NATIONAL ENERGY TECHNOLOGY LABORATORY

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

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Overview

- **NETL has evaluated the opportunity to improve the efficiency of coal-fired power plants as a way to reduce GHG emissions**

- **Increasing coal-fired power plant efficiency makes sense**
  - US has enormous coal reserves
  - It is expensive and takes a long time to build new power plants
  - Side benefits of improved air quality and reduced water usage
  - Momentum toward carbon capture and storage

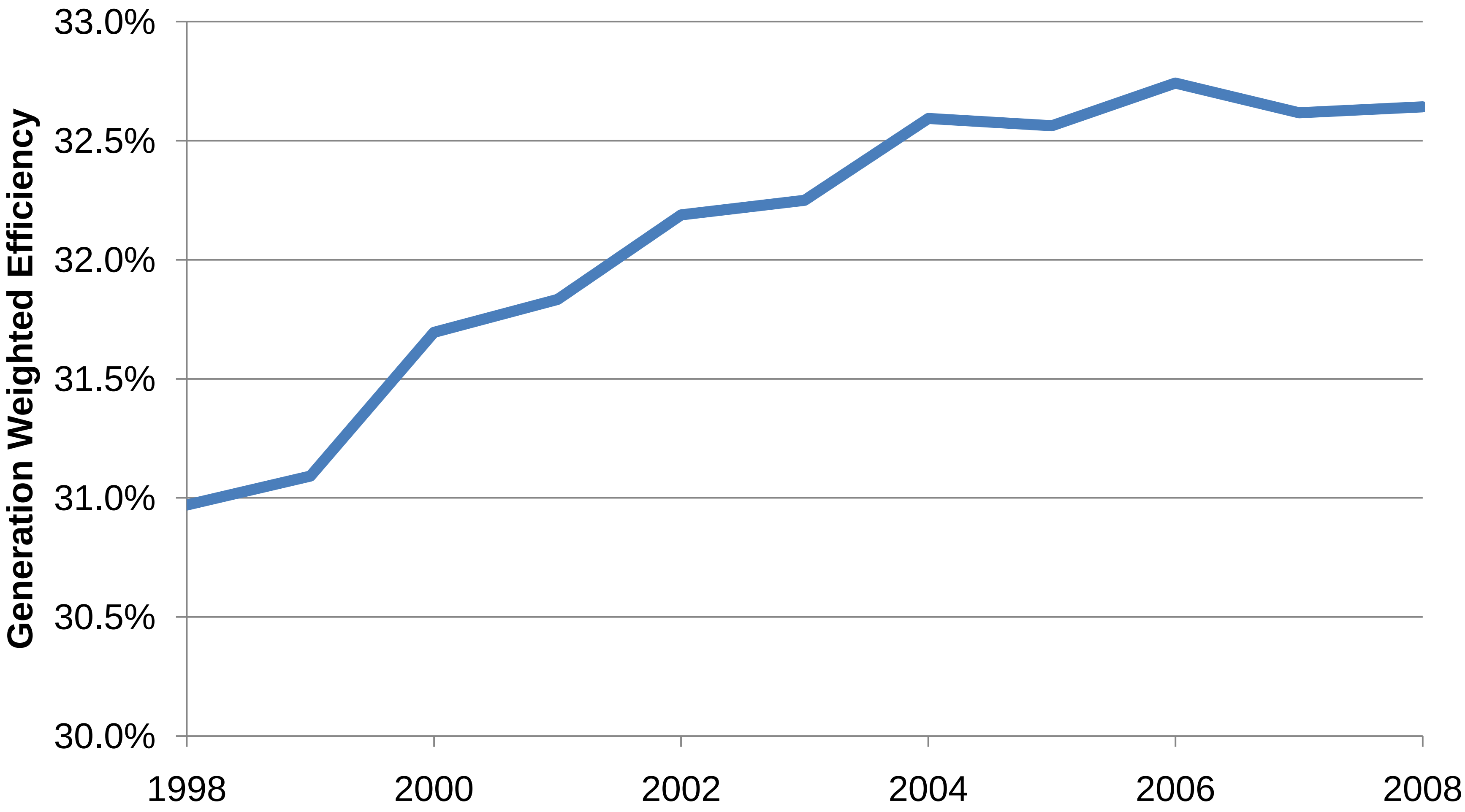
- **Analysis results**
  - Average efficiency of coal generating units can be improved from 2-5 percentage points, from the current average efficiency of 32.4% to 34.4% - 37.2%
  - Under a constant generation scenario from coal, GHG emissions reduced by 100-240 MMmtCO_2/yr (1.5%-3.3% of total U.S. emissions)

