Exergy and Water Efficiency in Combined Heat and Power Plants: UT-Austin vs. ERCOT

Presented by:
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Objectives

- Introduction to exergy and how the evaluation technique can be applied to district energy
- Get familiar with the water efficiency benefits of combined heat and power
- See how an established university campus CHP system performs versus the grid

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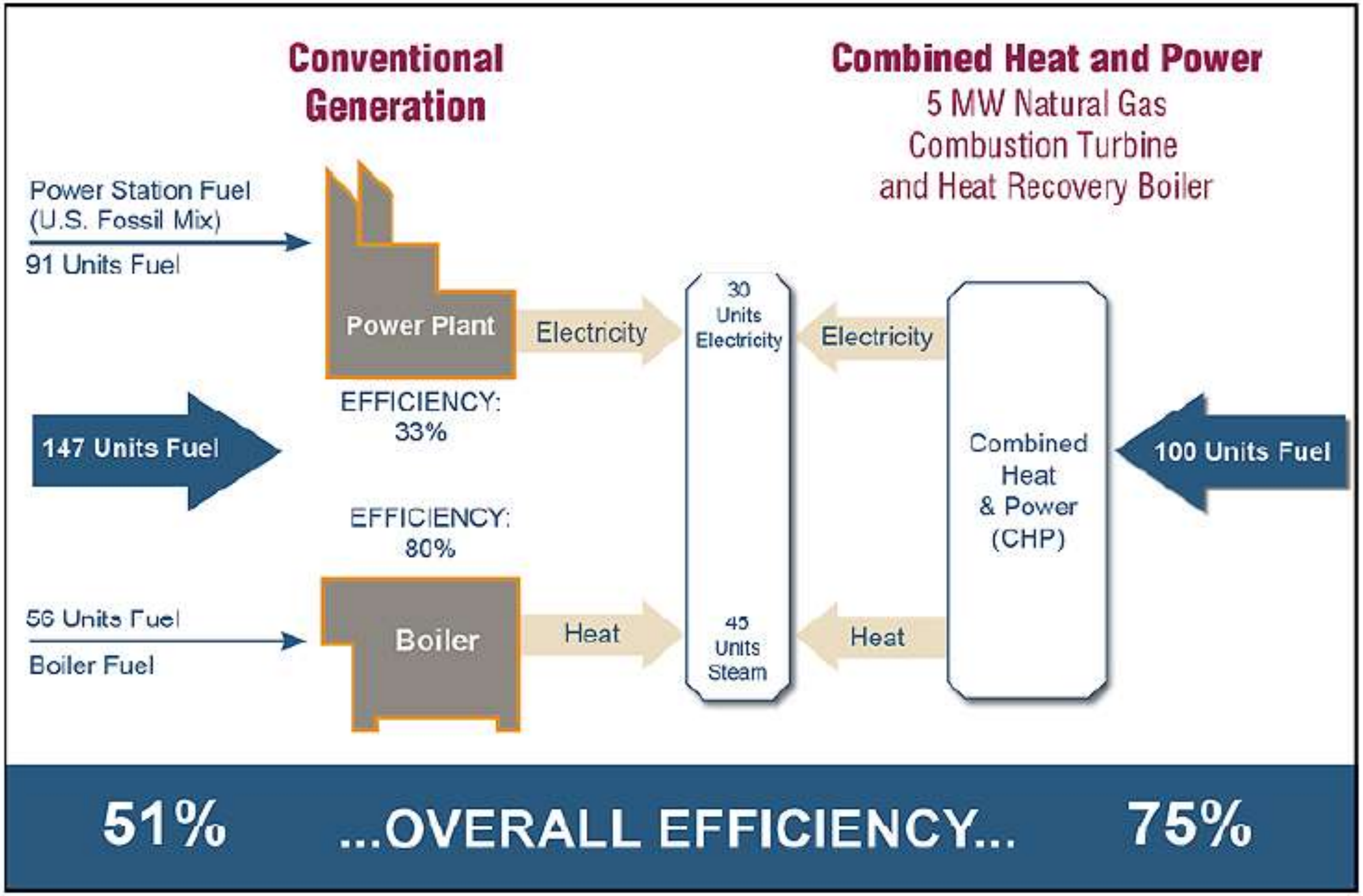
Why is CHP Beneficial?



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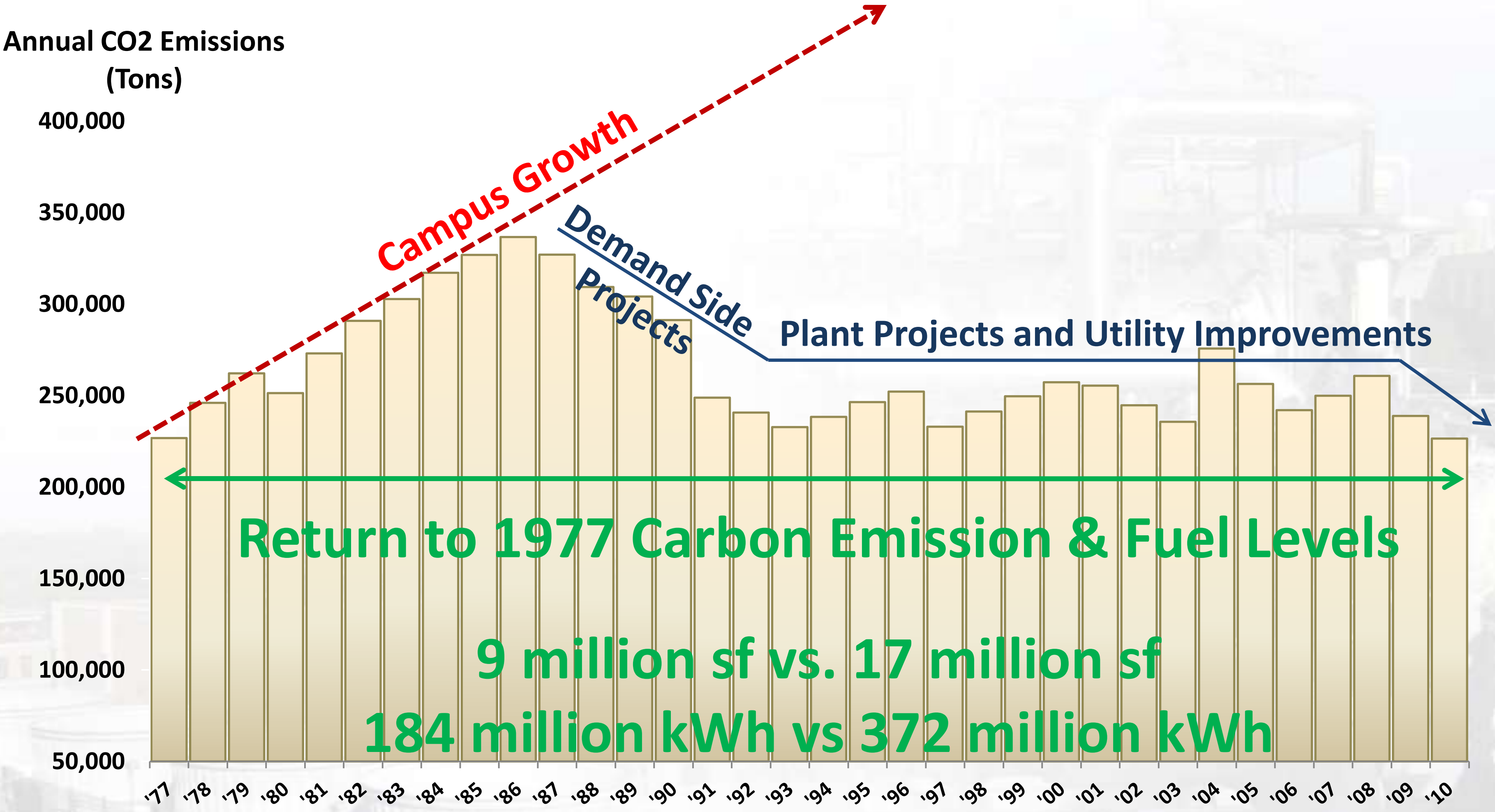
CHP at UT-Austin



