World Energy Needs: A Role for Coal in the Energy Mix

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ABSTRACT

The last 18 months have been a landmark period for climate, environment and development negotiation processes with the delivery of the Sustainable Development Goals and the Paris Agreement at the 21st Session of the Conference of the Parties (COP21). Energy access and climate goals are not competing priorities. As demonstrated by the Intended Nationally Determined Contributions (INDC) submitted in the lead-up to the Paris summit, each nation will choose an energy mix that best meets its needs. For this reason many countries have identified a continuing role for coal. Coal is a critical enabler in the modern world. It provides 41% of the world's electricity and is an essential raw material in the production of 70% of the world's steel and 90% of the world's cement. This chapter provides an introductory overview of coal, its use in building modern societies and its role in delivering low-cost on-grid electricity while integrating environmental commitments.

1 Introduction

There is little doubt that the 'Paris Agreement' delivered at the 2015 Climate Change Conference represented a landmark accomplishment. Equally, the rapid endorsement by national governments and the private sector to implement the deal is a welcome development.

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Looking ahead, as the deal becomes a reality it is vitally important that its delivery integrates environmental imperatives with the aims of universal access to energy, energy security and social and economic development. Only by balancing these elements can the agreement produce emissions reductions consistent with its vision while maintaining legitimate economic development and poverty alleviation efforts.

Energy is vital to development. Access to affordable and reliable electricity is the foundation of prosperity in the modern world. The Paris Agreement, however, has given countries an added impetus to ensure that improving energy access is balanced with action on reducing emissions.

Energy access and climate goals are not competing priorities. This understanding formed the basis of national climate pledges that were submitted in the months prior to the Paris climate negotiations and ultimately provided the foundation for the Agreement. Known as the Nationally Determined Contributions (NDCs), these pledges will act as strategic roadmaps for countries' climate, energy and development priorities.

Twenty four countries, representing over 50% of the world's emissions, submitted Intended Nationally Determined Contribution (INDCs) that identified a continuing role for coal.[1] No doubt as the INDC process is formalised this figure will rise.

Coal is a critical enabler in the modern world. It provides 41% of the world's electricity and is an essential raw material in the production of 70% of the world's steel and 90% of the world's cement.[2] Fossil fuels today provide over 80% of the world's primary energy, a percentage not forecast to change significantly for decades to come.[3] With the use of coal projected to continue to grow over the coming decades, a low-emission technology pathway for coal is required to meet emissions targets.

This pathway begins with deployment of high-efficiency, low-emissions (HELE) power stations using technology that is available today. These facilities are being built rapidly and emit 25–33% less CO_2 and eliminate other emissions, such as oxides of sulfur and nitrogen and particulates.[4] Moreover, HELE technology represents significant progress on the pathway towards carbon capture, use and storage (CCUS), which will be vital to achieving global climate objectives.

This chapter provides a comprehensive overview of coal and the role it plays in supporting sustainable development. It covers how coal is formed, how it is mined, through to its use and the impact it has on our societies and natural environments. It describes coal's role as an energy source and how coal – along with other sources of energy – will be vital in meeting the world's rapidly growing development needs along a sustainable pathway.

2 What Is Coal?

2.1 Coal Formation

Coal is a combustible, black or brownish-black sedimentary, organic rock, which is composed mainly of carbon, hydrogen and oxygen.

At its most basic level, coal is the altered remains of prehistoric vegetation that was originally located in swamps and peat bogs. Like all living organisms, these plants stored energy from the sun through a process known as photosynthesis. Generally, as plants die this energy is released during decay. At times, however, interruption of the decay process through the build-up of silt and other sediments, combined with tectonic movements, buried vegetation to great depths. In turn, buried vegetation underwent chemical and physical changes as a result of millions of years of pressure and heat transforming it into coal.

The process of coal formation began 360 to 290 million years ago during the Carboniferous Period – also known as the first coal age.

Several factors, including temperature, pressure and age, determined the quality of each coal deposit. Peat, in the first instance, was converted into lignite or ‘brown coal’. Over millennia, pressure and temperature combined to transform lignite coal to more energy-intensive ‘sub-bituminous’ coal. Further chemical and physical changes occurred until these coals became harder and blacker, forming the ‘bituminous’ or ‘hard’ coals. Under the right conditions, the progressive increase in the organic maturity continued, finally forming anthracite.

2.2 Coal Classification

The degree of change that coal undergoes as it matures from lignite to anthracite is known as ‘coalification’. The process has an important bearing on the physical and chemical properties of coal and is referred to as the ‘rank’ of the coal. Ranking is determined by the degree of transformation of the original plant material to carbon and is illustrated in Figure 1.

Low-rank coals – lignite and sub-bituminous – are low in carbon but high in hydrogen and oxygen content, and therefore lower in energy content. Low-rank coals are typically softer, friable materials with a dull, earthy appearance.

High-rank coals are high in carbon and therefore in heat value, with conversely lower levels of hydrogen and oxygen. Generally, high-rank coal is harder, stronger and often has a black, vitreous lustre. At the top of the rank

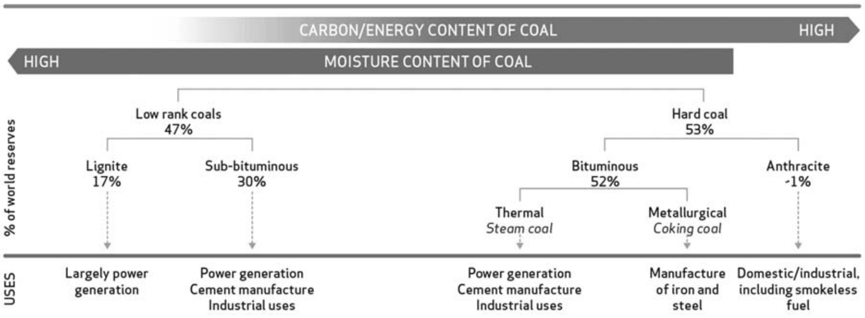


Figure 1 Types of coal.

scale, anthracite has the highest carbon and energy content, with the lowest levels of moisture.

