COAL-TO-POWER

Asia moves towards 'high-efficiency, low-emissions' coal power

Like it or not, the outlook for coal and coal-fired power stations is very different in Asia than in Europe and North America. So it's important that power plants there employ the least polluting and most efficient technology options, argues *Toby Lockwood* of the IEA Clean Coal Centre.

From a European or American perspective, it has become easy to think that coal power is a dying technology. However, it bears remembering that coal remains, by some distance, the largest source of power generation worldwide, and it has increased more than any other source even over the last two decades. This remarkable proliferation has been driven by rapidly growing Asian economies, where coal represents readily available, low-cost power and energy security.

For these countries, coal power plants are not relics of an industrial past, but the engines of an industrialising present. Well over half of the world's current 2 TW of coal capacity was built in the last 20 years, and over 90% of that expansion has taken place in Asia – primarily in China, but also India, and increasingly South-East Asia, Pakistan, and Bangladesh.

Most forecasts see a gradual levelling off in global coal capacity over the next two decades, as decline in the West is offset by continuing growth in these markets and new ones in Africa. Over 140 GW of new coal capacity is currently under construction, and more is planned.

Given the undeniable toll of coal-fired power generation on the environment, both in terms of climate change and impact on air and water quality, there is an urgent need to ensure the best available technologies are used for new and existing plants. Tough coal phase-out policies of the kind being implemented in many European countries are simply not feasible for economies with rapidly growing energy demand, especially where access to natural gas is limited.

The recently built plants are therefore here to stay for at least a couple of decades, and need cleaning up. In the coal power industry, the contentious term 'clean coal' is being increasingly replaced by 'HELE' – high-efficiency, low-emissions.

Shenergy-operated Waigaoqiao 3 has implemented a series of efficiency upgrading technologies to become one of the most efficient coal power plants in China

Photo: IEA Clean Coal Centre

Whatever the terminology, the focus is on more efficient power plants which generate less carbon dioxide (CO_2) per kWh of energy generated, as well as on flue gas cleaning equipment which can scrub out pollution like sulphur dioxide (SO_2), oxides of nitrogen (NO_x), particulates, mercury and, ultimately, CO_2.

Bigger, hotter, more efficient plants

Since the first coal power plant fired up in London nearly 140 years ago, the technology has got progressively bigger, hotter and more efficient – see **Figure 1** and **Table 1**. Raising steam at higher temperatures and pressures is the key to running turbines at higher efficiency and, since the 1960s, the best plants have used 'supercritical steam' – the phase of water which behaves somewhere between a liquid and a gas – allowing efficiencies of up to around 43%.

Efforts to push the boundaries of coal plant efficiency have always been dictated by materials. In the early 1990s, new types of steel (Gr 91, then Gr 92) allowed a new generation of plants dubbed 'ultrasupercritical' or USC.

Although steadily improved to reach up to 47.5% efficiency (600–620°C steam), this fundamental design still represents the state of the art in coal power, and is increasingly adopted even in lower-income economies such as Bangladesh, Indonesia, and Vietnam. India commissioned its first USC power plant last year, while the technology already represents nearly a quarter of China's fleet.

Although these efficiency improvements may seem incremental, such is the scale of global coal power, that raising the global average efficiency to the state of the art would equate to a CO_2 saving of around 2bn tonnes.

With steam conditions pushing steels to the limits of their capabilities, for around 20 years the obvious next step for coal power has been thought to require use of the nickel-based 'superalloys' used in jet engines, which could allow a leap to over 700°C steam and 50% efficiency.

Unfortunately, developing these materials for use in the envisaged 'advanced ultrasupercritical' (AUSC) coal plant has been a slow

	Subcritical	Supercritical	Ultrasupercritical	A-USC
Main steam temperature	≤540°C	538-566°C	593-610°C	700-760°C
Steam pressure	16-18 MPa	>22 MPa	25-30 MPa	35-36 MPa
Efficiency (LHV, net)	30-39%	39-43%	Up to ~47.5%	≥50%
CO2 intensity	>870 g/kWh	800-870 g/kWh	720-870 g/kWh	<690 g/kWh

Table 1. Typical operating parameters of the different generations of coal power plant

and difficult process which has struggled against declining interest in coal in the EU and the US. More recently, India has taken up the baton of this research, and is looking to back development of a full-scale plant in the next few years.