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Exergy Defined

<u>Energy Balance</u>

$$\begin{aligned}&Energy\ in\\&\quad = Useful\ Energy\ Output\\&\quad + Energy\ of\ Waste\ Stream\end{aligned}$$

FLT

<u>Exergy Balance</u>

$$\begin{aligned}&Exergy\ in\\&\quad = Useful\ Exergy\ Output\\&\quad + Exergy\ of\ Waste\ Stream\\&\quad + Exergy\ Destroyed\end{aligned}$$

SLT

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Why Are We Concerned with Exergy?

Exergy Characteristics

- A system in complete equilibrium with its environment has exergy of zero (there is no driving force for a thermodynamic process)
- The exergy of a system increases the more it deviates from its environment.
- When energy loses its quality, exergy is destroyed.
- Exergy efficiencies represent an approach to ideality (full reversibility).

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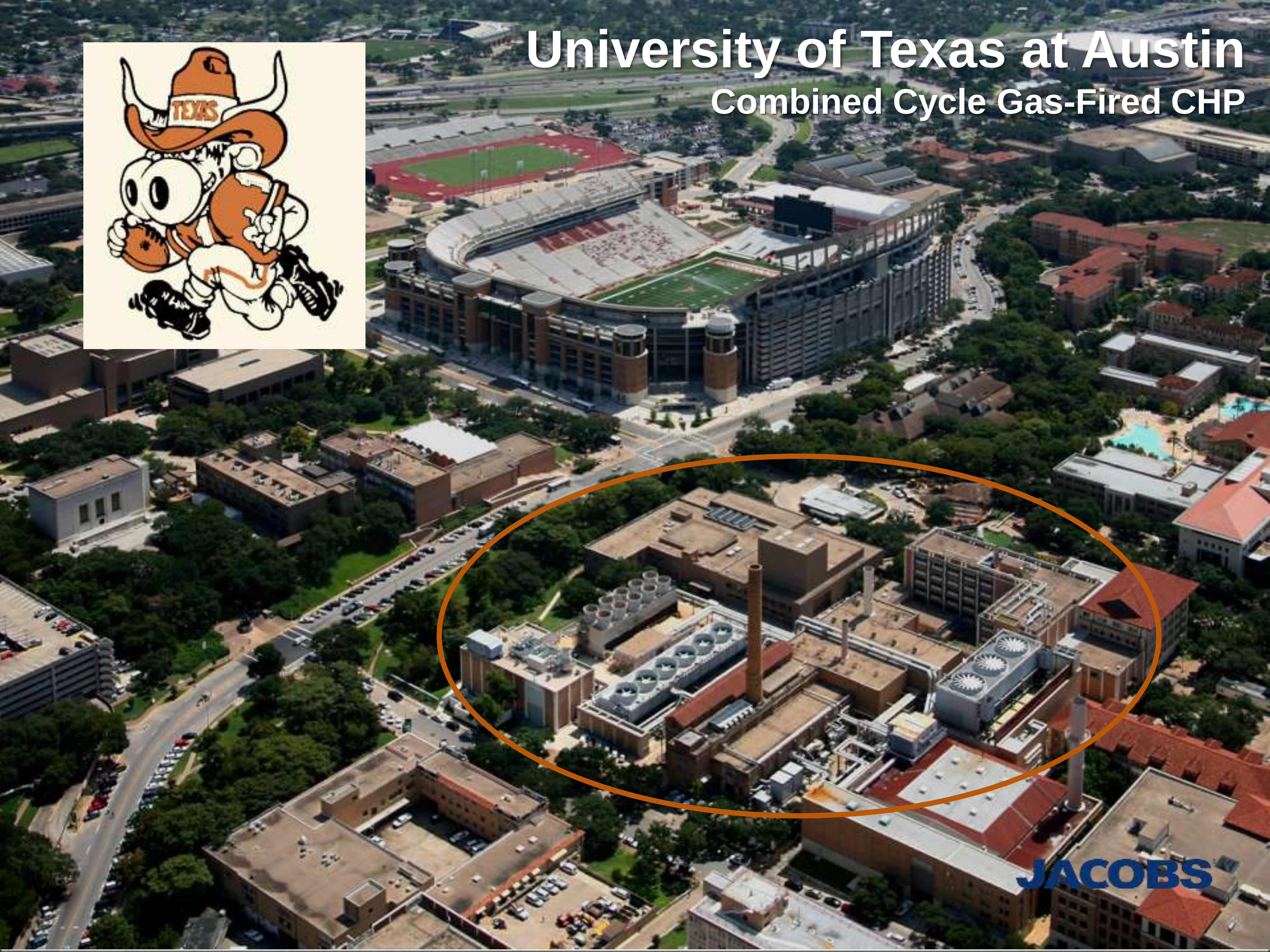
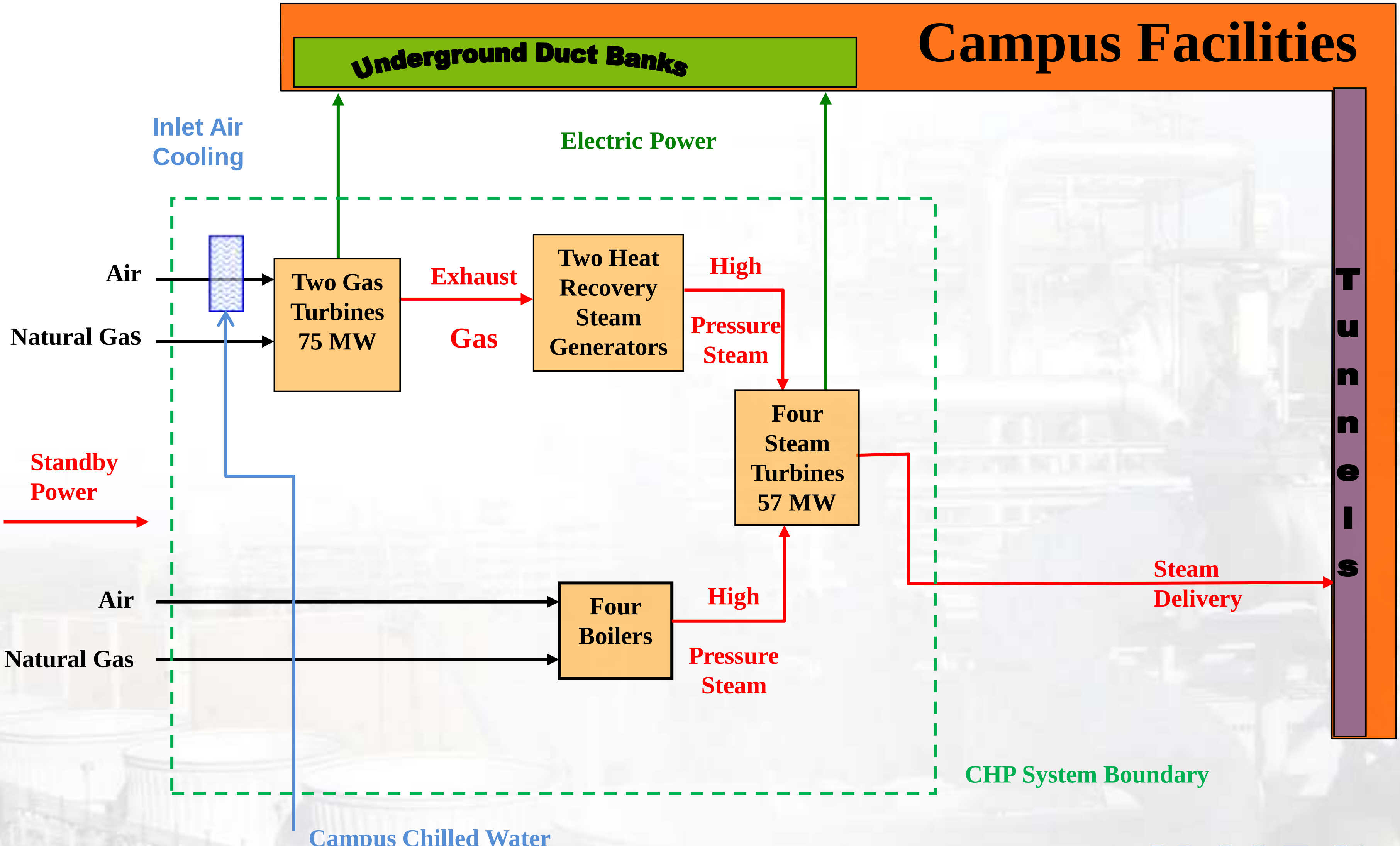
Combined Cycle Gas-Fired CHP




