**Issue Paper: Building Block #1**

**Heat Rate Improvements for Coal-Fired Power Plants**

## What is Efficiency and Heat Rate?

EPA's Clean Power Plan proposes to use a number of different "building blocks" to gauge the adequacy of state plans to reduce $CO_2$ emissions from the existing fossil-fueled fleet of electric generating units. This paper discusses the first "building block," improvements in the heat rate (or efficiency) of the existing coal-fired generating units.

The First Law of Thermodynamics, also known as the Conservation of Energy states that for any system, the energy out is equal to the energy put in. The energy that is produced can come in various forms (heat, sound, light, etc.). What is most important is the amount of "useful energy" produced from the process to meet a given objective. The amount of useful energy output from a given energy input determines a system's efficiency. Take, for example an automobile engine. The First Law states that 100% of the energy from the gasoline will be released in the engine when the fuel is burned. However, only about 20% of the energy produced in the vehicle's engine is useful in meeting the objective (moving the car from point A to point B). If so, then that engine is 20% efficient. The remaining 80% is lost through heat loss and friction in other parts of the engine and drivetrain system (e.g. pistons, valves, transmission, lubrication systems, fans, belts, etc.). There is no piece of equipment or system that is 100% efficient.

In the case of a fossil fuel-fired power plant, energy enters the plant in the form of fuel (e.g. coal, natural gas, etc.). The fuel is burned to release energy in the form of heat, which is then converted to mechanical energy by various means to turn a generator to produce electricity. In a coal-fired steam generating power plant, the energy from burning coal is used to heat water to steam. That steam then powers a turbine, which turns a generator to produce electricity. As with the car example above, not all of the energy produced by the combustion of coal is used to actually produce electricity. Much of that energy is lost in the form of waste heat, friction, sound, and other means by various parts of the process. All of these losses impact the overall efficiency of the plant. Technological innovations along with the ability to more closely monitor and reliably control processes have effectively improved the efficiency of fossil fuel fired power plants.

A measure of efficiency in a power plant is heat rate, which is how much fuel energy is used to make electricity. Lower heat rate values mean that the same amount of electricity is produced with less fuel, which means the system is more efficient. Power plant operators are motivated to optimize and lower heat rate (improve efficiency) because it lowers the cost of producing electricity. Technically, heat rate is the energy required (expressed in British Thermal Units or Btu) to generate 1 kilowatt of electricity, for 1 hour (also known as a kilowatt-hour or kWh). Assuming zero energy losses, it would take 3,412 Btu to produce 1 kWh. A theoretical power plant that is 100% efficient would then have a heat rate of 3,412 Btu/kWh. As discussed in more detail below, the efficiency of most existing fossil power plants is in the 30 to 40% range.

**How is Heat Rate Measured?**

Heat rate is periodically calculated for coal-fired power plants based on measurements of coal consumption, laboratory analyses of coal samples to determine an average Btu content in the coal consumed, and the total kilowatt-hours generated during the time period. The calculation follows below:

$$\text{Heat Rate (Btu / kwh)} = \frac{\text{lbs coal consumed x heat content of coal (Btu/lb)}}{\text{total kilowatt-hours generated}}$$

Existing monitoring techniques do not provide accurate instantaneous or continuous measurements of heat rate. In particular, the variability of fuel energy content and thermal fluctuations like ramping up/down on load can produce significant swings in instantaneous heat rate. In addition, the current methods used to estimate and report fuel heat input to EPA are not sufficiently precise to consistently detect a heat rate improvement rate of 6% or less.

Power plant heat rates can be expressed as a gross value or a net value. Gross unit heat rate is represented by the total energy input from the fuel divided by the total kilowatt-hours generated by the generator. Net heat rate subtracts out the generated electricity that is used by the plant to run the fuel handling equipment, water treatment systems, emissions control systems, lighting and various other systems and components (collectively termed auxiliary load) that make up the complete power plant. Auxiliary load for a coal-fired plant is typically on the order of 5-10% of the total generator output. Typical practice in the industry is to report net unit heat rate, so as heat rate is discussed in the remainder of the paper, it is assumed to mean net heat rate. Below is a table from the U.S. Energy Information Administration that shows the 2012 average net unit heat rates for various power generating technologies using various fuels. The actual range of heat rate values within each category varies significantly due to a number of unit-specific design, fuel, and operational differences that are discussed in the sections that follow below.