2.3 Where Is Coal Found?

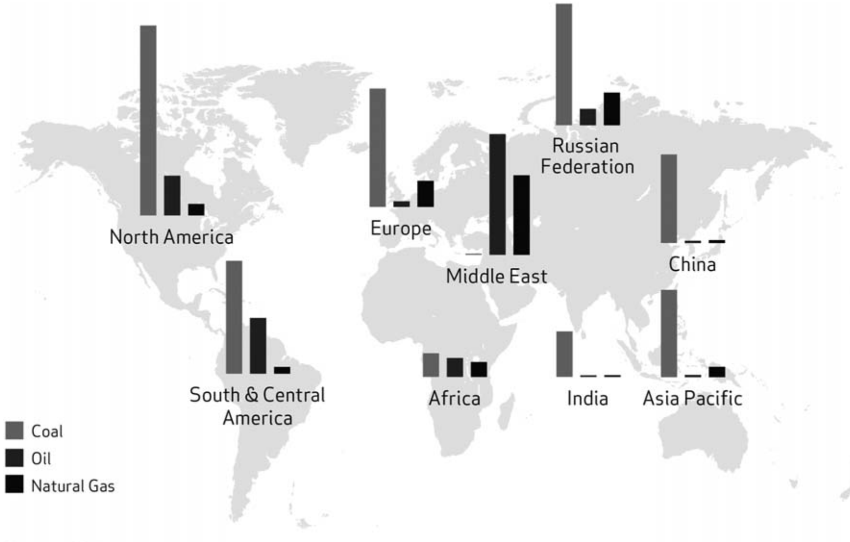
According to the International Energy Agency (IEA), there are over 985 billion tonnes of proven coal reserves worldwide.[5] At the current rate of production there are enough coal reserves to last around 128 years.[5]

Moreover, while it is estimated that current coal reserves could sustain demand well into next century, this could extend still further through a number of developments, including:

- The discovery of new reserves through ongoing and improved exploration activities
- Advances in mining techniques, which will allow previously inaccessible reserves to be reached.

As seen in Figure 2, coal reserves are available in almost every region, with recoverable reserves in almost 70 countries.[6] Although the largest reserves are in the USA, Russia, China and India, coal is actively mined in more than 70 countries. By contrast, Russia, Iran and Qatar control over half of the world's gas reserves and close to 50% of the world's oil reserves are located in the Middle East.[6]

Most coal is consumed domestically and only 17% is traded internationally.[7] In a number of countries coal is also the only domestically available energy



Source: BP 2015

Figure 2 Location of the world's main fossil fuels reserves (million tonnes of oil equivalent).

fuel and its use is motivated by both economic and energy security considerations. This is the case in countries and regions such as Europe, China and India, where coal reserves are much higher than oil or gas reserves. Most of the world's coal exports originate from countries that are considered to be politically stable – a characteristic which reduces the risks of supply interruptions.

2.4 Coal Exploration

Coal reserves are discovered through exploration activities. The process usually involves creating a geological map of the area, then carrying out geochemical and geophysical surveys, followed by exploration drilling. This allows an accurate picture of the area to be developed.

The area will only ever become a coal mine if it is large enough and of sufficient quality that the coal can be economically recovered. Once this has been confirmed, mining operations can begin.

2.5 Coal Mining

Coal is mined by two methods – surface (opencast) or underground (deep mining).

The choice of mining method is largely determined by the geology of the coal deposit. Underground mining currently accounts for about 60% of world coal production,[8] although in several important coal-producing countries surface mining is more common. Surface mining accounts for around 80% of production in Australia, while in the USA it is used for about 67% of production.[8]

2.5.1 Underground Mining. There are two main methods of underground mining: room and pillar and longwall mining.

In room and pillar mining, coal deposits are mined by cutting a network of 'rooms' into the coal seam and leaving behind 'pillars' of coal to support the roof of the mine. These pillars can be up to 40% of the total coal in the seam,[8] although this coal can sometimes be recovered at a later stage. This can be achieved in what is known as 'retreat mining', where coal is mined from the pillars as workers retreat. The roof is then allowed to collapse and the mine is abandoned.

Longwall mining involves the full extraction of coal from a section of the seam or 'face' using mechanical shearers. A longwall face requires careful planning to ensure favourable geology exists throughout the section before development work begins. The coal 'face' can vary in length from 100–350 m. Self-advancing, hydraulically-powered supports temporarily hold up the roof while coal is extracted. When coal has been extracted from the area, the roof is allowed to collapse. Over 75% of the coal in the deposit can be extracted from panels of coal that can extend 3 km through the coal seam.

The main advantage of room and pillar mining over longwall mining is that it allows coal production to start much more quickly, using mobile machinery that costs under $5 million (longwall mining machinery can cost $50 million).

The choice of mining technique is site-specific but always based on economic considerations; differences even within a single mine can lead to both methods being used.

2.5.2 Surface Mining. Surface mining – also known as opencast or opencut mining – is only economic when the coal seam is near the surface. This method recovers a higher proportion of the coal deposit than underground mining as all coal seams are exploited – 90% or more of the coal can be recovered.[8] Large opencast mines can cover an area of many square kilometres and use very large pieces of equipment, including: draglines which remove the overburden; power shovels; large trucks which transport overburden and coal; bucket wheel excavators; and conveyors.

The overburden of soil and rock is first broken up by explosives; it is then removed by draglines or by shovel and truck. Once the coal seam is exposed, it is drilled, fractured and systematically mined in strips. The coal is then loaded on to large trucks or conveyors for transport to either the coal preparation plant or direct to where it will be used.

2.6 Coal Preparation

Coal straight from the ground, known as run-of-mine (ROM) coal, often contains unwanted impurities such as rock and dirt and comes in a mixture of different-sized fragments. However, coal users need coal of a consistent quality. Coal preparation – also known as coal beneficiation or coal washing – refers to the treatment of ROM coal to ensure a consistent quality and to enhance its suitability for particular end-uses.[8]

The treatment depends on the properties of the coal and its intended use. It may require only simple crushing or it may need to go through a complex treatment process to reduce impurities. To remove impurities, the raw run-of-mine coal is crushed and then separated into various size fractions. Larger material is usually treated using ‘dense medium separation’. In this process, the coal is separated from other impurities by being floated in a tank containing a liquid of high specific gravity, usually a suspension of finely ground magnetite. As the coal is lighter, it floats and can be separated off, while heavier rock and other impurities sink and are removed as waste.[8]

The smaller size fractions are treated in a number of ways, usually based on differences in mass, such as in centrifuges. A centrifuge is a machine which turns a container around very quickly, causing solids and liquids inside it to separate. Alternative methods use the different surface properties of coal and waste. In ‘froth flotation’, coal particles are removed in a froth produced by blowing air into a water bath containing chemical reagents. The bubbles attract the coal but not the waste and are skimmed off to recover the coal fines. Recent technological developments have helped increase the recovery of ultra-fine coal material.[8]

2.7 Coal Transportation

The way that coal is transported to where it will be used depends on the distance to be covered. Coal is generally transported by conveyor or truck over short distances. Trains and barges are used for longer distances within domestic markets, or alternatively coal can be mixed with water to form a coal slurry and transported through a pipeline.