Top-performing Coal-fired Power Plants, 5pp more efficient than average

Decile	Number of Units	Capacity (GW)	Capacity Factor	2008 Total Generation (BkWh)	2008 Capacity -Weighted Efficiency (HHV)
1	194	30.5	62%	165	27.5%
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	32.4%

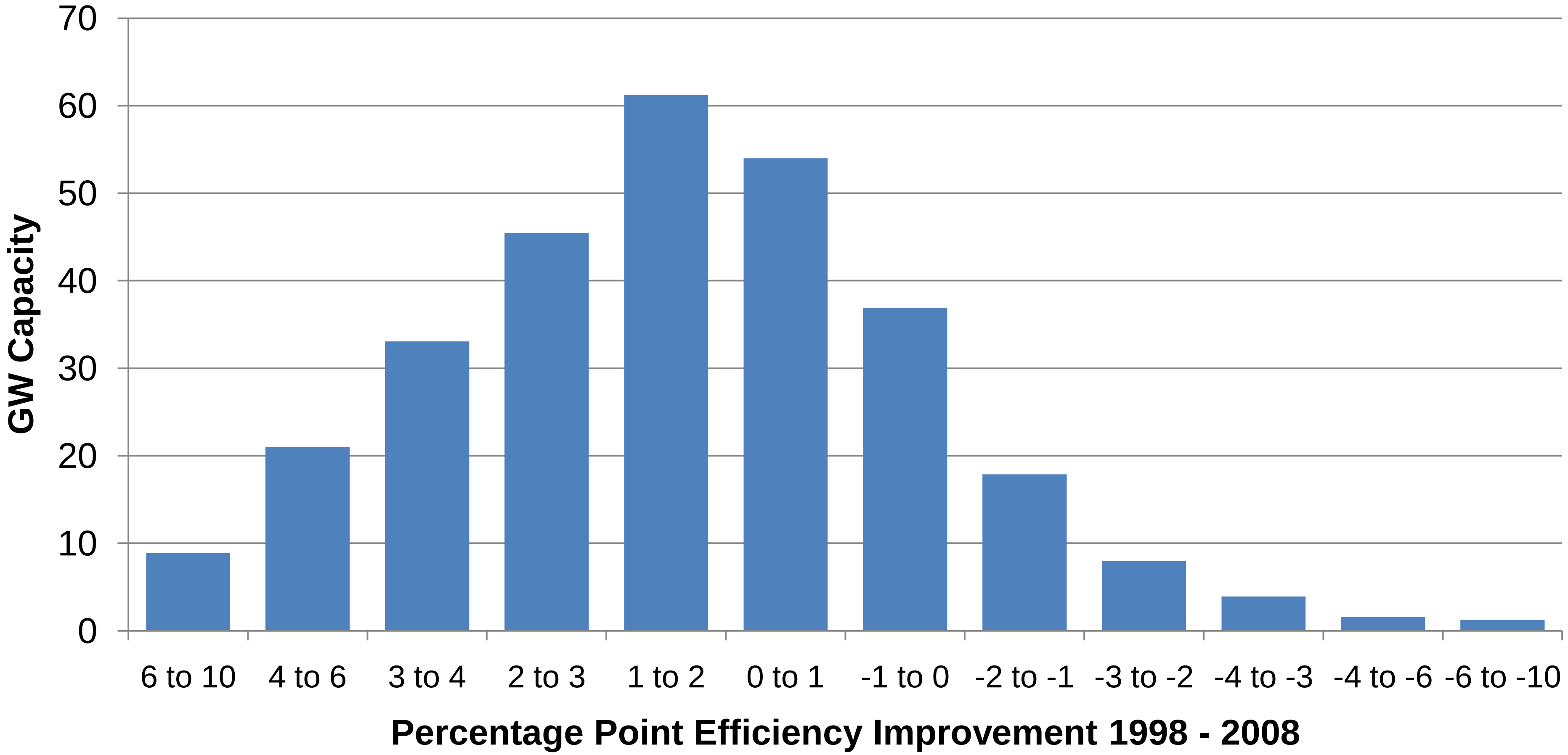
Data Source: Ventyx's Energy Velocity 2008 average net heat rate data for coal-fired units using 97% or more coal. Heat rates were weighted by capacity and units with missing or anomalous data were omitted. Omitted units accounted for 3% of generation