Campus Facilities
Underground Duct Banks
Inlet Air Cooling
Electric Power
Air
Natural Gas
Two Gas Turbines 75 MW
Exhaust
Gas
Two Heat Recovery Steam Generators
High
Pressure
Steam
Four Steam Turbines 57 MW
Standby Power
Air
Natural Gas
Four Boilers
High
Pressure
Steam
Steam Delivery
Tunnels
CHP System Boundary
Campus Chilled Water
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UT CHP – Major Equipment

Combustion Turbines	Heat Recovery Steam Generators	Steam Turbines	Boilers
GT-8	HRSG-8	ST-4	B-1
GT-10	HRSG-10	ST-5	B-2
		ST-7	B-3
		ST-9	B-7

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Metered Operational Data

	Natural Gas Usage (Therms)								
Date	GT 8	HRSG 8	GT 10	HRSG 10	B1	B2	B3	B7	Total
12/1/2013	40	10	66,213	2,083	12	0	0	14,912	83,270
12/2/2013	42	10	70,826	0	12	0	0	14,883	85,773
12/3/2013	41	10	71,640	3,169	12	0	0	17,762	92,634
12/4/2013	43	10	73,050	9,996	13	0	501	16,169	99,781
12/5/2013	40	9	70,890	13,615	11	0	191	16,503	101,258
12/6/2013	35	9	67,678	20,259	9	0	44	20,076	108,111
12/7/2013	34	8	63,658	19,504	8	0	38	27,169	110,420
12/8/2013	37	9	62,780	19,043	8	0	200	24,293	106,370
12/9/2013	40	9	68,062	19,361	9	0	259	21,671	109,412
12/10/2013	40	10	61,390	17,307	10	0	2,725	29,430	110,910
12/11/2013	39	10	66,488	16,530	10	0	603	19,110	102,790
12/12/2013	41	9	67,297	15,909	11	0	592	17,653	101,512

Ref. 2

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Metered Operational Data

	Electrical Generation (MWh)						
Date	ST 4	ST 5	ST 7	ST 9	GT 8	GT 10	Total
12/1/2013	134.183	0.000	0.000	0.000	0.000	629.139	763.322
12/2/2013	128.794	0.000	0.000	0.000	0.000	696.356	825.150
12/3/2013	67.415	0.000	0.000	109.626	0.000	706.660	883.701
12/4/2013	0.000	0.000	0.000	226.991	0.000	719.366	946.357
12/5/2013	0.000	0.000	0.000	136.799	0.000	690.797	827.596
12/6/2013	0.000	0.000	0.000	125.129	0.000	644.088	769.216
12/7/2013	0.000	0.000	0.000	139.554	0.000	585.544	725.098
12/8/2013	0.000	0.000	0.000	141.761	0.000	580.134	721.894
12/9/2013	0.000	0.000	0.000	135.465	0.000	652.939	788.403
12/10/2013	0.000	0.000	0.000	167.857	0.000	579.704	747.561
12/11/2013	0.000	0.000	0.000	132.862	0.000	641.782	774.644
12/12/2013	0.000	0.000	0.000	124.214	0.000	646.668	770.881

Metered Operational Data

	Campus Steam Delivery				
	Pressure	Temperature	Quantity Delivered	Enthalpy	Energy Delivered
Date	psig	°F	lb	Btu/lb	Therms
12/1/2013	147.265	484.611	1,929,874	1,265.12	24,415
12/2/2013	147.081	476.775	1,842,219	1,260.93	23,229
12/3/2013	150.460	469.943	1,829,926	1,256.84	22,999
12/4/2013	156.469	462.833	1,803,668	1,252.22	22,586
12/5/2013	151.159	455.192	2,943,686	1,248.68	36,757
12/6/2013	145.061	453.368	3,917,377	1,248.46	48,907
12/7/2013	141.768	479.851	4,274,925	1,263.18	54,000
12/8/2013	144.653	475.632	3,906,236	1,260.59	49,242
12/9/2013	145.209	460.886	3,877,580	1,252.55	48,569
12/10/2013	143.985	422.049	3,942,146	1,231.17	48,535
12/11/2013	148.536	387.739	3,405,060	1,210.33	41,212
12/12/2013	149.050	460.497	3,358,075	1,251.86	42,038

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Efficiency Calculations

- Combined Electrical & Thermal Energy Efficiency:

$$\eta_{tot} = \frac{Eo + THo}{Ei + THi} * (100\%)$$

- Combined Electrical & Thermal Exergy Efficiency:

$$\psi_{tot} = \frac{Eo + THo * \tau}{Ei + THo} * (100\%)$$

- Exergetic Temperature Factor:

