Efficiency Performance and CO_2 Emissions from Coal Power Plants

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1. INTRODUCTION

1.1 Background

Coal is the world's most abundant and widely distributed fossil fuel with reserves for all types of coal estimated to be about 990 billion tonnes, enough for 150 years at current consumption (BGR, 2009).[1] Coal fuels 42% of global electricity production, and is likely to remain a key component of the fuel mix for power generation to meet electricity demand, especially the growing demand in developing countries. To maximise the utility of coal use in power generation, plant efficiency is an important performance parameter. Efficiency improvements have several benefits:

- prolonging the life of coal reserves and resources by reducing consumption;
- reducing emissions of carbon dioxide (CO_2) and conventional pollutants;[2]
- increasing the power output from a given size of unit; and
- potentially reducing operating costs.

The calculation of coal-fired power plant efficiency is not as simple as it may seem. Plant efficiency values from different plants in different regions are often calculated and expressed on different bases, and using different assumptions. There is no definitive methodology.[3]

In their 2005 *Plan of Action* on climate change, clean energy and sustainable development, agreed at the Gleneagles Summit in 2005, G8 leaders addressed this topic (G8, 2005):

"We will support efforts to make electricity generation from coal and other fossil fuels cleaner and more efficient by:
(a) supporting IEA work in major coal using economies to review, assess and disseminate widely information on energy efficiency of coal fired power plants; and to recommend options to make best practice more accessible."

Their commitment provided a sound basis for a review of how power plant efficiency data are prepared, disseminated and used, including how different methods can be reconciled. A better understanding of power plant efficiency leads quickly to the question of how it might be improved through further development and dissemination of technologies that are not yet widely deployed.

1 Quantity that is estimated to be economically recoverable using current mining techniques.

2 A one percentage point improvement in efficiency can result in a 2.5 percentage points reduction in CO_2 emissions.

3 For example, the heat rate of European power plants can appear to be 8%-10% lower than their US counterparts (and so appear 3-4 percentage points more efficient). This may be partly due to real plant differences, but differences between calculation methodologies for identical plants can also be of this magnitude.

1.2 Objective

Measuring coal-fired power plant efficiency consistently is particularly important at the global level, yet significant regional differences exist. Similarly, at the local level, the performance of individual generating units and power plants can only be compared if measured consistently. Although variations in efficiency may arise from differences in plant design and maintenance practices, the practical and operational constraints associated with different fuel sources, local ambient conditions and electricity dispatch all play significant roles. Misunderstanding these factors can result in the misinterpretation of efficiency data.

Thus, reconciling different efficiency measurement methodologies is not simply concerned with theoretical design efficiency, but with the actual operational efficiency of existing power plants and all the associated issues and constraints found in the real world.

This course proposes a generic methodology which can be applied to determine the efficiency and specific CO_2 emissions of coal-fired power generation processes. The application of such a reference methodology would provide a potential route to gauge how coal might be deployed more cleanly and efficiently in the future. To this end, the major objective of this report is to review the methods used to calculate and express coal-fired power plant efficiency and CO_2 emissions, and determine whether these can be reconciled for comparison using a common basis.

The target audience for this report includes technical decision makers in industry and policy makers in government who must master the details of efficiency measurement if they are to effectively manage and regulate power plants. Early conclusions from this report guided IEA policy recommendations on cleaner fossil fuels presented to the G8 Hokkaido Summit in 2008 (IEA, 2008).

1.3 Course structure

Section 2 explores, in some technical detail, those aspects of power plant design, monitoring and operation that can influence efficiency measurement and comparison. A generic methodology is prescribed in Section 3 to adjust reported data and reconcile efficiencies reported on different bases. Section 4 briefly looks at historic and likely future trends in power plant efficiency. Section 5 summarises recommendations made by the IEA at the G8 Hokkaido Summit and makes further recommendations to implement the methodology and compile a database of efficiency data that would allow the performance of power plants to be contrasted and compared. Appendices support the main report with additional technical background, an example efficiency calculation and accounts of how power plant efficiency and emissions are measured and reported in a number of different IEA member and non-member countries, all being large users of coal for power generation.