Efficiency Increased 1.7pp Since 1998



Data Source: Ventyx's Energy Velocity 1998-2008 average net heat rate data for coal-fired units using 97% or more coal. Heat rates were weighted by capacity and units with missing or anomalous data were omitted. Omitted units accounted for 3% of generation

10% of the Coal Fired Power Plant Fleet Improved Efficiency by more than 4pp



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Big Improvements, 6-10pp tend to be larger, newer plants. Other improvements, 1-6pp were achieved by all types.

PP Improvement (2008 - 1998)	Capacity (GW)	1998 Efficiency	2008 Efficiency	Ave. Capacity (GW)	Average Age	% Bit. Coal	% w/ SO2 Controls	PP Change in LF	% NSR
6 to 10	9	28.5%	35.7%	554	36	64%	50%	1.3	19%
4 to 6	21	28.3%	33.5%	351	43	58%	33%	2.3	36%
3 to 4	33	29.3%	32.6%	394	42	54%	42%	2.8	34%
2 to 3	46	29.3%	32.0%	367	43	55%	33%	2.8	31%
1 to 2	61	30.6%	32.3%	380	42	56%	30%	2.8	17%
0 to 1	54	30.8%	31.5%	358	42	59%	36%	1.0	19%
-1 to 0	37	31.3%	30.6%	305	43	65%	31%	-0.3	21%
-2 to -1	18	30.8%	29.5%	325	41	51%	44%	1.7	18%
-3 to -2	8	31.0%	29.3%	294	41	52%	44%	2.0	29%
-4 to -3	4	32.6%	28.8%	219	43	29%	17%	1.8	36%
-4 to -6	2	34.0%	28.1%	198	44	57%	13%	1.5	20%
-6 to -10	1	33.3%	24.2%	209	51	93%	16%	11.5	9%
Whole Fleet	***293***	***31.0%****	***32.4%****	***353***	***42***	***57%***	***34%***	***1.7***	***24%***

*Whole Fleet Efficiency is capacity weighted, rest of chart is unweighted average unit efficiency.

Source: Ventyx Energy Velocity Suite. Includes plants over 25MW that burn 97% or more of coal. Plants with missing or anomalous data omitted.

Analysis Methodology 1: Best Year Efficiency

Decile	2008 Efficiency	Max Efficiency
1	27.5%	29.8%
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%	36.8%
9	35.7%	37.7%
10	37.6%	39.7%
Average	**32.4%**	**34.4%**

- **Assuming each unit can meet the highest efficiency it achieved during the 1998-2008 time period yields overall fleet efficiency that is 2pp higher than 2008.**
- **Increase may be due to better operation or maintenance cycle.**

Data Source: Ventyx's Energy Velocity 1998-2008 average net heat rate data for coal-fired units using 97% or more coal. Heat rates were weighted by capacity and units with missing or anomalous data were omitted. Omitted units accounted for 3% of generation