$$\tau = 1 - \left(\frac{T_0}{T_{use}}\right)$$

Ref. 3

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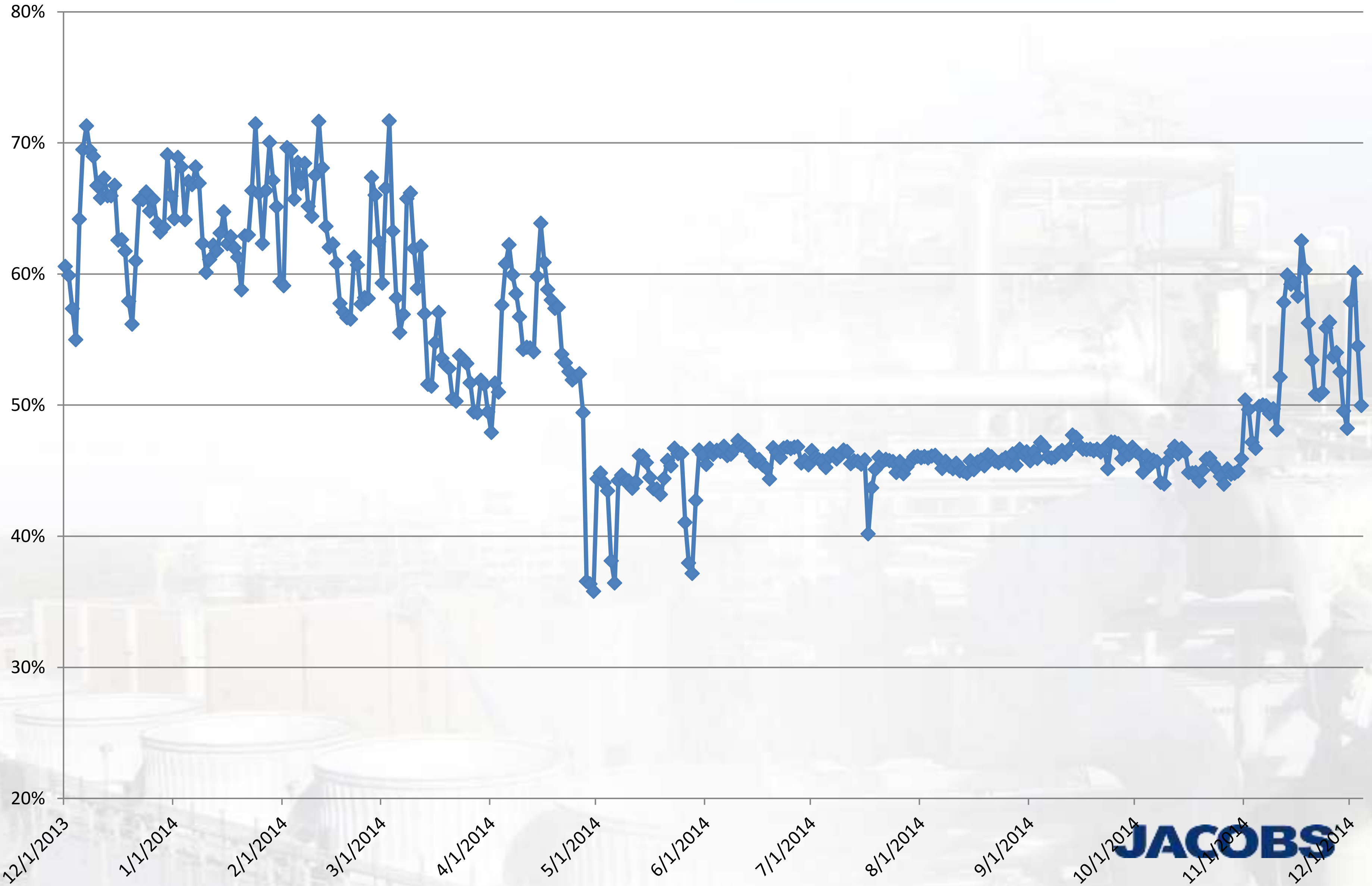
UT CHP – Combined Electrical & Thermal System Energy Efficiency



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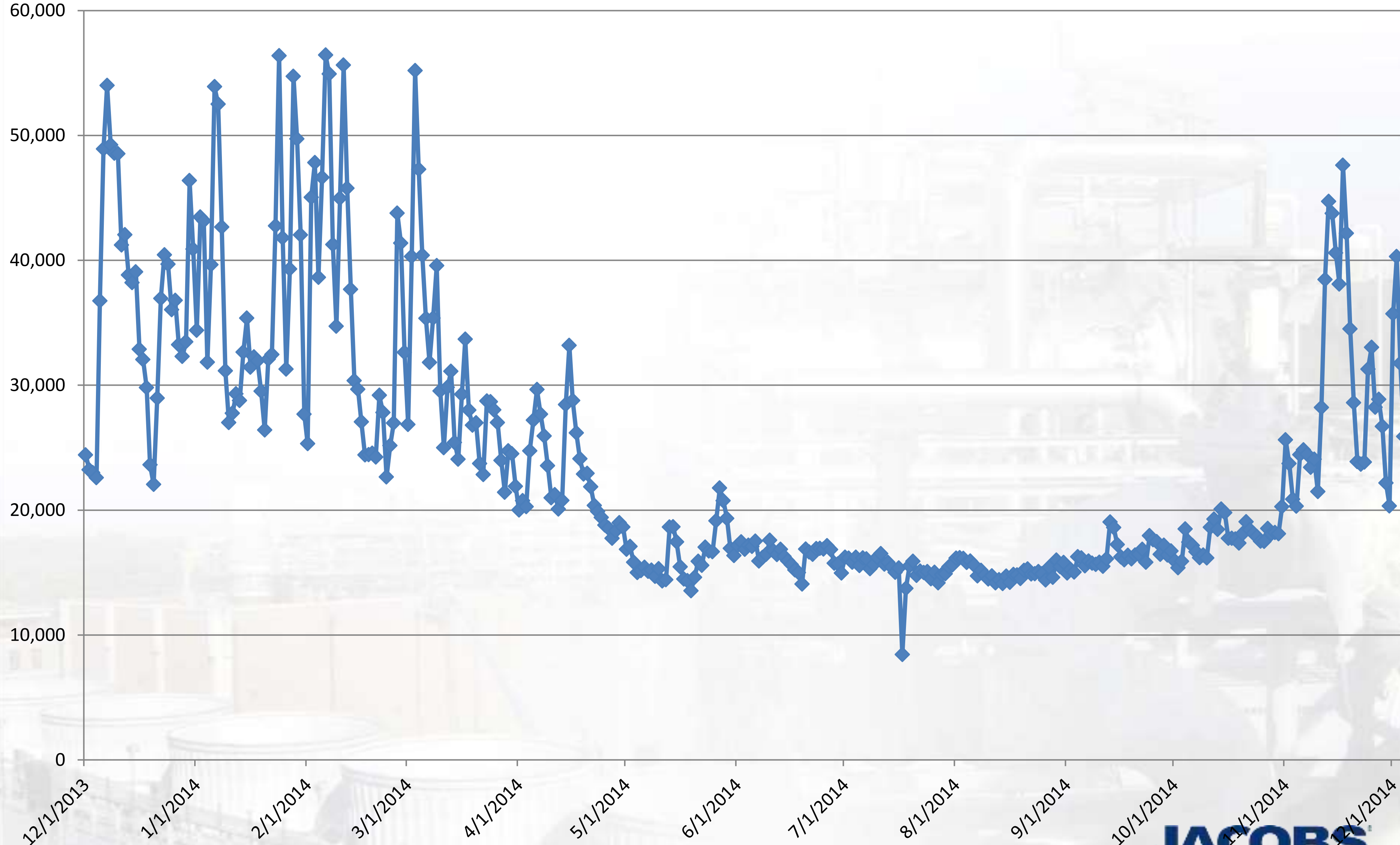
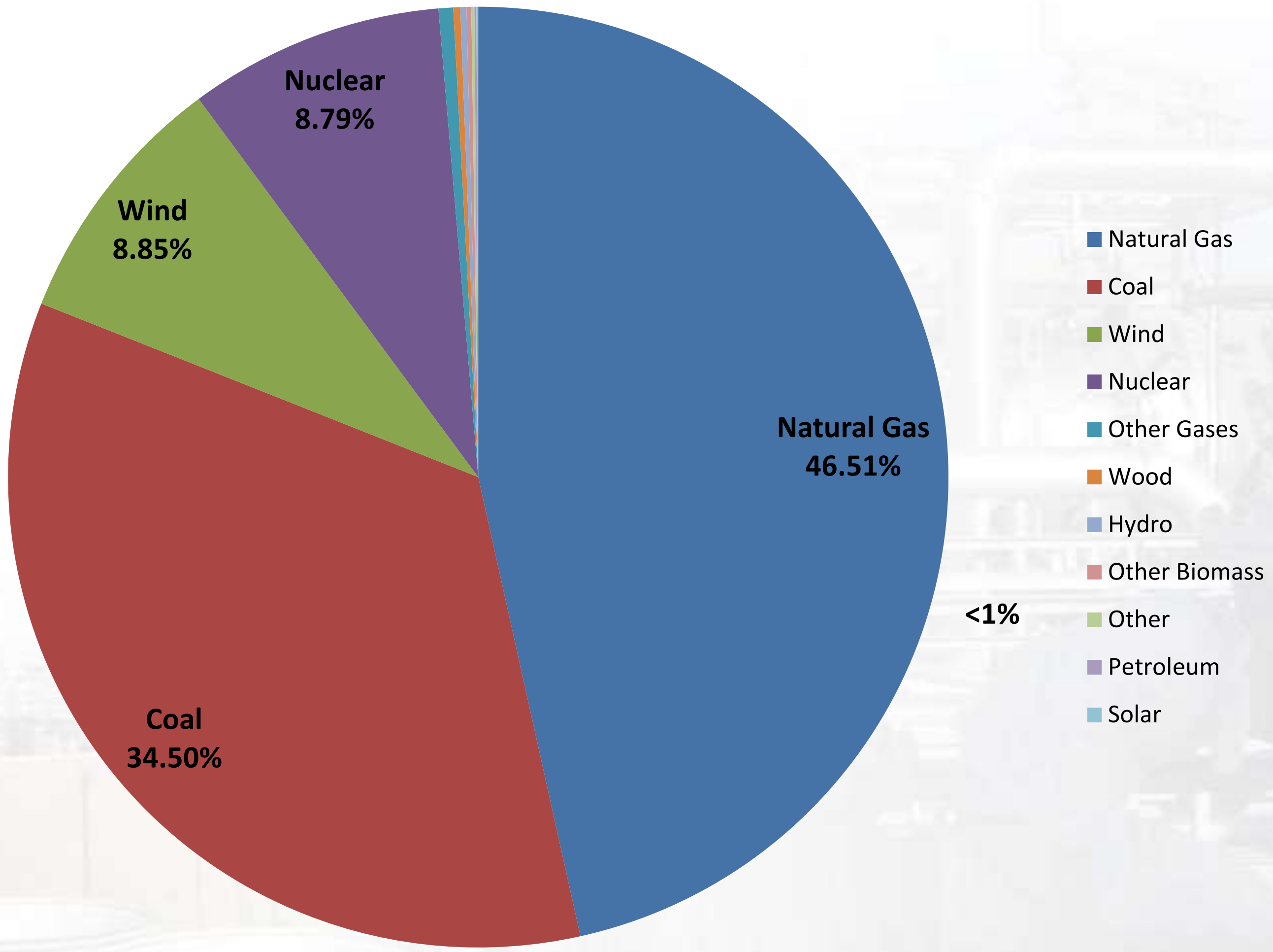
UT Campus Steam Daily Delivery (Therms)