2. FACTORS INFLUENCING POWER PLANT EFFICIENCY AND EMISSIONS

This section explores aspects of power plant design and operation that influence efficiency performance. It focuses on practical issues; to aid understanding of the discussion, some theoretical aspects of power plant efficiency are set out in Appendix I. The section also reviews the relevance of current power plant performance measurement standards and how these might be reconciled using a common methodology to allow performance benchmarking. The section continues with a summary of the reporting bases and the required information sources for calculating the efficiency of a whole plant according to national standards. CO_2 emissions from fossil fuel use are closely related to plant efficiency and the section concludes with a review of how these are monitored and reported in practice.

2.1 Differences in reported efficiency values

Apparent efficiency differences

Differences in reported efficiencies between plants can sometimes be artificial, and not reflective of any underlying differences in their actual efficiencies. The reported efficiency of two identical plants, or even the same plant tested twice, could potentially be different owing to:

- the use of different assessment procedures and standards;
- the use of different plant boundaries and boundary conditions;
- the implementation of different assumptions or agreed values within the scope of a test standard;
- the use of different operating conditions during tests;
- the use of correction factors to normalise test results before reporting;
- the expression of results on different bases (*e.g.,* gross or net inputs and outputs);
- different methods and reference temperatures for determination of fuel calorific value (CV);
- the application of measurement tolerances to the reported figures;
- differences in the duration of assessments;
- differences in the timing of assessments within the normal repair and maintenance cycle;
- errors in measurement, data collection and processing; and
- random performance and measurement effects.

These effects are difficult to quantify, especially when assessing the performance of major sub-systems that are interconnected with other parts of the plant.

Gross and net values

Assessments of efficiency often refer to "gross" or "net" bases, both for the determination of the heating values of fuel inputs and for the energy outputs from a process. In the latter case, the terminology usually relates to the use of a proportion of the output energy by the process itself: the output being referred to as "gross output" before any deduction, or "net output" after the deduction for own-use. This most commonly applies to the consumption of electrical power by a plant where "generated" power is referred to as "gross output", and "sent-out" power, following deduction of on-site power use, is referred to as "net output" or "gross-net". This analysis can be complicated further for multi-unit sites where some parts of the process may be fed directly from a common import power supply, shared between all generating units. This power must also be deducted from generated power to derive a true "net output" for the plant; an output that may be referred to as "gross-net-net" or "station net export".

For fuels, the difference between gross calorific value (GCV) and net calorific value (NCV) stems from the assumptions made about the availability of the energy present in the moisture in the combustion products.[4] The GCV measures all the heat released from fuel combustion, with the products being cooled back to the temperature of the original sample. In the NCV assessment, it is assumed that water in the combustion products is not condensed, so latent heat is not recovered. Using the NCV basis is questionable: a modern condensing boiler could potentially achieve a heating efficiency in excess of 100%, in violation of the first law of thermodynamics. Although some regions and industries prefer to use lower heating values in daily business, the true energy content of a fuel is its GCV or higher heating value. Another complication, associated with fuel heating values, is the reference temperature used for their determination. Typically, calorific values are quoted based on a 25 °C reference temperature; however, 15 °C is also commonly used and other temperatures may be used after correction, if these differ from the temperature of the reactants and products at the start and end of the combustion test. Obviously, the use of values calculated on different reference temperature bases would result in different apparent heat inputs. Some technical standards provide equations for the correction of calorific values between different reference temperatures.

Electrical power imports and exports

Electricity produced and consumed within the plant should not affect plant performance assessment, providing the system boundary is drawn at the outer plant boundary. Electrical power imported into the plant can be deducted directly from exported power in order to calculate the overall net power generation for efficiency assessment. In general, it is recognised that power exports should be referenced to the conditions at the transmission side of the generator transformer and thus account for transformer losses.

Efficiency differences due to real constraints

It is reasonable to expect that there will be differences in efficiency between particular plants because of the constraints within which they were constructed and operate. Considerations which can impact significantly on efficiency include:

- fuel moisture content (influences latent and sensible heat losses);[5]
- fuel ash content (impacts on heat transfer and auxiliary plant load);
- fuel sulphur content (sets design limits on boiler flue gas discharge temperature);
- use of closed-circuit, once-through or coastal cooling-water systems (determines cooling-water temperature);
- normal ambient air temperature and humidity;

4 GCV is also known as higher heating value (HHV), while NCV is also known as lower heating value (LHV). GCV measures a fuel's heat of combustion assuming all water in the flue gas is condensed; NCV excludes this latent heat.

5 Latent heat is absorbed or released during a change of state with no change in temperature, *e.g.,* boiling a liquid to a gas, or condensing a gas; sensible heat is associated with changes in temperature, *e.g.* superheating steam.