Analysis Methodology 2: Benchmark Regression to Predict Fleet Efficiency

Adopted benchmark regression method developed by Goudarzi and Roberts in 1998

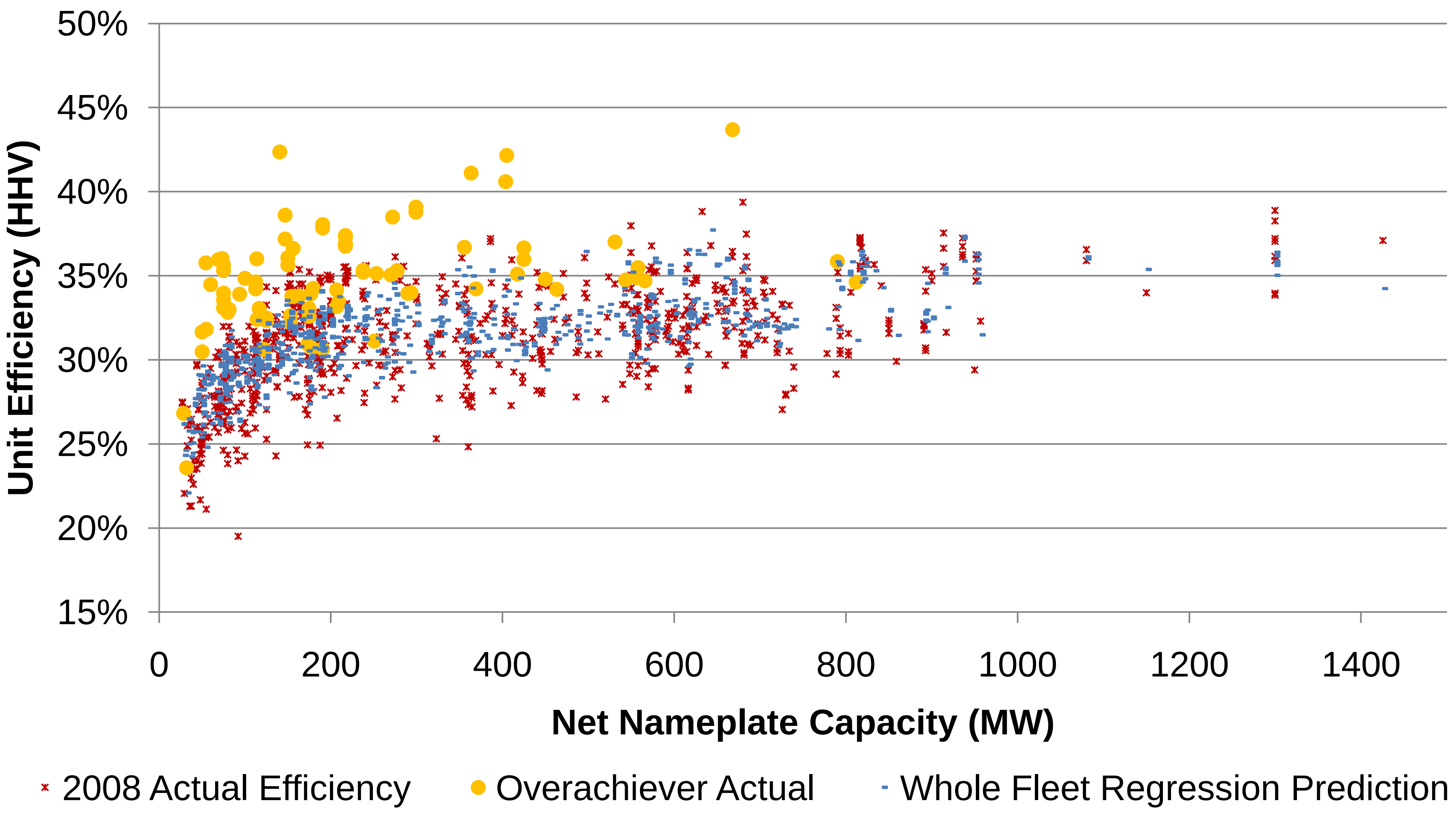
1. Perform an initial regression with power plant efficiency as the dependent variable (R^2 of 0.49)

2. Identify and rank "overachievers" through a benchmarking process, i.e. the generating units that beat the regression predicted efficiency.

