Abstract

A significant quantity of coal is consumed globally to provide process heat and steam for commercial and industrial processes (excluding power generation). Coal-fired industrial boilers play a key role for process and comfort heat in the industrial, residential and commercial sectors. Currently no international world’s best practice (WBP) for efficient coal-fuelled industrial and commercial boilers exists. This is due to several factors including the type of coal, efficiency and size of the boiler. This report examines the opportunities and barriers to establishing WBP for stoker-fired and pulverised-fired units between 3 MW and 20 MW. This report discusses the different designs of industrial boilers, methods to improve their efficiency and the potential benefits.
### Acronyms and abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AAU</td>
<td>assigned amount unit</td>
</tr>
<tr>
<td>AFBC</td>
<td>atmospheric fluidised bed combustion</td>
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<tr>
<td>AR4</td>
<td>Fourth Assessment on Climate Change</td>
</tr>
<tr>
<td>BAT</td>
<td>best available technique</td>
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<tr>
<td>CFBC</td>
<td>circulating fluidised bed combustion</td>
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<td>CAA</td>
<td>Clean Air Act</td>
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<tr>
<td>CCS</td>
<td>carbon capture and storage</td>
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<td>CDM</td>
<td>clean development mechanism</td>
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<tr>
<td>CER</td>
<td>certified emission reduction (for CDM)</td>
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<tr>
<td>CH4</td>
<td>methane</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
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<tr>
<td>CHP</td>
<td>combined heat and power</td>
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<tr>
<td>DTI</td>
<td>Department of Trade and Industry</td>
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<tr>
<td>ETS</td>
<td>Emission Trading System</td>
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<tr>
<td>EIA</td>
<td>Energy Information Agency</td>
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<td>ETP</td>
<td>Energy Technology Perspectives</td>
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<td>EC</td>
<td>European Commission</td>
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<tr>
<td>EEA</td>
<td>energy and environment analysis</td>
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<tr>
<td>EU</td>
<td>European Union</td>
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<tr>
<td>EUA</td>
<td>European Union Allowance (for EU-ETS)</td>
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<tr>
<td>EU-ETS</td>
<td>European Union Emissions Trading Scheme</td>
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<tr>
<td>FBC</td>
<td>fluidised bed combustion boilers</td>
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<tr>
<td>GEF</td>
<td>global environment facility</td>
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<tr>
<td>GHG</td>
<td>greenhouse gas</td>
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<tr>
<td>Gt</td>
<td>gigatonne</td>
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<tr>
<td>HAP</td>
<td>hazardous air pollutants</td>
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<tr>
<td>HCFCs</td>
<td>hydrochlorofluorocarbons</td>
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<tr>
<td>HFCs</td>
<td>hydrofluorocarbons</td>
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<tr>
<td>IB</td>
<td>industrial boiler</td>
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<tr>
<td>ICI</td>
<td>industrial/commercial/institutional boilers</td>
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<tr>
<td>IEA</td>
<td>International Energy Agency</td>
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<tr>
<td>IET</td>
<td>International Emissions Trading</td>
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<td>IETA</td>
<td>International Emissions Trading Association</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>IPR</td>
<td>Intellectual Property Rights</td>
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<tr>
<td>JI</td>
<td>Joint Implementation</td>
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<td>KP</td>
<td>Kyoto Protocol</td>
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<tr>
<td>LCPD</td>
<td>Large Combustion Plant Directive</td>
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<td>LEA</td>
<td>limiting excess air</td>
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<tr>
<td>LPHW</td>
<td>low pressure hot water boilers</td>
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<td>LHV</td>
<td>lower heating value</td>
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<tr>
<td>MACT</td>
<td>maximum achievable control technology</td>
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<tr>
<td>MBtu</td>
<td>million British thermal units</td>
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<tr>
<td>MS</td>
<td>Member State</td>
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<tr>
<td>MtCO₂</td>
<td>million tonnes of CO₂</td>
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<tr>
<td>MtCO₂-e</td>
<td>million tonnes of CO₂ equivalent</td>
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<tr>
<td>Mtoe</td>
<td>million tonnes of oil equivalent</td>
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<tr>
<td>MW</td>
<td>megawatt</td>
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<tr>
<td>NAP</td>
<td>National Allocation Plan</td>
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<td>NAAQS</td>
<td>national ambient air quality standards</td>
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<tr>
<td>NESHAP</td>
<td>National Emission Standards for Hazardous Air Pollutants</td>
</tr>
<tr>
<td>NZMFE</td>
<td>New Zealand Ministry for the Environment</td>
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<tr>
<td>N₂O</td>
<td>nitrous oxide</td>
</tr>
<tr>
<td>PFBC</td>
<td>pressurised fluidised bed combustion system</td>
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<td>PC</td>
<td>pulverised coal fired boilers</td>
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<tr>
<td>PFCs</td>
<td>perfluorocarbons</td>
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<tr>
<td>R&amp;D</td>
<td>research and development</td>
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<tr>
<td>SMEs</td>
<td>small and medium sized enterprises</td>
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<tr>
<td>SIP</td>
<td>State Implementation Plan</td>
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<tr>
<td>SO₂</td>
<td>sulphur dioxide</td>
</tr>
<tr>
<td>SF6</td>
<td>sulphur hexafluoride</td>
</tr>
<tr>
<td>tCO₂</td>
<td>tonnes of CO₂</td>
</tr>
<tr>
<td>tCO₂-e</td>
<td>tonnes of CO₂ equivalent</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
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<td>US EPA</td>
<td>United States Environmental Protection Agency</td>
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<tr>
<td>VER</td>
<td>verified emission reduction</td>
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<tr>
<td>VA</td>
<td>Voluntary Agreements</td>
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<tr>
<td>WBP</td>
<td>world’s best practice</td>
</tr>
<tr>
<td>WRI&amp;WBSCD</td>
<td>World Resources Institute and World Business Council for Sustainable Development</td>
</tr>
</tbody>
</table>
## Contents

Acronyms and abbreviations .......................................................... 2

Contents ......................................................................................... 3

1 Introduction .................................................................................. 5

2 Industrial boiler design ................................................................. 7
   2.1 The nature of coal ................................................................. 7
   2.2 Types of boilers ................................................................ 9
      2.2.1 Fire-tube boiler ......................................................... 10
      2.2.2 Water-tube boilers .................................................. 10  
   2.3 Overview of stoker technology ............................................. 11
      2.3.1 Overfeed stoker ....................................................... 11
      2.3.2 Mass-feed stokers ................................................... 11
      2.3.3 Spreader stokers ..................................................... 11
      2.3.4 Underfeed stoker .................................................... 11
      2.3.5 Coking stoker ......................................................... 12
      2.3.6 Moving bed stoker .................................................. 12
      2.3.7 Chain grate stoker .................................................. 12
   2.4 Grates .................................................................................. 13
      2.4.1 Travelling grate ....................................................... 14
      2.4.2 Vibrating grate ....................................................... 14
      2.4.3 Dumping grate ....................................................... 14
      2.4.4 Static grate ............................................................ 15
      2.4.5 Windswept spout .................................................... 15
      2.4.6 Vekos firing system ................................................ 16
   2.5 Industrial boiler thermal efficiency ........................................ 16
   2.6 Summary ............................................................................. 16

3 Countries using coal-fired industrial boilers .................................. 17
   3.1 China ............................................................................... 17
   3.2 India ............................................................................... 18
   3.3 USA ............................................................................... 19
   3.4 EU ................................................................................. 21
      3.4.1 Poland ................................................................. 21
   3.5 New Zealand ................................................................. 21
   3.6 Environmental legislation for industrial boilers .................. 21
      3.6.1 Air quality standards .............................................. 22
   3.7 Summary ........................................................................... 23

4 Methods to improve efficiency of industrial boilers ...................... 24
   4.1 Coal preparation and washing ........................................... 24
   4.2 Coal sorting ..................................................................... 25
   4.3 Storing and management of coal fuel ................................... 25
   4.4 Clinkering and slagging .................................................... 25
   4.5 Fouling and scaling .......................................................... 26
   4.6 Economiser ................................................................. 26
   4.7 Recuperators ................................................................. 26
   4.8 Other combustion measures to reduce emissions ............... 27
   4.9 Load management .......................................................... 28
   4.10 Tuning the boiler ............................................................ 28
   4.11 Air levels ........................................................................ 28
   4.12 Blowdown ...................................................................... 28
   4.13 Post-combustion techniques ........................................... 29
   4.14 Performance optimisation ............................................... 29
   4.15 Summary ........................................................................ 31
I Introduction

Industrial boilers (IB) are used all over the world and play a key role for process and comfort heat in the industrial, residential and commercial sectors in developed and developing countries. Boilers play a major role in manufacturing, heating and electricity generation.

Depending on the design, industrial boilers can burn natural gas, oil, coal and other solid fuels such as biomass. Natural gas requires minimal fuel preparation, mixes well with the combustion air supply and burns with a low flame. Oil, depending on its grade, will need heating and screening prior to atomisation and then vaporisation before mixing with the combustion air supply. Coal combustion can be separated into three categories: grate firing, fluidised bed firing and suspension firing. The majority of smaller boiler units are stoker or grate fired (Payne and others, 1996).

Industrial or utility boilers are designed to burn fuel to produce steam. The steam can be used for electricity production or industrial processes. There are three significant differences between utility and industrial boilers:

- size;
- design;
- the application for the hot water and steam produced.

The design of industrial boilers will have an impact on their efficiency and operating costs. The industrial sector has developed new and more efficient boiler designs through research and technological developments. This is an important factor given that coal use is increasing in many countries combined with the introduction of more stringent emission regulations placing limits on nitrogen oxides (NOx), sulphur dioxide (SO2) and other gases and particulates. These regulations are to improve air quality as well as reduce greenhouse gas (GHG) emissions.

The options for reducing emissions through fuel substitution with biomass and improving efficiencies are also examined. There is the potential option of the Kyoto Protocol mechanisms to obtain carbon credits. This option could encourage the development of more efficient industrial boilers in developing countries, such as China and India. In particular, with developing countries the use of the clean development mechanism (CDM) could be used to encourage the uptake of more efficient industrial boilers. The options for CO₂ emissions reduction from industrial coal use concerning boilers include:

- sizing and grading of coal;
- improving operating practices;
- inexpensive equipment modifications;
- automatic boiler controls;
- cofiring and biomass;
- refurbishment/retrofit of FBC (Smith and Nalbandian, 2000).

This report does not cover the residential use of coal or power generation from utilities. Instead the focus is on industrial boilers in the iron, steel and cement industries within the range of 0.5–50 MWth and examines:

- pollution control requirements;
- control technologies;
- cost implications for industrial energy from coal.

Currently there is no international best practice for efficient coal-fuelled industrial boilers. Individual manufacturers of boilers provide guidelines to operate and maintain their boilers and operators with new boilers are likely to follow these guidelines to ensure that if any problems occur they are covered for the duration of any warranty. While there is uniformity in the generic design of industrial boilers they can differ due to factors such as the type of coal fired, efficiency and size of the boiler and fuel-feed systems. Pre- and post-combustion control techniques can also differ from manufacturer to manufacturer.

Steam generation consumes about 15% of global final industrial energy use. In some cases the efficiency of steam boilers is as high as 85%, but average efficiencies are often much lower (IEA, 2006). Efficiency measures that exist for boilers and distribution systems include general maintenance, improved insulation, combustion controls and leak repair in the boiler, improved steam traps, and condensate recovery. Boiler systems can also be upgraded to cogeneration systems (IPCC, 2007).

This report provides a check list of generic guidelines that can be applied to industrial boilers and which result in improved efficiency and consequently reduced emissions. The report provides an overview of current boiler technology employed internationally and assesses the best operating practices and technologies for a range of commonly used boilers with regard to maximising efficiency and minimising emissions.

Research has been published on improving the efficiency of industrial boilers through technological, operational and performance changes. In addition, boiler manufacturers design boilers for specific types of coal and publish guidelines on how to get the best performance from the boiler. This is also the case with large-scale utility boilers in the electricity generation sector where there is a wealth of information. However, much of this information, particularly for industrial boilers, is ad hoc and not available from one central source.

This makes it difficult to obtain consistent information on how best to operate a boiler and obtain maximum performance. This is especially true for boiler operators in developed and developing countries with small-to-medium sized industrial boilers in major industries such as food, manufacturing, district heating and the steel industry with coking coal. Where best practice technologies for coal combustion in boilers has been used the lessons learned can often be transferred to other countries without adequate resources or knowledge but with similar boiler stock.

Increasingly, governments are becoming more concerned about climate change, energy security and air quality issues resulting in more regulation and standards for carbon dioxide...
(CO₂) emitting industries. According to the Intergovernmental Panel on Climate Change (IPCC), the use of energy audit and management programmes can assist in providing guidance for a company or an organisation that wants to improve their management of energy. Many countries including India and the USA have systems in place to encourage energy management or energy audits. These can be used to identify ways to improve efficiency, performance, reduce waste and consequently reduce emissions. However, for such a system to be successful it requires identification of existing practices and how to make step by step improvements that become part of the company’s or organisation’s work culture (IPCC, 2007).

Coal-fired industrial boilers are subject to increasingly stringent environmental regulations and air quality limits or standards. A major advantage of some types of industrial boilers such as stoker-firing and fluidised bed combustion boilers (FBC) is their ability to produce relatively low emissions of pollutants. However, industrial boilers are normally small and unable to benefit from economies of scale with operators having fewer resources available for investment in pollution control equipment. In the future it is expected that internationally PM₁₀ emissions will come under increasingly stringent controls, and in some locations low PM₂.₅ emission levels may be enforced.

This study assesses the industrial boiler sector in the following areas:
- combustion;
- boilers;
- control and measurement equipment;
- emissions control;
- incentives and barriers to the introduction of more efficient industrial boilers.

An independent assessment of what could constitute current best practice for a range of boiler sizes was undertaken. This report identifies current information and training resources as well as different countries’ codes of practice for efficient use of coal in industrial boilers. There are several publications and websites in the references of this report that provide checklists to aid in trouble shooting boiler performance problems and are freely available. Some of these publications are useful for identifying the appropriate boiler to fit the parameters for a particular process or task at an early stage of a project. Incentives for encouraging the more efficient use of industrial boilers are discussed as well as the barriers to their uptake.

Chapter 2 examines the different types of boilers, stokers, grates and other technologies concerning industrial boilers. There have been major developments in recent years on improving the design, efficiency and safety of boilers. Chapter 3 details how several countries use industrial boilers including China, India, USA, the European Union (EU), Poland and New Zealand. In Chapter 4 methods to improve the efficiency of boilers in different process industries for heating, drying, fluid heat transfer to vapour refrigerating are examined. Chapter 5 outlines actual case studies of problems with boilers and identifying solutions with industrial boilers. This chapter also outlines options to implement CDM projects with industrial boilers and guidelines on undertaking a boiler improvement project. Finally a discussion on whether best practice is feasible for industrial boilers is outlined and the advantages and disadvantages of such an approach.
Since the publication by the IEA Clean Coal Centre in 2000 of *Industrial coal use – prospects for emissions control* which excludes the electricity power generation sector there has been little improvement in the collection of data on coal use within the industrial sector (Smith and Nalbandian, 2000). Energy must first be released from the combustion of the coal to operate a coal-fired boiler. The heat released is used to raise steam which can then be used to supply process heat or generate electricity. The system comprises the boiler, fuel supply, combustion air system, feedwater system and exhaust gases that must be vented. All of these systems need to operate together otherwise problems will arise affecting the performance of different parts of the systems.

The following criteria are important in the design of industrial boilers:
- steam pressures that are controlled by the specific process;
- high reliability with minimum maintenance;
- use of one or more locally sourced inexpensive fuels, including process by-products and waste fuels;
- low initial capital and operating cost;
- operating pressures ranging 1.0–12.5 MPa or 150–1800 pounds per square inch (psi) with saturated or superheated steam (Woodruff and others, 2005).

According to Basu and others (2000) a boiler’s design will vary depending on several factors including the type of fuel, the method used to fire the fuel, its application, how it is cooled and the pressure of the steam. Table 1 lists the different types of boilers that use a range of fuels.

The most common boiler thermal output used within industry is between 3 MWth and 20 MWth. There have been several technological improvements in the design of industrial boilers in recent years. In particular, improvements in the use of automatic controls has allowed better optimisation of performance including management of fuel quality, flow rate, pressure and temperature. Industrial boilers have heat input capacities ranging 3–70 MWth. Those that have heat inputs higher than 70 MWth) are on the scale of utility boilers. Commercial or institutional boilers can have heat input capacities of less than 3 MWth.

The efficiency of a coal-fired boiler is dependent on several factors including the firing system, the type of boiler or furnace and the coal quality. Optimisation of parameters such as temperature, fuel quality, pressure and flow has improved boilers efficiencies. An old, poorly-tuned boiler can use 10–15% more fuel than a modern boiler system. There are opportunities to retrofit or replace boilers with modern high efficiency units with heat recovery options to improve fuel consumption. These improvements, including high turndown burners and computerised controls can improve the efficiency of the boiler system by more than 25%.

This chapter examines the factors that influence the performance of industrial boilers. First, the nature of coal is a critical element in industrial boilers with the chemical composition of the coal influencing the design of the boiler. A brief overview of combustion and the types of analysis used to determine the best use of the coal is presented. Second, the types of industrial boilers are described, with a focus on the two main types: fire-tube and water-tube boilers. In a fire-tube boiler hot gases are channelled through cylindrical tubes that are surrounded by the fluid to be heated in an outer pressure vessel. In a water-tube boiler the fluid to be heated passes through the tubes which are surrounded by hot gases. Water-tube boilers are available in larger sizes and feature faster recovery times as well as being able to handle pressures up to 34 MPa. Boiler design and performance specifications for industrial boilers include heat output or capacity, maximum temperature, maximum pressure, and thermal efficiency. The various types of grates are covered. The various type of stoker technology and grates used in industrial boilers are described below.

### 2.1 The nature of coal

The design of an industrial boiler (IB) will depend to a large

<table>
<thead>
<tr>
<th>Firing method</th>
<th>Energy source</th>
<th>Use of steam</th>
<th>Water circulation</th>
<th>Steam pressure</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stoker</td>
<td>Coal</td>
<td>Utility</td>
<td>Natural</td>
<td>Atmosphere</td>
<td>Packaged (Shell)</td>
</tr>
<tr>
<td>Front firing burner</td>
<td>Liquid fuel</td>
<td>Industrial</td>
<td>Forced</td>
<td>Subcritical</td>
<td>Packaged (water-tube)</td>
</tr>
<tr>
<td>Tangential firing burner</td>
<td>Gas</td>
<td>Domestic</td>
<td>Once-through</td>
<td>Supercritical</td>
<td>Field erected</td>
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<tr>
<td>Opposed firing burner</td>
<td>Solid wastes</td>
<td>Marine</td>
<td>Combined</td>
<td>Sliding pressure</td>
<td></td>
</tr>
<tr>
<td>Downjet firing burner</td>
<td>Biomass</td>
<td>Naval</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclone firing</td>
<td>Bubbling fluidised</td>
<td>Recovery</td>
<td>Hot gas boiler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circulating fluidised</td>
<td>Waste heat</td>
<td>Cogeneration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No firing method</td>
<td>Nuclear fuel</td>
<td></td>
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</tbody>
</table>
degree on the chemical composition of the coal used to fuel the boiler. As well as carbon, oxygen, nitrogen and hydrogen coal contains some water and impurities which are usually made up of mercury, sulphur and ash. All of these can cause problems with emissions from industrial boilers. Figure 1 illustrates the different types of coal that can be used for combustion.

