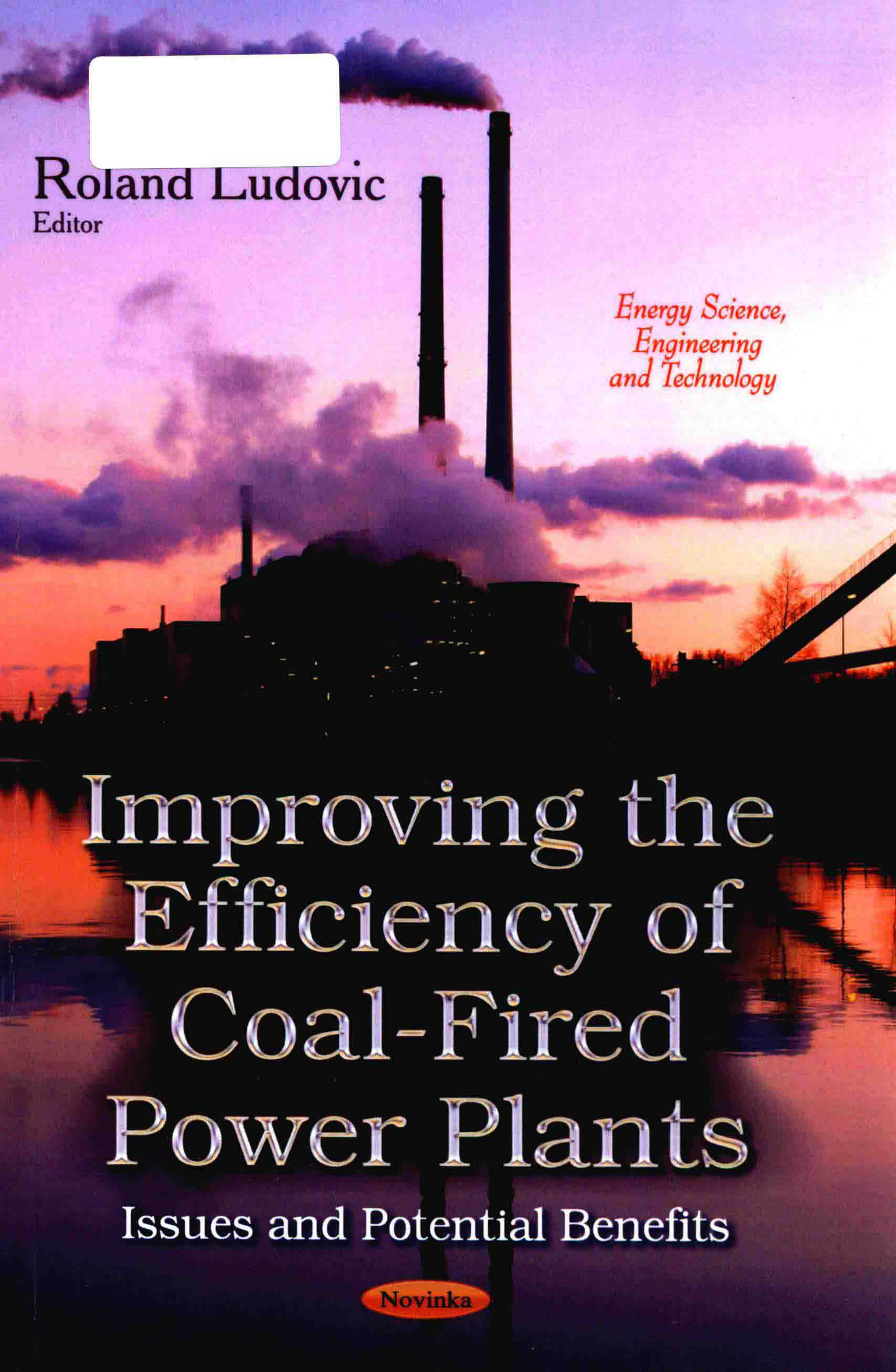

Roland Ludovic
Editor

Energy Science, Engineering and Technology

Improving the Efficiency of Coal-Fired Power Plants

Issues and Potential Benefits

Novinka

ENERGY SCIENCE, ENGINEERING AND TECHNOLOGY

IMPROVING THE EFFICIENCY OF COAL-FIRED POWER PLANTS

ISSUES AND POTENTIAL BENEFITS

ROLAND LUDOVIC
EDITOR

New York

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PREFACE

This book focuses on efficiency improvements to power plants, and discusses retrofits, technologies, and other modifications to facility operations which offer the potential to improve power plant efficiency and reduce CO2 emissions.