Ships are commonly used for international transportation, in sizes ranging from Handymax (40–60 000 deadweight tonnage or DWT), Panamax (approximately 60–80 000 DWT) to large Capesize vessels (>80 000 DWT).[9] Around 1311 million tonnes (Mt) of coal was traded internationally in 2015 and around 90% of this was seaborne trade.[10] Coal transportation can be very expensive – in some instances it accounts for up to 70% of the delivered cost of coal.[9]

2.8 Coal Mining and the Environment

Measures are taken at every stage of coal transportation and storage to minimise environmental impacts.

Coal mining – particularly surface mining – requires large areas of land to be temporarily disturbed. This raises a number of environmental challenges, including soil erosion, dust, noise and water pollution, and impacts on local biodiversity. Steps are taken in modern mining operations to minimise these impacts. Good planning and environmental management minimises the impact of mining on the environment and helps to preserve biodiversity.[11]

2.8.1 Land Disturbance.

In best practice, studies of the immediate environment are carried out several years before a coal mine opens in order to define the existing conditions and to identify sensitivities and potential problems. The studies look at the impact of mining on surface and ground water, soils, local land use, and native vegetation and wildlife populations. Computer simulations can be undertaken to model impacts on the local environment. The findings are then reviewed as part of the process leading to the award of a mining permit by the relevant government authorities.[12]

2.8.2 Mine Subsidence.

A problem that can be associated with underground coal mining is subsidence, whereby the ground level lowers as a result of coal having been mined beneath. Any land use activity that could place public or private property or valuable landscapes at risk is clearly a concern. A thorough understanding of subsistence patterns in a particular region allows the effects of underground mining on the surface to be quantified. This ensures the safe, maximum recovery of a coal resource, while providing protection to other land uses.[11]

2.8.3 Water Pollution. Acid mine drainage (AMD) is metal-rich water formed from the chemical reaction between water and rocks containing sulfur-bearing minerals. The runoff formed is usually acidic and frequently comes from areas where ore- or coal-mining activities have exposed rocks containing pyrite, a sulfur-bearing mineral. However, metal-rich drainage can also occur in mineralised areas that have not been mined. AMD is formed when the pyrite reacts with air and water to form sulfuric acid and dissolved iron. This acid runoff dissolves heavy metals such as copper, lead and mercury into ground and surface water. There are mine management methods that can minimise the problem of AMD, and effective mine design can keep water away from acid-generating materials and help prevent AMD occurring. AMD can be treated actively or passively. Active treatment involves installing a water treatment plant, where the AMD is first dosed with lime to neutralise the acid and then passed through settling tanks to remove the sediment and particulate metals. Passive treatment aims to develop a self-operating system that can treat the effluent without constant human intervention.[11]

2.8.4 Dust and Noise Pollution. During mining operations, the impact of air and noise pollution on workers and local communities can be minimised by modern mine planning techniques and specialised equipment. Dust at mining operations can be caused by trucks being driven on unsealed roads, coal crushing operations, drilling operations and wind blowing over areas disturbed by mining. Dust levels can be controlled by spraying water on roads, stockpiles and conveyors. Other steps can also be taken, including fitting drills with dust collection systems and purchasing additional land surrounding the mine to act as a buffer zone between the mine and its neighbours. Trees planted in these buffer zones can also minimise the visual impact of mining operations on local communities. Noise can be controlled through the careful selection of equipment and insulation and sound enclosures around machinery. In best practice, each site has noise and vibration monitoring equipment installed, so that noise levels can be measured to ensure the mine is within specified limits.[13]

2.9 Mine Rehabilitation

Coal mining is only a temporary use of land, so it is vital that rehabilitation of land takes place once mining operations have stopped. In best practice a detailed rehabilitation or reclamation plan is designed and approved for each coal mine, covering the period from the start of operations until well after mining has finished.[11]

2.10 Mining Safety

The coal industry takes the issue of safety very seriously. Coal mining deep underground involves a higher safety risk than coal mined in opencast pits. However, modern coal mines have rigorous safety procedures, health and safety standards and worker education and training, which have led to significant improvements in safety levels in both underground and opencast mining.[14]

Further detail on mining is given in Chapter 2 of this book.

3 The Global Coal Market

Coal is used by a variety of sectors – including power generation, iron and steel production, cement manufacturing and as a liquid fuel. The majority of coal is either utilised in power generation (steam coal or lignite) or in iron and steel production (coking coal).

3.1 Coal Production

Over 7700 Mt of coal is currently produced worldwide – a 70% increase over the past 20 years.[15] Coal production has grown fastest in Asia, while Europe has actually seen a decline in production. The largest coal-producing countries are not confined to one region – the top five producers are China, the USA, India, Australia and Indonesia.[16]

Global coal production is expected to increase by a further 4% through to 2040 – with developing Asia accounting for the vast majority of increased demand over this period.[20] Steam coal production is projected to have reached around 4.8 billion tonnes, with coking coal reaching 861 million tonnes.[17]

3.2 Coal Consumption

Coal plays a vital role in power generation and this role is set to continue. Coal currently fuels 41% of the world's electricity and this proportion is expected to remain at similar levels over the next 30 years.[18]

The biggest market for coal is Asia, which currently accounts for 75% of global coal consumption,[19] although China is responsible for a significant proportion of this. Many countries do not have natural energy resources sufficient to cover their energy needs, and therefore need to import energy to help meet their requirements. Japan, Chinese Taipei and Korea, for example, import significant quantities of steam coal for electricity generation and coking coal for steel production.

It is not just a lack of indigenous coal supplies that prompts countries to import coal but also the importance of obtaining specific types of coal. Major coal producers such as China, the USA and India, for example, also import quantities of coal for quality and logistical reasons. Coal will continue to play a key role in the world's energy mix, with demand in certain regions set to grow rapidly. Growth in both the steam and coking coal markets will be strongest in developing Asian countries, where demand for electricity and the need for steel in construction, car production, and demands for household appliances will increase as incomes rise.