There are three main factors that determine the properties of coal and they are the rank, type and grade. Table 2 illustrates the five different types of coals.

The type, rank and composition of coal to be used influences the design of the boiler. The coal is analysed as part of the design process. Due to the versatility of coal it can be used for many types of applications including:
- as fuel in stationary boilers used to power industry;
- in power boilers used to generate electricity;
- as a reducing agent in chemical processes;
- as a source of carbon in the steel making industry; and
- as gasifier feedstock in the production of syngas and hydrogen (Levi and Trolove, 2008).

The properties of coal are not uniform which means that a coal suitable for one application may not be suitable for another. The selection of the coal is influenced by its chemical and physical properties. There are several key properties that can be tested using different methods when selecting a coal for use and they include:
- moisture;
- proximate analysis (fixed carbon, volatile matter, ash);
- ultimate analysis (carbon, hydrogen, nitrogen, oxygen, sulphur, and chlorine);
- gross caloric value (as received and on a dry basis);

<table>
<thead>
<tr>
<th>Rank</th>
<th>Depth of burial, km</th>
<th>Maximum temperature during burial, °C</th>
<th>Moisture content, %</th>
<th>Fixed carbon content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat</td>
<td>0–0.2</td>
<td>0–25</td>
<td>50–80</td>
<td>10–20</td>
</tr>
<tr>
<td>Lignite</td>
<td>0.2–1.5</td>
<td>25–40</td>
<td>30–50</td>
<td>20–35</td>
</tr>
<tr>
<td>Subbituminous</td>
<td>1.5–2.5</td>
<td>45–75</td>
<td>10–30</td>
<td>35–45</td>
</tr>
<tr>
<td>Bituminous</td>
<td>2.5–6</td>
<td>75–180</td>
<td>5–10</td>
<td>45–80</td>
</tr>
<tr>
<td>Anthracite</td>
<td>&gt;6</td>
<td>&gt;180</td>
<td>&lt;5</td>
<td>80–96</td>
</tr>
</tbody>
</table>

Figure 1 Types of coal (World Coal Institute, 2005)

Table 2 Rank classification of coal (Levi and Trolove, 2008)
There are three types of fluidised bed combustion boilers:

- Good practice for industrial coal-fired boilers
- An industrial boiler can operate for several decades if
- pressurised fluidised bed combustion (PFBC).
- atmospheric circulating (fast) fluidised bed combustion (CFBC);
- pressurised fluidised bed combustion (PFBC).

Boilers are designed to use different types of coals. There are four main classes of coal from high quality anthracitic, bituminous, subbituminous to low quality brown and lignitic coal. To ensure coal is used efficiently in boilers engineers need to know the quality of the coal which can be determined by analysis. There are three types of analysis: proximate analysis, ultimate analysis and heating value. Proximate analysis examines the behaviour of the coal when it is heated to identify its variability by determining the level of volatile matter, ash, the fixed carbon in the coal and its moisture content. Proximate analysis is useful in determining the best practical application of the coal in industrial boiler applications. Ultimate analysis is a procedure to determine the principal chemical elements in coal, which are carbon, nitrogen, oxygen, sulphur and hydrogen (Carpenter, 1988). Lastly, there is the heating value test which identifies the quantity of energy that can be generated by burning the coal, known as either the calorific value or heating value.

2.2 Types of boilers

According to Orland (2002), there are three options to classify industrial/commercial/institutional (ICI) boilers:

- Water-tube or fire-tube units. This classification recognises how the water and combustion gases are designed to pass through the unit.
- Boilers can be classified by their heat sources in that they are referred to as coal-fired, gas-fired, oil-fired, or solid fuel-fired boilers. Coal-fired boilers can be divided further based on the technology used to fire the boiler. The three major coal-fired boiler subclasses are pulvurised coal (PC) fired, stoker-fired, and fluidised bed combustion (FBC) boilers.
- Boilers can be defined or distinguished by their method of fabrication. Packaged boilers are assembled in a factory, mounted on a skid, and transported to the site as one package ready for connection to auxiliary piping. Shop-assembled boilers are built up from a number of individual pieces or sub-assemblies. After these parts are aligned, connected, and tested, the entire unit is shipped to the site in one piece. Field-erected boilers are too large to transport as an entire assembly. They are constructed at the site from a series of individual components (Orland, 2002).

There are three types of fluidised bed combustion boilers:

- atmospheric fluidised bed combustion (AFBC);
- atmospheric circulating (fast) fluidised bed combustion (CFBC);
- pressurised fluidised bed combustion (PFBC).

An industrial boiler can operate for several decades if designed correctly and well maintained. A boiler should include the following:

- simplicity in construction, excellent workmanship, materials conducive to low maintenance cost, high efficiency, and high availability;
- design and construction to accommodate expansion and contraction properties of materials;
- adequate steam and water space, delivery of clean steam, and good water circulation;
- a furnace setting conducive to efficient combustion and maximum rate of heat transfer;
- responsiveness to sudden demand and upset conditions;
- accessibility for cleaning and repair;
- a factor of safety that meets any code requirement (Woodruff and others, 2005).

The first step before designing the boiler is to calculate the stoichiometric quantity of air required, how much flue gas will be produced from the fuel and how much heat is released per unit weight of coal burnt (Basu and others, 2000).

A good understanding is needed of the various elements that allow a boiler to operate at its most efficient level. This knowledge can improve the performance and efficiency of industrial boilers. One aspect of this is to use the correct fuel or coal as the nature of the coal will affect the performance and efficiency of the boiler. Another key element is the boiler operator or site engineer. Their knowledge and skills in operating the boiler could make a major difference in its performance.

Stoker firing and FBC can produce low levels of emissions and pollutants. However even if there is a desire to reduce pollutants, the fact that many industrial boilers are small means they cannot benefit from economies of scale and operators are likely to have fewer resources available for investment in pollution control.

A further major element in using industrial boilers is tougher regulatory requirements with increasingly stricter standards. This is particular the case in Europe and USA. The US Clean Air Act (CAA) introduced in 1970 with major amendments in the 1990s has resulted in better air quality and improvements in technology. In Europe there are several directives which can have an impact on the use of industrial boilers, as discussed in Chapter 3.

Stoker-fired boilers are usually water-tube boilers with a mechanical system to feed the coal into the boiler. The hot combustion gas is circulated around the water-filled tubes lining the walls of the water-tube boiler. In fluidised bed combustion (FBC) boilers the coal is burned on a bed of hot particles suspended by an upward flow of combustion air. FBCs can burn a variety of fuel types and achieve higher rates of efficiency in comparison to other water-tube boilers. Bubbling FBC have better fuel flexibility than stoker-fired boilers, lower NOx emissions and can utilise an in-bed sorbent for SO2 control.

Bubbling FBC boilers are designed with a high degree of flexibility in the provision of air between the bed and the overfire air system. This allows the fuel delivery and gas
recirculation volumes to be varied. The advantage of bubbling FBC is the variety of fuels that can be used including those with a high moisture content. Some of the fuels that can be useful with bubbling FBC include:

- woodwastes and bark;
- paper mill sludges;
- sewage sludge;
- tyres;
- coal with peat and many forms of biomass.

In comparison to stoker technology the circulating FBC has many advantages such as a larger furnace size limit, lower NOx and carbon monoxide (CO) emissions, higher efficiency with unburnt carbon being lower, no moving parts, in-bed SO2 control, no cyclone dust collectors are needed and fuel variations will not cause unstable steam generation.

### 2.2.1 Fire-tube boiler

Industrial boiler manufacturers produce both fire-tube and water-tube boilers. Fire-tube boilers operate by forcing heat through tubes immersed in water. They are normally used in low-pressure applications. The water is circulated within the water-tube boiler enclosure. Hot flue gases are passed over the tubes, resulting in heating of the water, and are then discharged through a stack. They are preferred to water-tube boilers as they are lower cost, compact and require little or no precise setting. In addition, the accessibility of the tubes makes replacement simpler than water-tube replacement. However, there are a number of disadvantages including limited capacity, and only moderate pressures, and steam temperatures. Water volume is large with poor circulation resulting in slower responses to steam demand (Woodruff and others, 2005).

Fire-tube boilers are also known as shell or drum boilers. They are relatively easy to manufacture but, as previously discussed, have limitations related to power output and pressure. Therefore they are small in size, usually between 1–10 MW, and with an operating pressure normally not greater than 1 MPa. Figure 2 illustrates a typical fire-tube boiler.

### 2.2.2 Water-tube boilers

In higher pressure applications, water-tube boilers are used as they have greater structural integrity. Figure 3 illustrates the layout of a water-tube boiler. The heated water is contained in tubes and the hot combustion gases pass over the outside of the tubes. Normally, a modern water-tube boiler uses two drums, referred to as the water or bottom drum, and the steam drum.

The tubes are arranged as a D formation and hot gases from the furnace pass over the tubes on the path out of the furnace. The furnace walls are constructed from water filled tubes which cool the steel as well as capture heat energy from the combustion chamber. Water-tube boilers are not subject to the same internal forces as fire-tube boilers and are utilised where higher pressures or power outputs are needed. Water-tube boilers are also more flexible and can respond quickly to changes in load demand due to their higher heating surface area and lower thermal mass within the boiler. Water-tube boilers range between 7 MW and 40 MW units and can be coupled together to provide higher outputs. They can reach sizes of 150 MW.
2.3 Overview of stoker technology

Stokers are classified according to the method of coal feeding and ash removal. There are several types of stoker technology including:

- overfeed stoker;
- mass-feed stoker;
- spreader stoker;
- underfeed stoker;
- coking stoker;
- moving bed stoker;
- chain grate stoker;
- reciprocating grate;
- travelling and chain grate;
- sprinkler;
- spreader;
- vibrating grate.

The firing systems with stokers must be integrated into the boiler design to achieve the most efficient combustion and heat recovery as well as minimising unburnt fuel and emissions. A stoker includes:

- a fuel admission system;
- a moving or stationary rate assembly grate that provides support for the burning coal and a pathway for the primary combustion air;
- an overfire air (OFA) system that supplies additional air to complete combustion and minimise atmospheric emissions;
- an ash discharge system (Orland, 2002).

The emissions of SO₂ from a stoker boiler depend on the sulphur content of the coal. Residues may have a carbon-in-ash content as high as 5% because of relatively inefficient combustion, and the restricted access of oxygen to all the combustible material. Fluidised bed boilers have been identified as a potential replacement for stoker-fired industrial boilers as they have the capacity to burn a range of coals including low quality coals and are more efficient and so can contribute to meeting pollutant emission standards.

2.3.1 Overfeed stoker

Overfeed stokers are generally classified as either mass-feed or spreader stokers. The designations reflect the way the fuel is distributed and burned within the boiler.

2.3.2 Mass-feed stokers

Mass-feed stokers introduce fuel continuously at one end of a grate. The fuel from the hopper spreads onto the grate under gravity. The height of the fuel bed is controlled by a gate which also controls the fuel movement speed. Inside the boiler the fuel burns as it travels along the grate. Ash that forms and remains is discharged at the opposite end. Primary combustion air flows upwards from beneath the grate and through the burning bed of fuel. The two primary mass-feed stokers are water-cooled vibrating grate and moving (chain and travelling) grate stokers.

2.3.3 Spreaders stokers

Spreader stokers using travelling grates are versatile and are the most commonly used stoker application for industrial boilers. The spreader stoker is relatively simple to use, has low maintenance requirements and can respond to different load demands. They can also operate effectively with coals that have a wide range of ash, volatile and moisture contents. Spreader stokers can produce high particulate emissions (Woodruff and others, 2005). In the spreader stoker arrangement, a high-speed rotor throws the coal into the furnace over a moving grate, to promote fuel distribution. Such boilers have commonly been used in sizes equivalent to 10–25 MWe, but emissions control tends to be uneconomic from such units, apart from the use of cyclones for particulate removal. Combustion is relatively unstable, so that there can be intermittent emissions of CO, NOx and organic compounds.

Spreader stokers are capable of distributing fuel evenly and to a uniform depth across the entire grate width by using a device (such as air injection, underthrow/overthrow rotors) that propels the individual fuel particles into the air above the grate. The bed depth gradually reduces from front to back of the grate. As the fuel is thrown into the boiler, fines ignite and burn in suspension. The coarser particles fall onto the grate and burn in a thin bed. Primary combustion air is supplied from an air plenum located beneath the grate. The grates are generally moving such as travelling grates, air-cooled vibrating grates or water-cooled vibrating grates (Orland, 2002).

2.3.4 Underfeed stoker

Underfeed stokers provide a well-established method of burning highly volatile coal (35–40%) efficiently and with a minimum of smoke emissions. They can be manufactured for use in sectional, shell and small water-tube boilers with outputs of up to 2 MWth.

Coal is transferred from a hopper to the combustion chamber by a screw feeder. Once in the combustion chamber, the coal slowly wells up out of a retort area around which are a series of jets or tuyeres where the primary air enters the chamber. As the volatiles are released below the incandescent zone of the fire bed, smoke is reduced without excessive secondary combustion air. The retort which contains the fire bed is critical to the combustion performance and several designs exist. Coal specification is generally limited to well-sized singles or doubles grade with a non-caking nature (although some caking coals can be used in high temperature applications).

A range of smaller industrial underfeed stokers have been developed, where the ash, in the form of a fused clinker, is easily removed. Some units use manual ash removal but others are available with automatic ash removal in the form of an adjacent grate of reciprocating bars. Volatiles are burned in the main retort, but residual coke is allowed to spill onto the reciprocating bars to burn completely; the ash falls through
the bars to an ash removal screw. Manual attention is not eliminated but is vastly reduced, as the stoker only needs to be attended once every three days.

Underfeed stokers are used on smaller water-tube boilers up to 7 MW as their boiler capacity is limited by the feed capability. Although this can be countered by fitting additional screws, it has been found that the installation and running costs of multiple screws make this an uneconomic approach.

### 2.3.5 Coking stoker

The coking stoker, shown in Figure 4 is a very well-established coal-firing system. The principle of operation has changed little over the years. However, modifications to the design have created a good system for automated, minimally attended boiler operation.

Coking stokers are normally used in boilers with outputs between 1.8–6 MWth. The coal is fed by a ram from a hopper, mounted at the front of the boiler, onto a grate consisting of a number of reciprocating bars. This is a continuous process and ignition of the coal takes place through back-radiation from a small refractory arch. The reciprocating bars move in sequence, driven via a system of cams, in such a way that the coal is walked along the length of the grate bars. As the coal travels along the grate, primary air is drawn up through the grate bars by an induced draught fan allowing combustion to take place. Ash falls off at the end of the bars and may be removed manually or automatically from beneath the furnace (DTI, 1998)

Secondary air may be supplied above the fire bed or, alternatively, steam jets may be used to create turbulence above the fire, thereby minimising smoke emissions. The addition of a rotary valve, or ‘firebreak’, between the coal feed hopper and the ram eliminates the possibility of the ignition front travelling back towards the coal feed hopper area. The original coking stoker design required manual attention to remove the build-up of ash-based deposits in the furnace. Recent modifications have removed this requirement, so modern systems of this type can be automated to a great extent.

Although the response to load changes of a coking stoker is less rapid than that of a static grate system, the use of a proportional integral derivative (PID) controllers means that this type of coal-firing system can be used in most industrial applications. Incorporation of variable speed motor drives and the ‘firebreak’ results in better control of air:fuel ratio, thus improving combustion performance and achieving high thermal efficiency.

The coking stokers normally operate with coals of specification similar to that for static grate stokers. It is possible to use coal of a wider size range with a top size of 25–32 mm, but this may increase the loss of unburnt coal dropping through the grate bars. Minimisation of the loss of this unburnt material is essential for high overall thermal efficiency and does require periodic checking and adjustment of the reciprocating grate bars to ensure appropriate clearance between the bars is maintained.

### 2.3.6 Moving bed stoker

The moving bed stoker (also known as the ram-type coking stoker) comprises a series of cast iron or heat resistant steel bars, that are layered in a series of shallow steps that slope towards an ash-collection pit. The lower end of the topmost bars overlaps the upper end of the next layer of bars down. When the bars are driven backwards and forwards, their movement draws fuel onto them, and then pushes the burning fuel down the bed. Fuel is usually fed to the grate using a mass-feed stoker.

The technology has great versatility and can handle a wide variety of coals except those that tend to cake. The gentle action of the bars means that they are able to cleanly burn coals with high ash content and large quantities of fines. This is very useful for New Zealand bituminous coals. This versatility also means that they are regularly used on biomass boilers for fuels which are difficult to handle. Little attention is needed to run this type of boiler, and the emissions are low if the bed is left undisturbed.

The main disadvantage of this boiler grate is the deep fuel bed that is present at the top end of the grate. The large mass means that the boiler is slow to respond to changes in demand.

### 2.3.7 Chain grate stoker

The chain grate stoker system, shown in Figure 5 and the closely related travelling grate stoker offer a versatile coal firing system and are particularly important for the larger end of the industrial boiler market. However, the outputs available using these systems vary widely (1.5–80 MWth) (DTI, 1998).

There have been many variations on the same theme, but all consist of a partially flexible, looped ‘mat’ made up of metallic links connected to a drive system. The top surface of the mat remains under tension and acts as a continuously moving grate. As with the coking stoker system, the coal is fed from a hopper at the front of the boiler. The top surface of

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**Figure 4** Coking stoker system (Levi and Trolove, 2008)
the grate is driven so that it moves away from the front of the boiler moving the coal with it. Ignition of the coal is effected by radiation from a refractory arch. Primary combustion air is provided by a forced draught fan feeding into a plenum chamber under the grate and then up through the bed of coal on the grate. Distribution of the air throughout the length of the grate must be carefully controlled as the resistance to flow varies with the thickness of the bed of coal and ash.

A great deal of development work has taken place to introduce baffles and control dampers into the plenum chamber to control air distribution through the fire bed effectively. Additional turbulence is generated above the main fire bed through the use of secondary air or steam jets. It is usual for the system to use an induced draught fan. The ‘firebreak’ concept has also been applied to this system to increase the level of automation, along with modifications to reduce the build-up of deposits within the furnace (DTI, 1998).