Chapter 1 – Coal has long been the major fossil fuel used to produce electricity. However, coal-fired electric power plants are one of the largest sources of air pollution in the United States, with greenhouse gas (GHG) emissions from burning of fossil fuels believed to be the major contributor to global climate change. Regulations under development at the Environmental Protection Agency (EPA) would impose new requirements on fossil-fueled (mostly coal-fired) power plants (CFPPs) to control GHG emissions. The first of these requirements was issued in September 2013 with proposed standards for the control of carbon dioxide (CO_2) emissions from new electric generating units burning fossil fuels. EPA's proposals for control of GHG emissions from existing power plants are expected by June 2014, with many options under consideration. EPA may target emissions on a state or plant-by-plant basis, with companies likely given choices for compliance. Within such a system, efficiency improvements can be an important contributor.

The overall efficiency of a power plant encompasses the efficiency of the various components of a generating unit. Minimizing heat losses is the greatest factor affecting the loss of CFPP efficiency, and there are many areas of potential heat losses in a power plant. Efficiency of older CFPPs becomes degraded over time, and lower power plant efficiency results in more CO_2 being emitted per unit of electricity generated.

The options most often considered for increasing the efficiency of CFPPs include equipment refurbishment, plant upgrades, and improved operations and maintenance schedules.

Cost of the improvements is often compared to the expected return in increased efficiency as a primary determinant of whether to go forward with a program. A study by the Asia-Pacific Working Group (APWG) found that at the low to medium end of cost expenditures are combustion, steam cycle, and operations and maintenance improvements. Replacing the older CFPPs with new power plants was not generally seen as being practical because the expenditure for a new plant could not be justified by the improved performance. Instead, efficiency and operational improvements were seen as a possible alternative considering a range of equipment upgrades and refurbishment options to various CFPP systems.

The National Energy Technology Laboratory (NETL) took APWG's analysis a step further, finding that while the average efficiency of U.S. plants was 32% in 2007, the efficiency of the top 10% was five points higher at 37.4%. NETL suggested that if GHG emissions reduction was a goal, then heat rate efficiency improvements could enable a power plant to generate the same amount of electricity from less fuel and decrease CO_2 emissions.

In 2010, NETL completed a new study of U.S. CFPP efficiency, concluding that if generation levels were held constant at 2008 levels, overall fleet efficiency could be raised from 32% to 36%, resulting in an overall reduction in U.S. GHG emissions of 175 million metric tonnes per year, or 2.5% of total U.S. GHG emissions in 2008.

According to subsequent analyses, NETL concluded that retirements of lower efficiency units combined with increased generation from higher efficiency refurbished units, and advanced refurbishments with improved operation and maintenance, would be necessary to achieve this goal. These improvements would generally be considered low to medium cost upgrades.

However, at the higher cost end are major plant retrofits and upgrades (i.e., conversion of subcritical CFPP units to super- or ultra-supercritical CFPP units), which would raise efficiencies more substantially.

One possible approach to achieve fleet-wide efficiency improvement might be to follow NETL's suggestion of using the top decile of CFPP efficiency as a benchmark for the U.S. fleet, and establish an "efficiency frontier" that would be revisited periodically to reset the benchmark. This could be combined with possible incentives to improve efficiency or retire less efficient power plants.

Other federal approaches could use tax incentives to encourage greater efficiency, or employ energy efficiency standards focused on improving efficiency of CFPPs. The overall cost of these or other programs to increase CFPP efficiency has yet to be determined.