| | 2012 Average Heat Rate (Btu/kWh) | | | |
|---|---|---|---|---|
| **Technology/Fuel** | **Coal** | **Petroleum** | **Natural Gas** | **Nuclear** |
| **Steam Generator** | 10,107 | 10,359 | 10,385 | 10,479 |
| **Gas Turbine** | -- | 13,622 | 11,499 | -- |
| **Internal Combustion** | -- | 10,416 | 9,991 | -- |
| **Combined Cycle** | -- | 10,195 | 7,615 | -- |

Heat Rate Source: U.S. Energy Information Administration, These average heat rate values above can be expressed as efficiencies in the following manner:

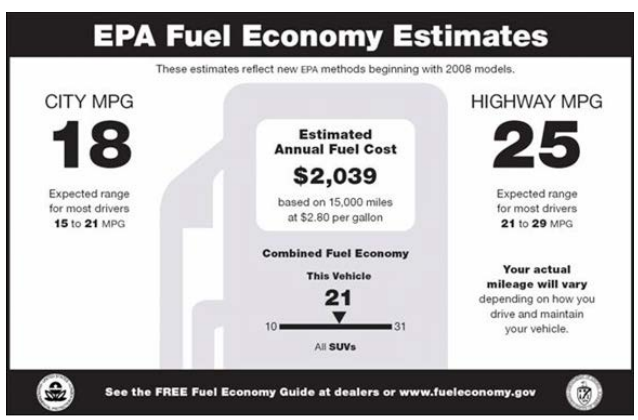
(3,412 Btu/kWh / Average Net Unit Heat Rate) x 100 = % Efficiency

| | 2012 Average Unit Cycle Efficiency (%) | | | |
|---|---|---|---|---|
| Technology/Fuel | Coal | Petroleum | Natural Gas | Nuclear |
| Steam Generator | 34% | 33% | 33% | 33% |
| Gas Turbine | -- | 25% | 30% | -- |
| Internal Combustion | -- | 33% | 34% | -- |
| Combined Cycle | -- | 33% | 45% | -- |

Existing U.S. coal-fired power plants had an average net unit heat rate of 10,107 Btu/kWh and were approximately 34% efficient in 2012. Note that **higher efficiency translates to a lower heat rate.** This makes sense when considering that higher efficiency means that it takes less fuel to generate the same kilowatt-hour output. Less fuel means fewer Btu, so in turn, a lower heat rate. Reducing the heat rate of the existing coal fleet by 6% (per Building Block #1 of USEPA's proposed 111(d) rule) would lower the average net unit heat rate of every unit by roughly 600 Btu/kWh, and increase the average cycle efficiency of every unit by roughly 2%.

**Is a Unit's Heat Rate Constant, and If Not, What Impacts Heat Rate?**

It is extremely important to point out that the heat rate of a unit is **NOT** a constant value and varies significantly due to numerous factors which can have both positive and negative effects. Everything from basic unit design, fuel characteristics, operating load conditions, age/condition of equipment, maintenance and cleanliness of components, can all impact the heat rate. A good analogy is that of automobile fuel efficiency. Fuel efficiency of an automobile (typically expressed in miles per gallon or MPG) is most notably impacted by "city" versus "highway" driving. The frequent stops, starts and speed changes associated with city driving result in worse gas mileage than when driving on a highway at a constant rate of speed with fewer changing conditions.