The boiler output is controlled by a combination of initial coal-bed thickness and the speed of the grate movement. This produces a very flexible combustion system but, without the ‘firebreak’, there are potential hazards relating to the ignition front moving towards the coal-feeding hopper. Traditionally, grate speed has been controlled through a mechanical gearbox, using a series of steps to change the speed to a required level. By introducing a variable speed motor drive instead of a gearbox, the grate speed can be varied widely, allowing a high turndown ratio to be achieved. Extensive development work has been carried out in recent years to optimise the control of the key parameters such as:
- grate speed;
- bed thickness (through the ‘firebreak’ rotary valve);
- air distribution;

Insulation improvements and combustion condition monitoring, along with this work, have resulted in a new packaged boiler/stoker system combination. With these additions, the response to load changes is good. The main disadvantages of chain grate stokers are the high capital cost and a comparatively high maintenance requirement. Travelling grates are normally used for larger boiler outputs, typically 15 MWth and above.

The chain grate and travelling grate systems can operate on a wide range of coals. One of the most important coal characteristics with this system is the need for an ash content of 5% or greater, as the ash layer on the grate provides protection from the potentially damaging heat in the fire bed. Development of neural network controllers for industrial boilers has been undertaken using a highly automated chain grate-fired plant (DTI, 1998).

Spreader stokers are used on water-tube boilers and may be underthrow or overthrow. Spreaders appear similar to overfeed stokers and may use a similar conveyor and hopper arrangement transporting the fuel to the furnace entry point. Where the overfeed stoker uses a rotating drum to place or drop coal onto a moving chain grate, the spreader stoker uses a high speed rotating drum to throw coal into a furnace.

### 2.4 Grates

The grate is a major working part of the stoker boiler and requires careful attention to design, maintenance, and operating conditions to enable reliable and constant boiler operation. The grate is also the initial collection point for bottom ash and the type of grate employed will dictate and be integral with whatever ash handling and disposal mechanism is employed.

Grates can be made from carbon steel, cast iron, or alloy and are unable to tolerate the high temperatures generated from a furnace. Therefore grates require cooling to prevent buckling, melting, and rapid failure. The grates can be either air-cooled...
with combustion air through its holes or they can be water-cooled using other systems.

A water-cooled grate consists of parallel boiler tubes welded together, with the air holes drilled through the steel strips between the tubes. The tubes are connected to headers at the front and back of the grate, forming a water circuit. The boiler feedwater can be passed through this circuit, or in the case of hot water boilers, the circuit is paralleled across the main flow and return lines.

The design of the fuel-feed systems will influence the performance of boilers. The type of fuel will influence the operational features of a fuel-feed system. The major functions of fuel-feed systems are to transfer fuel into the boiler while also spreading or distributing the fuel within the boiler to provide for uniform and complete combustion.

There are several different types of fuel-feed systems for coal stoker units that include spreader, overfeed and underfeed. In overfed or underfed, the coal is transported directly on to the burning bed. Underfeed and static grate systems are only used on very small plant, primarily for steam raising for heating water rather than power generation. In contrast, in a spreader stoker the coal is introduced into the furnace where it is partly burned in suspension before combusting on the grate. With these types of stokers there are several different styles of grates including chain, dumping, stationary, travelling and vibrating. Each type of grate will need a particular coal specification with regard to coal fineness and ash characteristics for optimal operation of the boiler (DTI, 1998).

### 2.4.1 Travelling grate

Travelling grate spreader stokers have been in existence since 1938 and are the most popular way to burn coal on stokers for boilers above 23,000 kg of steam/h. The travelling grate stoker is similar to the chain grate in that it involves a continuous conveying of fuel across the combustion zone and discharge of the remaining ash into the ash removal system. The difference is that the fuel is carried on heat-resistant grate clips which are mounted on the chain and provide a surface for the fuel to burn on and protect the chain from the heat. This feature makes them useful for a wide range of coals with different characteristics, as well as difficult to handle biomass materials.

Chain and travelling grate furnaces have similar characteristics. Coal lumps are fed continuously on to a moving grate or chain (Johnson, 2002). Air is drawn through the grate, and through the bed of coal on top. As the coal enters, it is heated by radiation from the refractory arch inside. Moisture and volatile matter are driven off. The grate moves the coal slowly into the region in which ignition is established, and the temperature in the coal bed rises. The carbon gradually burns off, leaving ash which drops off at the end into a receptacle, from which it is removed for disposal. The ash formed may have a carbon content as high as 4–5%.

On a given unit and fuel, the grate speed is a function of load.

### 2.4.2 Vibrating grate

The vibrating grate is used only on water-tube boilers. Like the travelling, and chain grates, combustion air is forced from beneath the grate through air holes into the burning mass of fuel sitting on top of the grate. Fuel is blown onto the vibrating grate by either windswept spouts or a spreader stoker. Vibrating grates are fixed in position, but have flexible mounts that allow the grate to vibrate. Periodically, the grate will be vibrated vigorously by a motor, generally under the control of a timer. The vibrating grate is usually mounted on an incline towards the ash pit, so that when vibration occurs, the ash is agitated towards and into the ash pit for removal. The depth of the coal feed is regulated by the gate at the hopper (Woodruff and others, 2005).

### 2.4.3 Dumping grate

The dumping grate has combustion air forced through the
grate from the plenum chamber below. The grate consists of a number of tiles that can hinge in unison and dump the contents of the grate into the ash-collection pit below. The dumping action is driven by linkages and a motor. On larger boilers the grate may be split into two sections, allowing one half of the grate to be dumped at a time. Dumping grates have difficulty in maintaining opacity limits. Each dumping action stirs up the fuel bed and disperses an amount of fines into the furnace. This usually triggers a high opacity event, meaning that dark smoke and particulates exit with the flue gas.

2.4.4 Static grate

The static grate principle provides a very flexible coal firing method for use in shell boilers. It provides a relatively low-cost package unit over a wide range of boiler output (600 kWth to 11 MWth) with a turndown ratio of up to 4:1. The coal is metered through a coal feed screw and fed onto a fixed grate consisting of a number of individual cast-steel grate bars. Ash is removed manually from the grate at intervals. The frequency of ash removal is dependent primarily on boiler load and fuel ash content. A schematic of the static grate is shown in Figure 6.

The pressure drop across the grate ensures even distribution of the primary air supplied through the grate. Secondary air is supplied around the coal-feed pipe above the bed. This secondary air supply is vitally important for the elimination of smoke and in achieving good combustion of the volatile matter. The volume, velocity and direction of this air must all be optimised to ensure satisfactory combustion. A great deal of effort has been into establishing optimum combustion conditions for this type of coal-firing system. As indicated, the grate bars act as the primary air distribution system when assembled. The design of these grate bars is crucial to ensure the correct distribution of the primary air through the fuel bed. Response to changes in boiler load is good with this system due to the relatively high-intensity combustion and low thermal inertia in the furnace. This has been further improved by development of solid-state proportional integral derivative (PID) control systems and installation of variable speed drive motors for the main air fans and coal feed screws. These modifications offer not only improved response times but facilitate much closer control over air distribution and air:fuel ratios. This leads to higher combustion efficiency and also reduced heat loss to flue gases and thus higher boiler efficiency over the whole operating range.

The main disadvantage of this system has always been the necessity for manual ash removal. The development of the ‘tipping grate’ system has enabled the same combustion principle to be used whilst allowing automatic ash removal. The static grate system requires a coal with low swelling characteristics that is size graded between 12.5 and 32 mm nominally. The size limit is related to the feed system where fine coal sizes would otherwise increase particulate emissions. A static grate fitted with an underfeed stoker will be able to handle a smaller coal size. Ash content is normally restricted to 5–8% mainly to avoid excessively frequent ash removal. A washed and size-graded coal is therefore a requirement for this type of stoker. As with the dumping grate, ash removal stirs up the fuel and ash bed leading to periods of very high particulate emissions and carbon monoxide. The cleanliness of the combustion during operation is also dependent on the operator skill because a poorly-raked grate leads to air bypass, greater emissions of CO and particulates, and poor efficiency.

2.4.5 Windswept spout

Windswept spouts are used on water-tube boilers. Fuel is metered into the draft of high velocity air nozzles and blown into the furnace to land on the grate. A rotating damper within the air swept spout ducting causes the intensity of the draft to vary giving the fuel a cycle between weaker and stronger throws. This allows the fuel to be thrown evenly from the front to the back of the grate.

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**Figure 6** Schematic of a static grate system (Levi and Trolove, 2008)
A bypass damper sets the minimum throw velocity and the speed of the windswept spout fans sets the maximum throw. These variables must be set correctly to give even grate cover and hence even heat release. The air admitted to the furnace from the spouts serves as secondary air and must be accounted for in the tuning of fuel:air ratios. An advantage of the windswept spout system is greater reliability due to fewer moving parts than other stoker systems.

2.4.6 Vekos firing system

Vekos boilers are of the fire-tube type but differ significantly in the way they are fired. Coal is pneumatically conveyed into the boiler. The fuel-laden airflow is guided by a pyramid or cone beneath the coal entry duct. This spreads the coal in an even layer across the bed. Usually the grate is stationary requiring periodic manual ashing out. Vekos boilers are prone to high emissions of particulates and have high operating and maintenance costs.

2.5 Industrial boiler thermal efficiency

As there are several ways a boiler efficiency can be measured it can sometimes be quite confusing. One important factor to consider when measuring efficiency is that all forms of heat loss are considered. The goal to increase efficiency is to optimise the boiler performance and to increase operational flexibility without having a major impact on the overall system.

The efficiency of a boiler is the capacity of the unit to maximise the conversion of fuel energy or the coal to thermal energy with minimal heat losses. The more efficient a boiler is the less coal is needed to produce a specific quantity of energy or steam. According to Payne and others (1996) there are four ways of defining boiler efficiency. The first is ‘as-found efficiency’ which is the efficiency measured in the workplace when boilers need to be repaired or maintained. This baseline is used to measure any subsequent efficiency improvements. The second is ‘tuned-up efficiency’ which is the efficiency after any adjustments or minor repairs have been made to a boiler. Thirdly, there is the ‘maximum attainable efficiency’ when the best available technology is used. Lastly, there is ‘maximum economically achievable efficiency’ when efficiency improvement equipment is added to a boiler if it is cost-effective to do so.

A common definition of general boiler thermal efficiency is the ratio of the heat output, $E_{\text{out}}$, over the heat input $E_{\text{in}}$. Measurements must be taken of the stack heat loss and, if possible, the heat losses outside the surface of the boiler to calculate the boiler thermal efficiency. The combustion efficiency is the measurement of how effective the burner is in providing the optimum fuel:air ratio for complete fuel combustion. In order to do this a standard thermal test would be taken of all heat inputs, outputs and losses from the overall system. Taking these measurements allows these factors to be compared with the design expectations and any losses of efficiency can be identified by analysis of the flue gases from several places. This would include:

- the gas content of the flue gas by percentage (oxygen, carbon dioxide and carbon monoxide);
- any unburnt solid fuel by weight;
- elemental fuel content;
- exact mass-flowrates and properties, such as humidity and air intake.

Quantification of the combustion efficiency requires determining losses from unburnt:

- carbon in the flue gas (CO);
- carbon in the solid residue (bottom ash and fly ash);
- unburnt hydrocarbons (UHC) in the flue gases (Orland, 2002).

2.6 Summary

The design of industrial boilers is determined by the type of coal used and there are several designs that can be applied. If industrial coal use in boilers is to retain a place in the world’s energy supply then a key factor will be cost. Coal-fired equipment costs are higher than those associated with gas or oil due to the high costs of coal and ash handling. Therefore coal will only be selected if less expensive than other fuels. In addition, even if coal has a low cost it is difficult to match the convenience of gas and comply with air quality standards especially OECD countries. It is important that to be competitive industrial boilers should be as automated as possible in storing the coal, transferring and feeding into the combustion equipment and removing ash for transfer offsite and utilisation. These are all difficult elements to address for small-to-medium sized industrial boilers and the key reasons why small-scale industrial use of coal has virtually disappeared in OECD countries (Topper, 2009).
3 Countries using coal-fired industrial boilers

The result of increasing industrial demand in developed and developing economies has resulted in more use of coal. There have been many advances and improvements in the last 20 years with combustion technologies. Many industrial facilities in developing countries are relatively new and use the latest technologies. However, old and inefficient industrial facilities still remain in both developing and industrialised countries (IPCC, 2007). Volatile oil and gas prices as well as issues surrounding energy security make it likely that countries with large indigenous coal reserves such as China, India and the USA will continue to increase usage. This will mean the continued use of coal-fired industrial boilers where there is no alternative or economic alternative to coal. However, the increasingly complex legislation to improve air quality and also limit CO₂ is having an impact on the use of industrial coal-fired boilers, in particular within the USA and EU.

In 2004, 85% of the total energy use in the industrial sector was by energy-intensive industries. This covers energy-intensive industries such as iron and steel, chemicals and fertiliser, cement, pulp and paper and non-ferrous metals. The remaining share of energy use was from small and medium sized enterprises (SMEs) which make up a considerable proportion in developing countries (IPCC, 2007). However, there remains a lack of detailed information on the use of industrial boilers, with little published literature. As a result there is little accurate coal use data and an absence of specific numbers on boilers in many countries, or on their industrial use of coal. This is particularly the case for small size boilers (Smith and Nalbandian, 2000).

This chapter examines countries where coal is used widely in industrial boilers and includes China, India, USA, the wider EU, Poland and New Zealand.

3.1 China

China is the biggest consumer and producer of coal globally. The Chinese economy and energy system is driven by coal with over 60% of primary energy demands met by coal. According to the IEA World Energy Outlook (WEO) Reference Scenario, China’s primary energy demand is projected to climb from 1742 Mtoe in 2005 to 3819 Mtoe in 2030, which translates to 63% of the total primary energy demand being met by coal. In 2005, the industrial sector used 478 Mtoe or 42% of the total final energy consumption. Two thirds of that energy use was in three sectors: iron and steel, non-metallic minerals, and chemicals and petrochemicals (IEA, 2007). Improvements to the performance of existing power stations, industrial boilers and other facilities could lead to a significant reduction in emissions from coal-fired facilities.

In 1991, China had approximately 500,000 industrial boilers used for light industry and district heating systems, consuming over 400 Mt of coal a year. Industrial boilers in China have small unit sizes compared to international standards. In the mid-1990s half of them produced 1–4 tonnes of steam per hour. Their efficiency levels were in the range of 60–65%, compared with up to 85% in developed countries (IEA, 2008a, b). Chinese coal is normally not of high quality and other factors such as load and poor maintenance can contribute to lower efficiencies. According to Yu and others (2008), the consumption of coal in different sectors was 12% for construction, 9% for metals and 6% for chemical engineering in 2002. This means that coal forms 90% of fuel used in industrial boilers and 40% of that in households. The IEA expects that over time China and India will use less coal in the industrial sector due to the improved operation of boilers and washing of coal. In addition, as a result of air pollution concerns in urban areas there has been more natural gas substitution for coal in small-scale boilers (IEA, 2008a, b).

Industrial boilers (IB) in China are defined as boilers operating at up to 6 MPa pressure and 130 t/h (around 90 MWth) steaming capacity (or hot water equivalent). Such boilers are manufactured by boilermakers who are graded by the government into categories ‘A’ to ‘E’. The IB manufacturing market in China has around 700 boilermakers supplying some 20,000 boilers annually, with a combined thermal output approaching 60,000 MWth (UK DTI, 2001). According to a World Bank report in 1990, medium- and small-scale IBs are defined as boilers that produce less than 65 t/h of steam. They consumed over 350 Mt of coal in China, or around 35% of the country’s coal use. China then produced 715 Mt of CO₂, amounting to 30% of total GHG emissions from energy consumption. In 1990 there was estimated to be half a million IBs in China with over half of these between 1 t/h and 4 t/h, and with an average size of only 2.3 t/h (World Bank, 1996). As China has large indigenous coal reserves and coal has cost advantages relative to other types of fuel, it is likely that small to medium boiler use will continue for the foreseeable future.

Of the approximately 500,000 industrial boilers in China, 90% are coal boilers with a design efficiency of 72–80% and operating efficiency of 65%. The government has a goal to improve efficiency by 5% through upgrades (Minchener, 2000). There have been several studies and assessments by different organisations including the World Bank to examine options to improve the efficiency of Chinese industrial boilers. The majority of Chinese industrial boilers are based on pre-1950 design principles and production methods. Improving the thermal efficiency of the current stock of IBs in China could reduce the consumption of coal and decrease emissions.

The Chinese Government has taken action to reduce emissions from industrial boilers and in its 11th Five-Year Plan (2006-10) the National Development and Reform Commission (NDRC) announced three measures to reduce the nation’s kiln and boiler consumption of coal:

- selection of high-quality coal and lump coal;
- renovation of medium and small sized boilers and kilns
with advanced techniques such as circulating fluidised bed (CFB) and pulverised coal firing;
- establishment of a scientific management and operation system.

It is expected by the Government that these measures will raise the efficiency of coal-burning kilns and boilers between 2–5 percentage points, saving between 10 Mt and 25 Mt of coal. The target for these measures are the 500,000 medium sized and small boilers currently with an average capacity of only 2.5 t/h and an actual efficiency around 65%. In total, 90% of these boilers are coal burning using 350–400 Mt/y, of which 70 Mt could be saved by the proposed measures (IEA, 2008a,b).

The complexity of implementing these actions successfully is reflected in Figure 7 which illustrates the multitude of public authorities involved. These organisations are responsible for clean coal technologies (CCT) diffusion and increasing efficiency, but competing roles makes the structure fragmented. To illustrate, several of the authorities have different political objectives. For example the State Environmental Protection Administration is concerned with raising environmental regulation standards and the Ministry of Commerce is concerned with economic aspects. There are also overlaps between different authorities in both the Ministry of Science and Technology and the Energy Research Institute in charge of developing CCT related R&D programmes as well as the State Environmental Protection Authority responsible for environmental R&D projects such as energy efficiency. According to Vallentin and Liu (2005), since the abolishment of the 1995 ‘State Clean Coal Technology Program Leading Group’, China lacks a central forum for co-ordinating CCT promotion policies and assisting in avoiding policy inconsistencies. This makes the likelihood of achieving China’s 11th Five-Year Plan (2006-10) actions problematic.

An analysis based on Global Environment Facility (GEF) statistical data for 1991 of the 500,000 industrial boilers also calculated that 400 Mt of coal were consumed annually. Due to the low boiler efficiency it was estimated that 75 Mt of coal is wasted and 130 Mt of excess CO₂ emitted. In three provinces six field visits were carried out and 250 boiler thermal-balance test certificates were analysed. The results were that boilers with efficiencies of less than 70% account for 75% of the total boiler population. The main causes of this were the low efficiencies, high excess air and unburnt carbon in the slag and fly ash. The analysis indicated that through simple measures such as size grading the coal, more education about improved boiler operating practice and with a few inexpensive equipment modifications the average boiler efficiency could be raised to 73% (Fang and others, 1999).