Chapter 2 – 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 90^{th} 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 [1] or 2.5% of total U.S. GHG emissions in 2008.

Chapter 3 – This document is one of several white papers that summarize readily available information on control techniques and measures to mitigate greenhouse gas (GHG) emissions from specific industrial sectors. These white papers are solely intended to provide basic information on GHG control technologies and reduction measures in order to assist States and local air pollution control agencies, tribal authorities, and regulated entities in implementing technologies or measures to reduce GHGs under the Clean Air Act, particularly in permitting under the prevention of significant deterioration (PSD) program and the assessment of best available control technology (BACT). These white papers do not set policy, standards or otherwise establish any binding requirements; such requirements are contained in the applicable EPA regulations and approved state implementation plans.

This document provides information on control techniques and measures that are available to mitigate GHG emissions from the coal-fired electric generating sector at this time. The primary GHG emitted by the coal-fired electric generation industry is carbon dioxide (CO_2), and the control technologies and measures presented in this document focus on this pollutant. While a large number of available technologies are discussed here, this paper does not necessarily represent all potentially available technologies or measures that that may be considered for any given source for the purposes of reducing its GHG emissions. For example, controls that are applied to other industrial source categories with exhaust streams similar to the cement manufacturing sector may be available through "technology transfer" or new technologies may be developed for use in this sector.

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In: Improving the Efficiency ...
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Chapter 1

INCREASING THE EFFICIENCY OF EXISTING COAL-FIRED POWER PLANTS*

Richard J. Campbell

SUMMARY

Coal has long been the major fossil fuel used to produce electricity. However, coal-fired electric power plants are one of the largest sources of air pollution in the United States, with greenhouse gas (GHG) emissions from burning of fossil fuels believed to be the major contributor to global climate change. Regulations under development at the Environmental Protection Agency (EPA) would impose new requirements on fossil-fueled (mostly coal-fired) power plants (CFPPs) to control GHG emissions. The first of these requirements was issued in September 2013 with proposed standards for the control of carbon dioxide (CO_2) emissions from new electric generating units burning fossil fuels. EPA's proposals for control of GHG emissions from existing power plants are expected by June 2014, with many options under consideration. EPA may target emissions on a state or plant-by-plant basis, with companies likely given choices for compliance. Within such a system, efficiency improvements can be an important contributor.

The overall efficiency of a power plant encompasses the efficiency of the various components of a generating unit. Minimizing heat losses is the greatest factor affecting the loss of CFPP efficiency, and there are

* This is an edited, reformatted and augmented version of Congressional Research Service Publication, No. R43343, dated December 20, 2013.

many areas of potential heat losses in a power plant. Efficiency of older CFPPs becomes degraded over time, and lower power plant efficiency results in more CO_2 being emitted per unit of electricity generated. The options most often considered for increasing the efficiency of CFPPs include equipment refurbishment, plant upgrades, and improved operations and maintenance schedules.

Cost of the improvements is often compared to the expected return in increased efficiency as a primary determinant of whether to go forward with a program. A study by the Asia-Pacific Working Group (APWG) found that at the low to medium end of cost expenditures are combustion, steam cycle, and operations and maintenance improvements. Replacing the older CFPPs with new power plants was not generally seen as being practical because the expenditure for a new plant could not be justified by the improved performance. Instead, efficiency and operational improvements were seen as a possible alternative considering a range of equipment upgrades and refurbishment options to various CFPP systems.

The National Energy Technology Laboratory (NETL) took APWG's analysis a step further, finding that while the average efficiency of U.S. plants was 32% in 2007, the efficiency of the top 10% was five points higher at 37.4%. NETL suggested that if GHG emissions reduction was a goal, then heat rate efficiency improvements could enable a power plant to generate the same amount of electricity from less fuel and decrease CO_2 emissions.

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Other federal approaches could use tax incentives to encourage greater efficiency, or employ energy efficiency standards focused on improving efficiency of CFPPs. The overall cost of these or other programs to increase CFPP efficiency has yet to be determined.