3.3 Coal Trade

Coal is traded all over the world, with coal shipped huge distances by sea to reach markets.

Over the last twenty years, seaborne trade in steam coal has increased on average by about 17% each year,[20] while seaborne coking-coal trade has increased by 3% a year. Overall international trade in coal reached 1158 Mt in 2015;[21] while this is a significant amount of coal it still only accounts for about 15% of total coal consumed.[21]

Transportation costs account for a large share of the total delivered price of coal, therefore international trade in steam coal is effectively divided into two regional markets – the Atlantic and the Pacific. The Atlantic market is made up of importing countries in Western Europe, notably the UK, Germany and Spain. The Pacific market consists of developing and OECD Asian importers, notably Japan, Korea and Chinese Taipei. The Pacific market currently accounts for about 73% of world steam coal trade.[22] Markets tend to overlap when coal prices are high and supplies plentiful. South Africa is a natural point of convergence between the two markets.

4 How Is Coal Used?

Coal is a critical enabler in the modern world. It provides 41% of the world's electricity and is an essential raw material in the production of 70% of the world's steel and 90% of the world's cement.

4.1 Coal and Electricity

Coal-generated electricity is produced through the use of steam coal (also known as 'thermal coal'). Coal is first milled to a fine powder, which increases the surface area and allows it to burn more quickly. In these pulverised coal combustion (PCC) systems, the powdered coal is blown into the combustion chamber of a boiler where it is burnt at high temperature (see Figure 3). The hot gases and heat energy produced converts water – in tubes lining the boiler – into steam.[23]

The high-pressure steam is passed into a turbine containing thousands of propeller-like blades. The steam pushes these blades causing the turbine shaft to rotate at high speed. An electricity generator is mounted at one end of the turbine shaft. After passing through the turbine, the steam is condensed and returned to the boiler to be heated once again.[24]

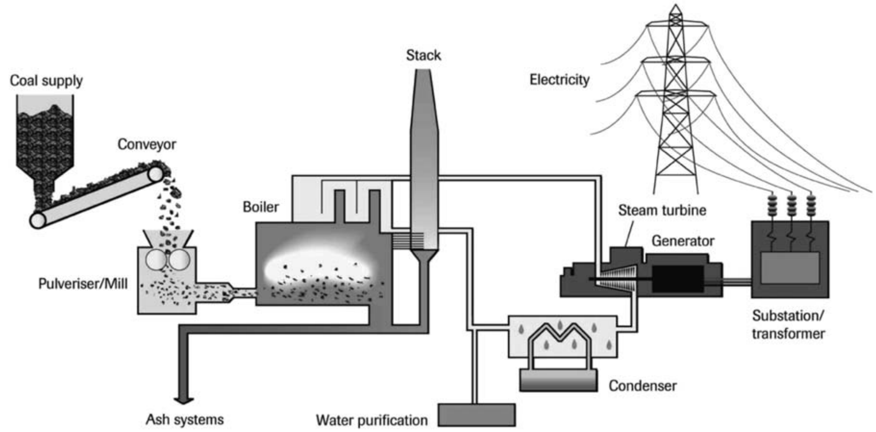


Figure 3 Converting coal to electricity.

The electricity generated is transformed into the high voltages (up to 400 kV) used for economic, efficient transmission *via* power line grids. When it nears the point of consumption, such as our homes, the electricity is transformed down to the safer 100–250 V systems used in the domestic market.[25]

Affordable, reliable and accessible energy is the foundation of prosperity in the modern world.

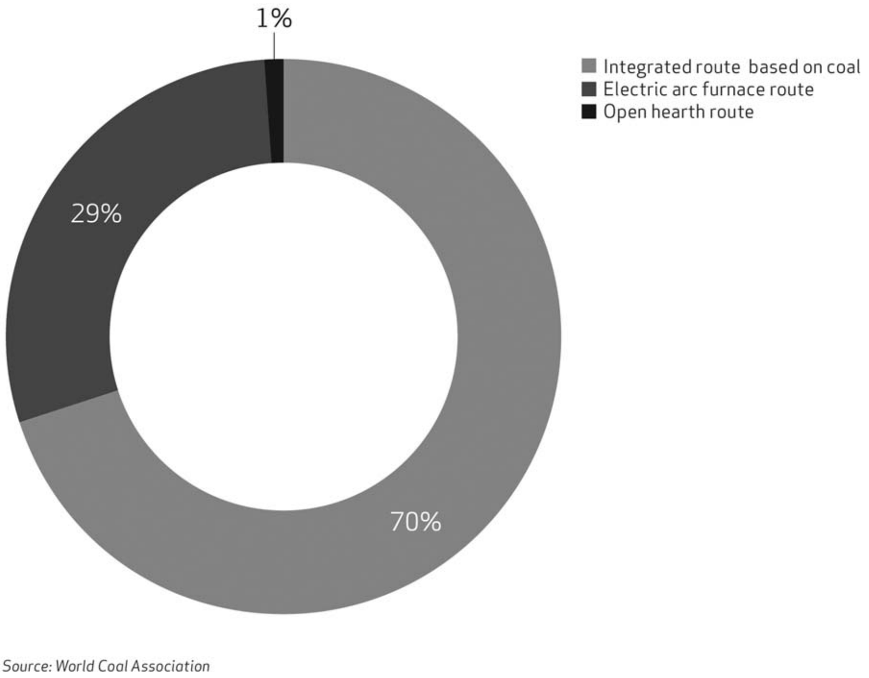
Since the 1980s, coal consumption has grown by over 140% in Brazil, 425% in India and 514% in China.[26] The economic and social progress made across these countries over the same period is well documented. China, in particular, has been a remarkable example of the role that affordable coal can play in improving access to energy and supporting economic development. Over the last three decades, according to World Bank estimates, 600 million people have been lifted out of poverty – almost all of those in China. Remove China from the mix and poverty levels in the rest of the world have barely improved. The link between access to affordable power from coal, economic growth and prosperity is clear. In China close to 99 percent of the population is connected to the grid.[27]

4.2 Coal's Role in Delivering Modern Infrastructure

Economic growth is dependent on the use of highly energy-intensive materials such as steel, cement, glass and aluminium. These materials are necessary for the construction and development of transport, energy, housing and water-management infrastructure.