The World Bank programme to improve the efficiency of industrial boilers in China had mixed success. One of the project’s aims was to subsidise the acquisition of licences for new boiler technologies by Chinese firms. The project experienced many problems and delays. Eventually it took six years to identify suitable technology licensors. This was in part due to the reluctance of major international firms to participate, due to concerns about the World Bank’s terms for the project. International boilermakers were also reluctant to take part due to concerns about intellectual property protection (Watson, 2005).

In China, there are three major issues to resolve about the consumption of coal. On a technical level, the 500,000 boilers are quite small and use outdated technologies with limited control and treatment systems. This results in low coal utilisation efficiency and pollution problems at a local level. There are also few incentives for the non-power sector to improve their boiler efficiency or reduce emissions. Lastly, and due to the fragmentation of the sector, subsectors have been unable to attract investment from outside investors to improve efficiency or update their boiler technology.

### 3.2 India

India is the world’s third largest coal user, after China and the USA (IEA, 2007). According to Mills (2007b) India generates approximately 66% of its total 146 GW of electricity from coal, with the majority of this coming from conventional subcritical pulverised plants.

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**Figure 7** Central level authorities in China involved in clean coal combustion technology deployment (Vallentin and Liu 2005)
The coal in India is normally of poor quality and has a heating value of around 4500 kcal/kg compared to over 6000 kcal/kg for the majority of internationally-traded coals. In addition, the coals have a high moisture content and are high in ash, which ranges between 30% and 50% (IEA, 2007). India uses mainly lignite which is mined domestically and is generally of poor quality, with a high ash content resulting in technical difficulties.

There are several sectors that use industrial coal-fired boilers and they include the iron and steel, fertilisers and chemicals, cement, textiles, pulp and paper and brick making industries. Due to the demand for coal and its low quality, the steel and iron industry rely on importing coking coal and there is also a growing demand for imported steam coal (Mills, 2007a). As in China, coal will remain the dominant fuel in India’s energy system. According to the IEA reference scenario for India, coal will account for 41% of industrial energy demand by 2030, an increase of 11% from 2005 (IEA, 2007).

The boiler market in India is split between two manufacturers. BHEL controls around 69% and Thermax 21%; together they control nearly 90% of the total boiler market in India. BHEL focuses on the utility market while Thermax dominates the industrial boiler market. The industrial boilers in India are designed also for specific niche areas including:
- dual pressure;
- multifuel firing;
- drum coil, stand-by and import steam heating.

### 3.3 USA

The USA has the largest reserves of hard and brown coal, it is second after China in consumption, and 51% of its electricity generation is from coal. According to the Energy Information Agency (EIA), approximately 1.03 Gt of coal was produced in 2007, and approximately 93% of it was consumed by the electricity power sector (EIA, 2008a). The next major user of coal is the industrial sector where there has been a decline in consumption. The other sector is the residential and commercial sector one, which is the smallest and accounts for less than one third of one percent of total US consumption. The industrial sector consumption of coal was down 5% in 2007 and the coking coal sector was down 1.1% (EIA, 2008a). Figure 8 indicates that the consumption of coal in the industrial sector from 1998 to 2007 has been relatively unchanged.

In 2005, Energy and Environmental Analysis (EEA) submitted a report on industrial and commercial boilers to the Oak Ridge National Laboratory. The report characterises USA boilers in the industrial and commercial sector by calculating the number of units, aggregate capacity, unit capacity, primary fuel, application and regional distribution. After EEA completed the inventory, they calculated that in the USA there were about 163,000 industrial and commercial boilers with an aggregate capacity of 791,000 MWh.

Breaking that down further, there were 43,000 industrial boilers with a total capacity of 468,000 MWh and 120,000 commercial boilers with a total capacity of 322,000 MWh. Industrial boilers tend to be larger than commercial units. There were 19,500 industrial boilers larger than 3 MWh, including more than 1300 larger than 73 MWh. The inventory identified commercial facilities with 26,000 boilers larger than 3 MWh but only about 130 larger than 73 MWh. It was found that most commercial boilers were smaller than 3 MWh (EEA, 2005). The largest boilers (82%) are within energy-intensive industries such as food, paper, chemicals, refining, and metals (Booz and others, 2007).

In total, around 226,000 manufacturing facilities have boilers with another 21,000 facilities outside that sector. The energy-intensive industries that had the most boilers were food, chemicals, refining, primary metals and paper with 71% of the boiler units and 82% of the boiler capacity. The chemical industry had the most boilers and capacity with 12,000 and 121,000 MWh. The paper industry while only having 3400 boilers had almost as much capacity with 110,000 MWh due to the large boilers they use. In other industries refining had 1200 units, with 50,000 MWh capacity. The food sector has the smallest boiler sizes, on average 6 MWh, with a total of 11,000 units and 61,000 MWh of capacity. Lastly, the primary metals industry has 3300 units and 33,000 MWh of capacity (EEA, 2005).

In comparing industrial and commercial boilers it was found the average size for an industrial boiler was 10 MWh, compared to 3 MWh for a commercial boiler. Beyond these sectors, the EEA also identified 16,000 industrial boilers in the non-manufacturing sector with an aggregate capacity of 76,000 MWh. In total, over 70% of the boiler units were less than 3 MWh, mostly in the commercial sector. However, because of their size these boilers make up only 15% of boiler capacity and have a lower utilisation rate than large industrial boilers (EEA, 2005).

In the USA, states manage permit programmes to control emissions from major sources. Included in the permit are detailed emission control requirements that cover performance and technology based requirements, compliance schedules, monitoring requirements and other conditions detailed in the Clean Air Act (CAA) and State Implementation Plan (SIP). This also includes industrial boilers under the New Source Performance Standards (NSPS) which establishes a performance standard, usually expressed as a maximum emission rate per million Btu for all sources and on a category by category basis. This applies to industrial
sectors which have industrial boilers such as iron and steel mills, pulp mills, glass manufacturers and chemical facilities (US EPA, 2007). The NSPS are uniform standards which are detailed in Table 3.

The CAA establishes the ambient air quality standards for CO, lead, particulate pollution, sulphur dioxide (SO2) and ozone (volatile organic compounds and oxides of nitrogen). Since the establishment of the CAA, air quality in the USA has improved with pollution levels continually falling and no corresponding decrease in economic growth, as illustrated in Table 4.

Since the introduction of the CAA in 1970 the six common air pollutants have decreased by more than 50%. Air toxics from large industrial sources have reduced by almost 70%.

### Table 3  US New source performance standards (Schreifels, 2007)

<table>
<thead>
<tr>
<th>Stationary source type</th>
<th>Heat input capacity</th>
<th>SO2 limit value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil-fuel Electric Power plants (constructed after 14 August 1971)</td>
<td>Heat input capacity &gt;250 MBtu/h</td>
<td>Coal: 544 g/MBtu and controlled to 90% below potential concentration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oil and gas: 363 g/MBtu</td>
</tr>
<tr>
<td>Fossil-fuel Electric Power plants (constructed after 18 September 1978)</td>
<td>Heat input capacity &gt;250 MBtu/h</td>
<td>Coal: 544 g/MBtu and controlled to 70% below potential concentration or 272 g/MBtu and controlled to 70% below potential concentration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oil and gas: 363 g/MBtu and controlled to 90% below potential concentration</td>
</tr>
<tr>
<td>Industrial boilers</td>
<td>Heat input capacity &gt;100 MBtu/h</td>
<td>Coal: 544 g/MBtu and controlled to 90% below potential concentration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oil: 363 g/MBtu and controlled to 90% below potential concentration</td>
</tr>
<tr>
<td>Industrial boilers</td>
<td>Heat input capacity ≤100 MBtu/h and ≥10 MBtu/h</td>
<td>Coal: 544 g/MBtu and controlled to 90% below potential concentration or 272 g/MBtu and controlled to 50% below potential concentration</td>
</tr>
<tr>
<td>Primary smelters (zinc, lead, or copper)</td>
<td>Not specified</td>
<td>0.065 %vol</td>
</tr>
<tr>
<td>Stationary gas turbines</td>
<td>Heat input capacity &gt;10.14 MBtu/h</td>
<td>0.015 %vol at 15% oxygen on a dry basis of gases emitted or fuels that contains sulphur ≤0.8% by weight</td>
</tr>
</tbody>
</table>

### Table 4  Summary of pollution levels and economic growth since 1970 Clean Air Act (Environmental Defense, 2005)

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Pollution cuts since 1970*, Mt/y</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxides of nitrogen (NOx)</td>
<td>5.8</td>
<td>23.8 decrease</td>
</tr>
<tr>
<td>Volatile organic compounds (VOC)</td>
<td>16.6</td>
<td>54.3 decrease</td>
</tr>
<tr>
<td>Particulate matter (PM)</td>
<td>8.2</td>
<td>74.6 decrease</td>
</tr>
<tr>
<td>Sulphur dioxide (SO2)</td>
<td>13.9</td>
<td>49.4 decrease</td>
</tr>
<tr>
<td>Lead</td>
<td>0.19</td>
<td>98.5 decrease</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>94</td>
<td>52.5 decrease</td>
</tr>
<tr>
<td>Gross domestic product</td>
<td>174 increase</td>
<td></td>
</tr>
</tbody>
</table>

* converted from short imperial tons to metric tonnes
addition, the production of ozone-depleting chemicals in the USA has stopped.

3.4 EU

The existing energy structure within the EU is, and will remain for the foreseeable future, heavily dependent on fossil fuels, including a significant amount of imported oil and gas. According to statistics produced by Eurostat, the EU is dependent on fossil fuels for 79% of its gross inland consumption. The remainder consists mainly of nuclear and biomass (Eurostat, 2007). Member States also must adhere to National Emission Ceilings or a limit on total emissions to achieve air quality limit values. The Member States must develop a plan to respond to air quality issues such as ambient concentration of a pollutant that exceeds the limit value set by the EU. The plan, which is applicable to industrial boilers, includes:

- where air quality exceeds the limit values, the size and composition of the population exposed to pollution, emissions sources responsible for the pollution, and the total quantity of emissions from those sources;
- details of any measures for air quality improvement, including timetables for implementation and estimates of expected improvements in air quality;
- details of any measures or projects planned for the long term (US EPA, 2007).

The European Commission oversees the air quality management plans and regularly checks and reviews the plans to make sure they are on track to meet the limit values. In terms of major users of coal which are affected by the air quality limit values, there are several countries that produce and utilise their coal to supply a major part of their energy demand. These nations include Poland, the Czech Republic, Romania, Bulgaria, Germany, Greece and the United Kingdom.

The Large Combustion Plants Directive (LCPD) for all new power plants with a thermal capacity >50 MW will play a limited role for industrial boilers >50 MW. However, the EU Emissions Trading Scheme (ETS) does impact on the industrial boiler sector where there are coal-fired combustion facilities with a capacity >20 MWth. This means those facilities currently have to buy and sell permits to release CO₂ into the atmosphere. It is likely that, where possible, boilers will be replaced with gas to lower emissions of CO₂.

3.4.1 Poland

Poland has large reserves of between 51 Gt and 65 Gt of hard coal and 37–45 Gt of lignite (Mills, 2007a). Coal is used to produce most of Poland’s electricity and two thirds of its primary energy. Many sectors use industrial coal-fired boilers either to generate electricity or heat, and in many cases coal-fired combined heat and power (CHP). The boilers are used in textile and paper manufacturers, steel, district heating and coke manufacture as well as within commercial and public service sectors in schools and hospitals (Mills, 2007).

According to Ericsson (2007), in 2003 the industrial sector used approximately 470 PJ (petajoules) of hard coal in the production of process heat. The type of boiler used in small-scale CHP plants, district heating plant and local boiler rooms is usually a grate boiler. In a market study publication on Poland the Export Council for Energy Efficiency (ECEE) estimated that the district heating sector in Poland was made up of almost 400 individual networks, including the world’s largest district heating network in Warsaw. The district heating sector has over 8000 boilers, and delivers about 488 PJ of heat annually with a peak rate of 45 GW. 170 PJ of this total heat production is made and used by industrial enterprises (ECEE, 1999).

3.5 New Zealand

New Zealand uses coal-fired industrial boilers in the agricultural and pastoral industries with many freezing works or abattoirs using them in their processes. New Zealand domestic coals are comprised of lignites, subbituminous and bituminous varieties and averages around 23 MJ/kg. New Zealand uses both fire- and water-tube boilers with the fire-tube normally the preferred option below 6 MW and where pressures above 1 MPa re not required. Fire-tube boilers are relatively standard using the overfeed stoker and chain grate firing method. However, water-tube boilers have a variety of grate and firing systems employed in varying combinations from boiler to boiler.

The fluidised bed boiler is also used in New Zealand and has the advantage of a design that can combust difficult fuels, and with reduced NOx and SOx capabilities. A range of control system options and levels of sophistication exist, with fail safe and self-checking standards in place for boiler level and pressure sensor systems. Computer controlled systems such as SCADA and PLC-based systems are quite commonplace, setting the way for the introduction of neural networks and artificial intelligence technology. This is seen as improving prediction and control of chaotic processes and reactions, and should lead to enhanced stability, efficiency, and reduced emissions.

3.6 Environmental legislation for industrial boilers

The main greenhouse gas from coal combustion in industrial boilers is carbon dioxide (CO₂) and small quantities of nitrous oxide (N₂O) and methane (CH₄). The quantity of emissions will depend on the quality of the coal, operating conditions and the impact of the technology being used on the conversion efficiency of the boiler. In recent years more stringent legislation has been introduced to control air quality and reduce gaseous particulate emissions from power stations. The legislation also impacts on the operation of industrial boilers. In the future this will have major ramifications for industrial and commercial boiler users who operate in the process industry, offices, schools and hospitals, producing CO₂ and other emissions. Stringent emissions standards and the increasing cost of coal make it important to obtain the best performance and efficiency from a boiler. The stringent emissions standards are following a trend first introduced into the power generation sector with the Clean Air Act in the
USA and European Union Emissions Trading Directive as well as the Large Combustion Plants Directive in Europe. The introduction of the EU emissions performance standard will have implications for industrial boiler operators.

The best available technique (BAT) approach to manage and control air pollutant emissions from industrial boilers is being used increasingly. The EU uses the BAT to assess and mitigate emissions. This has not changed since a previous IEA CCC publication (Smith and Nalbandian, 2000) and includes the following steps:

- identification of the key environmental issues for a sector;
- examination of the techniques most relevant to address those key issues;
- identification of the best environmental performance levels, on the basis of internationally available data;
- examination of the conditions under which these performance levels were achieved, such as cross-media effects and the main driving forces involved in the implementation of these techniques;
- selection of the BAT and the associated emission levels for a sector in a general sense according to Council Directive 96/61/EC (Smith and Nalbandian, 2000).

The steps can be applied to most industrial sectors and are discussed in more detail in Chapter 4.

### 3.6.1 Air quality standards

An air quality standard is a concentration or exposure level of a pollutant that is set by a regulatory authority such as a government and which is enforceable. A regulatory authority can use several instruments that measure the efficiency of the regulation to ensure that the standard or concentration level is met. This includes monitoring and reporting requirements as well as penalties for non compliance. In some cases guidelines are also used with a recommendation for protection of health or the environment from the adverse effects of a pollutant. An example of a standard that would apply in part to the emissions from an industrial boiler is the recently published EU Directive 2008/50/EC of the European Parliament, and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. Article 1 of the new Directive outlines all the measures that:

- define and establish objectives for ambient air quality designed to avoid, prevent or reduce harmful effects on human health and the environment as a whole;
- assess the ambient air quality in Member States on the basis of common methods and criteria;
- obtain information on ambient air quality in order to help combat air pollution and nuisance and to monitor long-term trends and improvements resulting from national and Community measures;
- ensure that such information on ambient air quality is made available to the public;
- maintain air quality where it is good and improve it in other cases;
- promote increased co-operation between the Member States in reducing air pollution (European Commission, 2008).

The new Directive merges four existing ones and one Council Decision into a single directive on air quality. The new Directive replaces five existing legal instruments including the directive on:

- ambient air quality assessment and management (96/62/EC);
- limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead (1999/30/EC);
- limit values for benzene and carbon monoxide (2000/69/EC);
- ozone (2002/3/EC);
- the decision on exchange of information from stations measuring ambient air pollution (97/101/EC).

The Directive defines objectives for ambient air quality designed to avoid, prevent or reduce harmful effects on human health and the environment as a whole. This is accomplished by setting out measures for the assessment of ambient air quality in Member States as well as for obtaining information on ambient air quality in order to help combat air pollution and nuisance. The Directive aims to increase co-operation between the Member States in reducing air pollution.

The Directive will set new standards and target dates for reducing concentrations of fine particles, which together with coarser particles known as PM10, are already subject to legislation. The focus of the legislation is to provide a new regulatory framework for PM2.5. Under the Directive, Member States must reduce exposure to PM2.5 in urban areas by an average of 20% by 2020 based on 2010 levels. It obliges them to bring exposure levels below 20 µg/m³ by 2015 in these areas. Throughout their territory Member States will need to respect the PM2.5 limit value set at 25 µg/m³. This value must be achieved by 2015 or by 2010 if possible. There are also limit and target values with an eight-hour mean of 120 µg/m³ for ozone by 1 January 2010; a one-hour limit of 200 µg/m³ for NO2 and an annual limit of 40 µg/m³ by 1 January 2010; confirmation of the existing PM10 daily limit of 50 µg/m³ not to be exceeded more than 35 times per year and an annual limit of 40 µg/m³; and a new PM2.5 annual target value of 25 µg/m³ by 1 January 2010, to become a limit value from 1 January 2015 (subject to review in 2013) with an indicative target of 20 µg/m³ from 1 January 2020.

In summary, the new EU Directive on Ambient Air Quality and Cleaner Air for Europe must be transposed into national law by 11 June 2010. The new Directive sets requirements for the assessment of air quality in Member States with regard to NO2 and NOx, PM10 and PM2.5, ozone, benzene, lead, CO and SO2. The responsibility of the Member States is to meet the air quality target values and long-term objectives. There is some leeway allowing Member States to postpone the deadlines for NO2, benzene or PM10 in a particular area for up to five years providing they establish an air quality plan and information on how they will achieve their objectives.

A report to the EC in 2004 proposed that a new Directive or extension of the LCPD could be considered, which would introduce emission limits for all installations down to 1 MWth, based on limits considered under existing national
legislation. The rationale behind this approach was that such a measure would need to consider a ‘light touch’ regulatory approach for sites less than 15–20 MWth, due to the number of sites that would be covered by such thresholds. The report went on to state that sites between 20 MWth and 50 MWth could be regulated under the IPPC or LCPD Directives. This was because:

- 20–50 MWth installations are far less numerous than smaller sites;
- the emission contribution per site (and potential for reduction) may justify the cost of this type of regulation;
- they have been identified comprehensively under the EU ETS, and in many countries under national-based legislation;
- the infrastructure for regulation of these installations may already be in place, if indeed the scope of the IPPC Directive is as far reaching as thought (EC, 2004).

A further option the report writers suggested was to consider NOx or SO2 emissions trading, although this may only be feasible for installations with an aggregated capacity of 20 MWth. The likely impact of such legislation is a move away from coal- to gas-fired boilers.