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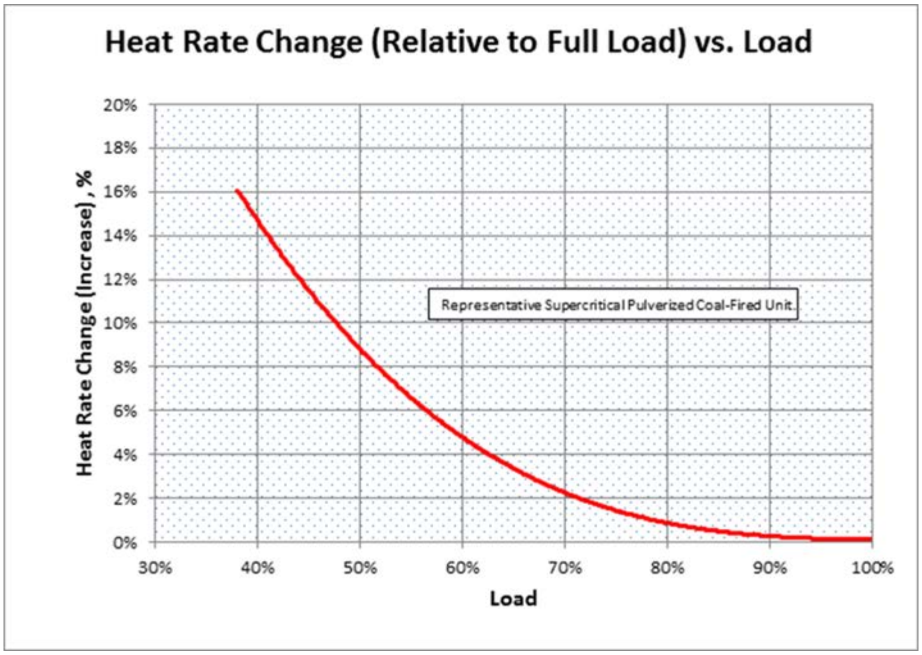
A fossil fuel fired power plant's heat rate is no different. Operating in a full-load steady-state condition versus cycling loads up and down, or running at minimum loads for which the unit was not optimally designed have a negative impact on heat rate, reducing the kilowatt-hours out for every Btu that goes in.  The relationship of unit load to heat rate is shown for a typical unit in the graph below.




City and highway driving is not the only variable that impacts an automobile's fuel efficiency. Things like the basic aerodynamic design of the car, the condition of the road (smooth or rough), the air pressure in the tires, the cleanliness of the engine's air and fuel filtration systems, the fuel type and even the outside air temperature and humidity can all impact the fuel efficiency of an automobile.  A power plant's heat rate can be similarly impacted by process and equipment design, maintenance and cleanliness of critical components, changes in weather conditions, changes in fuel energy content or fuel delivery, changes in process water and cooling water temperatures, etc.

The balance of this paper focuses on coal-fired power plants and discusses how achieving and sustaining heat improvement is extremely challenging – not just to accomplish, but also to measure.

**Is Every Coal Fired Steam Generating Unit Designed with the Same Heat Rate?**

The answer to this question is **absolutely not**.  The diversity of the existing coal-fired generating fleet is not unlike the diversity of automobiles on the highway.  The existing coal fleet is comprised of units of various ages, which were designed by different manufacturers to burn different types of coal.  For example, the John W. Turk, Jr. Plant in Arkansas began operation in 2012.  Turk utilizes a state-of-the-art ultra-supercritical steam cycle that allows for a greater transfer of heat energy from the combustion of coal to the steam circulating through the system.  This design produces higher temperature and pressure steam than is typical in most units, which results in a higher overall efficiency for the Turk Plant (on the order of 38%) over conventional coal-fired steam generators. Turk's average net unit heat rate as a result of its state-of-the-art design is approximately 9,000 Btu/kWh. It has only been in the last decade, with advances in steam piping materials that designs like the Turk Plant have become feasible to build and operate. Currently, Turk is unique as it is the only operating ultra-supercritical unit in the U.S.

It is important to differentiate between a unit's average heat rate and its "design heat rate." Design heat rate is a theoretical target that represents an optimal, full-load, steady-state condition and is considered the best a unit could potentially achieve under its original design conditions. Units may achieve their design heat rate when new with all components in their best condition, but it is well-understood that the unit will not, and should not be expected to achieve its design unit heat rate under all operating conditions or throughout the life of the unit. The age of the unit, historic operations and maintenance over its life, as well as the retrofit of any auxiliary equipment like emissions controls will all negatively impact the heat rate over the life of the unit resulting in an average unit heat rate that is higher than the unit's original design heat rate. While there are similarities between units, and often even identically designed units at the same plant site, the heat rates of each unit are as unique as fingerprints, because each unit has been operated and maintained differently.

