157.9
New Jersey	7,134	2,718	19,010	172,589	265	201,716	38.6	14.9	114.4	944.1	1.6	1,113.6
New Mexico	1,638	650	11,083	34,881	92	48,344	6.3	3.0	54.8	190.0	0.5	254.6
New York	27,152	21,811	13,944	184,881	3,340	251,128	146.5	127.8	83.4	993.4	20.5	1,371.6
North Carolina	8,404	5,172	14,934	133,787	528	162,825	36.2	25.3	83.1	713.5	3.1	861.2
North Dakota	1,776	735	9,312	16,100	69	27,991	7.3	3.7	52.9	88.2	0.4	152.6
Ohio	7,130	3,824	34,091	174,413	2,481	221,940	31.1	20.1	202.6	941.7	14.8	1,210.3
Oklahoma	2,150	1,302	16,964	71,505	24	91,945	8.3	6.6	100.9	388.3	0.1	504.1
Oregon	1,125	1,181	5,943	57,515	6	65,769	5.3	6.2	34.9	312.6	(s)	359.0
Pennsylvania	21,396	6,333	40,379	173,357	1,143	242,609	113.7	33.3	224.8	934.3	6.8	1,313.0
Rhode Island	3,223	883	1,675	11,678	23	17,483	18.4	5.0	10.4	62.4	0.1	96.3
South Carolina	1,895	1,382	9,413	84,923	281	97,895	7.8	6.6	55.5	457.7	1.7	529.2
South Dakota	1,449	574	3,598	16,383	18	22,022	5.8	2.6	20.7	89.2	0.1	118.5
Tennessee	3,109	1,728	14,404	111,044	397	130,681	12.5	9.2	85.8	599.5	2.3	709.2
Texas	5,357	5,283	721,979	498,447	1,144	1,232,209	20.6	25.9	3,058.0	2,729.9	6.8	5,841.2
Utah	463	831	6,963	40,946	81	49,284	1.8	4.2	40.9	222.9	0.5	270.3
Vermont	3,418	1,510	932	9,804	5	15,670	16.8	7.4	5.3	52.3	(s)	81.8
Virginia	7,099	3,190	9,372	136,294	2,160	158,115	34.4	15.5	55.4	734.1	13.1	852.6
Washington	3,352	2,713	22,324	110,283	37	138,709	14.8	14.5	132.0	604.2	0.2	765.7
West Virginia	1,198	479	7,909	28,103	271	37,961	5.3	2.3	46.8	151.4	1.6	207.4
Wisconsin	7,399	1,633	12,412	81,928	1,080	104,452	30.7	7.7	72.5	440.0	6.5	557.4
Wyoming	897	910	9,538	18,510	104	29,959	3.5	4.4	56.2	102.9	0.6	167.6
United States	243,362	130,756	1,649,483	4,914,968	62,178	7,000,747	1,141.9	688.1	8,227.4	26,646.1	378.3	37,081.7

Where shown, (s) = Physical unit value less than 0.5, or Btu value less than 0.05.
Notes: Total petroleum includes fuel ethanol blended into motor gasoline. • Totals may not equal sum of components due to independent rounding.

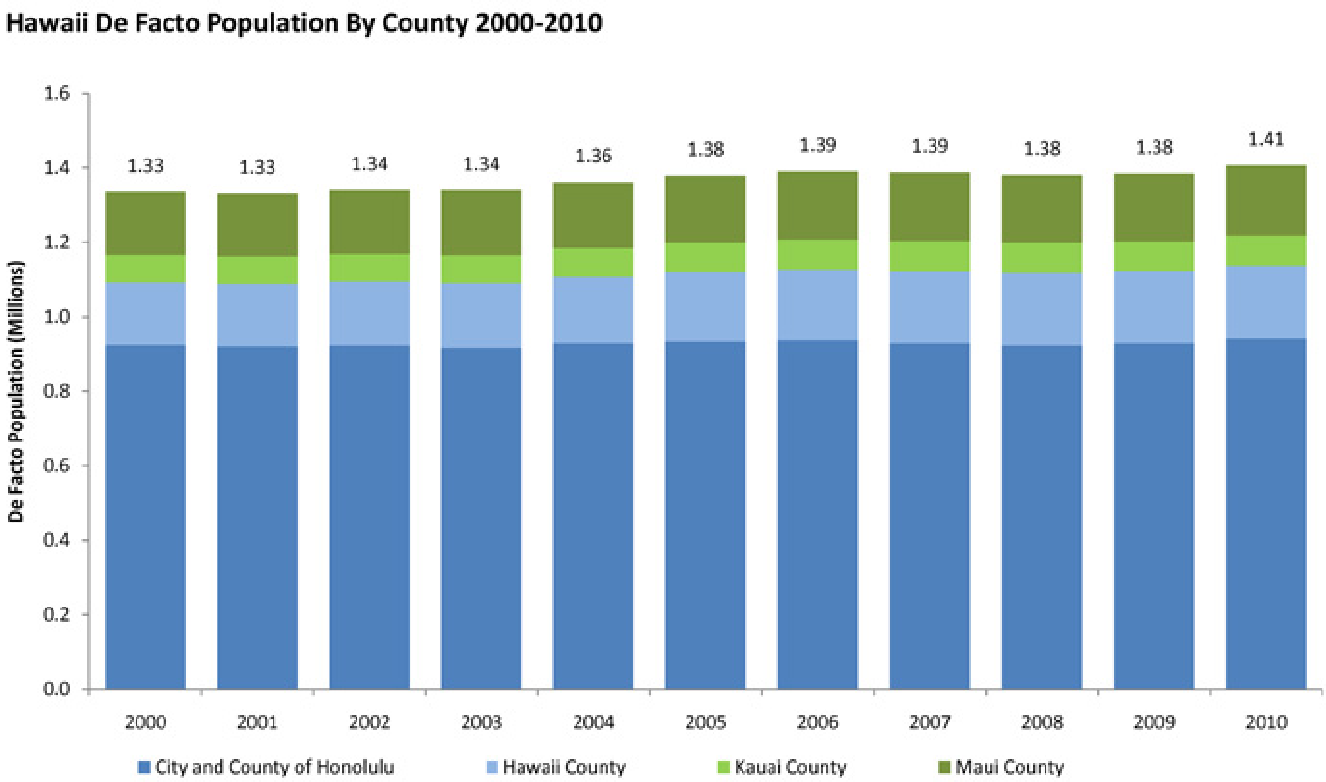
Sources: Data sources, estimation procedures, and assumptions are described in the Technical Notes.