INTRODUCTION

Coal has long been the major fossil fuel used to produce electricity. However, the Environmental Protection Agency (EPA) lists coal-fired electric power plants as one of the largest sources of air pollution in the United States, with greenhouse gas[1] (GHG) emissions from burning fossil fuels believed to be the largest contributor to global climate change.

Regulations under development at EPA would impose new requirements on power plants to control GHG emissions. First, in September 2013 EPA proposed standards for the control of carbon dioxide (CO_2) emissions from new electric generating units burning fossil fuels. EPA has suggested that utilization of carbon capture and storage (CCS) is a viable means for new coal-fired power plants to comply with the proposed standards.[2] But higher efficiency components and processes are unlikely to be sufficient to meet the proposed new plant standards.

As requirements for new sources (i.e., new power plants), EPA's proposed standards do not directly apply to existing power plants currently producing electricity. EPA's proposals for control of GHG emissions from existing power plants are expected by June 2014,[3] with many options for reducing GHGs under consideration. EPA may target emissions on a state or plant-by-plant basis, with companies likely given choices for compliance, and increasing coal-fired power plant (CFPP) efficiency may be one of those choices.

Improving the efficiency of existing coal plants could potentially result in significant reductions of CO_2 emissions per unit of electricity produced. However, certain modifications to power plants to increase power output can potentially increase pollutant emissions, thus triggering new source review[4] (NSR) requirements.

Therefore, any modifications made must be shown to reduce pollutants if NSR is to be avoided. Expenditures to increase efficiency would likely be evaluated on a cost vs. benefits approach, with modifications to improve efficiency varying according to many factors, including the type of fuel burned, and the age and the physical condition of the power plant.

Carbon capture and sequestration (CCS) will not be a focus of improvements discussed in this report, as there are no CCS technologies considered as commercially available for full-scale application to the broad majority of existing coal-fired power plants,[5] and EPA has stated that it does not expect to require CCS at *existing* plants.

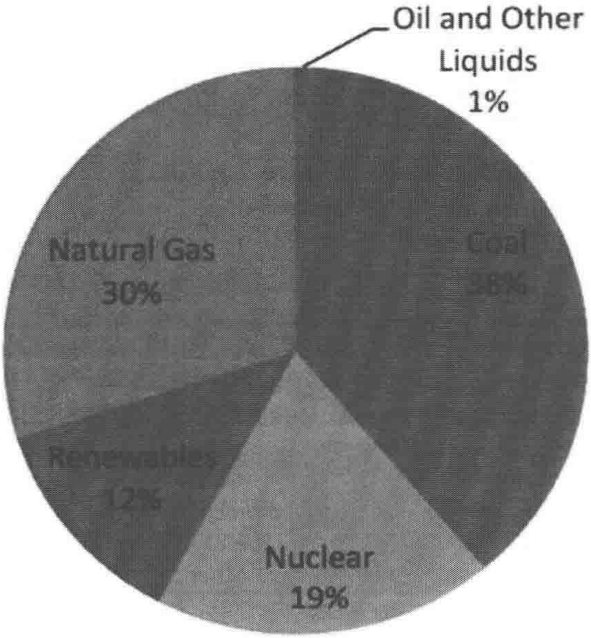
This report focuses on efficiency improvements to power plants, and discusses retrofits, technologies, and other modifications to facility operations which offer the potential to improve power plant efficiency and reduce CO_2 emissions.

Some in Congress have expressed concerns about the potential impacts on electricity reliability and fuel diversity from retirements of coal plants due to pending and new environmental regulations. Increasing efficiency of coal plants may help to address these concerns by reducing emissions without reducing output. Additionally, Congress may want to consider whether such efficiency improvements could be accelerated if these were implemented in a program focused on increasing the efficiency of the coal-fired power plant sector.