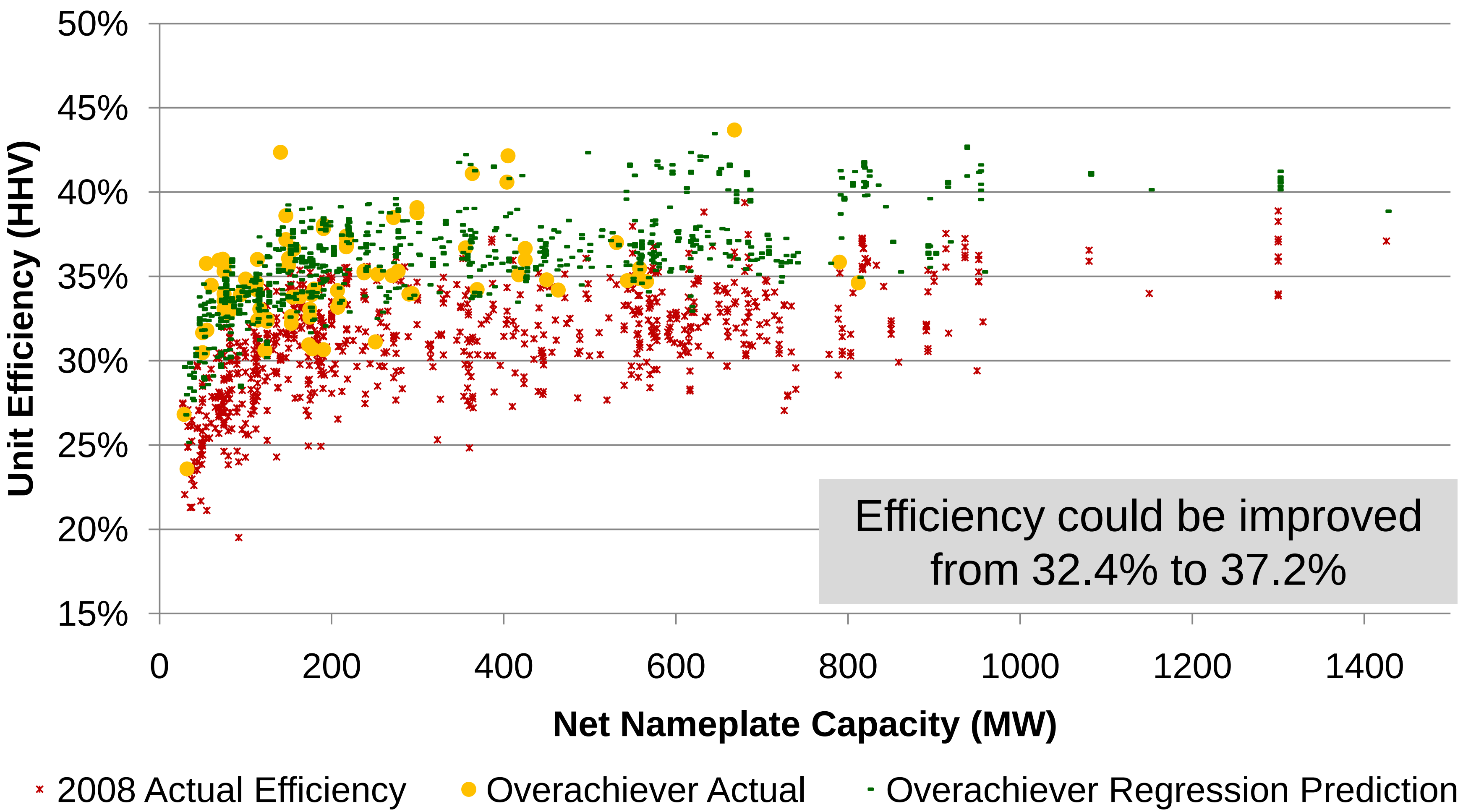
3. Perform a 2nd regression on the top 10% identified though benchmarking process, the "best overachievers", with plant efficiency as the dependent variable (R^2 of 0.74)

4. Predict efficiency for fleet using factors from the 2nd regression.
   - Represents what each generating unit could accomplish if it adopted practices of the overachievers.