ATTACHMENT 7

HAWAII ENERGY STATISTICS

Hawaii Energy Statistics

The following charts provide general information and insights into Hawaii, its energy goals, and its energy consumption trends.



Source: *Resident De Facto Population by County and Island: 1990 and 2000*, State of Hawaii Date Book (DBEDT)

Hawaii De Facto Population by County 2000-2010

Hawaii State Energy Office

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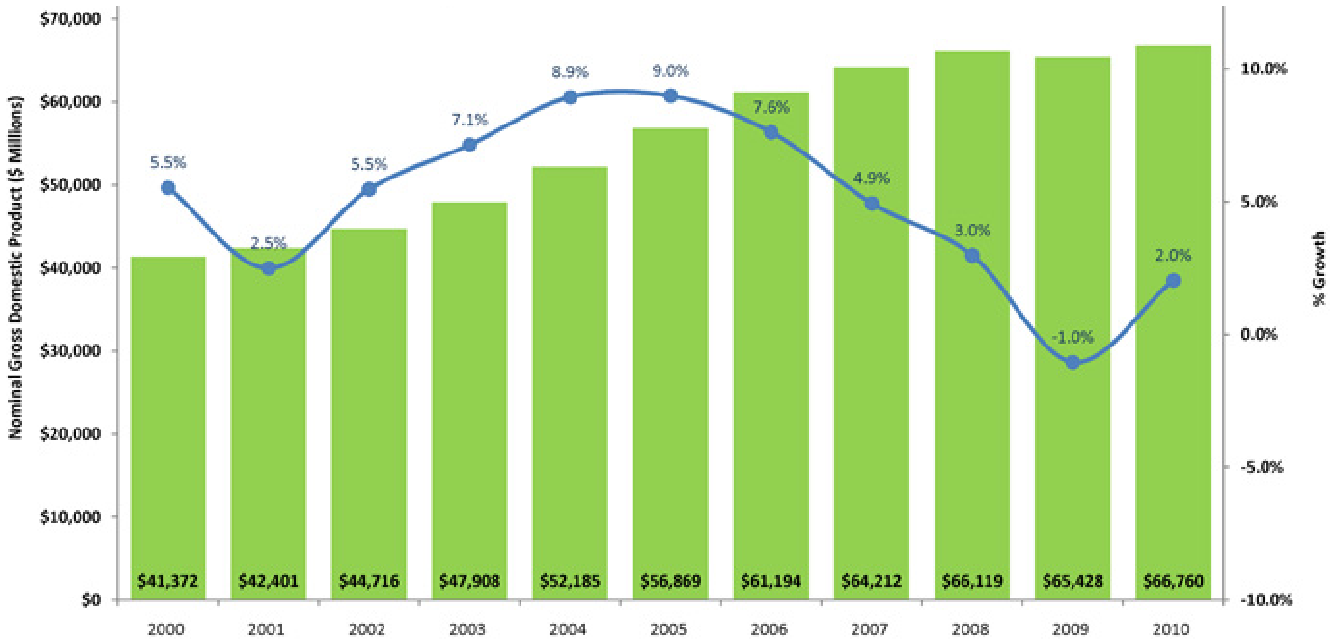
Our island environment is not only the basis for our quality of life, it is also the lifeblood of our economy. We look at environmental issues with future generations in mind, and as we explore Hawaii's boundless, clean energy potential, we trust they will benefit from our stewardship.