Perhaps more promisingly, efforts to make the jump to AUSC plant have also given rise to new steels and technologies which have unlocked a more incremental progression. GE typified this approach with its never-realised 'SteamH' design released in 2017, which used advanced steels and minimal nickel alloys to reach 650°C main steam temperature and over 49% efficiency.

However, since GE's recent exit from new coal, the market has been left largely to Chinese, Japanese and Korean manufacturers. In China, there is also a drive towards 650°C, as well as innovation in steam cycle design such as the idea of raising the turbine close to the top of the boiler (where the hottest steam is produced), thereby minimising pressure drops and the need for costly steam piping.

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Shanghai-based company Shenergy is close to realising this concept on a 1,350 MW unit at Pingshan power plant, where an efficiency of over 49% is targeted. This unit also uses a double reheat cycle, in which steam is twice reheated and re-run through the turbine. This higher-efficiency design has been around for years, once breaking records at Denmark's Nordjylland plant, but is currently experiencing a revival in China as a means of getting the most out of USC technology.

Gasification options

An alternative vision for coal power is to exploit the high efficiency of gas turbines by first converting the coal to syngas (a mix of carbon monoxide and hydrogen) in a gasifier. This can then be used to fuel a combined cycle gas turbine in an arrangement known as an integrated gasification combined cycle (IGCC). This concept has, again, struggled historically, as early demonstrations in the US and Europe in the 1990s were soon seen as costly and overly complex relative to advancing USC technology.

Today, the technology lives on in Japan, where Mitsubishi is soon expected to commission two new 540 MW IGCC units in Fukushima. Designed to reach 48% efficiency, these plants are seen as well suited to dealing with coal containing low-melting point ash, which can damage conventional steam boilers.

A more novel variant is being trialled at Japan's Osaki Coolgen project, where coal-derived hydrogen will be fed to a high-efficiency, solid oxide fuel cell.

Smarter analytics

Given the sheer scale of coal power deployed in the past decade, ensuring that the existing plants run as cleanly as possible is arguably of even greater importance than developing new designs. To this end, the coal power sector is making increasing use of 'digitalisation' – gathering more data and running ever-smarter analytics and control systems in order to keep power plants running at the sweet spot of high efficiency and low emissions.

This has become even more essential as coal plants are increasingly required to ramp their output up and down as flexible back-up to wind and solar, presenting a complex and dynamic problem for control systems. Plant operators can now run 'digital twins' or simulations of plant processes to help optimise and explore the range of its capabilities.

Greater connectivity is also allowing manufacturers to monitor and tune their equipment from remote control centres. In this respect, the coal technology business is increasingly a service industry.

For major improvements in the efficiency of older, 'subcritical' plant types, changes not just to software, but to hardware are needed. Stringent efficiency standards for all coal units in China have driven in interest in ambitious unit upgrades, such as the Xuzhou project, where the replacing key components of the boiler and turbine allowed an increase in temperature from