**What Can Be Done to Improve Heat Rate?**

Improving the heat rate of a unit usually means targeting one or more of the systems or components that make up the power plant for a specific improvement. The 2009 Sargent & Lundy (S&L) study on heat rate improvements, which EPA referenced in Building Block #1 of their proposed Clean Power Plan evaluated a series of potential heat rate improvements opportunities, and estimated potential ranges of heat rate reduction. S&L then applied their findings to two case studies to estimate potential improvements. The approach S&L used to determine potential heat rate improvements in the study was reasonable and practical. However, Sargent & Lundy's study was not intended to address the many variables that impact the measurability, feasibility and sustainability of the improvement opportunities which were identified. Since the study does not contain any evidence that the recommendations from the case studies were actually implemented and heat rate improvements measured, there is no empirical data demonstrating that the estimated improvements were actually achieved or could be maintained.

EPA inappropriately used the study to assume that the types of improvements estimated by S&L are equally applicable and achievable at each and every coal-fired power plant in the country. This is simply **not** the case. For ADEQ's information and use, we have summarized the heat rate improvement strategies identified in the Sargent & Lundy report, and noted how these strategies are applicable (or not) to SWEPCO's units in Arkansas in the table below.

| HR Improvement Strategy | Sargent & Lundy Description | Applicability to SWEPCO Units |
|---|---|---|
| Boiler Island – Materials Handling | VFDs provide no substantial reduction in plant heat rate. Pulverizer upgrades warranted only if facility is switching fuels. Ash handling is not considered a prime area of investment for plant heat rate reduction. | No feasible measures identified. |
| Boiler Overhaul | Major changes to a furnace are not undertaken due to regulations currently in place (NSR enforcement).<br><br>Economizer replacements do occur during some SCR retrofit projects. | No opportunities for meaningful gains beyond original design at Turk Plant.<br><br>No opportunities for meaningful gains at Flint Creek. |
| Neural Network | Used to optimize plant performance during load changes. | No opportunities for meaningful gains beyond original design at Turk Plant.<br><br>Existing systems provide similar benefits at Flint Creek. |
| Intelligent Sootblowers | Applicable to units burning PRB and lignite fuels - engages DCS with system controls for the sootblowers. | Already in use at Turk Plant.<br><br>Planned for installation at Flint Creek with retrofits. |
| Air Heaters | Replace seals to reduce leakage and examine during emissions controls retrofits.<br><br>Control acid dew point, particularly in connection with SCR retrofits. | No opportunities for meaningful gains beyond original design at Turk Plant.<br><br>Opportunities addressed in connection with retrofits at Flint Creek. |

| HR Improvement Strategy | Sargent & Lundy Description | Applicability to SWEPCO Units |
|---|---|---|
| Turbine Overhaul | Degradation and improved designs can be addressed, but greatest reductions are associated with changes in design, and performance will degrade over time. | No opportunities for meaningful gains beyond original design at Turk Plant.<br><br>Opportunities addressed in connection with regular turbine inspections at Flint Creek. |
| Feedwater Heaters | Cost of increasing heat transfer surfaces is prohibitive due to small incremental reductions in heat rate. | No feasible measures identified. |
| Condensers | Regular cleaning schedule has varying impacts on heat rate depending on location and cooling water characteristics. | Turk uses closed-cycle cooling and regular cleaning schedule.<br><br>Flint Creek uses regular cleaning schedule and monitors backpressure, and replaces tubes during regular maintenance. |
| Boiler Feed Pumps | Ordinary wear and tear degrades performance and is addressed during overhauls or upgrades. | Regular inspection and overhaul schedules are maintained at both facilities. |
| Fans and VFDs | Installation of upgrades usually made in connection with emissions controls. | No opportunities for meaningful gains beyond original design at Turk Plant.<br><br>Opportunities addressed in connection with retrofits at Flint Creek. |
| Emission Control Technologies | Discussion of potential improvements associated with older emission control system designs. | No opportunities for meaningful gains beyond original design at Turk Plant.<br><br>Opportunities addressed in connection with retrofits at Flint Creek. |
| Boiler Water Treatment | Most power plants already have advanced water treatment systems installed. | No feasible measures identified. |

| HR Improvement Strategy | Sargent & Lundy Description | Applicability to SWEPCO Units |
|---|---|---|
| Cooling Water Treatment | Proper maintenance of water quality in the cooling system maintains efficiency that could be lost through fouling. | Proper maintenance procedures are in place for cooling water treatment. |
| Advanced Cooling Tower Packing | Optimization of cooling water temperatures and fan requirements must be conducted to investigate effectiveness of upgrading fill or implementing VFDs for older fans. | No opportunities for meaningful gains beyond original design at Turk Plant.<br>No assessment available for Flint Creek. |
| Other Improvements | Motor replacement programs can yield minor heat rate improvements. | No opportunities for meaningful gains beyond original design at Turk Plant.<br>Evaluated as necessary at Flint Creek. |