4.3 Steel Production

Coal is a vital component of global steel production. One tonne of metallurgical coal is required to produce 1.3 tonnes of steel, equivalent to that



Source: World Coal Association

Figure 4 Crude steel production by process.

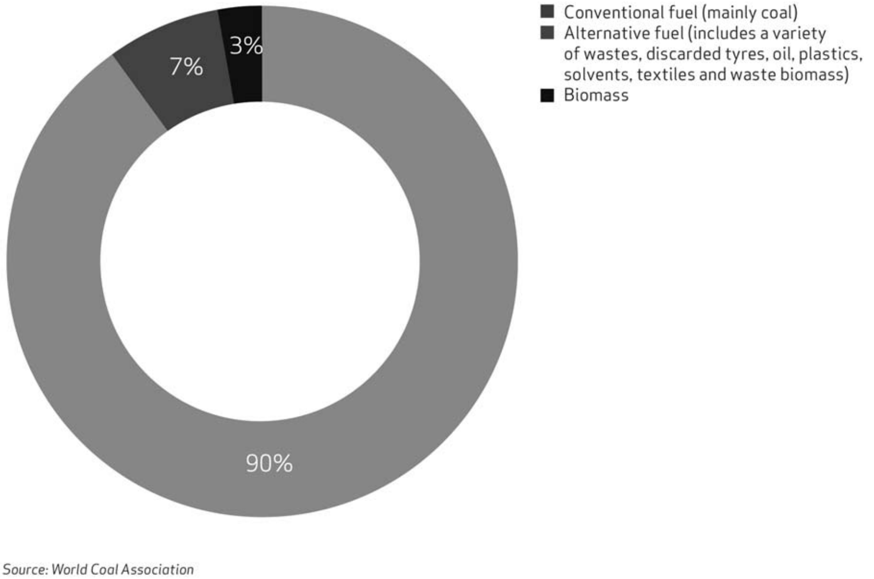
needed to produce 18 household refrigerators.[28] Since 2001, average world steel use *per capita* has steadily increased from 150 kg in 2001 to 217 kg in 2014.[29] This is indicative of the rising living standards in the developing world and consequent demand for consumer goods.

There are two main steel production routes: the integrated steelmaking route and the electric arc furnace route. Coal is an essential raw material and energy fuel in both of them (see Figure 4). The integrated route, based on the blast furnace and basic oxygen furnace, uses on average 770 kg of coal, 1400 kg of iron ore, 150 kg of limestone and 120 kg of recycled steel to produce a tonne of crude steel. The electric arc furnace route uses, on average, 880 kg of recycled steel, 150 kg of coal and 43 kg of limestone to produce a tonne of crude steel.[30]

Steel production is critical in the construction of modern infrastructure such as transport, residential housing and commercial buildings. Manufacturing steel delivers the goods and services an advanced economy requires – healthcare, construction, telecommunications, improved agricultural practices, better transport networks, clean water and access to reliable and affordable energy.

4.4 Cement Production

Cement is the key ingredient in the production of concrete, an essential building material for society's infrastructure around the world, second only



Source: World Coal Association

Figure 5 Total fuel consumption by cement.

to water in total volumes consumed annually. Cement is essential for building houses, bridges, roads, dams, harbours and airports. Coal is used as an energy source in cement production to melt raw materials – limestone, silica, iron oxide and alumina (see Figure 5). It takes about 200 kg of coal to produce one tonne of cement and about 300–400 kg of cement is needed to produce one cubic metre of concrete.[31]

China provides an indication for the scope of cement (and therefore coal) demand that will be required over the coming decades. During the rapid period of industrialisation and urbanisation from 2011–2013, China produced more cement than the USA used in the entire 20th century.[32]

4.5 Coal Liquefaction

Coal-derived fuels, as well as coal-based electricity, can play a significant role in responding to the growing energy needs of the transport sector.

Liquid fuels from coal provide a viable alternative to conventional oil products and can be used in the existing supply infrastructure. Several coal-to-liquids (CTL) demonstration plants are being developed in China. CTL currently provides 20% of South Africa's transport needs, including 7.5% of jet fuel.[33]

Converting coal to a liquid fuel – a process referred to as 'coal liquefaction' – allows coal to be utilised as an alternative to oil. There are two different methods for converting coal into liquid fuels:

4.5.1 Direct Liquefaction. This works by dissolving the coal in a solvent at high temperature and pressure. This process is highly efficient, but the liquid products require further refining to achieve high-grade fuel characteristics.

4.5.2 Indirect Liquefaction. This process gasifies the coal to form a ‘syngas’ (a mixture of hydrogen and carbon monoxide). The syngas is then condensed over a catalyst – the ‘Fischer–Tropsch’ process – to produce high quality, ultra-clean products.

Coal-derived liquid fuels are also sulfur-free, low in particulates, with low levels of oxides of nitrogen, providing local and regional air quality benefits in comparison to oil. Over the full fuel cycle, CO_2 emissions from liquid fuels derived from coal can be reduced by up to 46%, compared to conventional oil products, if co-processing of coal and biomass is undertaken and combined with carbon capture, use and storage (CCUS).

Further detail on coal liquefaction is given in Chapter 6 of this book and on CCUS in Chapter 7.

4.6 Other Uses of Coal

Other important uses of coal include alumina refineries, paper manufacturers, and the chemical and pharmaceutical industries. Several chemical products can be produced from the by-products of coal. Refined coal tar is used in the manufacture of chemicals such as creosote oil, naphthalene, phenol and benzene. Ammonia gas recovered from coke ovens is used to manufacture ammonium salts, nitric acid and agricultural fertilisers. Thousands of different products have coal or coal by-products as components: soap, aspirins, solvents, dyes, plastics and fibres, such as rayon and nylon.

Coal is also an essential ingredient in the production of specialist products:

- Activated carbon – used in filters for water and air purification and in kidney dialysis machines.
- Carbon fibre – an extremely strong but light-weight reinforcement material used in construction, mountain bikes and tennis racquets.
- Silicon metal – used to produce silicones and silanes, which are in turn used to make lubricants, water repellents, resins, cosmetics, hair shampoos and toothpastes.