Texas Electric Generation Mix



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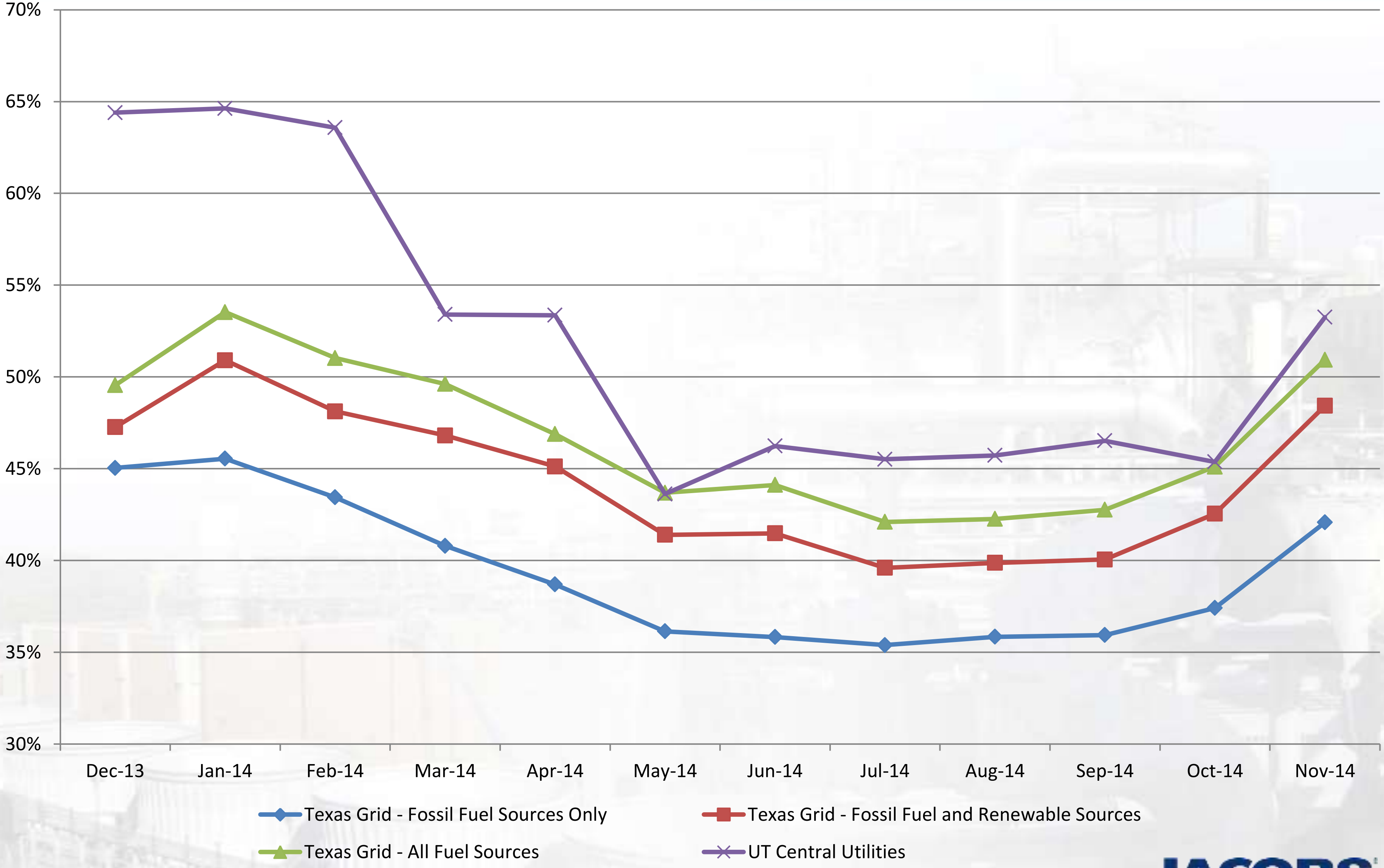
Energy Efficiency Comparison