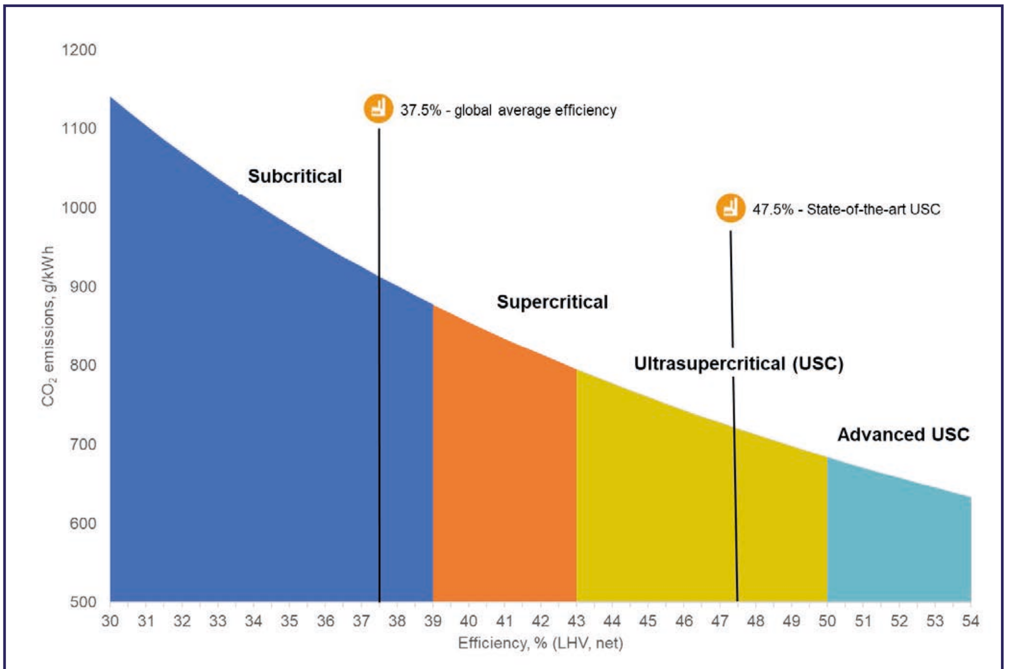

Figure 1. The reduction in carbon dioxide emissions intensity with increasing efficiency

538 to 600°C – essentially converting the unit to near-USC efficiency levels.

Air quality issues

Negative perceptions of coal power are mostly fuelled by its more visible, near-term impact on air quality, through emissions of harmful particulates and the acidic gases SO2 and NOx. As technologies to remove these pollutants from coal flue gas have existed for many years, the main challenge is to ensure they are as deployed as widely as possible.

While most plants worldwide are equipped with electrostatic precipitators or bag filters to remove particulates, control measures for SO2 and NOx are only recently being legislated for in major coal-users such as India, Indonesia, and South Africa. Following a stringent crackdown on air pollution over the last decade, China has led the way in optimising existing flue gas desulphurisation and NOx removal technologies, with some plants achieving below 20 mg/m^3 concentrations of both pollutants – compared with limits of 100–200 mg/m^3 coming into force in the EU.

On this front, there is no reason why a coal plant should pollute any more than a gas-fired plant.

Carbon capture and storage

The ultimate goal for coal power is to properly tackle the problem of CO2 emissions with carbon capture and storage (CCS) technology, which could remove up to 98% of the greenhouse gas emitted (although 90% is a more common target). Despite a spate of international interest in applying CO2 capture to coal power plants around 2010, only two facilities were realised – Boundary Dam 3 in Canada and the Petra Nova project in Texas, which both benefit from the use of captured CO2 to boost oil well production.

A recent revival in CCS has sought to reframe the technology as a solution for non-power sector emissions, but interest in coal power remains in the USA, where five new full-scale projects are currently in the design stage. While developments in China have so far been limited, the country's recently announced aim of reaching net-zero by 2060 must surely require a major role for CCS.

From the US/Europe to Asia

There is some irony in the story of coal technology development over the last 20 years. Just as coal power plants have multiplied across Asia, declining interest in Europe and North America has often helped put the brakes on development of the very technologies needed to address this growing problem. Technology developers in India and China have taken up the challenge, often going further than counterparts in the West, while Japan retains its role as an exporter of some of the most high-tech plants.

However, unconstrained by OECD lending rules, China is also happy to build and finance less efficient plants in new markets such as Africa. There is a real danger in losing institutional expertise and technological capability as leading manufacturers and researchers leave the game, just as there is more need than ever for new solutions. ●

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