COAL AND EXISTING U.S. COAL POWER PLANTS

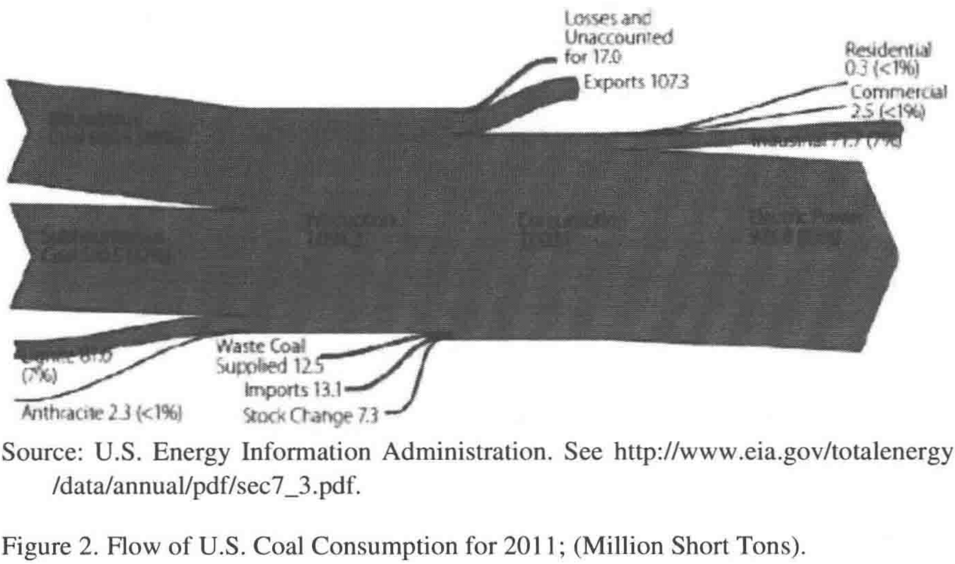
For most of the history of power generation in the United States, coal has been the dominant fuel used to produce electricity. In 2012, coal was used to fuel approximately 38% of power generation in the United States, as shown in **Figure 1**. Coal has been the fuel of choice for many decades because of its wide availability, and the relatively low cost of producing electricity in large, coal-burning power plants. Coal's low-priced, high energy content enabled the building of power plants able to take advantage of economies of scale in steam-electric production.

In a steam power plant, coal (or other combustible fuel) is burned to provide heat for turning water into steam in a boiler.[6] The steam is then forced under pressure into a steam turbine-driven generator which produces electricity. As of 2012, the U.S. coal-powered generation fleet consisted of 1,337 units[7] with a nameplate capacity of almost 313 gigaWatts (GW) of generating capacity.[8]



Source: U.S. Energy Information Administration, Electric Power Monthly, September 2013.

Figure 1. Electricity Generation by Fuel, 2012.



Source: U.S. Energy Information Administration. See http://www.eia.gov/totalenergy/data/annual/pdf/sec7_3.pdf.

Figure 2. Flow of U.S. Coal Consumption for 2011; (Million Short Tons).

