NATIONAL ENERGY TECHNOLOGY LABORATORY

Improving the Efficiency of Coal-Fired Power Plants for Near Term Greenhouse Gas Emissions Reductions

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EXECUTIVE SUMMARY

In 2008, the U.S. coal-fired power plant (CFPP) fleet had a generation-weighted average efficiency of 32.5% while the top ten percent of the fleet had an efficiency of 37.6%, five percentage points higher. The generating units in the top ten percent are diverse (they are not all new, large, super critical plants), indicating an opportunity for fleet-wide efficiency improvement. The National Energy Technology Laboratory (NETL) segmented the fleet into 13 groups based on characteristics that limit efficiency, and calculated the best-in-class efficiency within each group. Based on each group achieving an average efficiency equal to its 90th percentile, the overall CFPP fleet average efficiency would be 35.2%. NETL sets forth a vision of 36% based on retirements of low efficiency units, and improvements within the best-in-class. Under a scenario where generation from coal is constant at the 2008 level, increasing the average efficiency from 32.5% to 36% reduces U.S. GHG by 175 MMmt/year[i] or 2.5% of total U.S. GHG emissions in 2008.

DECILE ANALYSIS

NETL examined coal generating unit efficiency data from the Energy Velocity (EV) database[1,ii] for the years 1998 through 2008. Figure 1 shows the performance of the CFPP fleet in 2008 ranked by efficiency and broken into ten deciles of equal capacity. The fleet generation-weighted average efficiency is 32.5%, while the top performing decile is over five percentage points higher, at 37.6%.

Figure 2 shows a comparison of the characteristics of the top decile to the rest of the fleet (deciles 1-9). While on average the top decile consisted of units with larger capacities, higher steam pressures, higher load factors, and a higher percentage burning bituminous coal, there was significant overlap with the rest of the fleet. For example, the average steam pressure at the turbine of the top decile is around 3000 psig, but there are ten units within the top decile with steam pressures in the 1800 psig to 2000 psig range. Also, the net nameplate capacity of the units in top decile, while larger on average, ranged from 114 MW to 1426 MW, indicating that even small plants can achieve higher than average efficiencies.

Figure 2 shows that the average age of the units in the top decile is roughly the same as the rest of the fleet, 40 years vs. 42 years, and both groupings contain units that are over 50 years old. Since coal generating units with SO_2 controls are expected to have lower efficiencies due to auxiliary load requirements, it is noteworthy that both the top decile and the rest of the fleet have almost the same percentage of units with sulfur controls.

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[1] EV stores a collection of public data on power generating units that is primarily obtained from the Energy Information Administration (EIA) and the Environmental Protection Agency (EPA). This analysis uses the average annual net heat rate to calculate efficiency. Units with anomalous data, capacity factors under 10%, using less than 97% coal, and gasification plants, were removed from the dataset. The units that were removed from the dataset represented 3% of the total generation from all coal units. The resulting dataset contained 892 units.

Figure 1. 2008 Generation Weighted CFPP Efficiency by Decile

Decile	Number of Units	Capacity (GW)	Capacity Factor	2008 Total Generation (BkWh)	2008 Generation - Weighted Efficiency (HHV)
1	194	30.5	62%	165	27.6%
2	102	30.3	67%	179	29.9%
3	88	30.7	65%	176	30.8%
4	86	30.6	69%	185	31.6%
5	75	30.7	70%	189	32.2%
6	83	30.8	66%	178	32.9%
7	71	31.0	68%	186	33.8%
8	79	30.6	68%	183	34.7%
9	61	30.8	67%	181	35.7%
10	53	30.7	74%	201	37.6%
Overall	892	307	69%	1823	32.5%*

*Using data from EIA form 923[iii] for 2008 produces a generation weighted efficiency of 33.0%. The EV dataset is based on the EPA Continuous Emissions Monitoring System and results in lower efficiencies on average for each plant when compared to the EIA.