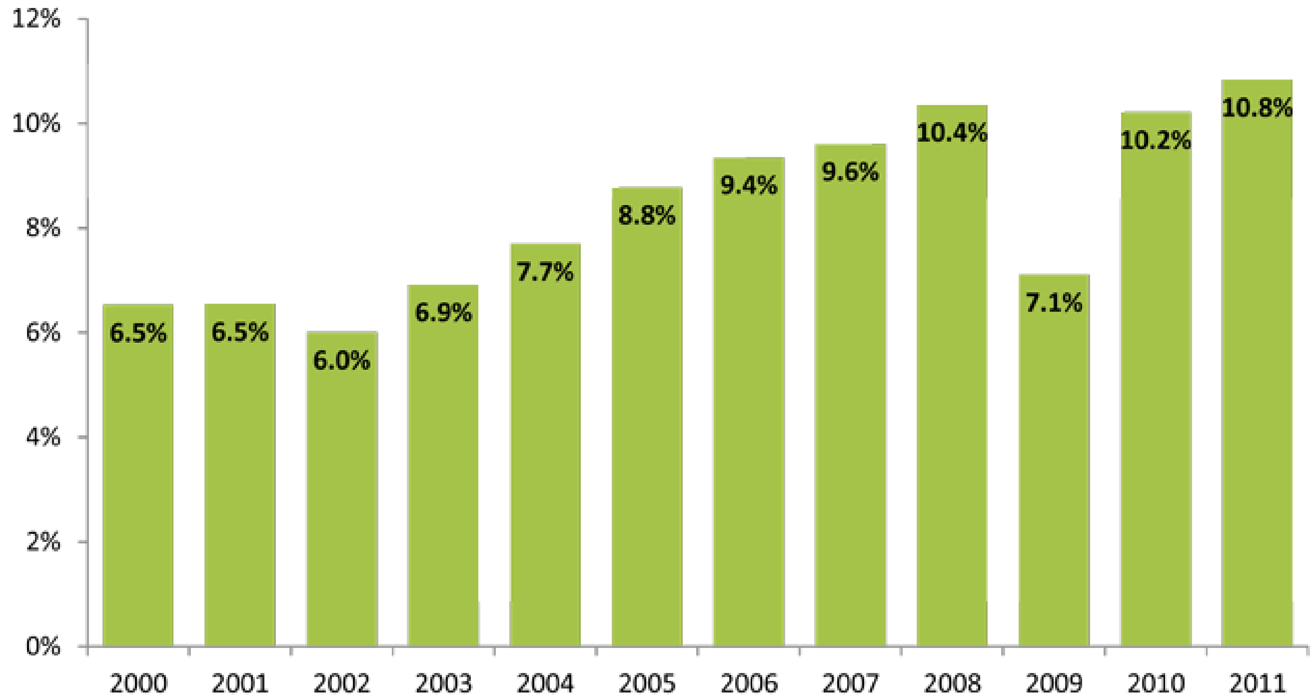
-Governor Neil Abercrombie



Source: *Gross Domestic Product, Total and Per Capita and Resident Population: 1963 to 2010*, State of Hawaii Date Book (DBEDT)

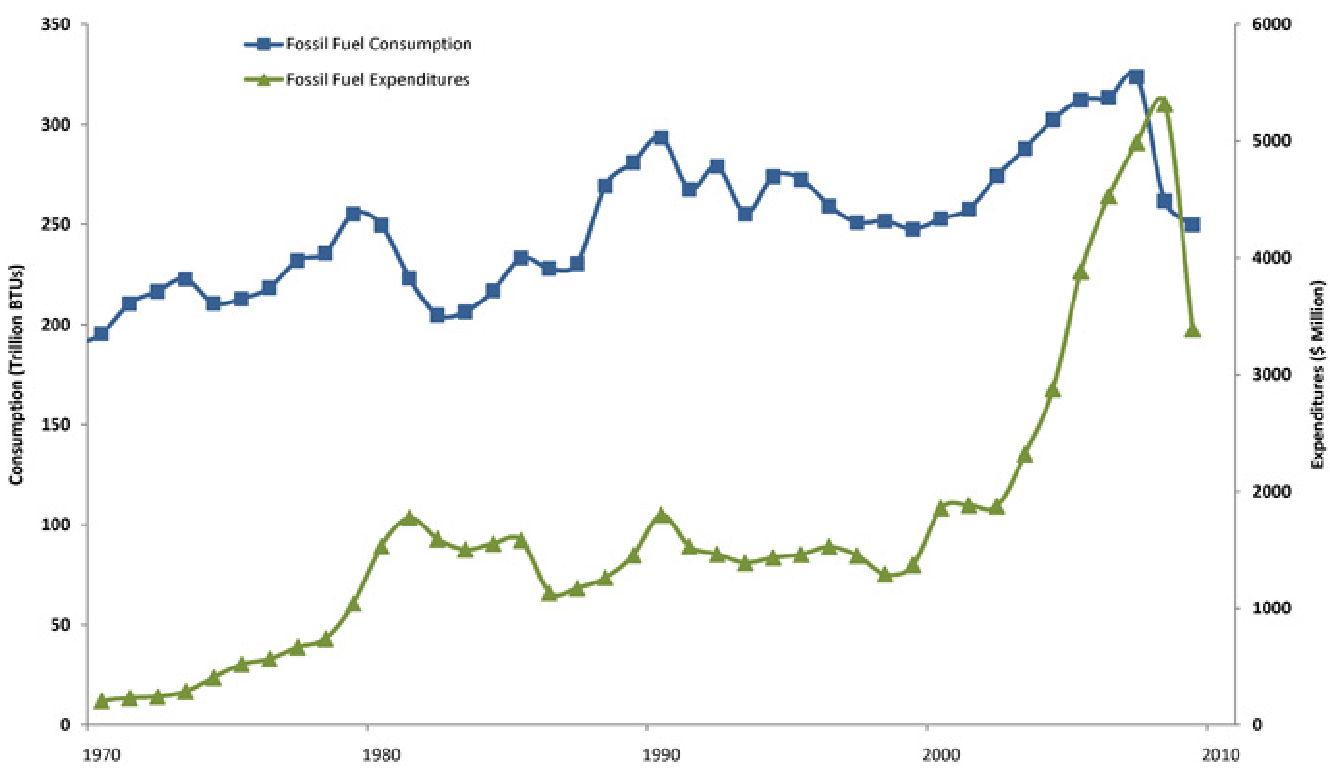
Hawaii Nominal Gross Domestic Product 2000–2010