Benchmark Regression Example



Benchmark Regression Example

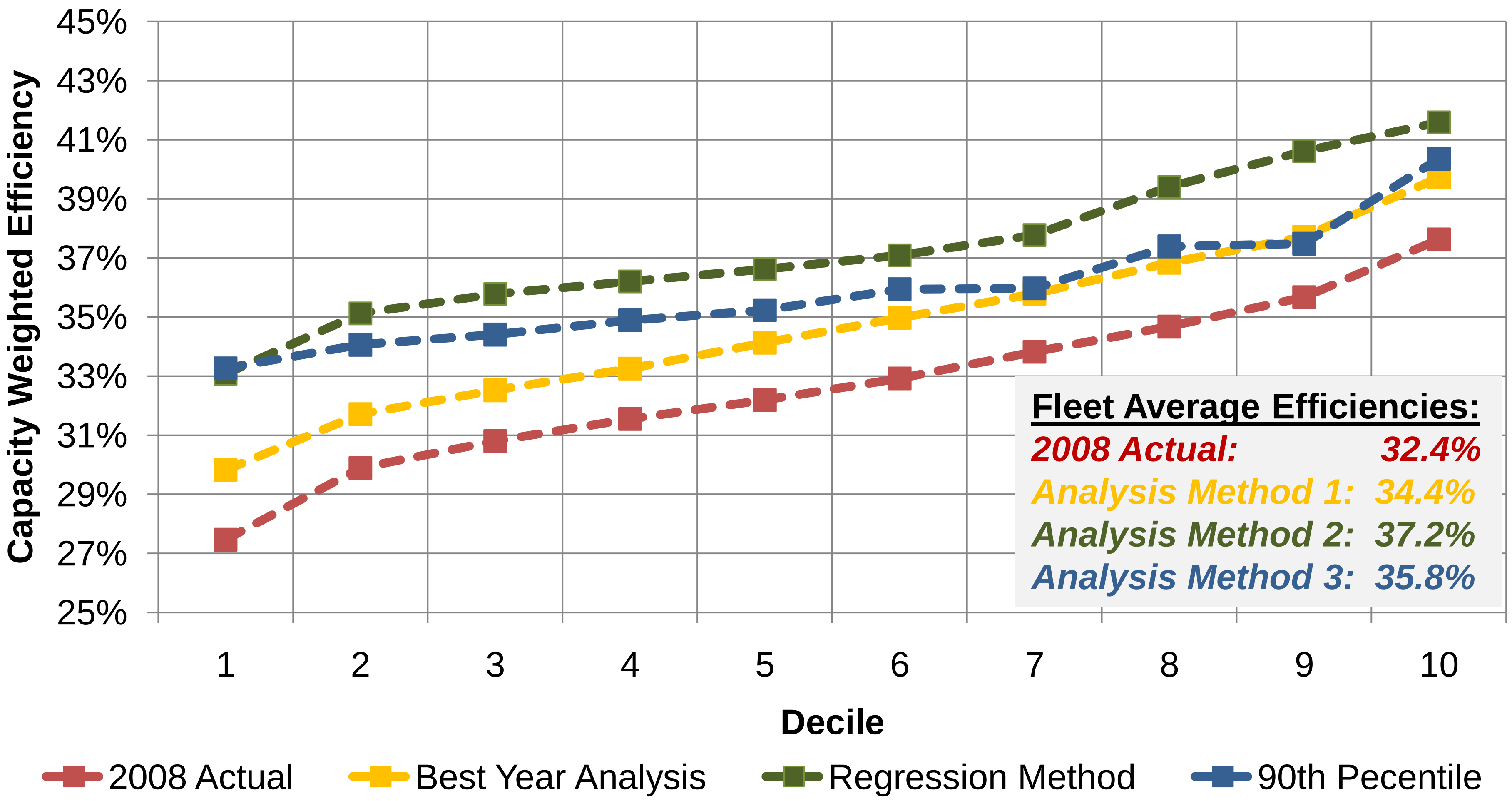


Analysis Methodology 3: Segmentation and Best in Class

Plant Type	Fuel Type	Size (MW)	Capacity (GW)	# Units	Average Efficiency	90th Percentile
Sub Critical	Bituminous	0-200	32.3	264	31.0%	34.5%
		200-500	36.6	113	32.8%	35.8%
		500+	29.6	48	32.7%	35.0%
	Subbituminous	0-200	12.3	111	29.2%	32.0%
		200-500	31.7	99	31.4%	35.6%
		500+	65.0	99	31.6%	34.1%
	Other Coal	NA	14.2	43	31.4%	34.8%
Super Critical	Bituminous	NA	61.4	80	34.8%	37.3%
	Subbituminous	NA	15.5	22	35.2%	38.0%
	Other Coal	NA	8.1	13	32.0%	34.8%

Setting each class to the average efficiency of the 90^{th} percentile produces a nameplate capacity weighted fleet efficiency of 35.8% which is 1.4pp lower than the regression analysis.

Efficiency Improvement Analysis Results by Decile



Summary

- **A 2-5 pp efficiency improvement target for the fleet is supported by:**
  - 30GW of the fleet improving efficiency 4pp or more since 1998,
  - Best year efficiency analysis: 2.0pp improvement
  - Regression Analysis: 4.8pp improvement
  - 90th Percentile Analysis: 3.4pp improvement
- **Improving efficiency from 32.4% to 34.4% - 37.2% reduces GHG emissions:**
  - 4.5% - 10.2% in the power sector
  - 100 – 240 MMmtCO_2/yr (1.5% - 3.3%) for the entire U.S.

Future Work

- **Collect cost data on plant refurbishment projects**
- **Collect data to enable us to estimate the design heat rate for each plant**
- **Case studies using ASPEN to model individual technology efficiency impacts**

Acknowledgements and for more information….

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