In the USA the Clean Air Act (CAA) makes it mandatory for each State to develop a State Implementation Plan (SIP) outlining how it will achieve national ambient air quality standards (NAAQS). The SIP describes how that State will achieve its air quality targets thorough standards, policies and programmes. The CAA was introduced in 1970 with major amendments in 1990 and is a federal law which is administered by the Environmental Protection Agency (EPA). The EPA sets limits on certain air pollutants. The EPA also has the authority to limit emissions of air pollutants coming from sources such as chemical plants, utilities, and steel mills.

It is interesting to compare the different emission performance standards for air quality in various countries. Table 5 compares the UK, China and USA ambient air quality standards.

### Table 5  UK, China and USA Ambient Air Quality Standards (Schreifils, 2007)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Averaging time</th>
<th>China Grade 1</th>
<th>China Grade 2</th>
<th>China Grade 3</th>
<th>USA</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO2</td>
<td>1 year</td>
<td>20</td>
<td>60</td>
<td>100</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>24 hours</td>
<td>50</td>
<td>150</td>
<td>250</td>
<td>365</td>
<td>350</td>
</tr>
<tr>
<td>PM10</td>
<td>1 year</td>
<td>40</td>
<td>100</td>
<td>150</td>
<td>N/A</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>24 hours</td>
<td>50</td>
<td>150</td>
<td>250</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>PM2.5</td>
<td>1 year</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>15</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>24 hours</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>35</td>
<td>N/A</td>
</tr>
<tr>
<td>NOx/NO2</td>
<td>1 year</td>
<td>40</td>
<td>80</td>
<td>80</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>24 hours</td>
<td>80</td>
<td>120</td>
<td>120</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The Directive sets limit and target values including an 8-hour mean of 120 µg/m³ for ozone by 1/1/2010; a 1-hour limit of 200 µg/m³ for NO2 and an annual limit of 40 µg/m³ by 1/1/2010; confirmation of the existing PM10 daily limit of 50 µg/m³ not to be exceeded more than 35 times per year and annual limit of 40 µg/m³ and a new PM2.5 annual target value of 25 µg/m³ by 1/1/2010, to become a limit value from 1/1/2015 (subject to review in 2013) with an indicative target of 20 µg/m³ from 1/1/2020.

### 3.7 Summary

It is clear that, where there is indigenous low cost coal, countries will continue to use it for industrial boilers in developed and developing countries. China is implementing legislation to improve the performance of small-to-medium sized boilers with a goal to reduce consumption of coal by 70 Mt in their Five-Year Plan (2006-10). However, the complexity of the multitude of public authorities involved in the goal of increasing efficiency does create obstacles. This is evident with the reluctance of international boiler makers to take part in a World Bank project to improve the efficiency of IB, due to concerns over intellectual property protection. India has problems with the high moisture and ash in the coals they use. The USA strict performance standards could impact on the use of coal-fired boilers. Poland is heavily reliant on coal with the district heating sector having over 8000 boilers – however, the size of those boilers is small scale and outside the scope of this report. New Zealand has been able to make continual improvements with the introduction of sophisticated computer controlled systems leading to improved performance and efficiency.

In all the countries an increasing stringency of new standards and targets for improving air quality or reducing emissions is evident. The EU is introducing a new Directive to replace five other legal instruments to increase co-operation between Member States and reduce air pollution.
4 Methods to improve efficiency of industrial boilers

There is a wide range of equipment available to improve the performance of industrial boilers. Boiler efficiency and performance are dependent on several factors. Industrial boilers normally come with manufacturer’s guidelines specific to the boiler that is installed, including information on the fuel specifications and how to operate the boiler to achieve the best possible performance. The increasing demand for fossil fuels, and in particular coal, makes it increasingly important to ensure that coal is used as efficiently as possible. Industrial boilers are used in many different process industries for heating, drying, fluid heat transfer and for example vapour refrigerating. In the last few decades boiler technology has undergone significant developments in its design, efficiency and improving safety.

Historically, the availability of a boiler was a key criterion. Today, there are more boiler manufacturers and so there are other factors to consider such as fuel availability, efficiency, technical issues and environmental concerns.

According to Orland (2002), a company that is selecting a new boiler should first consider the following key factors:

- geographical location and site accessibility;
- plan area and height requirements;
- fuel type, price, and availability;
- boiler type, size, efficiency, price, and reliability;
- heating loads and load variations including: acceptable pressure and temperatures ranges, and required rates of heat delivery;
- federal, state, and local environmental regulations;
- regional air quality;
- emission limitations and options for controlling regulated pollutants;
- construction and operating permit requirements.

The most important factor is the type of fuel selected. This determines the size and design of the boiler as well as what type of pre-combustion or post-combustion technology can be used prior, during and after fuel combustion.

There are several key principles that manufacturers of boilers and operators must follow to ensure high efficiency and reliability. The first is to control the air supply which depends on the fuel, type of equipment used for combustion and operating conditions. All of these elements are determined by the manufacturer who undertakes performance tests and recommends guidelines to get the best performance from the boiler. The second principle is the mixing of the fuel and the air which must be done thoroughly to ensure uniform combustion as discussed previously. The third principle is that the temperature is high enough to ensure combustion. If it is too low then incomplete combustion can take place and excessive smoke can be formed. Lastly, the air supply, mixing of fuel and air, and temperature all determine the rate at which combustion will occur. Time is needed for combustion and if the equipment is operated at a high capacity then incomplete combustion occurs and results in unburnt fuel (Woodruff and others, 2005).

With regard to existing boilers, there are several factors that can improve their efficiency. A high heating value of the fuel improves input to the boiler and results in better efficiency. If waste heat energy losses from the stack gases and expelled waste water can be reduced, the efficiency of the boiler improves. If a boiler is not operating correctly or is not well maintained, the efficiency could be reduced by incomplete combustion with unburnt fuel becoming trapped in the refuse.

According to a study carried out to improve the efficiency of coal-fired industrial boilers in Shanxi, China, the application of several simple and inexpensive measures to coal-fired boilers can improve the operating efficiency and reduce emissions. The results indicated that the average efficiency of industrial boilers could be improved from 60% to 70% in the Shanxi area resulting in a potential saving of 3 Mt of coal and a reduction of 5 Mt of CO₂ annually. The study also estimated that the health benefits would be around US$86 million and prevent 700 premature deaths annually (Fang and others 2002).

4.1 Coal preparation and washing

After raw coal is mined, there are several steps which can be taken to improve the characteristics of the coal for its end use and for transportation. A coal washing plant located near the mine is one option. This and other options have several advantages and benefits for the coal and include:

- improving the deliverable heat content;
- removing unnecessary minerals that can damage or foul boilers;
- sorting and removing non-combustible material that results in less weight and lower shipping costs as well as reduced wear and tear on coal grinding equipment and boilers (EIA, 2006).

The preparation first crushes and screens the mined coal removing non-coal material. If the coal is from a thick-bedded surface, it is more likely to be just crushed and screened before transportation. Further mechanical cleaning involves using a liquid to separate out impurities; this is known as ‘washing’.

Washing of coal removes sulphur-laden particles and ash-bearing materials and reduces emissions. This pre-combustion emission control technique is used where there is adequate water, although it can increase the cost of handling. Beneficiation can improve the coal quality by mechanical, chemical, or other means of cleaning. In some cases beneficiation of coals can reduce the sulphur content by up to 50% with a corresponding reduction in SO₂ emissions (Orland, 2002).

Prepared coal is also often dewatered to reduce moisture as this degrades the deliverable heat content in the coal and the moisture also adds weight to the shipping costs. There are several dewatering techniques including filters, vibrating...
screens, or centrifuges and heated rotary kilns or dryer units. Prior to combustion in many developed countries, such as the USA, almost all coal for industrial boilers is pulverised or crushed and sized. Washing coal can be less expensive than downstream options for removing ash and sulphur (EIA, 2006).

4.2 Coal sorting

The mining, cleaning and transport of coal can generate large quantities of fine coal. Fine coal is sometimes unsuitable for the end process and can retain large quantities of water (10–30%) which makes it difficult and inefficient to handle, transport and burn. Briquetting the coal can enable it to be handled, transported and used as normal lump coal.

Coal sorting is a technology that can sort coal particles in layers by size in a multi-layer structure with large particles at the bottom of the coal hopper, medium sized particles in the middle and smallest at the top. The result of this multi-layer structure is that the airflow resistance is more uniform over the grate and reduces the amount of unburnt carbon in the slag. Therefore the efficiency of the boiler can increase by 7–10 percentage points, or from 60% to 70%. This type of technology is most suited for chain stoker boilers with a steam capacity of 1–35 t/h (Fang and others, 2002).

4.3 Storing and management of coal fuel

Coal can be delivered to a site for use in several ways including by barge, truck, train or a belt conveyor. Normally, it is stockpiled for storage. If the boiler is fed by a direct-fired system it is much simpler as there are fewer components. If the coal is not handled correctly and is exposed to the atmosphere it can become wet which may cause feeding and combustion problems. These problems result in high ash carbon levels and boiler efficiency losses due to the boiler being operated at high excess air levels to complete combustion. Coal should be stored in a dry area if possible or in a coal pile that allows for drainage of excess water.

If the coal is crushed to an incorrect size range inappropriate for the boiler design, inefficient combustion and high ash carbon levels result. A further problem that can arise with the coal fuel that if it is stored for a long period of time, or at the bottom of a coal pile, it may lose some of its volatile content. This creates minor problems with delayed ignition.

4.4 Clinkering and slagging

Before examining the methods to improve efficiency of coal-fired boilers, it is useful to examine the technical challenges facing small-to-medium sized industrial boilers that differ from the utility industry. One of those challenges is the behaviour of ash. The design and operation of the combustion system must be able to cope with this. The behaviour of ash is complex and can follow several pathways after combustion resulting in the minerals reacting in different ways and forming new species. Depending on the temperature, the new species may remain solid, partially melt, completely melt, sinter or even recrystallise. According to Schobert there are three types of problems that can arise from ash and they are:
- clinkering which occurs in the grate;
- slagging during the radiant section;
- fouling during the convection pass (Schobert, 1987).

Clinkering or slag formation is an issue in the power generation industry, but is more of a problem for small industrial stoker-fired boilers. Clinkering occurs in the furnace when the coal is not uniformly distributed over the grate resulting in an unequal resistance of the fuel bed to the flow of gases. Clinker or slag is then formed and is a hard, compact concealed mass of fuel matter (Woodruff and others, 2005). Clinkering blocks air passages in the coal bed by forming a crust or surface patch that restricts air access to the coal. As a result there is inefficient combustion and consequently less heat generation. Another problem with clinkering is that large clinkers can jam up the ash handling system of the boiler.

Slagging and fouling are two of the biggest problems for coal-fired boilers. They cause expensive outages for heat plant and reduce the efficiency of the heat transfer surfaces. Slagging and fouling are complex processes dependent on several elements including the nature or chemistry of the coal, and the temperature profile within the combustor. This means that analysis of the problem should be done on a site by site basis to determine the particular factors for the site and its fuel supply. Once an analysis is undertaken, the combustion engineer can provide a set of guidelines for blends of fuel and design of the operation to reduce the slagging and fouling for that particular site. The IEA CCC update on Slagging and fouling in coal-fired boilers, reports in more detail into recent technological developments on reducing these problems (Barnes, 2009).

Reducing slagging and fouling will result in savings in the investment and operational costs as well as improvements in the performance and efficiency of the boiler, and lower emissions. Units such as cyclones are designed to operate with slag, but it is important that the material remains a liquid. A cyclone burner burns coal that has been crushed to pass through a screen with 5 mm openings and the burning occurring in a cylindrical, water-cooled combustion chamber (Schobert, 1987). The air and the coal mix in a rapid whirling motion and can reach combustion temperatures of more than 1648°C. Due to these high temperatures the coal ash melts and turns to a liquid slag that runs down the walls and drains from the boiler.

The advantages of cyclones are many, including a high rate of heat production. They can also be designed to use almost any coal from brown coal to bituminous coal with a low volatile content. It is also important that the slag is fluid or sticky enough to coat the walls and flow to the bottom where it can be drained via the slag tap. Moisture in the coal also must be monitored to avoid changing the fluid behaviour of the slag. This is because the temperature decreases the viscosity or the ability of the fluid to flow increases.
4.5 Fouling and scaling

Fouling occurs when ash deposits form on boiler tubes. This acts as an insulator as the ash deposits reduce heat transfer to the tubes and consequently reduce steam generation. In major cases the ash deposits can become so large that they completely clog the passageways for gases. This results in an inefficient combustion process and the boiler operates at a lower rate. Fouling can happen during combustion of low rank or high rank coal, although it is more of a major problem with low rank coal.

In order to prevent fouling the internal surfaces of a boiler in contact with water and steam must be kept clean and free of deposits to ensure that there is efficient heat transfer in the generation of steam. Several methods can be used to chemically clean a boiler.

High purity feedwater ensures that a boiler’s steam generation systems operate correctly. High purity feedwater reduces the need for a boiler to use chemicals in blowdown and also the frequency of the blowdown. Lower frequency of blowdown results in lower coal fuel costs as well as reduced build-up of scale which can foul heat transfer surfaces due to the small concentration of impurities in the boiler feedwater. This lower level of impurity also results in less corrosion in the boiler. In addition, if a boiler is used to run a steam turbine then it results in less turbine blade erosion, because of the higher purity of steam generated. There are several problems that can occur due to the build-up of scale on a boiler which can result in an increase in the tube wall temperature and consequently a boiler tube rupture, which decreases the boiler efficiency, resulting in higher energy costs and increased boiler downtime.

High excess air and unburnt carbon in the fly ash and slag are major causes of poor efficiency with boilers. The use of online automatic flue gas analysis can improve efficiency by measurement of the carbon content in the ash and adjusting operating conditions. An option to improve the efficiency of coal combustion is to convert it to briquettes. This is done as many types of lower grade coal with high moisture content burn inefficiently and can also spontaneously combust which can make it too expensive and dangerous to transport. In order to briquette coal, binders or glues are used to reform the low grade coal in to a usable size and quality for boilers.

Another option to remove slag deposits from the heat transfer surfaces of a boiler is the use of wall blowers. Soot blowers can also be used to remove soot deposits or fly ash from the convective passes of a boiler. These deposits can reduce the heat transfer and, if left unchecked, clog the boiler. Some manufacturers claim that the use of soot blowing can improve efficiency by up to 1%.

4.6 Economiser

An economiser is a heat-transfer surface that transfers heat from the flue gas to the boiler feedwater. An economiser provides the option of saving a portion of the heat energy that would otherwise be lost from the boiler stack. The heat energy saved is used to provide additional preheating to the boiler feedwater. An economiser is suitable when flue gas temperatures are quite high. In most cases this requires a stack temperature of more than 200°C. This is to prevent the economiser causing the flue gas temperature to drop below dew point, and also to allow sufficient thermal draw for gases to rise high enough into the atmosphere for dilution and dispersion.

The economiser consists of a gas-to-liquid heat exchanger installed in the passage of flue gases as they exit the boiler furnace and enter the stack. The feedwater, already preheated by the feed tank, passes through this heat exchanger prior to its entry into the boiler. The economiser operates under pressure and is fitted with its own safety pressure relief valve. Often a bypass valve is fitted and a proportion of feedwater is not passed through the economiser. Outlet temperature is monitored by a control and the proportion of feedwater flowing through the economiser is varied to achieve the set temperature.

According to Payne and Thompson (1996), economisers have several advantages for industrial sized units including:

- lower initial capital costs;
- no impact on NOx emissions;
- lower draft losses;
- minimal auxiliary power requirements.

In a typical application the economiser might reduce the flue gas temperature by 100°C, and raise the feedwater temperature from a typical 85°C to 105°C. Efficiency gains of 3–7% can be expected.

4.7 Recuperators

Another common feature used in industrial boilers is a recuperator which is also known as an air preheater. Recuperators are used to preheat the supply air to the boiler by passing the air through an air-to-air heat exchanger with the hot flue gases on the other side. Preheating the air allows for a reduction in the fuel needed to reach the targeted heat output from the boiler, resulting in increased boiler efficiency. Recuperators are commercially available down to very small sizes and can be retrofitted to existing plant provided the space is available to accommodate them. Fuel savings of up to 30% can be achieved.

The size of an air preheater is determined by various factors including:

- space available for the air preheater;
- type of fuel burned;
- air and gas flow requirements;
- design or arrangement and size of air and gas passages;
- desired final combustion air and flue gas temperature;
- pressure drop requirements.

As well as fuel savings and improved efficiency, air preheaters have other advantages such as improved combustion efficiency and better fuel ignition. This means that more flexible load ranges are possible. More steam results due from the higher furnace temperature and heat
absorption. Improved burning means less fouling occurs so less cleaning is required. The disadvantages are increased maintenance costs for the furnace refractory and stoker. There can also be a build up of deposits in the gas passages that reduce the gas flow and can result in damage if they ignite.

4.8 Other combustion measures to reduce emissions

There are several techniques available to operators for controlling emissions during combustion which are outlined in Table 6.

Commonly, cyclones are used on industrial boilers depending on their size to remove particulates instead of the precipitators used in large utility boilers. This could have implications for air quality standards for smaller industrial boiler operators. The correct oxygen level is also critical for the performance and efficiency of a boiler. A boiler that is operating efficiently will have the correct oxygen levels, lower emissions and achieve energy savings.
Combustion chamber temperatures should operate close to the maximum temperature limits of the boiler materials. Increasing the temperature in the combustion chamber results in improved efficiency of heat transfer due to a higher temperature differential between the hot gases and the boiler water. It also ensures complete combustion of volatiles and complete conversion of carbon to carbon dioxide.

If the temperature is too low it is likely to result in an increase of carbon monoxide in the flue gas. This is a toxic gas and also indicates inefficient combustion. Generally an efficient combustion chamber should operate at around 800°C but the temperature can be higher depending on the boiler materials and design. Reference to a flue gas oxygen meter or combustion gas analyser should be undertaken before adjusting the combustion settings.

There are several publications and manufacturer guidelines for operating boilers efficiently. Below are a list of the problems that may occur with a boiler (Sections 4.9 to 4.14).

### 4.9 Load management

This is an important tool in reducing fuel use in a facility with several boilers. The efficiency of a boiler varies and depends on several elements such as the boiler design, age, fuel and load. If a facility has several boilers it is better to utilise the most efficient boilers first and the least efficient boilers last. Consequently, when a boiler is not needed the least efficient should be turned off first.

### 4.10 Tuning the boiler

Any boiler will require tuning to identify problems as well as to improve and maintain performance. A boiler manufacturer normally offers tuning services and recommends periodic inspections and tuning to maintain a boiler’s efficiency and performance as well as to maintain its safety and reliability. This check-up on the boiler can be on a daily, weekly, monthly or annual basis. A regular check-up can identify problems early on and result in avoidance of fuel wastage and expensive maintenance. There are several common boiler operational problems and they fall under four areas:

- coal is not stored or prepared correctly;
- excess air levels;
- design problems with the combustion instrumentation being in a difficult location;
- lack of combustion uniformity.