Energy Costs as a Percent of GDP



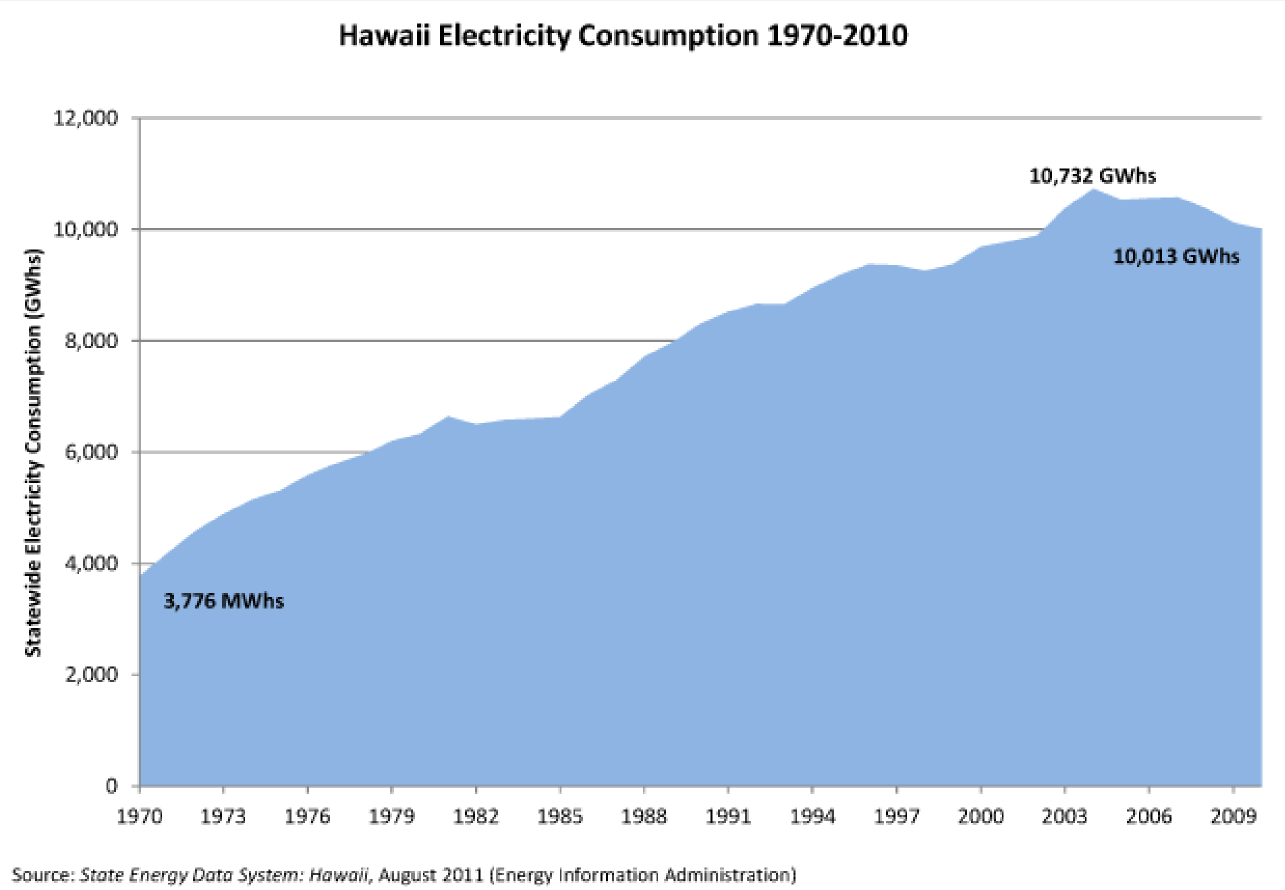
Source: Energy Information Administration and U.S. Bureau of Economic Analysis