5 Meeting Future Energy Demand

One of the major challenges facing the world at present is that approximately 1.2 billion people – 16% of the world’s population – live without any access to modern energy services.[34] A further 2.7 billion, or more than one in three people, use wood, charcoal, or animal waste for cooking and heating (see Figure 6).[35] In recent years, efforts to mobilise action in this area have

Source: *International Energy Agency, World Energy Outlook 2016*

Figure 6 People without access to modern energy services by region.

moved to the mainstream of development policy through initiatives such as the G20's Energy Access Action Plan, the UN's Sustainable Development Goals and the UN Secretary General's Sustainable Energy for All.

While progress to improve access to energy has been made in the recent past, quality of supply remains a significant challenge. The IEA attributes this to a variety of factors, including intermittent sources of energy in generation capacity. Such factors vary regionally, however, the implications are broadly the same: an economy that fails to operate at full potential.

Coal is a logical choice for providing universal, stable energy supplies in many countries impacted by energy poverty, as it is widely available, reliable and relatively low cost. It is for this reason that coal has become the *de facto* energy source for electrification. Research indicates that between 1990 and 2010 more than three quarters of a billion people – the vast majority of these being in developing countries – gained access to electricity due to coal-fired generation. The importance of coal for energy access is even clearer when compared with intermittent sources of power. Over the same twenty-year period, research finds that for every person who gained access to electricity from wind and solar, around 13 gained access due to coal.[36]

Coal use is forecast to rise over 11% through to 2040, with developing countries responsible for most of this increase to meet electrification rates.[37] Coal will therefore play a major role in supporting the development of base-load electricity where it is most needed, helping to bring economic growth to the developing world.

Further supporting this forecast, the IEA has projected that more than half of the on-grid electricity needed to meet their 'energy for all' scenario would need to come from coal.[38] It should be noted the even this scenario is not particularly ambitious, delivering an equivalent of five hours of electricity a day and excluding electricity for basic amenities, such as businesses, industry, hospitals, schools and public buildings.

5.1 Coal as an Important Element in the Balanced Energy Mix

The IEA, in its latest World Energy Outlook (2016), projects that global energy demand will grow by almost a third over the next 25 years. Most of this growth will take place in developing countries, particularly in South and Southeast Asia. At present, the average citizen of India, for instance, uses less than one tenth as much energy as the average OECD citizen.[39] Inevitably, development across the region will narrow this gap, necessitating a significant increase in their reliance on electricity and transportation and requiring major new supplies of energy.

To meet this need, the world cannot ignore any of the sources of energy available – including coal. Even in a world where renewables play a larger role in the energy mix, coal still has an important role to play. For example, in Germany, despite a surge in renewables, coal still provides base-load energy to ensure secure and reliable power supply.

It is therefore important that energy stakeholders pursue the most efficient pathway to ensure climate and energy goals. A balanced energy mix will make use of a variety of fossil fuels, nuclear and intermittent generation sources, with centralised and distributed models. Indonesia provides a clear example supporting this premise. The country has committed to adding 35 GW of additional electricity over the coming years to sustain economic growth and address electrification challenges.[40] Large, centralised coal plants will supply low-cost electricity to population and economic centres in Java, while off-grid renewables will be deployed for more remote parts of the archipelago. This approach, according to the World Economic Forum, will minimise expensive 'transmission and distribution construction, take advantage of local fuel sources and ensure affordable access to all'.

5.2 Coal as a Guarantor of Energy Security

The global coal market is large and diverse, with many different producers and consumers from every continent. Coal supplies do not come from one specific area, which would make consumers dependent on the security of supplies and stability of only one region. They are spread out worldwide and coal is traded internationally. There are enough coal reserves to last for around 110 years at the current rate of production. In comparison, proven oil and gas reserves are expected to last an equivalent of approximately 51 and 53 years, respectively, at current production levels.[41]

Many countries rely on domestic supplies of coal for their energy needs – such as China, the USA, India, Australia and South Africa. Others import coal from a variety of countries; in 2015, Germany, for example, imported coal from Russia, Colombia and the USA, as well as smaller amounts from a number of other countries and its own domestic supplies.

Coal therefore has an important role to play in maintaining the security of the global energy mix, complementing other fuels and energy sources that are generally more vulnerable to disruption. Coal contributes to security of the energy mix in a variety of ways:

- Coal reserves are very large and will be available for the foreseeable future without raising geopolitical or safety issues.
- Coal is readily available from a wide variety of sources in a well-supplied worldwide market.
- Coal can be easily stored at power stations and stocks can be drawn on in emergencies.
- Coal-based power is not dependent on the weather and can be used as a backup for wind and hydropower.
- Coal does not need high-pressure pipelines or dedicated supply routes.
- Coal supply routes do not need to be protected at enormous expense.

These features help facilitate efficient and competitive energy markets and help stabilise energy prices.

5.3 On-grid Electricity

In recent years, renewable energy has proven particularly adept at providing off-grid electricity for remote communities in the least-developed economies. Urbanising and industrialising economies, however, will require the development of on-grid base-load electricity. Renewables are an intermittent source of electricity – the wind doesn't blow all the time, the sun doesn't shine 24 hours a day. Base-load power is essential to support reliable, stable electricity grids. Fossil fuels, including coal are major providers of base-load power. Development of base-load infrastructure enables societies to provide greater modern lifestyle services, such as refrigeration and air-conditioning, but will also ensure reliable electricity for businesses, hospitals, public services and industry.

Indeed, this understanding was recently articulated by India's Power, Coal and Renewable Energy Minister, Piyush Goyal, who stated "We will be expanding our coal-based thermal power. That is our base-load power. All renewables are intermittent. Renewables have not provided base-load for anyone in the world".[42]

5.3.1 The Logical, Low-cost, Base-load Power Choice.

The link between access to affordable power from coal, economic growth and prosperity is clear. In India, for example, electricity produced from coal-based power plants is 30% cheaper than electricity produced from renewables (and 16% cheaper than domestic natural gas).