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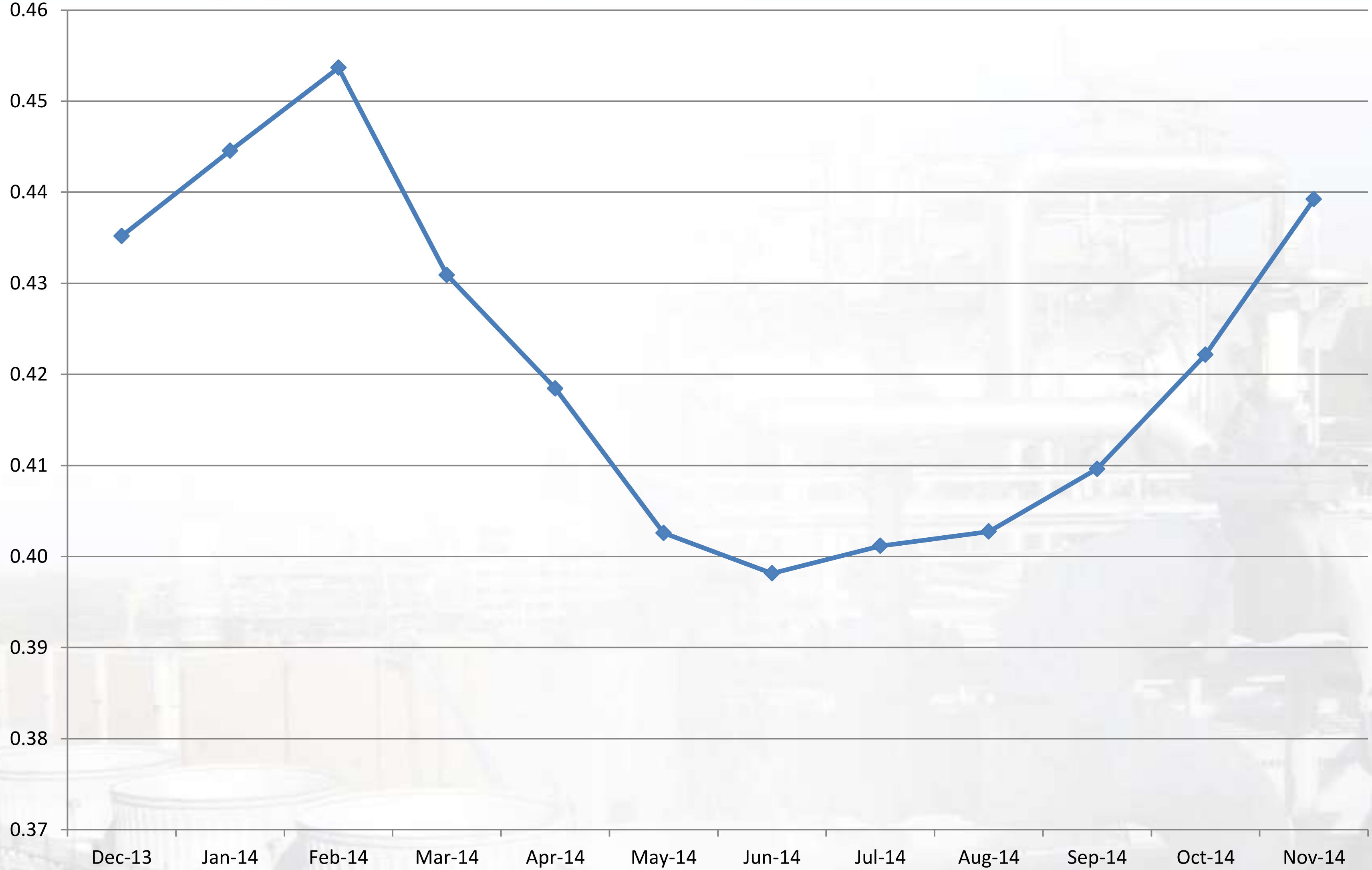
Exergetic Temperature Factor



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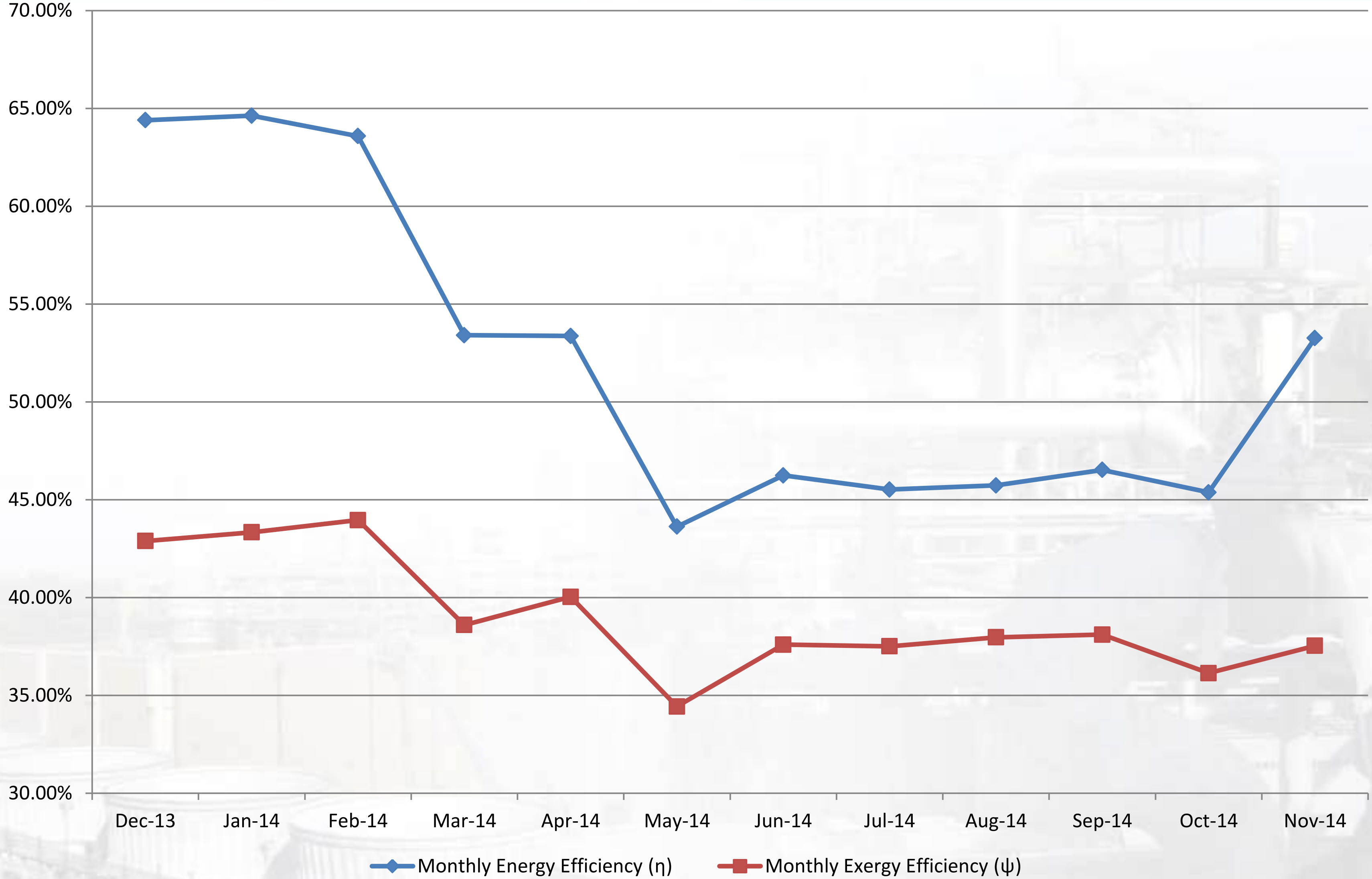
UT Austin – Energy and Exergy Comparison