Hawaii Fossil Fuel Consumption and Expenditures 1970-2009

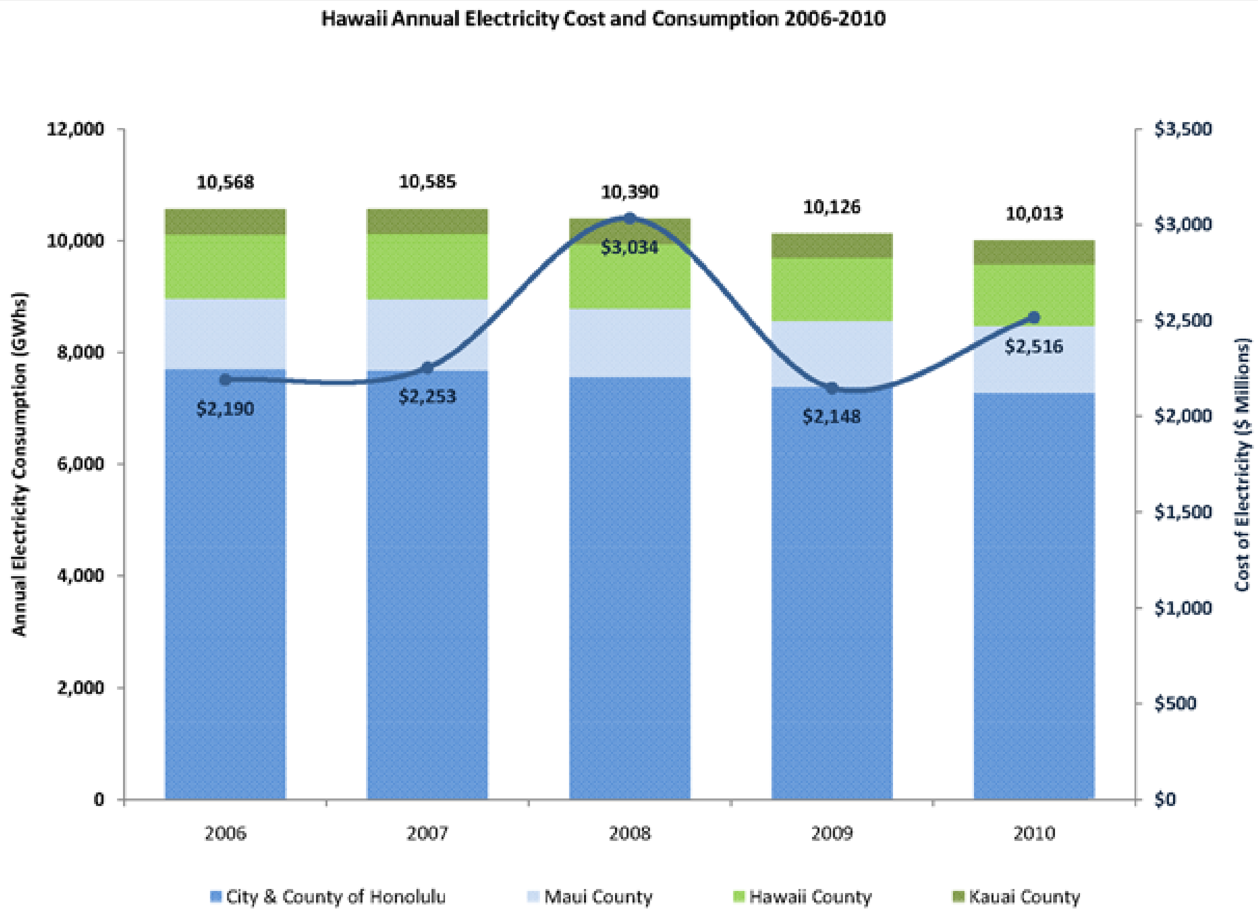


Source: *State Energy Data System: Hawaii Primary Energy Use*, June 2011 (Energy Information Administration)