Most boilers operate throughout their entire firing range from low, medium to high firing. Opportunities exist to improve low and medium fire inefficiency. Typically, boilers are calibrated to operate at high fire and often boilers are only calibrated once or twice a year. Loads may be weather dependent, for example, a high fire during winter could be calibrated downwards in summer for low to medium fire. Calibration should occur monthly to improve excess air control in boilers. A combustion analyser is required to monitor excess air levels during calibration and the technician undertaking the calibration must be aware of the boiler’s firing rate and range during the calibration period.

It is also important to have good boiler house design to ensure that the coal and ash handling systems operate efficiently. Normally, the larger the rate of coal input, the more important it is that the coal and ash handling systems work well together.

### 4.11 Air levels

Combustion involves the combination of the combustible elements of the coal and oxygen resulting in the production of heat. The mixing of the air and fuel must take place at high temperatures. Air supplied to boilers contains the oxygen needed for combustion. If the availability of oxygen exceeds that required for complete fuel combustion or there is excess air, the oxygen left over is released back into the atmosphere along with the flue gas. A boiler operating with less air reduces efficiency losses since less air is heated at stack temperature. The efficiency improvement depends on the initial stack temperature and actual excess air at the boiler exit. Excess air therefore must be carefully controlled. NOx formation can be reduced by lowering the concentration of oxygen in the combustion zone. A technique that is used to optimise the combustion process is limiting excess air (LEA). LEA allows for minimising the excess air without increasing unburnt fuel emissions. To achieve LEA requires changes in either the control system settings or operating procedures and in some cases both (Orland, 2002).

It is a common problem for boilers not to operate at their optimum excess air level. Reasons why this occurs include:

- operators are making too many and incorrect O2 calibrations;
- not enough air supply when combustion occurs at full load;
- there is air in-leakage upstream of the facility O2 analyser.

Combustion uniformity is needed to ensure the complete combustion of the coal fuel. This is relatively simple to achieve in the case of small industrial boilers in comparison to larger industrial boilers where there are multiple burners and/or a large travelling grate stoker. Problems with combustion can arise when the air and fuel are not evenly distributed to multiple burners and they are not receiving the same fuel:air ratio. Other issues that cause combustion problems are a plugged air heater and uneven coal flow from the pulverisers.

### 4.12 Blowdown

Water quality is a key factor for the efficient operation of a boiler. The feedwater for a boiler will contain impurities in the solution and suspension. Left untreated these impurities will result in the destruction of the boiler and its components (Woodruff and others, 2005). Therefore it is important to include water treatment on a regular basis to maintain efficiency and avoid damage to the boiler system. The process of blowdown can be continuous or intermittent. Boiler water contains dissolved and suspended solids which can be
controlled by the removal of high solids boiler water and its replacement with low solids feedwater. This lowers the solid concentration in the boiler. It is important to blowdown correctly as insufficient blowdown could lead to deposits remaining where as excessive blowdown wastes heat, water and chemicals. Table 7 lists the recommended feedwater chemistry limits.

There are two types of blowdown: bottom blowdown and skimming blowdown. Bottom blowdown removes particulates and sludge from the bottom of the boiler. It is a periodic blowdown and normally occurs according to a set schedule. Blowdowns can be done automatically or on a manual basis. If manual blowdown is used then operators of the boiler must check samples several times a day and either use a schedule, or blowdown when needed. In comparison, automatic blowdown involves monitoring the boiler water conductivity and blowdown can occur when needed to maintain the desired water chemistry. This is done by a probe which measures the conductivity and the operator is able to keep the blowdown rate at a level that allows for the maximum allowable dissolved solids level which consequently reduces energy losses.

When undertaking a bottom blowdown the boiler operator should follow the boiler manufacturer’s guidelines as it is dangerous to use with higher pressure boilers above 4 MPa and can result in water starvation in some portions of the boiler circuit. This type of blowdown should be undertaken periodically with several blowdowns performed quickly rather than one longer blowdown. This is better for the boiler. Skimming blowdown removes the top layer of water at the water/steam interface. It is better to do this type of blowdown on a continuous basis to remove dissolved liquids and particulates. The use of skimming blowdown also allows the use of heat recovery equipment.

Most of the impurities occur in the boiler water as the steam is pure. Regular water maintenance treatment should remove any of the scale forming calcium and magnesium salts from the solution. Lack of maintenance results in a concentration of suspended solids. This forms a scale on the boiler heating surfaces which reduces heat transfer and raises the tube metal temperatures, consequently reducing the boiler efficiency and raising stack gas temperatures. There are several benefits that occur with boiler blowdown and include:
- reduction in maintenance costs and repairs from deposits;
- more efficient and cleaner steam;
- lower operating costs with the consumption, disposal, treatment and heating of water;
- less fuel, water and treatment chemicals are required;
- reduced energy loss from boiler blowdowns can save up to 2% of a facility’s total energy use.

A commonly used ratio to calculate the amount of boiler blowdown needed is:

\[
\text{Required Blowdown} = \frac{C_{\text{feedwater}}}{C_{\text{blowdown}}}
\]

where:

- \(C_{\text{feedwater}}\) = the measured concentration of the selected chemical in the feedwater
- \(C_{\text{blowdown}}\) = the measured concentration of the same chemical in the blowdown.

Heat can be recovered from boiler blowdown by using a heat exchanger to preheat boiler make-up water. A heat exchanger is only worthwhile if the boiler has continuous blowdown exceeding 5% of the steam rate.

### 4.13 Post-combustion techniques

Fuel processing and combustion control techniques are not sufficient to prevent all emissions of NOx, SO2, and PM and they may not meet acceptable levels. There are further options to reduce these emissions and to treat the flue gas before it reaches the atmosphere. Normally flue gas treatment techniques are downstream from the boiler. Table 8 describes several control techniques that can be used to reduce NOx, SO2 and PM emissions.

### 4.14 Performance optimisation

A systems approach allows for analysis of the supply and demand sides of a system and how they interact together as a total system. By taking a systems approach, an engineer or
Methods to improve efficiency of industrial boilers

Table 8  Techniques for controlling emissions after combustion (Orland, 2002)

<table>
<thead>
<tr>
<th>Emissions</th>
<th>Control technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>Selective catalytic reduction (SCR)</td>
<td>Reducing NOx emissions can be accomplished using the SCR technique in which a reductant (ammonia gas) is injected in the flue-gas stream before it passes through a catalyst bed. This technique disassociates NOx to nitrogen gas and water vapour.</td>
</tr>
<tr>
<td>SO2</td>
<td>Selective non-catalytic reduction (SNCR)</td>
<td>Reducing NOx emissions can also be accomplished using the SNCR technique in which a reagent is injected in the flue gas stream where NOx is reduced to nitrogen gas and water vapour. Ammonia gas and aqueous urea are the two reagents most often used for this purpose.</td>
</tr>
<tr>
<td></td>
<td>Flue gas desulphurisation (FGD) using - nonregenerable (throwaway) processes - regenerable (recovery) processes</td>
<td>Removing SO2 from flue gas is most often accomplished in a wet scrubber where the flue gas is contacted with an aqueous slurry of lime or limestone. Reactions between the lime or limestone and the SO2 produce a calcium salt waste product. Circulating a sodium-based compound through a scrubber will also reduce SO2 emissions. Effluent from the scrubber is then mixed with lime or limestone to produce a calcium-sulphur waste product. Injecting a calcium-based sorbent such as lime into the flue-gas steam is also an effective technique for reducing SO2 emissions. Methods such as spray absorption, spray drying, or semi-wet scrubbing produce a dry waste product that is collected along with the PM. Removing SO2 dispersed in flue gas can be accomplished by various advanced FGD techniques. Resulting sulphur compounds that have value include gypsum (wallboard), sulphur, and sulphuric acid.</td>
</tr>
<tr>
<td>PM</td>
<td>Cyclone separator</td>
<td>Separating PM dispersed in flue gas can be accomplished using a mechanical collector known as a cyclone. Separation is achieved as the particles are subjected to centrifugal and gravitational forces. Inside the cyclone, solid particles exit through an opening in the bottom, and the cleaned flue gas exits through an opening in the top.</td>
</tr>
<tr>
<td></td>
<td>Wet scrubber</td>
<td>Removing PM dispersed in flue gas can be accomplished using a wet scrubber in which the particles impact water droplets. A spray tower is one type of low-pressure-drop wet scrubber, and a venturi-type scrubber is a high-pressure-drop wet scrubber.</td>
</tr>
<tr>
<td></td>
<td>Electrostatic precipitator (ESP)</td>
<td>Charging particles that are dispersed in flue gas with electrical energy is an effective technique for reducing PM emissions. In an ESP, the particles are electrically charged and then attracted to a collecting surface rather than discharged into the atmosphere.</td>
</tr>
<tr>
<td></td>
<td>Fabric filter (baghouse)</td>
<td>Collecting PM dispersed in flue gas can be accomplished by allowing the particle-laden gas to flow through a fabric filter. These fine-mesh filters are located inside a gas-tight structure known as a baghouse.</td>
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</tbody>
</table>

boiler operator can evaluate the entire system and not just individual components. There are often several common steam improvement opportunities for industrial facilities. Table 9 identifies common performance opportunities for an industrial steam system.

The US Department of Energy Office of Industrial Technologies has also developed a number of tip sheets for best practice and to assist in increasing awareness for industry about options to improve boiler performance. The tip sheets include:
- inspect and repair steam traps;
- insulate steam distribution and condensate return lines;
- use feedwater economisers for waste heat recovery;
- improve the boiler’s combustion efficiency;
- clean boiler waterside heat transfer surfaces;
- return condensate to the boiler;
- minimise boiler blowdown;
- recover heat and boiler blowdown;
- use vapor recompression to recover low-pressure steam;
- flash high-pressure condensate to regenerate low-pressure steam;
- use a vent condenser to recover flash steam energy.

These are just some of the tips available on the US DOE Office of Industrial Technologies. More details about these tips and other resources are available from the OIT best practice website [www1.eere.energy.gov/industry/bestpractices/index.html](http://www1.eere.energy.gov/industry/bestpractices/index.html).

There are several advantages and benefits to firms that
improve the performance of boilers. There can be an improvement in an overall plant as well as boiler system performance, efficiency, and safety while reducing the total cost of operations. A boiler with a higher efficiency uses less fuel and saves on fuel expenditure over a long period of time. This means an annual saving on a long-term basis. Improving the efficiency also reduces costs of environmental compliance with the firm less likely to face penalties for breaching air quality standards.

### 4.15 Summary

Industrial plants sometimes have several types of boilers which can add to the complexity of operating boilers efficiently. The boiler as a key component for the operation of a plant must be operated correctly by following boiler manufacturers guidelines and regular maintenance. Fuel and energy costs as well as environmental legislation mean that it is important to maintain the boiler reliability and overall system performance.

There are several options to increase the efficiency of industrial boilers including routine tune ups, attention to coal handling and storage, and use of modern technology. Heat exchangers or economisers can be fitted to existing industrial boilers to preheat the boiler feedwater, thus transferring some of the heat in the stack gases to the water. The use of

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Description</th>
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<tbody>
<tr>
<td>Minimise excess air</td>
<td>Reduces the amount of heat lost up the stack, allowing more of the fuel energy to be transferred to the steam</td>
</tr>
<tr>
<td>Clean boiler heat transfer surfaces</td>
<td>Promotes effective heat transfer from combustion gases to the steam</td>
</tr>
<tr>
<td>Install heat recovery equipment (feedwater economizers and/or combustion air preheaters)</td>
<td>Recovers available heat from exhaust gases and transfers it back into the system by preheating feedwater or combustion air</td>
</tr>
<tr>
<td>Improve water treatment to minimize boiler blowdown</td>
<td>Reduces the amount of total dissolved solids in the boiler water, which allows less blowdown and therefore reducing energy loss</td>
</tr>
<tr>
<td>Recover energy from boiler blowdown</td>
<td>Transfers the available energy in a blowdown stream back into the system thereby reducing energy loss</td>
</tr>
<tr>
<td>Add/restore boiler refractory</td>
<td>Reduces heat loss from the boiler and restores boiler efficiency</td>
</tr>
<tr>
<td>Optimise deaerator vent rate</td>
<td>Minimises avoidable loss of steam</td>
</tr>
<tr>
<td>Repair steam leaks</td>
<td>Minimises avoidable loss of steam</td>
</tr>
<tr>
<td>Minimise vented steam</td>
<td>Minimises avoidable loss of steam</td>
</tr>
<tr>
<td>Ensure that steam system piping, valves, fittings, and vessels are well insulated</td>
<td>Reduces energy loss from piping and equipment surfaces</td>
</tr>
<tr>
<td>Implement an effective steam-trap maintenance programme</td>
<td>Reduces passage of live steam into condensate system and promotes efficient operation of end-use heat transfer equipment</td>
</tr>
<tr>
<td>Isolate steam from unused lines</td>
<td>Minimises avoidable loss of steam and reduces energy loss from piping and equipment surfaces</td>
</tr>
<tr>
<td>Utilise backpressure turbines instead of pressure reducing valves</td>
<td>Provides a more efficient method of reducing steam pressure for low-pressure services</td>
</tr>
<tr>
<td>Optimise condensate recovery</td>
<td>Recovers the thermal energy in the condensate and reduces the amount of makeup water added to the system, saving energy and chemicals treatment</td>
</tr>
<tr>
<td>Use high-pressure condensate to make low-pressure steam</td>
<td>Exploits the available energy in the returning condensate</td>
</tr>
</tbody>
</table>
combustion controls that automatically operate burners to match the steam or hot water demands on industrial boilers can also increase efficiency rather than relying on manual control. Another option is the use of air preheaters to increase the temperature of the fuel and air mixture prior to combustion. Oxygen trim controls also allow for optimum efficiency by measuring the concentration of oxygen in the stack gas and automatically adjusting the inlet air at the burner.
This chapter examines the operation of industrial boilers in several countries and lessons that can be identified to improve the efficiency of similar boilers using the same type of coal. The use of case studies can assist in disseminating information and best practice to countries or sectors using similar types of boilers. However, it should be recognised that there are several potential obstacles to improving best practice. Commonly, manufacturers of industrial boilers recommend a specific rank and quality of coal to guarantee and achieve the best performance from a boiler. Boilers can use different types of coals that could cost less and affect the performance or efficiency of the boiler to a large degree.

This chapter outlines generic guidelines for industrial boiler owners considering a project to increase the efficiency or reduce the emissions from a boiler and the factors that need to be considered before it. This information is drawn from publications by the GHG Protocol Initiative, the US DOE and the Energy Federation of New Zealand (EFNZ). Briefly, the use of the Kyoto Protocol mechanisms as an incentive for boiler owners is also discussed (EFNZ, 2003).

Two clear obstacles between suppliers and users are education and information awareness. This has implications for the transfer of technology in developing countries with inadequate information for workers or consumers using industrial boilers. In addition, if a boiler operator is not trained properly or is unaware of measures to improve a boiler’s efficiency it could result in a cost for the company in terms of efficiency and output. A further issue is how companies work within different regulatory frameworks as countries differ in their legal and regulatory systems as well as in their capacity and practice of law enforcement. Across all borders there are some common elements that provide avenues to improve the efficient use of industrial boilers. This includes the use of information and education programmes, government incentives and commitments to reducing GHG emission and economic development strategies.

In all countries there is the issue of consumer acceptance as many technologies are only used because of consumer demand. The energy generated by industrial boilers is used to produce consumer products. There is evidence to suggest that consumer’s increasing awareness of life-cycle issues does influence a company and can lead to a response to consumer pressure over environmental factors. This consumer pressure may be about the type of fuel used to produce a product, such as coal. Therefore improving the boiler’s performance will provide evidence that the company is responding to consumer’s concerns.

Environmental stewardship is an important factor in many countries. It becomes an important element for companies in responding to regulatory trends, compliance with their own environmental policies and management systems, as well as growing middle-class and environmental NGOs concerns over air quality and GHG mitigation. In this context it is important to take due account of the full life-cycle of the industrial boiler. Another important element linked to consumer acceptance is marketing. Companies use marketing as a tool to promote and encourage the use of their technology and it needs to be considered in the application of industrial boilers.

Historically, industrial boilers have been improving steadily in terms of risk management. The perceived risk related to technical and economic performance (including safety) and market structure impacts on the development of a technology. A lack of infrastructure and incentives to manage risk are factors that influence the transfer and diffusion of technology. Boiler manufacturers recognise they have a responsibility to provide technologies that are safe for the environment, as well as for their workers and the wider community wherever they operate.

Many industries take into account a number of elements when deciding on cost estimates such as the technology’s performance, its cost to produce and manufacture, consumer acceptability, safety, enabling infrastructure, regulatory compliance and the technology’s impact on the environment. This is difficult to do and it is likely that only an estimate can be made, as it is complicated to estimate future costs and market potential accurately. This is because technologies compete in many interacting ways for raw materials and market share. In the case of industrial boilers, natural gas as a fuel may become more highly sought after because of its lower emissions. Thus, it is more important to develop a better understanding of the key characteristics of competing technologies, such as critical inputs and factors that affect relative performance, than to focus on limited scenarios that fail to reveal the complex interactions of modern markets. According to many industry experts, it is not possible to make accurate estimates of future costs and future market potentials of technologies (IPCC, 2005).

5.1 China case study

Industrial boilers (IB) in China are defined as boilers working at up to 6 MPa operating pressure and 130 t/h or around 90 MW thermal steaming capacity (or hot water equivalent). These boilers are manufactured by boiler-makers who are government graded into categories ‘A’ to ‘E’. According to Minchener (2001), in 1991 there were 553 graded boilermakers and that had risen to 706 in 2001. The Grade ‘A’ boiler manufacturers construct to the highest standards with a focus on electrical power utility boiler production, above the pressure and thermal criteria for IBs. The manufacture of IB is done mainly with manufacturers of Grades ‘B’, ‘C’ and ‘D’, totalling 207. Grade ‘E’ manufacturers (currently some 490) provide for the very lowest pressure criteria and produce boilers with an average thermal rating of only 1 MW. Grade ‘E’ manufacturers produce small, low pressure hot water (LPHW) boilers, which do not require adherence to strict manufacturing codes and are not considered to come within the definition of a ‘true’ IB. In addition to the ‘A’ to ‘E’ grades of IB manufacturer, another 1000 or more ‘ungraded’
manufacturers operate at the fringe of the industrial boiler market, manufacturing small LPHW boilers. These LPHW boilers are hand fired with coal and have no emissions control (Minchener, 2001).

The most common combustion system for the IB sector is some form of mechanised, continuously moving, grate. In China, all forms of moving grate boiler are generically referred to as chain grate boilers, irrespective of the design of their grate castings and the method of providing the motive force to the grate ‘mat’. These IB combustion systems were once common in the EU and USA, covering a thermal demand range of some 1–50 MWth. However, most of these have been replaced by natural gas fired units in recent years.