Figure 2. Characteristics of Top Decile and Rest of Fleet

	2008 Top Decile		2008 Rest of Fleet	
	Average	Range	Average	Range
Generation Weighted Efficiency	**37.6%**	36.3% - 43.7%	32.0%	19.5% - 36.2%
Capacity (MW)	580	114 - 1426	329	27 - 1300
% of units that are Super Critical	55%	-	10%	-
Steam Pressure (psig)	2935	1800 - 3500	2088	600 - 5000
Age (yrs)	40	1 - 54	42	1 - 69
Load Factor*	83%	67% - 99%	75%	24% - 105%
% of units burning Bituminous Coal	66%	-	56%	-
% of units with SO2 Controls	36%	-	35%	-

* Load factor = annual net generation / (net nameplate capacity * operating hours during the year). Operating hours is defined as the number of hours the unit is online and does not include the time the unit is shut down for maintenance or other reasons. Load factors may be artificially high for the top decile relative to the rest of the fleet because nameplate capacity corresponds to design efficiency not actual efficiency.

SETTING A CFPP FLEET EFFICIENCY TARGET

Figure 3 shows 860[2] coal generating units segmented by steam pressure[3,iv], coal type, and nameplate capacity[4]. If each segment is able to refurbish underperforming units to achieve a generation-weighted efficiency equal to that of the 90th percentile unit, then the generation-weighted CFPP fleet efficiency can be improved from 32.5% to 35.2%[5]. This efficiency target takes into account the differences between the top decile and the rest of the fleet.

Figure 3. Segmentation Analysis of the CFPP Fleet

Segment Criteria			Sub-population Characteristics			Efficiency	
Unit Type	Coal Type	Size (MW)	Capacity (GW)	# Units	Generation (BkWh)	Average	90th Percentile
Low Pressure Sub Critical (600 - 1600 psig)	Bit.	0-200	10.3	127	44	29.6%	33.0%
	Subbit.		4.6	59	26	27.5%	29.8%
	Other		0.6	7	2	27.4%	30.5%
High Pressure Sub Critical (1800 - 2600 psig)	Bit.	0-200	21.6	134	112	32.1%	34.8%
		200-500	33.4	103	189	32.8%	35.6%
		500+	29.7	48	176	32.7%	35.0%
	Subbit.	0-200	7.2	47	42	30.7%	32.5%
		200-500	31.2	97	191	31.4%	35.6%
		500+	64.4	98	401	31.6%	33.8%
	Other		11.1	28	72	31.7%	35.1%
Super Critical (3334+ psig)	Bit.		60.7	79	372	35.1%	37.3%
	Subbit.		15.0	20	90	35.2%	37.2%
	Other		8.1	13	55	31.8%	34.9%
Whole fleet			**298**	**860**	**1772**	**32.5%**	**37.6%**

[2] An additional 32 units were omitted from the segmentation analysis due to missing or anomalous steam pressure data.

[3] Steam pressure data was obtained from the 2008 Platts UDI database and combined with the dataset obtained from EV.

[4] In some cases units were not broken into capacity categories because the populations were small and mostly homogeneous. Although load factor for the top decile was an average of 83% compared to 75% for the rest of the fleet, it was deemed to be changeable through better dispatch.

[5] To calculate fleet efficiency target: 3412 / (Σ (3412/90th percentile eff. * generation) / 1772)

NETL is setting forth a vision for CFPP fleet-wide average efficiency of 36% based on (1) retirements of lower efficiency units combined with increased generation from higher efficiency refurbished units and (2) advanced refurbishments and improved operation and maintenance practices to increase average efficiency of some segments beyond the best-in-class.

The low pressure subcritical units and the 0-200 MW subbituminous units in Figure 3 had 90th percentile efficiencies that were significantly lower than the rest of the fleet. Retiring these units and relying on increased generation from the more efficient segments to maintain constant coal generation yields a fleet efficiency target of 35.6%.

Aggressive refurbishments could allow some segments to improve beyond the 90th percentile level. For example, the high pressure subcritical, subbituminous, 500 MW segment had a 90th percentile efficiency of 33.8% while the same segment in the 200-500 MW size had a 90th percentile of 35.6%. Also, all of the high pressure subcritical and supercritical, bituminous coal segments achieved average efficiencies below the NETL bituminous baseline study[v] which sets an efficiency of 36.8% for a new subcritical CFPP and 39.1% for a new supercritical CFPP using existing technology.