Hawaii Fossil Fuel Consumption and Expenditures 1970-2009

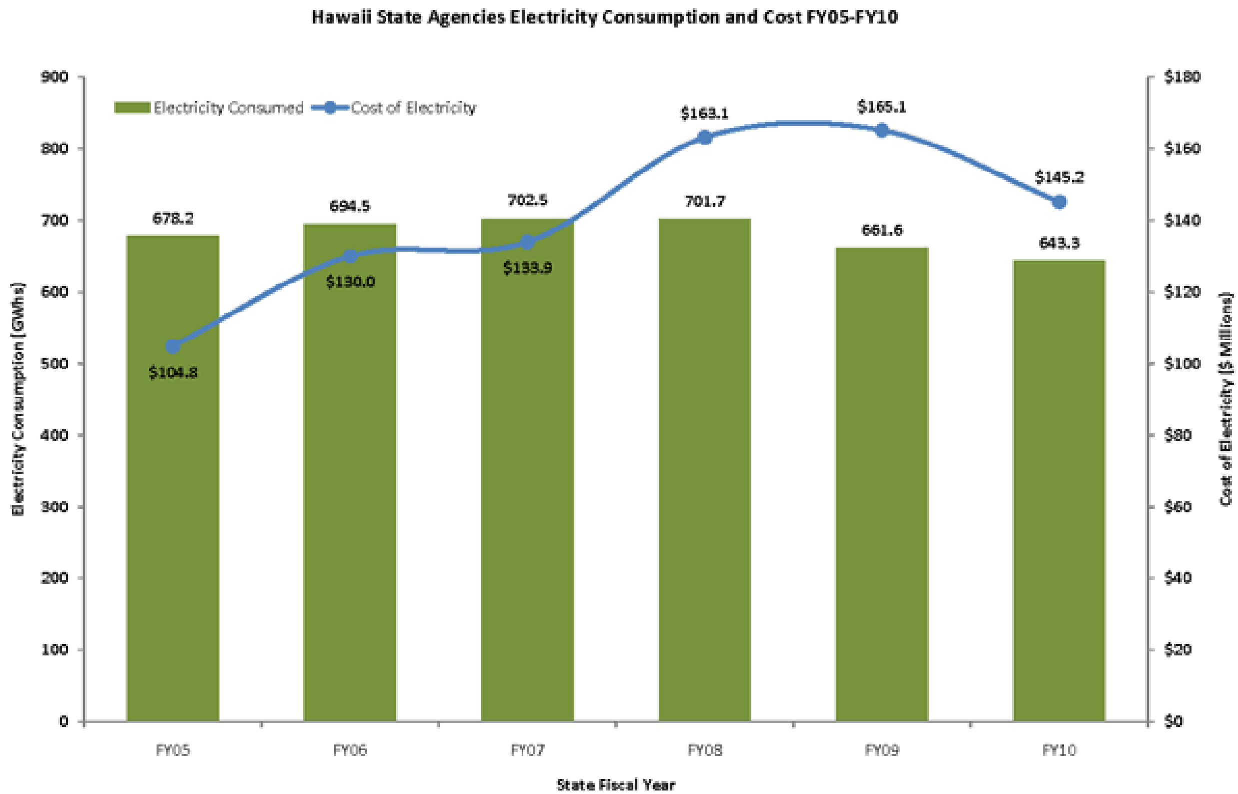


Hawaii Electricity Consumption 1970-2010



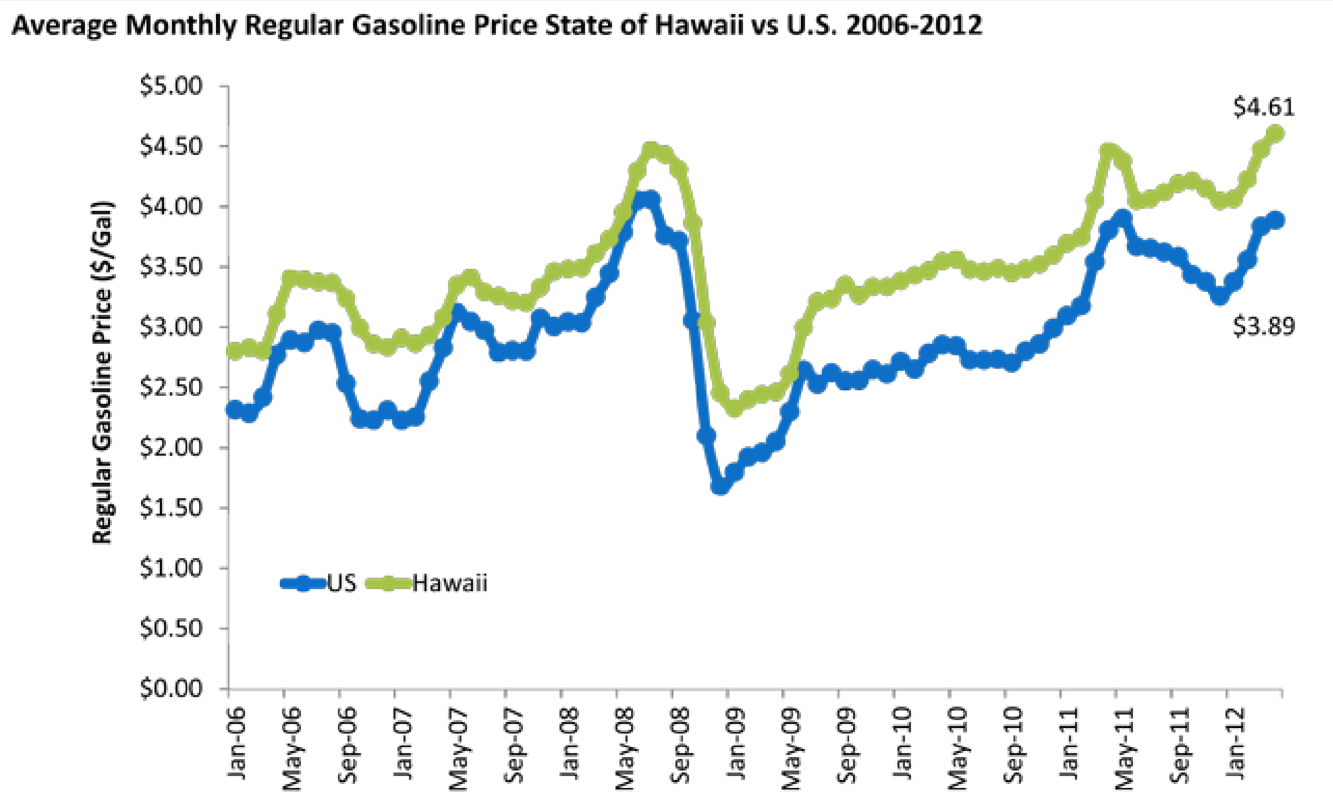
Source: *Monthly Energy Trends*, 2006-2010 (DBEDT)