By 2010, this consumption is expected to have grown by 3–5 %/y in overall terms. At the same time, the percentage of oil/gas being used is expected to increase in percentage terms. However, coal will still remain the primary fuel for the IB market, with an estimated 90% of the thermal input in 2010. In a growing market sector, this represents an actual increase in annual coal burn compared to 2000. Table 10 shows the estimated fuel consumption of IB in China up to 2010 (Minchener, 2001).

There are two key sources of demand in industrial boilers and they are the light and textile industries which need process heat and power to manufacture products, and district heating for residential and commercial buildings. This demand has resulted in the market for industrial boilers continuing to grow. The industrial boiler manufacturing market in China has approximately 700 boilermakers competing to supply some 20,000 boilers each year, with a combined thermal output approaching 60,000 MWth. It is expected that the market will grow annually up to 2010 by 3–5% with around 30,000 boilers per annum of total capacity 100,000 MWth. The total of IBs is still around 500,000 using 400 Mt/y of coal. By 2010 there could be 620,000 boilers with an average size of 2 MWth as illustrated in Table 11 (Minchener, 2001).

There have been rapid improvements in the efficiency of the power sector in China. Now the non power sector is also improving. Due to old coal utilisation technology there was low efficiency and few pollution control measures in the small-to-medium industrial boiler sector with kilns, furnaces and boilers. Historically, the energy consumption per unit GNP in China was 4 to 14 times higher than that of developed countries in the western world.

The majority of industrial boilers in China are not equipped with desulphurisation units and SO2 emissions generally exceed the figures specified in the standards issued by the government. The main reasons for this are poor quality of raw coal (variable size and characteristics, unwashed) and Chinese boiler designs. The coal is not size-graded or washed resulting in ash content averages of 20%, with values to 30% being common. Fines content, that is coal <3 mm, can reach 60%, while ‘lump’ coal, >10 mm, may be only 15–30%. In addition, IB coal is not selected with regard to its ‘coking’ that is its swelling tendency on heating. Coal which swells excessively can form sticky coke masses on the grate, which adhere together and prevent the free flow of combustion air. Lastly, besides coking and ash properties, there are no specified limits for volatile content, calorific value and sulphur content. This makes it very difficult to define the typical properties for a Chinese industrial coal (Minchener, 2001).

Unwashed coal is due to a shortage of water in many parts of China. In addition, while washed coal would improve boiler efficiencies, the market is price and not environmentally driven. Washed coal in Beijing can cost 290 ¥/t compared to

### Table 10 Estimated fuel consumption of industrial boilers in China (Minchener, 2001)

<table>
<thead>
<tr>
<th>Year</th>
<th>Million tonnes of coal or equivalent</th>
<th>Units of fuel</th>
<th>Thermal, %</th>
<th>Thermal, %</th>
<th>Units of fuel</th>
<th>Thermal, %</th>
<th>Thermal, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>390</td>
<td>390 Mt</td>
<td>98.0</td>
<td>3</td>
<td>5</td>
<td>1.75 Mt</td>
<td>0.8</td>
</tr>
<tr>
<td>2000</td>
<td>400</td>
<td>400 Mt</td>
<td>96.9</td>
<td>5</td>
<td>8</td>
<td>3 Mt</td>
<td>1.2</td>
</tr>
<tr>
<td>2010</td>
<td>460</td>
<td>460 Mt</td>
<td>89.3</td>
<td>10</td>
<td>45</td>
<td>6 Mt</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 11 Projected size range and numbers within the annual boiler demand of China by 2010 (Minchener, 2001)

<table>
<thead>
<tr>
<th>Capacity of boiler, MWth</th>
<th>Demand, %</th>
<th>Annual capacity of demand, MWth</th>
<th>Annual numbers of boilers</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.7</td>
<td>4–5</td>
<td>2800–3500</td>
<td>6000–9000</td>
</tr>
<tr>
<td>1.4–4</td>
<td>55–60</td>
<td>38,500–42,000</td>
<td>12,000–18,000</td>
</tr>
<tr>
<td>&gt;7</td>
<td>35–41</td>
<td>24,500–28,700</td>
<td>2000–3000</td>
</tr>
</tbody>
</table>
unwashed coal at 230 ¥/t, so there is little likelihood of washeries being introduced. As a result of this, unsized, run-of-mine raw coal is prevalent although an initiative has been introduced which will require grading of coal supplies to city centres (Minchener, 2001). Table 12 indicates the percentage of IB production during the 1990s of boiler types, firing systems and the fuel used.

Several reasons have been identified in China that contribute to poor combustion efficiency including:
- excessive fines in the raw coal, as well as poor quality grate construction resulting in partly burnt coal which can be lost by sifting through the grate links and into the combustion air chamber or windbox;
- excessive coal fines, inadequately moistened before firing which increase the carbon lost as flyash in the boiler exit, resulting in an increase of the solids load entering the downstream particulate capture equipment;
- excessive mineral matter in the raw coal, combined with inappropriate coal swelling characteristics that slows down the rate of coal burning, resulting in incomplete combustion at the end of the grate;
- variations in the coal size grading which causes an imbalance in the air flow from the undergrate windbox. This means parts of the fire bed receive excess combustion air and other parts are air starved. There is also poor edge sealing around the grates which lets air bypass the fire bed and results in further starving of the fire bed and impeding of the rate of combustion (Minchener, 2001).

All of these problems in China and elsewhere can be improved. In 1996 a GEF China Efficient Industrial Boilers project was approved and ran until 2001. The objective of the project was to reduce GHG emissions, as well as emissions of total suspended particulates (TSP), sulphur dioxide (SO2) and nitrogen oxides (NOx). This aim was to be achieved through three elements:
- the development of affordable, energy efficient and cleaner industrial boiler designs;
- the mass production and marketing of improved boiler models that have successfully met performance criteria;
- the broad dissemination of more energy efficient and cleaner industrial boiler technologies throughout China through institutional strengthening, improved information exchange, and energy efficiency and environmental policy reform.

The rationale behind this project was that emissions from coal-fired industrial boilers were a major contributor to severe

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<tbody>
<tr>
<td>Vertical</td>
<td>1.33</td>
<td>0.52</td>
<td>0.69</td>
<td>1.64</td>
<td>0.11</td>
</tr>
<tr>
<td>Horizontal shell</td>
<td>3.56</td>
<td>4.47</td>
<td>6.51</td>
<td>6.60</td>
<td>10.81</td>
</tr>
<tr>
<td>Water and fire tube</td>
<td>45.28</td>
<td>39.01</td>
<td>35.32</td>
<td>28.60</td>
<td>23.67</td>
</tr>
<tr>
<td>Single drum</td>
<td>9.90</td>
<td>12.66</td>
<td>10.15</td>
<td>27.04</td>
<td>21.62</td>
</tr>
<tr>
<td>Bi-drum</td>
<td>35.55</td>
<td>39.63</td>
<td>38.08</td>
<td>34.77</td>
<td>35.11</td>
</tr>
<tr>
<td>Forced circulation</td>
<td>3.81</td>
<td>2.28</td>
<td>2.85</td>
<td>2.20</td>
<td>2.45</td>
</tr>
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<tbody>
<tr>
<td>Fixed grate</td>
<td>4.65</td>
<td>4.12</td>
<td>3.81</td>
<td>10.40</td>
<td>2.45</td>
</tr>
<tr>
<td>Chain grate</td>
<td>60.84</td>
<td>68.74</td>
<td>67.20</td>
<td>64.47</td>
<td>57.87</td>
</tr>
<tr>
<td>Reciprocating grate</td>
<td>16.73</td>
<td>7.68</td>
<td>7.59</td>
<td>6.04</td>
<td>6.92</td>
</tr>
<tr>
<td>Bubbling FBC</td>
<td>2.0</td>
<td>1.55</td>
<td>0.55</td>
<td>6.17</td>
<td>1.20</td>
</tr>
<tr>
<td>Circulating FBC</td>
<td>0.92</td>
<td>5.77</td>
<td>1.66</td>
<td>4.62</td>
<td>1.31</td>
</tr>
<tr>
<td>Waste heat</td>
<td>0.5</td>
<td>1.42</td>
<td>0.56</td>
<td>3.46</td>
<td>3.54</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Anthracite coal</td>
<td>1.43</td>
<td>1.81</td>
<td>2.39</td>
<td>0.84</td>
<td>1.31</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>88.61</td>
<td>88.51</td>
<td>84.50</td>
<td>82.65</td>
<td>74.23</td>
</tr>
<tr>
<td>Oil and gas</td>
<td>5.62</td>
<td>6.01</td>
<td>9.35</td>
<td>8.36</td>
<td>12.21</td>
</tr>
</tbody>
</table>
ambient air pollution in many Chinese cities and that industrial boilers also contribute up to 30% of CO₂ emissions. In addition, the emissions were contributing to acid rain problems in south and central China. The project had four components:

- upgrading existing Chinese boiler models through the introduction of advanced combustion systems and auxiliary equipment from abroad, especially the application of simple automatic controls;
- adoption of new, high efficiency boiler models through the introduction of modern manufacturing techniques and boiler designs suitable for burning Chinese coals;
- technical assistance and training for boiler producers and consumers;
- monitoring and evaluation, and project management.

The first two components included nine international boiler technology transfer packages benefitting nine domestic boiler manufacturers and nine domestic boiler auxiliary equipment makers. The aim was to cover, as broadly as possible, the main boiler types and sizes in the Chinese coal-fired boiler market ranging from small and medium chain grate boilers to more sophisticated circulating fluidised bed combustion (CFBC) boilers. The technology transfer packages were designed to either improve existing boiler models and technologies or fill certain technology gaps in the Chinese industrial boiler sector. The selection of technologies and areas of assistance were made based on extensive market studies. The project was undertaken in two phases. The first phase involved the diffusion of the technology transfer and the Chinese participants receiving technologies, developing and testing prototypes, and making production, financial and sales plans. Once this phase was completed and the results approved by the GEF, the commercial production and sales of the new boilers would commence, supported and co-financed by the GEF (World Bank, 2004).

All nine boiler manufacturers successfully completed phase one and eight went on to commercial production of GEF-supported boiler models with increases of fuel efficiency of 5 percentage points. A key improvement was the use of the diaphragm wall, which reduced the weight of the furnace housing by 50%. This is traditionally made of refractory bricks. It made the furnace more air tight. Other important aspects of the project resulted in improved grate design and manufacture for chain grate boilers, and the use of efficient secondary air-induction systems.

Through the project there has been an improvement in the thermal and environmental performance of popular domestic industrial boiler models, in the 1–20 t/h (small-to-medium) size range. This part of the project involved six boiler manufacturers and four auxiliary equipment makers. Five of the six boiler manufacturers have successfully adopted the GEF-supported designs and manufacturing upgrades.

A further component of the project was the eleven technical assistance and training projects that were completed, which covered six areas:

- establishment of a systematic training curriculum and certification procedure for boiler operators;
- revision of technical and environmental standards and improvement of design for industrial boilers and boiler houses;
- verification testing and technical evaluation of GEF-supported boiler models;
- production planning and marketing assistance to project beneficiaries;
- general sales and marketing assistance to GEF-supported boilers;
- replication and dissemination of GEF-supported boiler technologies (World Bank, 2004).

The project was also reassessed on its cost-effectiveness based on an estimate of CO₂ emission. The assessment included eight of the boiler manufacturers and the Yongning Foundry Factory (boiler grate). The technology transfer of the improved boiler grate technology from Sinto Co of Japan to the Yongning Foundry Factory, has resulted in them becoming a major supplier of new, high-efficiency grates to chain grate boiler manufacturers throughout China. The overall assessment estimates the impact of the new boilers and grates, with a conservative projection of annual new boiler sales (reaching a maximum of 24,000 tonnes per hour of steam by eight boilermakers by 2009, compared with the original assumption of 27,000 tonnes per hour of steam annually by 2002). The results were that the project could achieve about 160 Mt of cumulative CO₂ emission reduction by 2019, compared with the original 180 Mt by 2016 (World Bank, 2004).

The option to improve boiler efficiency through the adoption of technologies that improve coal-fired boiler and kiln efficiencies is ongoing. It has been estimated that by adopting clean coal technologies and improving system management, coal-fired boiler efficiency could be increased from 65% to about 70%. This increase in efficiency for kilns alone could reduce the use of coal by 35 Mt by 2020 (Ministry of the Environment, 2005).

5.2 USA case study

In 2002, the United States government announced a comprehensive strategy to reduce the GHG gas intensity of the USA economy by 18 % between 2002 and 2012. GHG intensity measures the ratio of GHG emissions to economic output. It was estimated that achieving this commitment would reduce carbon equivalent emissions by over 100 Mt/y by 2012 and by approximately 500 Mt (cumulatively) between 2002 and 2012.

The US EPA plays a significant role in helping the Federal government reach the United States’ intensity goal. The US EPA undertakes several initiatives involving industry and boilers that encourage voluntary reductions from a variety of stakeholders. One of these initiatives is ‘Climate Leaders’ which is an industry-government partnership that works with companies to develop comprehensive climate change strategies. According to the US EPA, there are 226 Climate Leaders partner companies with 102 partners publicly announcing their GHG reduction goals, 18 of which have
been achieved. The US EPA estimates that the Climate Leaders partners emit more than 13 Mt of carbon equivalent emissions per year. Partner companies commit to reducing their impact on the global environment by completing a corporate-wide inventory of their GHG emissions based on a quality management system, setting reduction goals, and annually reporting their progress to the US EPA (US EPA, 2008).

A part of this programme was the development of several Climate Leaders Offset Project Methodologies. The methodology uses a standardised approach to determine project eligibility, address additionality, select and set the baseline, identify monitoring options, and quantify reductions. This approach aims to ensure that the GHG emission reductions from offset projects meet four key accounting principles they must be real, additional, permanent, and verifiable. In August 2008 the US EPA published several modules as guidance for businesses interested in making sure their offset projects were eligible and also to provide measurement and monitoring guidelines for offset projects. The two modules on commercial and industrial boilers are useful documents for improving the efficiency and performance of boilers (US EPA, 2008).

Project activities must be surplus to regulation to be eligible as offsets. Projects are also required to demonstrate additionality by achieving a level of performance with respect to emission reductions and/or removals that is significantly better than business-as-usual. Business-as-usual is determined from similar, recently undertaken or planned practices, activities or facilities in the same geographic region. This level of ‘performance’ may be defined as an emissions rate, a technology standard or a practice standard. Data used in setting the performance standard are primarily collected from publicly available, historic data although planned and projected activities are permissible in some cases. The performance standard approach minimises the risk of accepting a project that is not additional or rejecting a project that is additional. A performance standard approach also reduces the complexity, cost, and subjectivity of constructing individual project-specific reviews (US EPA, 2008).

In contrast to China, in the USA there are approximately 70,000 industrial boilers in use and the majority of them are natural gas fired. Those that are coal-fired are normally pulvred coal boilers and as such are usually in excess of 50 MWh. The remainder are also quite large and fluidised bed fired. The reasons why the USA switched to natural gas fired boilers were twofold: the ease and convenience of operation, plus they are more cost-effective in meeting tougher environmental standards. In the USA numerous environmental requirements apply to industrial facilities that use coal. The two key ones are:

- control of air pollution emissions;
- control of solid and liquid wastes that are produced.

According to the EIA (2005), a final rule was issued as part of the CAA. This is the National Emission Standards for Hazardous Air Pollutants (NESHAP) to reduce emissions of hazardous air pollutants (HAPs) from industrial, commercial, and institutional boilers and process heaters. The rule requires industrial boilers and process heaters to meet limits on HAP emissions to comply with a Maximum Achievable Control Technology (MACT) ‘floor level’ of control. This is the minimum level such sources must meet to comply with the rule. The major HAPs targeted to be reduced were hydrochloric acid, hydrofluoric acid, arsenic, beryllium, cadmium, and nickel.

The MACT standards apply to major sources of HAPs, or units that emit or have the potential to emit a single HAP at 10 t/y or more or a combination of HAPs at 25 t/y or more. The EPA estimates that 58,000 existing boilers and process heaters, and 800 new boilers and process heaters built each year over the next five years will be subject to the rule. Existing boilers and process heaters have to comply with the rule within three years. Owners of existing units may petition for an extra year to comply. New boilers and process heaters must comply when they become operational.

5.3 Clean development mechanism

Cost is often a barrier to improving the operation of a boiler. One potential way to generate additional revenue for developing countries and for some developed countries is the use of the Clean Development Mechanism (CDM) or Joint Implementation (JI). These mechanisms were introduced under the Kyoto Protocol. Both offer an incentive for boiler operators to either retrofit or replace their boilers with more efficient models and generate carbon credits as additional revenue. The CDM allows developed countries with emission reduction targets to undertake mitigation projects in developing countries and purchase emission credits to offset their targets. JI allows developed countries to undertake projects in another developed country and also obtain carbon credits to be used to meet Kyoto Protocol commitments in the investor country.

There is a large potential to increase small-to-medium sized industrial boiler retrofits or replacements through the CDM in developing countries. China alone has up to 500,000 industrial boilers. Increasing the performance and efficiency of these boilers would reduce CO₂ emissions. However, there are two key reasons why this is not occurring and is unlikely to change unless there are major changes to the CDM. First, one individual boiler retrofit or replacement project would generate only a few carbon credits that would not even cover the transaction costs of the CDM process. Considering the expense of retrofitting or replacing a boiler, there is little incentive for boiler operators or owners to use the CDM process. Second, educating and informing small to medium boiler operators about the opportunities and options of CDM project bundling or several boiler retrofits is needed. There have been several campaigns by different organisations in educating and informing potential applicants about the CDM.

5.4 Guidelines for industrial boiler emission reduction project

There are currently no world’s best practice guidelines for improving emissions or efficiency for industrial boilers.
However, there are specific manufacturer guidelines for operating boilers with optimum performance. In addition, there are several generic guidelines for reducing emissions from boilers. Separately, there are also options for boiler owners wanting to retrofit or improve their boiler’s performance to undertake specific projects. The process can be divided into three key categories:

- **describe the project**;
- **select baseline or the situation before the project was implemented**;
- **estimate the emissions**.

In describing the project, a company with a boiler must first establish a boundary and make it clear which greenhouse gases are included, such as CO₂ or N₂O. The company must then also decide on a base year. The base year is the year with which a comparison is made over a period of time to assess emissions. Upon selection of a base year the data must be gathered according to the project boundary.

### 5.4.1 Assessing the baseline

The next step is selecting a baseline in order to estimate emission reductions from a project, such as improving the efficiency of the boiler or using biomass with the coal. To establish a baseline using historic emissions from the boiler will allow for the development of a hypothetical trend throughout the life of the project, using output and fuel use data. There are two broad approaches for gathering emission baselines from projects. The first is to use historical data of normal operations with the boiler without any improvements and to average this over the last four years of emissions. The other option is to use forecast data, either projected or modeled, of what the emissions would be without a project to improve efficiency of the boiler.