Looking ahead, coal is likely to remain the most affordable fuel for power generation in many developing countries for decades to come. Analysis presented in the World Coal Association's (WCA's) 2016 study, *The Power of*

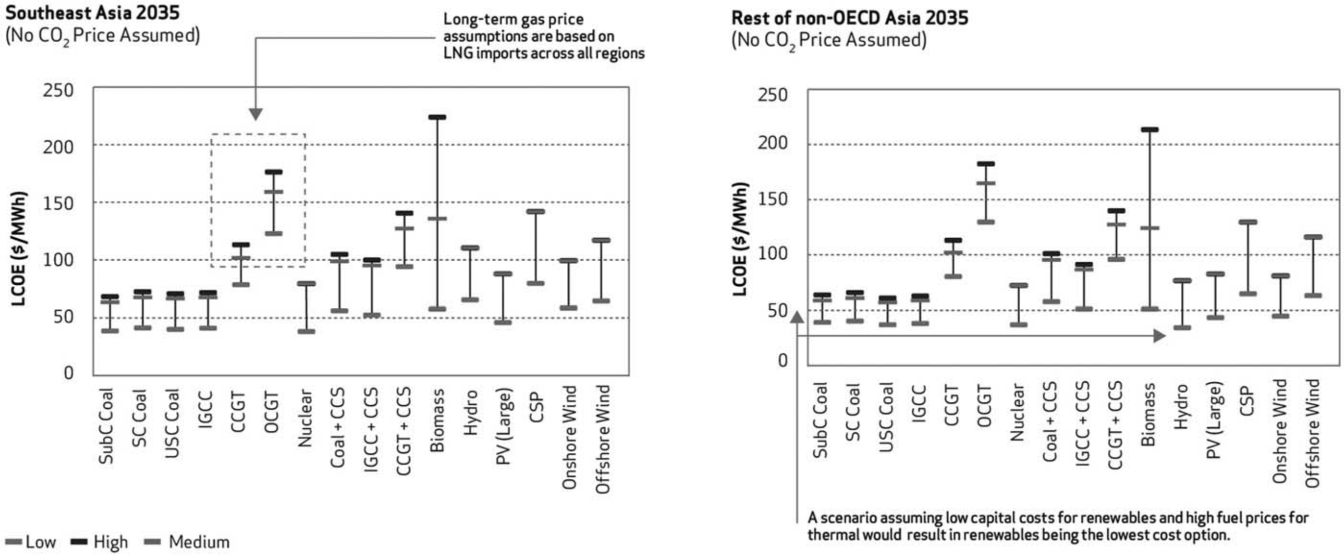
High Efficiency Coal, supports this forecast. The report considers the Levelised Cost Of Electricity (LCOE) for various technologies in non-OECD Asia. The LCOE provides an estimated price that generators are likely to incur producing electricity from various sources. The metric takes into account all of a system's expected lifetime costs (including construction, financing, fuel, maintenance, taxes, insurance and incentives), which are then divided by the system's lifetime expected power output (kWh). The calculation is vitally important for national power development plans to compare the costs of different technologies.

In 2035, data suggest that coal will generate electricity at a lower cost than other technologies – including gas – in The Association of Southeast Asian Nations (ASEAN) countries plus India, Bangladesh, Sri Lanka and Pakistan (grouped as South East Asia in Figure 7). The LCOE cost for the HELE technologies – supercritical coal (SC), ultra-supercritical coal (USC) and integrated gasification combined cycle (IGCC) – ranges from 55 to 60 $\$\,\mathrm{MWh}^{-1}$. In comparison, the LCOE cost of Open Cycle Gas Turbine (OCGT) is almost double. It should also be taken into consideration that for many of these countries coal is more readily available than gas, which requires the development of pipeline infrastructure for its delivery. The comparative cost advantages of coal generation are even clearer in China – the main economy represented in the 'Rest of non-OECD Asia' in Figure 7. The various HELE technologies have an LCOE of around $50 MWh^{-1}, a third of the price of open-cycle gas turbines.[43]

5.3.2 Low-cost Electricity from Coal Aids Industrialisation. Stable and affordable energy pricing is a vital consideration for developing countries working to build industrial capacity, particularly in energy-intensive industries. Fluctuating fuel prices and high electricity costs can lead to a loss of competitive advantage and, in prolonged cases, loss of the industry altogether.

As noted earlier, electricity produced from coal-based power plants is 30% cheaper in India than electricity produced from renewables (and 16% cheaper than domestic natural gas). This has clear benefits for citizens through reduced energy costs, but the effect of lower energy prices are even clearer for business. Lower energy prices are a key factor in fostering industrial competitiveness. Lower cost electricity produced by coal results in lower production costs, increasing profits for industry (and thereby the country), and in turn promoting further economic activity.

The recent construction of the Sasan Power coal-fired power station in Madhya Pradesh, India, supports this premise. The facility has been credited with adding $2.5 billion to the local economy through improved energy access for local businesses. Improved energy access has allowed electric pumps to be deployed in the state's farming and allied services sector. Farmers have also benefited from improved access to market information, such as online agricultural market places. These developments have led to productivity gains through increased yields and more crop diversity.[44]



Southeast Asia 2035
(No CO_2 Price Assumed)

Long-term gas price assumptions are based on LNG imports across all regions

Rest of non-OECD Asia 2035
(No CO_2 Price Assumed)

A scenario assuming low capital costs for renewables and high fuel prices for thermal would result in renewables being the lowest cost option.

Source: World Coal Association analysis, 2015

Figure 7 Lifetime cost of electricity *per* MWh across generation technologies in 2035. (Subcritical coal: SubCCoal; supercritical coal: SCCoal; ultra-supercritical coal: USC Coal; integrated gasification combined cycle: IGCC; open cycle gas turbine: OCGT; coal with carbon capture storage: Coal + CCS; large-scale photovoltaics: PV large; concentrated solar power: CSP).

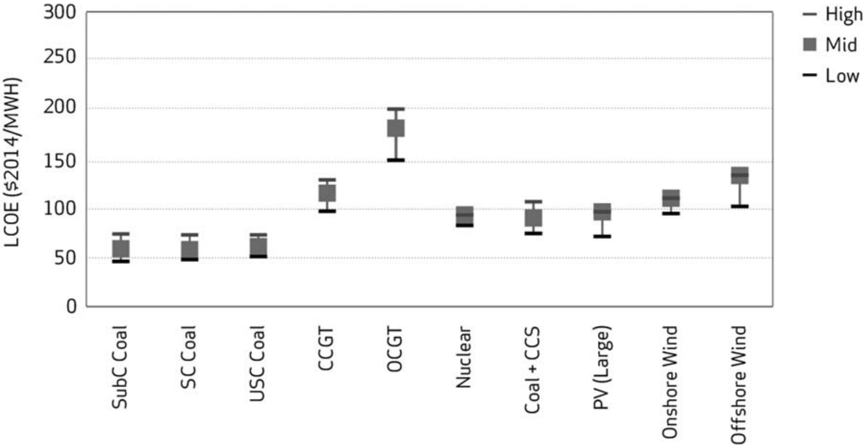


Figure 8 India Levelised Cost Of Electricity (LCOE) in 2035. (Subcritical coal: SubCCoal; supercritical coal: SCCoal; ultra-supercritical coal: USC Coal; IGCC; combined cycle gas turbine: CCGT; open cycle gas turbine: OCGT; coal with carbon capture storage: Coal + CCS; large-scale photovoltaics: PV large).