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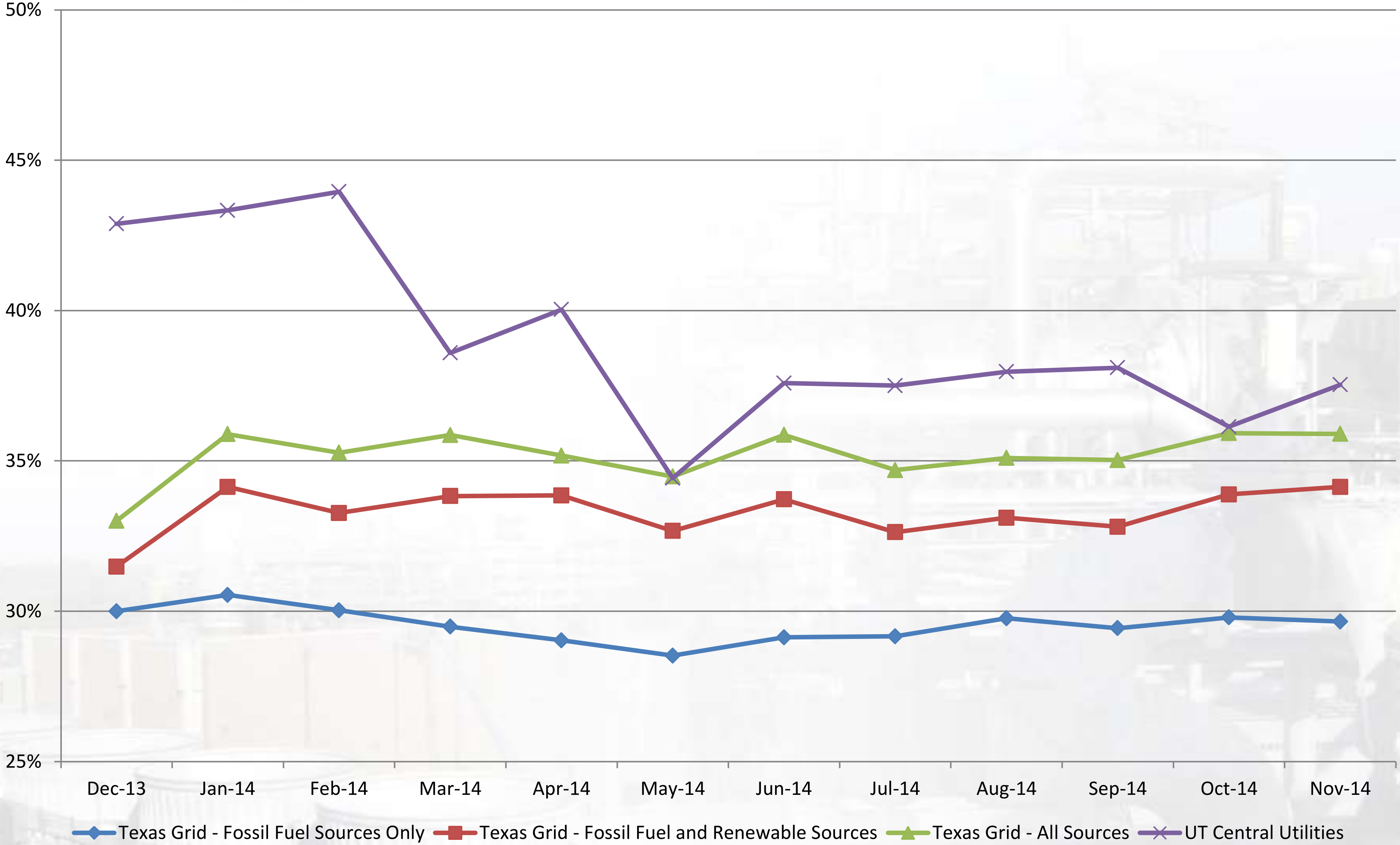
Exergy Efficiency Comparison



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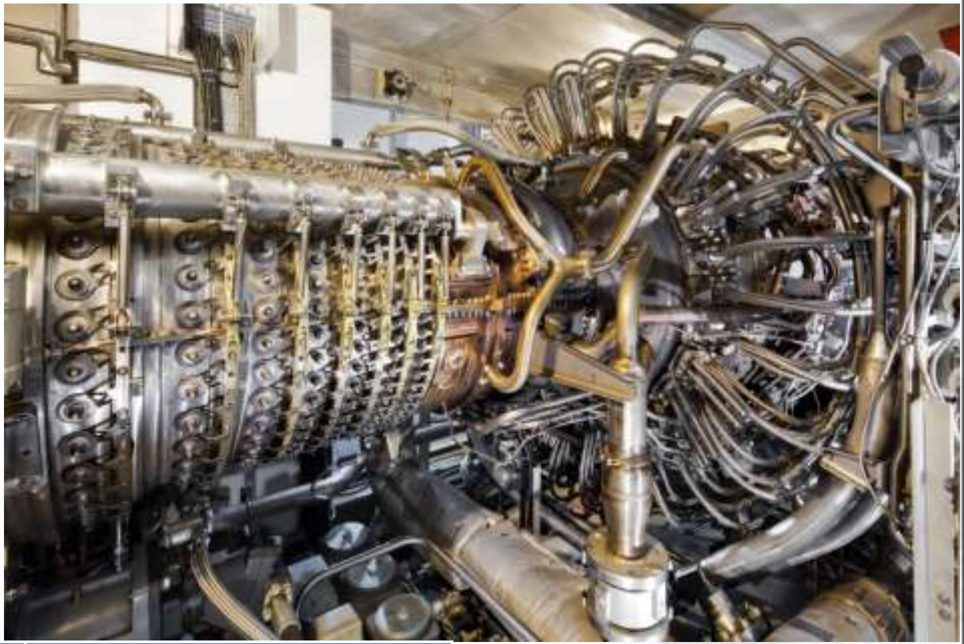
Results Summary

Energy Savings between UT-Austin CHP Plant and the grid in Texas:



Scenario	Energy Savings (Therms/yr)	# of US Homes Offset
Fossil Fuel Only	11,917,616	174,635
Fossil Fuel + Renewables	6,366,957	93,299
All Grid Sources	3,987,158	58,426