The information and guidelines from the following sections are taken from several sources including the US DOE Climate Protection Partnerships, the Energy Federation of New Zealand and the Greenhouse Gas Protocol. The GHG Protocol was a major initiative involving the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) over ten years to develop a tool that would allow businesses and governments to understand, quantify, and manage GHG gas emissions. In 2006, the International Organisation for Standardisation (ISO) adopted the corporate standards as the basis for its ISO 14064-1: Specification with guidance at the organisational level for quantification of GHG emissions and removal (WRI & WBCSD, 2008). The GHG Protocol Initiative has produced several publications that are useful for boiler owners developing or considering implementing projects to reduce GHG emissions or improve the efficiency of their boilers (WRI & WBCSD, 2005).

### 5.4.2 Types of baselines

Below, are three types of baselines that could be used for industrial boilers:

- **project-by-project baselines** are designed for individual projects on a case-by-case basis. This procedure means that the baseline scenario is specific to the proposed project activity (WRI & WBCSD, 2005). This approach is a combination of site-specific analysis and engineering judgement based on project-specific assumptions and measurements for key parameters. To illustrate, this approach could be used for an energy efficiency project implemented to improve the efficiency of an industry boiler at a specific installation;
- **sectoral baselines** are again also based on the assumptions, measurements or simulations of key parameters and are specific to a particular sector. This baseline is intended to be relevant to all projects within a specific sector;
- **benchmark or multi-project baselines** can be designed using an engineering approach and to standardise emissions rates or levels across a number of similar projects for a particular industrial sector or technology. Using this approach, the analyst can produce an estimate of baseline emissions using a GHG emission rate derived from a numerical analysis of the GHG emission rates of all baseline candidates. This approach is also known as a performance standard (WRI & WBCSD, 2005).

All of these baselines can be either static or dynamic. A dynamic baseline is one that is revised over the life of a project depending on changes in output or other project variables, such as fuel or growth. This approach reduces the certainty about the quantity of emission reductions or carbon credits the project could generate over its lifetime. In comparison, a static baseline is fixed over the duration or lifetime of the project. This means that only one estimate needs to be undertaken, reducing the transaction costs. In addition, there will be lower monitoring and reporting costs. The project’s technical and economic lifetime will depend on the type of project. For example, a steam insulation upgrade project life could be as little two years depending on the cycle of normal maintenance.

The static baseline emission rate is more appropriate for GHG projects for technologies where it is unlikely that the basic operating parameters will change over a fixed time period. In contrast, dynamic baseline emission rates are suited to GHG projects that are part of a system that changes significantly over time (WRI & WBCSD, 2005).

The GHG Protocol Initiative has identified six key principles that project developers should follow and these apply also to projects involving industrial boilers. The principles are relevance in using data, methods, criteria and assumptions that are appropriate for the intended use of the reported information. Therefore, it is important when undertaking a retrofit boiler project that only the information that is relevant to the decision makers on whether to proceed is included.

The second principle is completeness, where all relevant information that may affect the accounting and quantification of GHG reductions is included. This includes the effects of the project. All potential options or technologies to improve the boiler should be considered and how different technologies or practices would affect the baseline. In addition, the monitoring plan should include how the data to
5.4.3 Using the CDM

The CDM is one of the market-based flexibility mechanisms (the others are Emissions Trading and Joint Implementation not used in developing countries) that were included in the Kyoto Protocol for project-based activities. Under Article 12 of the Protocol, the CDM shall assist non-Annex I countries to achieve ‘sustainable development’ and contribute to the ultimate objective of the Convention, and shall assist Annex I countries or developed countries to achieve compliance with their quantified emission limitation and reduction commitments. This mechanism allows Annex I countries to earn ‘certified emission reductions units (CERs)’ whenever they undertake projects that contribute to sustainable development in a non-Annex I country and result in real, measurable and long-term GHGs reductions.

Under the supervision of an executive board, private and public funds may be channelled through this mechanism to finance projects in developing countries. Any party ‘may involve private and/or public entities’ in the regime. A share of the proceeds from project activities is used to cover the administrative expenses of the CDM and another is part used to help particularly vulnerable developing countries meet the costs of adapting to a changing climate. CDM projects must have the approval of all parties involved and this may be gained from designated national authorities (to be set up by each Annex I and non-Annex I country). The national authority is the official body representing the government, which takes part in the arrangement and approval of CDM projects in the host country.

In 2007, the CDM Executive Board approved methodology AM0056 which allows the retrofitting or replacement of inefficient industrial or utility boilers and fuel switching. The key features of the methodology are procedures to calculate specific fuel and energy consumption of baseline equipment taking into account best possible operating conditions of the old boiler system. AM0056 is applicable for single and for multi boiler installations. However, it is unlikely this will be a speedy process. This can be measured by the fact that by the end of 2008 there were still no registered CDM projects using this methodology.

There is a huge potential to apply this type of CDM project using the AM0056 methodology in China. According to Longhai (2006) during the 11th Five-Year Plan period the Chinese Government plans a project to upgrade coal-fired industrial boilers (kilns) raising their efficiency by 5%. This could result in an estimated saving of 25 Mt of coal. In addition, the efficiency of coal-fired kilns will be raised by 2%, with 10 Mt of coal saved. Projects that are marginal could use the CDM to make them more economically viable.

Any CDM industrial boiler project must meet the following mandatory CDM criteria:

- only GHGs covered by the Kyoto Protocol are eligible;
- the host country must be a party to the Kyoto Protocol;
- the emission reductions of the project must be additional (project additionality) to any that would occur in the absence of the project;
- if a project is financed by public funding, this must not result in a diversion of official development assistance, and the sources of public funding must be separate and not count towards the financial obligations of the Annex I countries;
- the project must contribute to the host country’s sustainable development objectives;
- the project should not result in unacceptable negative impacts on the environment. If it is expected that the unintended environmental impacts of the project are significant, then an environmental impact assessment should be carried out in accordance with the procedures as required by the host country;
- the project concept must be acceptable to the host country and conform to its CDM requirements;
- the project should lead to the transfer of environmentally safe and sound technology, and expertise;
- the project developer should define the period over which CERs will be claimed;
- the emission reductions of the project need to be measurable and need to be validated/determined and verified by an Operational Entity (OE)/Independent Entity.

5.5 Summary

The evidence from the few case studies in published literature is that improvements in the performance and efficiency of boilers can be achieved using case studies to apply lessons where boilers are similar and using the same type of coal. More dissemination of information and publication of case studies would assist in raising education and awareness of boiler operators. In particular, this should be translated into the language of the boiler operator. There is also the option of applying the CDM to replace or retrofit industrial boilers, although, few projects have currently been undertaken. There are publications offering guidelines on how to undertake industrial boiler emission reduction projects which can also led to improved performance and efficiency of the industrial boiler.
Identifying specific best practice guidelines for small-to-medium sized industrial boilers within a range of 3–20 MWth is possible with generic guidelines. It is difficult to develop specific guidelines due to the different types of industrial boilers. Guidelines need to consider a wide range of factors including the type of coal, boiler design and boiler operator. There are generic guidelines that are applicable to solving many boiler problems with various options available to improve boiler performance. This has been illustrated and discussed in the chapter describing industrial boilers and by the various case studies. All of these countries have similar lessons that can be applied generically to improve industrial boilers performance and efficiency. The key conclusion of this report is that it would be difficult to have specific world best practice guidelines for small-to-medium sized boilers because of the variety in the use of coal, design of the boiler, and different countries’ legislative standards.

The chemical and physical nature of coal are variable. Industrial boilers reflect this by normally having recommended types or rank of coal by the manufacturer, to obtain the best efficiency and emission performance from a boiler. There is a wide variety of boilers and manufacturers are normally only willing to guarantee and repair their boilers in the warranty period if the operator adheres to the fuel specification. This means that if a coal not covered in the warranty is used, the guarantee will lapse. This is a major challenge and obstacle in developing world’s best practice. A further key issue is that improving a boiler’s efficiency will greatly depend on the company, site engineer or boiler operator’s willingness to explore and implement efficiency measures. This is usually driven by cost and the need to meet legislative regulations.

The nature of the coal dictates the type of industrial boiler that can be used. In selecting a boiler, an analysis would be carried out by the boiler manufacturer using performance tests with different ranked coals to identify the best type of coal. This will ensure that the boiler operates most efficiently, although if the coal is cheap to source then efficiency may not be a high priority.

An industrial boiler owner can examine the options to make considerable savings by using a different, cheaper rank of coal than specified by the manufacturer. This may have no or little impact on the efficiency of the boiler. However, before using the alternative coal a pilot test should be run because if a major problem arises with the boiler, the manufacturer may not be liable under the warranty to cover any repairs, if the boiler is still under guarantee. There are many expensive publications on how to operate specific boilers and how to achieve the best performance. However, if the boiler manufacturer’s guidelines on how the boiler is operated are followed, then problems should be limited. A key element is training of the boiler operator to identify problems arising and how to resolve them.

Industrial boiler manufacturers produce two basic design of boilers: fire-tube and water-tube. Although there are many specific guidelines for industrial boilers and improvements are happening in both developed and developing countries, the literature indicates that there is room for improvement. This could include the further development, publication and distribution of generic boiler guidelines. This action could lead to substantial improvements in performance and efficiency, as well as a reduction in carbon emissions, especially as coal remains a key and globally important energy source for the foreseeable future. Coal will continue to account for a large proportion of primary industrial energy needs, particularly in developing countries due to its low cost and availability. In some countries there is competition to switch from coal- to gas-fired boilers which is evident in the use of gas-fired small-to-medium sized industrial boilers in the USA and Europe.

The term ‘world’s best practice for industrial boilers’ covers a wide range of different boiler designs and technologies. It is evident that the driving factor for efficiency is to reduce costs. For many countries another driver is the tightening up of air quality standards which place limits on ambient pollutants. Increasingly, stricter air quality limits will lead to more industrial boiler operators improving the performance of their coal-fired boilers or possibly switching to gas to reduce their boiler’s emissions. There are several generic options that industrial boiler users can undertake to improve the performance of their boiler. An example of improving industrial boiler’s performance is the reduction of excess air and unburnt carbon in the fly ash and slag which if untreated will result in low boiler efficiency. This can be remedied by the use of online automatic flue gas analysis efficiency and adjusting operating conditions to a suitable level.

Given the importance of the role of coal in the industrial sector and the problems that arise from operating boilers, an international boiler operating practice is needed with generic guidelines. A best practice for industrial boilers would have to be generic due to the different types of coals, boiler designs and regulations differing from one country to another. There would also be minimal impact unless governments intervene with standards or guidelines agreed in cooperation with boiler manufacturers. Many boilers are designed for a specific type of coal and any flexibility in the coal used could lead to serious boiler problems. It would be more realistic to continue with boiler manufacturers providing specific manuals on how to operate their boilers efficiently and governments working together with boiler manufacturers to produce generic guidelines on improving the efficiency of boilers.

There is also a problem concerning the time that any introduction of guidelines to improve industrial boilers will take. A good example of this was a World Bank programme to improve the efficiency of industrial boilers in China. One of the project’s aims was to subsidise the acquisition of licences for new boiler technologies by Chinese firms. The project experienced many problems and delays. For example it took six years to identify suitable technology licensors due to the
reluctance of major international firms to take part because of concerns over intellectual property protection and the World Bank’s terms for the projects. Any form of world’s best practice industrial guidelines is likely to experience these and other problems, such as less rigorous air quality standards in one country compared to another and the sheer scale of educating and training boiler operators.

In the literature review a number of pre- and post-combustion control techniques were identified that work successfully and do improve the efficiency and performance of the boiler. They are detailed in Chapter 4. There also several common tips identified by the US DOE including:

- inspect and repair steam traps;
- insulate steam distribution and condensate return lines;
- use feedwater economisers for waste heat recovery;
- improve the boiler’s combustion efficiency;
- clean boiler waterside heat transfer surfaces;
- return condensate to the boiler;
- minimise boiler blowdown;
- recover heat and boiler blowdown;
- use vapour recompression to recover low-pressure steam;
- flash high-pressure condensate to regenerate low-pressure steam;
- use a vent condenser to recover flash steam energy.

If the boiler operator wishes to replace the existing boiler with a new one the following key factors should be considered:

- geographical location and site accessibility;
- plan area and height requirements;
- fuel type, price, and availability;
- boiler type, size, efficiency, price, and reliability;
- heating loads and load variations including: acceptable pressure and temperatures ranges, and required rates of heat delivery;
- federal, state, and local environmental regulations;
- regional air quality;
- emission limitations and options for controlling regulated pollutants;
- construction and operating permit requirements.

The most important factor before identifying which boiler to buy is to determine what type of coal or fuel will be used. Identifying the correct rank and type of coal will determine the size and design of the boiler including the type of grate, whether it is a fire- or water-tube boiler and will determine the type of pre-combustion or post-combustion technology that can be used prior, during and after fuel combustion. Considering and understanding these factors will reduce clinkering, fouling and slagging and improve the performance of the boiler in the long run.

The technical challenges that small-to-medium sized industrial boilers face differ from the utility industry. One challenge is the behaviour of the ash; the boiler design and operation of the combustion system must respond to this challenge. The three problems that occur with ash are clinkering in the grate, slagging in the radiant section and fouling during the convection pass. To solve clinkering the use of the correct grate and fuel-feed system is important.

The use of coal sorting, washing and an economiser or air preheater will reduce slagging and fouling as well as improve the performance of a boiler. The other two problems of clinker or slagging and fouling for coal-fired boilers can result in expensive outages for heat plant and reduce the efficiency of the heat transfer surfaces. Ensuring that the boiler is tuned correctly and does not have excess air will create uniform and complete combustion. Regular water maintenance treatment through blowdown prevents and reduces suspended solids forming scale on the boiler heating surfaces. This scale reduces heat transfer and raises the tube metal temperatures, consequently reducing the boiler efficiency with the increase in stack gas temperatures. The benefits from regular boiler blowdown include:

- reduction in maintenance costs and repairs from deposits;
- more efficient and cleaner steam;
- lower operating costs with the consumption, disposal, treatment and heating of water;
- less fuel, water and treatment chemicals are required;
- reducing energy loss from boiler blowdowns can save up to 2% of a facilities total energy use.

It is important to calculate the correct blowdown as insufficient blowdown could lead to deposits remaining, while excessive blowdown will waste heat, water and chemicals.

The manufacturer undertakes performance tests and recommends guidelines to achieve the best performance from their boiler. Boiler operators should adopt the following principles to ensure high efficiency and reliability:

- control the air supply;
- mix the fuel and the air thoroughly to ensure uniform combustion;
- ensure the temperature is high enough for combustion and not too low where incomplete combustion can take place;
- timing of the air supply, mixing of fuel and air is calculated correctly so that the boiler is not operated at too high a capacity resulting in incomplete combustion and unburnt fuel remaining.

All of these principles will assist a boiler operator to obtain the best performance out of their boiler. The site engineer or boiler operator is also an important element in obtaining a better performance from a boiler. If they are well trained and motivated to improve the performance of a boiler, this will result in medium -to long-term economic savings and improved output.

A key barrier for World’s Best Practice for industrial boilers is that regulators may not have the technical knowledge to understand the complexity of the processes involved in an industrial plant, let alone the boilers which differ in design and types of coals used. In addition, if different blends of coal are used in the same boiler it will react differently. All of these factors and others result in each facility having its own specific requirements and guidelines. Therefore the transaction costs to implement, monitor and verify different regulations would be prohibitively expensive.

Countries using industrial boilers have specific characteristics such as their current economic and political infrastructure and
natural resources. Other specific characteristics include limited infrastructure/support services, weak economic conditions with slow economic growth and high deficits, or prevailing corrupt practices by officials. In many countries there is also limited availability of intellectual skills in various fields, such as engineering and management. The scale of facilities can also differ, for example China’s steel industry involves thousands of small units in steel making using boilers, compared with Japan where there are only a relatively few steel making companies.

If industrial coal use in boilers is to retain a place in the world’s energy supply they must also be competitive. Coal-fired equipment costs are higher than gas or oil due to coal and ash handling costs. In OECD countries there are also more stringent air quality regulations, climate change policy as well as the convenience of gas versus coal. If industrial boilers are to be competitive they need to be automated as much as possible in storing the coal, transferring and feeding into the combustion equipment and ash removal for transfer off site and disposal. These are all difficult elements to address for small-to-medium sized industrial boilers and the key reasons why small-scale industrial use of coal has virtually disappeared in OECD countries.

The development of new designs and better processes has improved the efficiency of industrial boilers. However, intellectual property rights can be a key obstacle to getting advanced technologies to the countries that need it, and to maintain the ability to invest in R&D for future innovation. Companies that invest in the research, development and commercialisation of new innovative technologies need to have their IPR protected in order to maintain their competitive advantage. Any advances in improving industrial boilers will have to deal with the issue of IPR.

Case studies provide an ideal avenue to improve information links and interaction between experts and industry representatives using industrial boilers that provide better efficiency. A World Bank study in China using case studies resulted in improvements in the design of boilers with Chinese manufacturers, although the project took several years to complete. A case study should be accessible via databases or links through relevant boiler manufacturer associations to be successful. Providing information about the efficient operation of industrial boilers will enable enterprises to make a fully informed choice on the best technological option for them. When preparing future projections or scenarios, it would be desirable to take account of technological realities and limitations by consulting relevant industries on the actual scope for improving their industrial boiler performance.

The CDM provides a tool for developing countries to increase the efficiency of industrial boilers with projects that involve retrofitting with better performing boilers.

The key conclusions are:

- No two boilers are alike. To improve an industrial boiler’s efficiency is very boiler specific. There are four key factors to consider: the fuel type, the combustion systems limitations, steam system operation
- Regulators designing regulations must understand that the one size fits all approach will not necessarily improve energy efficiency as older boilers with fixed designs have limitations, so any switch in the type of coal used could result in a loss of efficiency.
- There are several publications and websites that offer valuable information for boiler operators and are freely available. An example is the US DOE Office of Industrial Technologies website which has tips and other resources from its best practice website at: www1.eere.energy.gov/industry/bestpractices/index.html. There is also the US DOE Climate Leaders Programme which has protocols for commercial- and industrial-scale boilers.
- To be competitive industrial boilers need to be automated as much as possible in storing the coal, transferring and feeding into the combustion equipment and ash removal for transfer off site and utilisation.
- Increasingly stringent air quality regulations are likely to result in more boiler operators switching to gas-fired boilers where the fuel is available at a competitive cost. Or they may examine the option of cofiring with biomass.
- The use of case studies is a valuable tool in identifying and implementing measures for boiler operators, especially when the coal used is similar to one they use. However, their use is limited when the boilers involved do not use similar coal or are designed for a different purpose. There is also limited published literature using case studies on small-to-medium sized boilers that is freely available.
- The boiler operator, or site engineer, plays a key role in obtaining the best performance out of a boiler and it is important that they are well trained and motivated to maintain and improve a boiler’s performance.
7 References


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