Improving fleet efficiency beyond the 90th percentile level is also supported by analysis of historical efficiency data (1998-2008). NETL examined a scenario where each unit achieved its best efficiency over the past ten years in the same year. The units were ranked by best year efficiency and grouped into new deciles of equal capacity using the same method to produce Figure 1. Figure 4 reports the generation-weighted average efficiency for the original 2008 decile analysis and the best year scenario. Note that deciles nine and ten (60 GW of capacity) achieve generation-weighted average efficiencies of 37.7% and 39.7% in their best years, which is higher than any individual 90th percentile segment. It is possible that units could routinely achieve the efficiency of their best year through better operation and maintenance practices[6]. Assuming that the CFPP fleet employs a combination of aggressive refurbishment and improved operation maintenance, 36% is a reasonable average efficiency target.

[6] NETL considered that units may achieve their best year efficiency when they are running at maximum load. To account for this we examined the correlation between best year efficiency and the year with the highest load factor and found no correlation. We also examined the years in which best year efficiency was achieved to see if there was any one year in which a preponderance of units achieved their best or worst year, and found that the years were evenly distributed.

Figure 4. Best Year Generation-Weighted Efficiency Analysis

Decile	2008 Efficiency	1998 - 2008 Best Year Efficiency
1	27.6%	29.9%
2	29.9%	31.7%
3	30.8%	32.5%
4	31.6%	33.3%
5	32.2%	34.1%
6	32.9%	35.0%
7	33.8%	35.8%
8	34.7%	36.9%
9	35.7%	37.7%
10	37.6%	39.7%
Average	**32.5%**	**34.5%**

NEW SOURCE REVIEW

The 36% CFPP fleet efficiency target does not take into account installing sulfur scrubbers at facilities that lack controls. New Source Review (NSR) requires that generating units over 73MW emit SO_2 under 1.4lbs/MWh or reduce emissions to 90-95% of the possible emissions[vi]. The EV dataset showed that 250 GW of the 307 GW CFPP fleet emits SO_2 above the 1.4lbs/MWh level, and that 165 GW lack any type of sulfur controls. If efficiency upgrades were done in conjunction with installing sulfur scrubbers on 165-250 GW of the fleet, the efficiency target would be reduced .5 to 1 percentage points.

SUMMARY

The segmentation analysis serves as the basis for the 36% average CFPP fleet efficiency vision. NETL expects that the fleet achieving efficiencies approaching the best-in-class will require a combination of improved operational and maintenance practices, capital investments in unit refurbishments, and application of advanced technologies.

FUTURE WORK

The analysis of the opportunity to increase CFPP efficiency could be improved by:

- Verification of coal generating unit efficiency data.
- Estimates of the cost of efficiency upgrades.
- Unit-specific data to enable estimation of the design heat rate for each generating unit.
- Case studies of efficiency upgrades at generating units, including ASPEN models, to provide concrete examples of the opportunity to improve efficiency.
- Detailed analyses of scenarios where some of the generating units are retired, some are refurbished and up-rated, and others are fixed with sulfur, NOx, and mercury controls.
- Analyses of how more efficient coal plants will dispatch, what other generating sources will be displaced, and the overall effect on GHG emissions.

REFERENCES

[i] Department of Energy, Energy Information Administration, Annual Energy Outlook 2009 NEMS Run Results. http://www.eia.doe.gov/oiaf/servicerpt/stimulus/aeostim.html.

[ii] NETL analysis of Ventyx's Velocity Suite 2008 net heat rate data for coal-fired units. Units with less than 10% capacity factor and using less than 97% coal were excluded from analysis. Units with missing or anomalous data were also excluded. The excluded units account for 3% of the electricity generated from coal in 2008. http://www.ventyx.com/velocity/vs-overview.asp

[iii] Department of Energy, Energy Information Administration, Utility, Non-Utility, and Combined Heat & Power Plant Database. http://www.eia.doe.gov/cneaf/electricity/page/data.html

[iv] 2008 Platts UDI World Electric Power Plant Database.

[v] Cost and Performance Baseline for Fossil Energy Plants Desk Reference (May 2007) http://www.netl.doe.gov/energy-analyses/pubs/deskreference/index.html

[vi] 40 CFR Part 60 – Standards of Performance for Electric Utility Steam Generating Units for Which Construction Commenced after September 18, 1978, Final Rule Amendments, February 27, 2006