Hawaii Annual Electricity Cost and Consumption 2006-2010

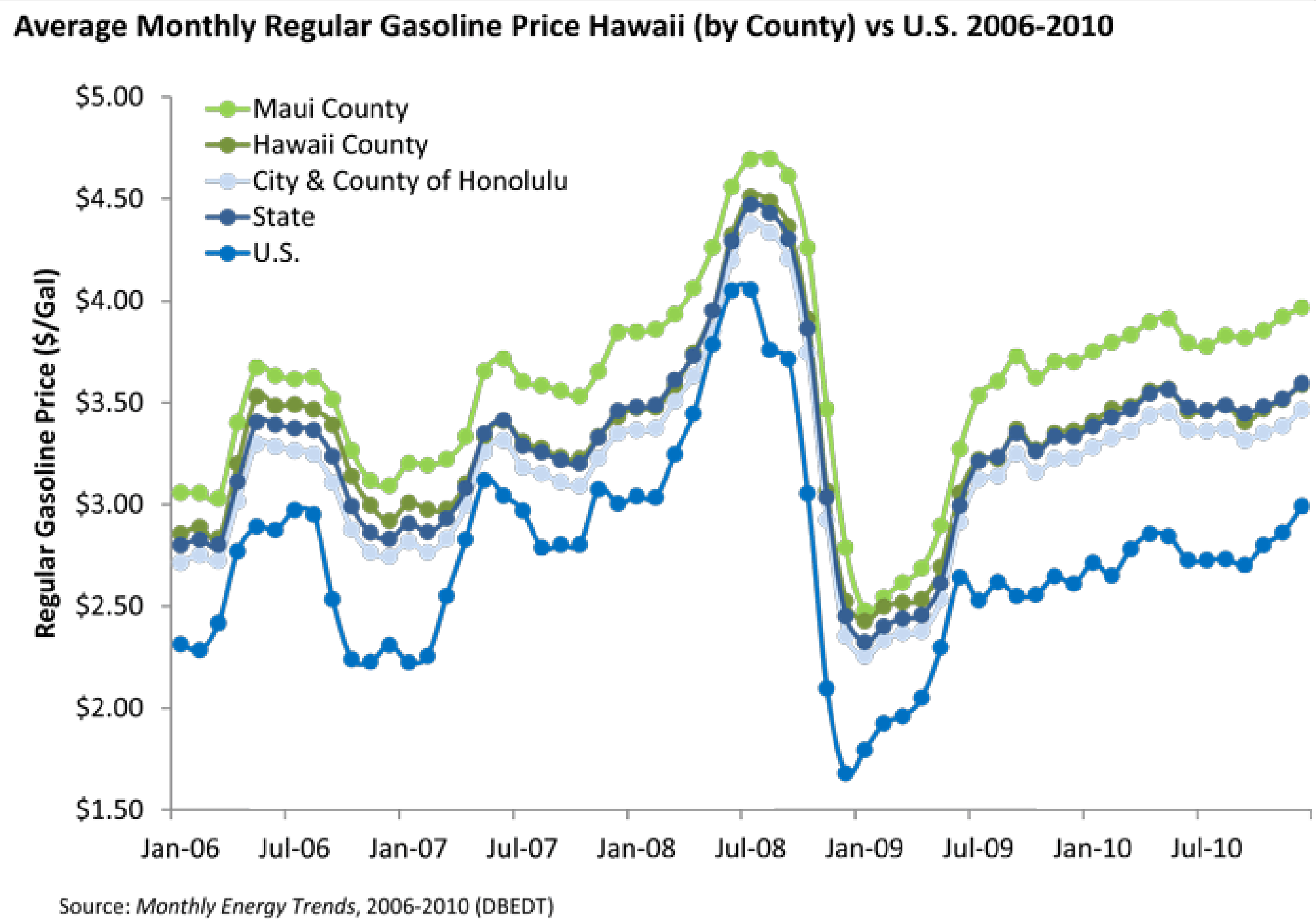


Source: Department of Business, Economic Development and Tourism, August 2011

Hawaii State Agencies Electricity Consumption and Cost FY05-FY10

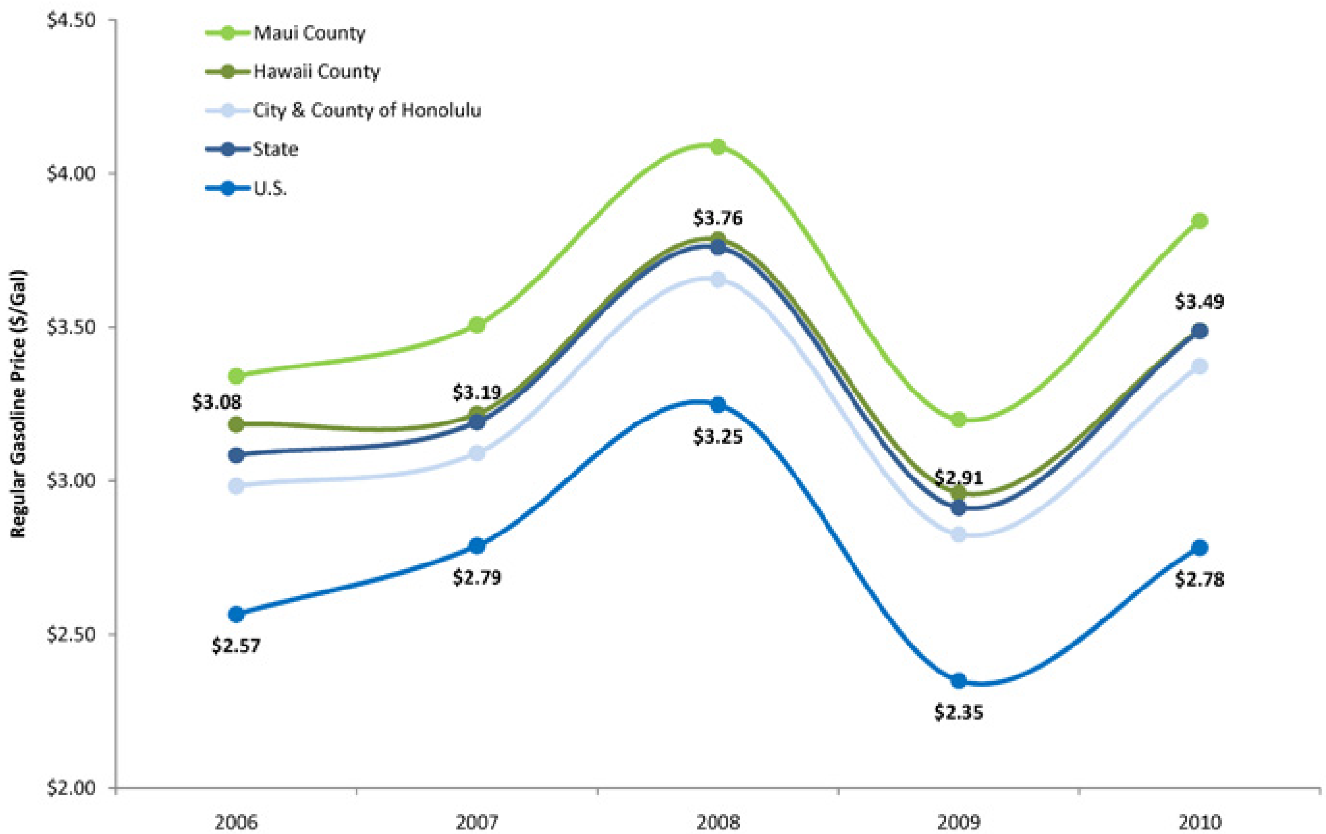


Source: *Monthly Energy Trends*, DBEDT



Average Monthly Regular Gasoline Price Hawaii vs. U.S. 2006-2010

Average Annual Regular Gasoline Price Hawaii vs U.S. 2006-2010



Source: *Monthly Energy Trends*, 2006-2010 (DBEDT)

Average Annual Regular Gasoline Price Hawaii vs. U.S. 2006-2010

The data shown on this website is measured and represented as accurately as possible and is subject to change as updates are provided by data sources.

ATTACHMENT 8

ENERGY-DATA-TREND
TABLE 5.8 RESIDENTIAL ENERGY CONSUMPTION PER HOUSEHOLD

Table 5.8 shows the residential energy consumption per household in Hawaii. From 1960 to 2008, residential energy consumption per household increased about 78 percent from 47 MBTU per household to 84 MBTU in 2008; residential electricity consumption per household increased about 108 percent from 3,382 kWh per household to 7,045 kWh per household.