In addition, there are several distinct caveats to the report's findings must be considered that are imperative for understanding the realistic applicability and opportunity that any potential heat rate improvement project might afford. These include:

- improvements are not uniform and what may work for one unit, may not for another;
- the heat rate benefit of multiple improvement projects is not necessarily cumulative meaning that improvements in one area can be masked by operations or conditions in another thus diminishing any significant overall heat rate improvement;
- outside influences beyond the control of the unit operators and outside the optimized equipment design performance can alter or erase heat rate improvements as these plants are dispatched based upon electricity demand, which is driven by external forces (e.g. customers, regional transmission operators, etc.);
- improvements must be cost effective and measurable to justify their implementation;
- space constraints may exist on a particular unit that prohibit the addition of equipment or re-routing of ductwork/piping to implement a heat rate improvement project;
- the benefit derived from many of the suggested heat rate improvement technologies is finite, and will diminish over time due to the age and operation of the unit;
- for some heat rate improvement projects the potential benefits will only be apparent at full load operations, but offer no measurable improvements for cyclic or minimum load operations;

- conversely, some base load units would show no benefit to heat rate if the improvement was obtained only at lower loading of the unit;

- EPA's 111(d) proposal suggests that future coal power plants will be dispatched and operated much differently than in the past, which means that the feasibility and benefits of any potential heat rate improvement must be evaluated more in context with future operations that may not afford the same magnitude of improvement potential.

It is evident that potential heat rate improvements are impacted by many variables that are both within and beyond the control of unit owners and operators. An analogy to simplify this point is the decision to replace the air filter in your car, which is known to improve fuel efficiency, typically at higher vehicle speeds. However, if the highway by which you commute to work is suddenly closed and you are rerouted through busy city streets, any fuel efficiency improvement from new air filter might go unseen. Similarly, if improvements are made to components or systems within the power plant, and then the unit adds emissions controls to meet a new regulation or is cycled more frequently to balance intermittent loads from new wind and solar generation, the heat rate improvements may never be fully realized. In fact, depending upon the situation, the unit's average heat rate might actually deteriorate. For example, AEP Engineering estimated that Flint Creek Plant may be able to improve its heat rate by upgrading the steam turbine and boiler sootblowing equipment to improve performance and efficiency. However, the planned installation of a dry $SO_2$ scrubbing system to meet environmental regulations is estimated to increase the unit's auxiliary load (power needed to run the new scrubber) by an amount that will increase the unit's net heat rate and essentially offset the heat rate improvements in the turbine and boiler.

**Heat Rate Improvement Opportunities Are Limited for New and Well-Maintained Plants**

It should not be misinterpreted that heat rate improvements are not valuable or can never be implemented. Most power plant owners and operators have historically made heat rate improvements and overall efficiency of their generating units a high priority because of its positive impacts on operating costs and equipment performance. Remember, better heat rate means less fuel, which lowers the cost of generating electricity and creates an economic driver to improve efficiency. Many of the units in the existing coal generating fleet have proactively pursued and actively performed projects to improve heat rate, all while utilizing preventative maintenance and routine cleaning practices that promote and sustain efficient operations. Yet, no credit for proactive efforts like these is available in the EPA's Clean Power Plan and the amount of heat rate improvement contemplated by EPA is very aggressive and overly ambitious for units that have historically been well maintained and operated. For the recently constructed coal units at Turk and Plum Point that were built with more advanced and more efficient technologies, many of the potential heat rate improvement opportunities listed above have already been incorporated into their designs. Any potential improvement opportunity will be minimal and certainly far from the level that EPA has considered in the proposed Clean Power Plan.