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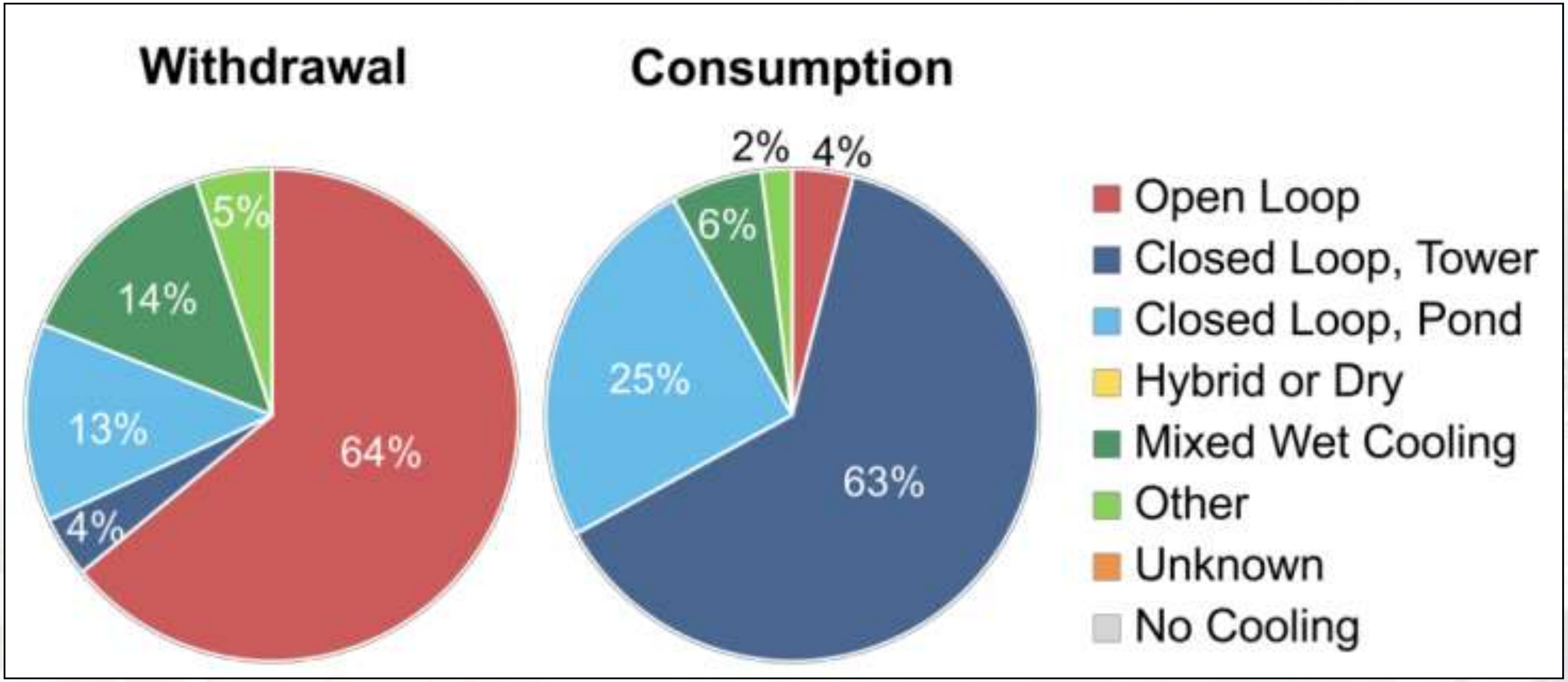
Water Withdrawals Vs. Consumption



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Water Consumption on the Texas Electric Grid

Energy Type	% Electric Generation	Water Consumption Rate (Gal/MWh)
Coal	42.6%	461
Conventional Hydro	0.3%	4,491
Natural Gas	35.0%	335
Nuclear	10.9%	463
Other Biomass	0.2%	35
Petroleum	<0.1%	368
Solar	0.1%	26
Wind	10.9%	0
Woody Biomass	0.1%	35
Total	**100%**	**376**

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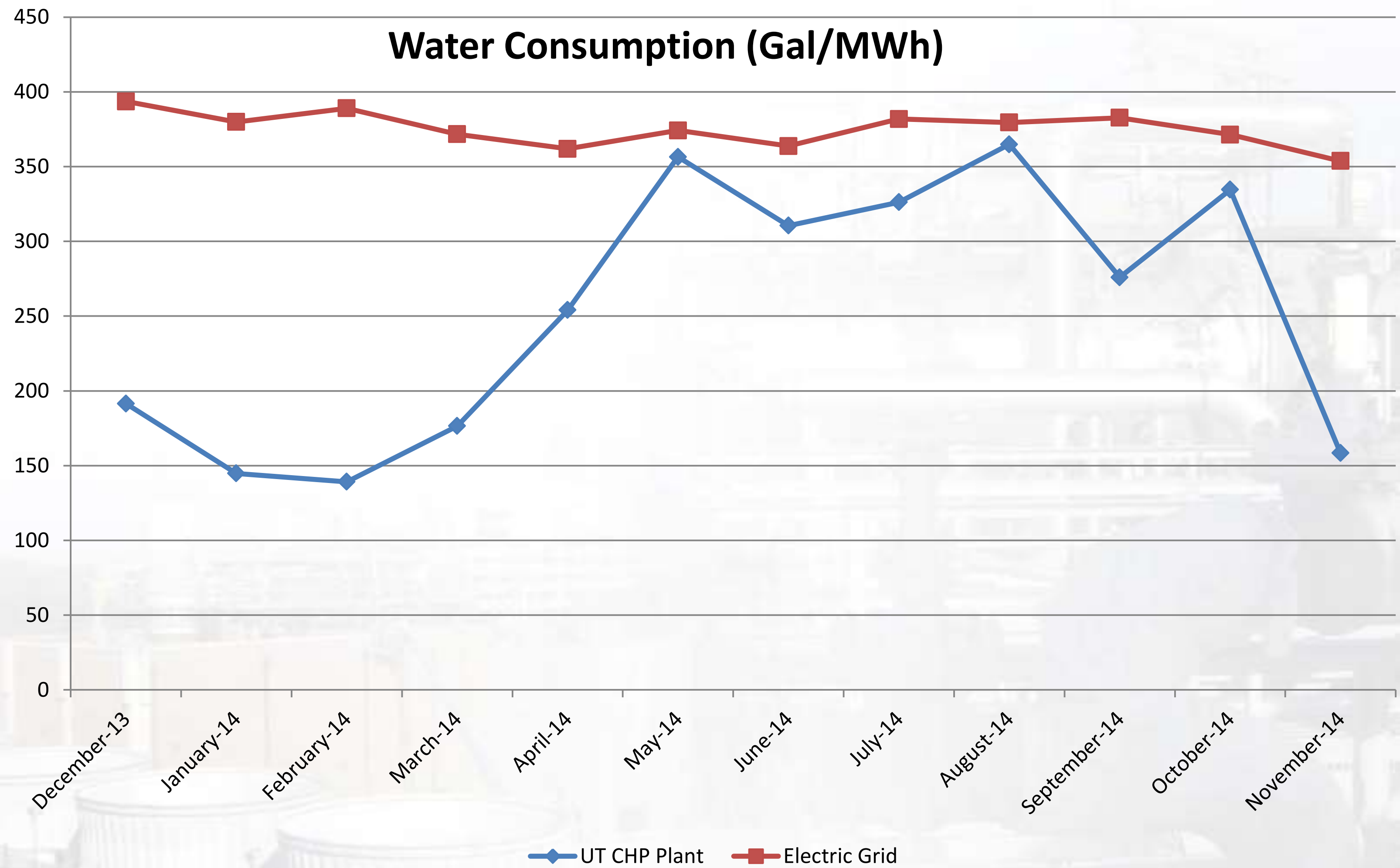
Water Consumption Results Comparison



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Water Consumption Results Comparison

UT CHP Water Consumption (Gal)	TX Grid Water Consumption (Gal)	Water Savings from CHP (Gal)
87,773,802	133,433,312,992	37,164,285

This water savings offsets the usage of 354 family homes

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CHP Conclusions for Exergy

- ✓ Makes greater use of energy quality when compared to purchased utilities
- ✓ Can be used to analyze equipment components as well as whole system
- ✓ CHP involves making better use of quality energy for end uses
- ✓ Both CHP and exergy analysis are useful sustainable development tools

CHP Conclusions for Water Use

- ✓ Most CHP systems will have better water use efficiency when compared to grid electrical generation
- ✓ The key to boosting CHP water efficiency is maximizing on-site heat utilization
- ✓ Heat lead CHP systems are expected to optimize performance on water use

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