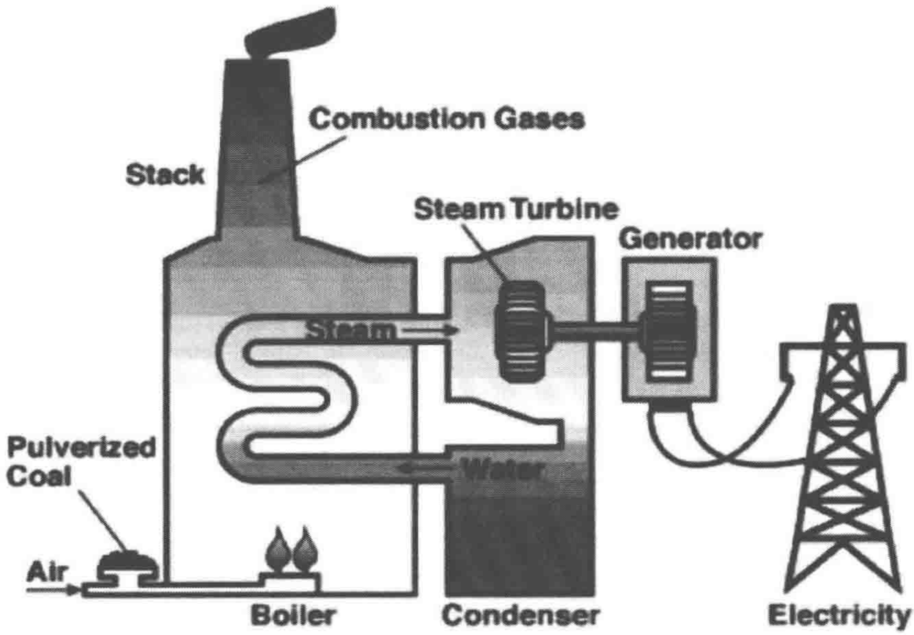
Coal and Greenhouse Gas Emissions

Coal is largely composed of carbon, hydrogen and oxygen, with varying amounts of carbon, sulfur, ash, and moisture content in the different types of coal mined in the United States. **Figure 2** shows the use of the four major types (also called "ranks") of coal produced in the United States, with bituminous and subbituminous coal dominating electric power generation.

> **Bituminous** is the most abundant form of coal in the United States, and is the type most commonly used to generate electricity. Bituminous coal has a carbon content ranging from 45% to 86%, and a heat value between 10,500 British Thermal Units (BTUs)[9] and 15,500 BTUs per pound.
>
> **Subbituminous** coal is mostly found in six western states and Alaska. It has a carbon content of between 35% and 45%, and a heat value of between 8,300 BTUs and 13,000 BTUs. Subbituminous coal generally has a lower sulfur content than other types of coal.
>
> **Lignite** has the lowest carbon content of the four types of coal generally used for electric power generation, averaging between 25% and 35%, and a high moisture and ash content. It also has the lowest heat value, ranging between 4,000 BTUs and 8,300 BTUs.
>
> **Anthracite** has the highest carbon content (between 86% and 98%), and a heat value of about 15,000 BTUs. Anthracite coal is a small part of the electric power market, and is mostly found in the Appalachian region of Pennsylvania.

The amount of CO_2 emitted from a coal-fired power plant (CFPP) varies with the type of coal burned. The combustion of coal in the presence of oxygen causes its carbon and hydrogen constituents to react, releasing CO_2 emissions and water, with varying amounts of other products such as oxides of nitrogen and sulfur, carbon monoxide, and fine particulate matter. Carbon dioxide is the primary emission of concern when considering GHG emissions from power plants.[10]

Generally, anthracite emits the largest amount of CO_2 per million BTUs (MMBTU) of coal burned, followed by lignite, subbituminous coal, and bituminous coal. Carbon dioxide emissions from coal-fired power plants could thus be reduced by burning a better grade of coal, or by increasing the efficiency of the power plant and reducing overall coal consumption, without a need to completely repower the plant (in, say, a coal to natural gas conversion). Fuel switching may be necessary if a greater degree of CO_2 emissions reduction is desired.



Source: Oncor Electric Delivery Company. Steam Turbine.
Notes: See http://www.c2es.org/technology/overview/electricity.

Figure 3. Electric Power Generation; Steam Turbine- Generator.

Types of U.S. Coal-Fired Power Plants

Steam turbines are at the heart of coal-fired power plants. As shown in the simplified schematic of a pulverized coal plant in **Figure 3**, a steam electric power plant consists of a number of basic components. Coal is crushed and fed into a boiler where it is burned to heat water into steam. The steam is injected under pressure into a turbine which turns a generator (where essentially a magnet turns in a coil of wire causing electrons to flow thus creating an electric current). Steam returning from the turbine is then cooled in a condenser, and the water is fed back by a feedwater pump to the boiler to continue the process. The expansion of water into steam vapor (and condensation back into liquid water) in this manner is called a Rankine Cycle,[11] and is the basis for most electric power generation in the United States.

A typical coal-fired power plant has multiple generating units, each with its own steam generating boiler. Usually, coal is pulverized by a combination