Table 5.8. Residential Energy Consumption per Household

	Hawaii	Residential Energy Consumption per Household					
	State	Total		Other	Index		
	Household	Energy	Electricity	Energy	Total Energy	Electricity	Others
Year	HH	MBTU/HH	kWh/HH	MBTU/HH	1970=100	1970=100	1970=100
1960	152,014	47	3,382	1	62	54	19
1965	174,998	56	4,920	1	75	78	32
1970	204,505	76	6,283	4	100	100	100
1975	251,986	75	6,599	2	99	105	57
1980	296,074	71	6,218	7	94	99	189
1985	322,687	62	5,823	3	82	93	70
1990	356,267	86	6,523	5	114	104	130
1991	361,403	72	6,629	5	96	106	133
1992	367,095	81	6,642	6	107	106	168
1993	371,002	81	6,654	5	107	106	134
1994	375,478	83	6,810	5	110	108	138
1995	382,340	84	6,817	5	111	108	138
1996	388,840	84	6,882	5	112	110	139
1997	391,637	84	6,813	5	111	108	146
1998	395,139	84	6,683	7	111	106	190
1999	399,712	83	6,728	6	110	107	163
2000	404,391	84	6,837	6	111	109	175
2001	409,863	80	6,838	6	106	109	172
2002	415,228	84	6,980	6	111	111	173
2003	421,614	81	7,181	6	108	114	161
2004	427,125	83	7,403	6	110	118	162
2005	432,097	83	7,323	6	110	117	167
2006	435,287	84	7,311	7	111	116	179
2007	434,297	85	7,370	7	113	117	189
2008	437,919	84	7,045	9	111	112	253

Source: Energy Information Administration, State Energy Data System