An economy that has unreliable energy cannot perform to its full potential. In a survey conducted by the World Bank that asked Indian business owners and top managers to select the most significant obstacle to their business, electricity was identified as second only to corruption.[45] In 2012, India endured a two-day blackout that affected 670 million people — more than 10% of the world's population. Shops, factories and offices were forced to close or rely on backup generators (often fuelled by diesel). The impact on daily commerce was felt across the entire supply chain as businesses not only had to compensate for outages in their own location, but also that of their suppliers. The Indian government has since adopted policies to promote energy security through the development of large-scale coal-fired power plants. The Sasan Power Station is a major part of this outcome. Madhya Pradesh's industrial sector has benefited from stable energy supply, reducing losses due to power shortages by over $1.5 billion.[46]

Productivity gains in the agricultural and industrial sectors are critical for a country's industrialisation and economic growth. A report by the National Council of Economic Research suggests that for each direct job created in the electricity sector a further 24.31 induced jobs are created in areas such as retail and agriculture.[47] As demonstrated in Figure 8, projections suggest that coal will continue to generate electricity at an affordable LCOE.

5.3.3 Coal Sector can Bring Broader Economic Benefits. HELE coal power plants are multi-billion dollar investments that require thousands of workers. Analysis conducted for the Coal Industry Advisory Board (CIAB) found that during the four-year construction of a supercritical facility in India over 5000 workers were directly employed. The economic activity that construction of the facility bought created a further 3700 indirect jobs. Once operational, HELE plants have life-cycles of several decades and directly employ engineers of various disciplines, managers, and personnel related to finance, administration, human resources and security. Indirect job creation continues once HELE facilities become operational. The CIAB analysis found that close to 4000 jobs were created through local contracts for manpower supply, housekeeping, horticulture works and vehicle supply. Moreover, the report found that employment created by the facility stimulated economic activity across the local community. Those directly or indirectly employed at the plant tended to have higher disposable incomes and spend more on in items like food, consumer durables and leisure activities. According to this analysis, this created close to 30 000 jobs over the construction and operational phases of the facility's lifecycle.[47]

Furthermore, developing coal reserves for use within the local electricity sector provides benefits across the economy. While coal extraction methods vary considerably across regions, a common characteristic is that mining is a highly capital-intensive process that results in much economic activity.

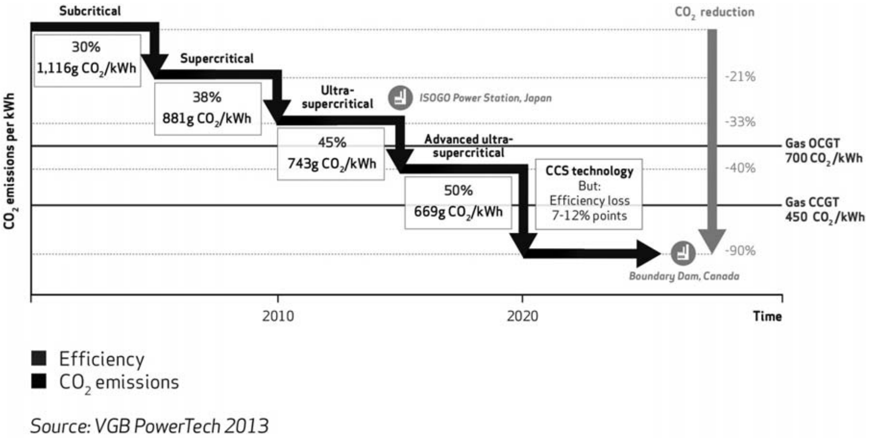
In South Africa, one of the world's major producers and consumers, the coal-mining industry comprises more than 17% of the mining workforce – that is, more than 85 000 workers. The country's Department of Mines Resources estimates that the coal industry in South Africa pays more than US$1.2 billion in wages to its workforce each year.[48] While the skill required for positions within coal mining varies, much of the training – such as mechanical, technical, health and safety – is provided through employment in the sector.

Coal-mining activities are also an important economic contributor for governments. In 2014, South Africa earned more than US$3 billion in export revenue from coal – roughly one-quarter of total mining GDP.[48] The sector is also a leading contributor to government revenues through royalties, which according to the National Treasury Revenue Estimates totalled US$ 400 million in 2013.

In the recent past, development of coal mining has also bought co-benefits through infrastructure development. Rail lines and roads required to transport coal from the mine/port can be utilised by a variety of other industries. For instance, Mozambique's Nacala port, which began operations in 2015, was originally developed as an export terminal for the country's coal resources. In addition to enabling the export of coal, the port has allowed Mozambique to develop as a regional transportation hub. Improved logistics have benefited other neighbouring economies, particularly Mozambique's landlocked neighbour Malawi.[49]

6 Coal and the Environment

As the Paris Agreement is formally adopted, it is vitally important that its implementation integrates environmental imperatives with the aims of universal access to energy, energy security and social and economic



Source: VGB PowerTech 2013

Figure 9 CO_2 reduction potential of coal-fired power plants by increased efficiency.

development. Only by balancing these elements can the agreement produce emissions reductions consistent with the vision of the Paris Agreement and with the broader development objectives.

Energy is an enabler of development. Access to affordable and reliable electricity is the foundation of prosperity in the modern world. As demonstrated by the Nationally Determined Contributions (NDCs), each nation will choose an energy mix that best meets its needs. For this reason many countries have identified a continuing role for coal. This is especially true for the rapidly urbanising and industrialising economies of Asia where coal is forecast to be an integral fuel source and vital to economic growth.

This begins with deployment of HELE power generation using technology that is available today. These facilities are being built rapidly and, as shown in Figure 9, emit 25–33% less CO_2 and significantly reduce or eliminate emissions, such as oxides of sulfur and nitrogen, and particulates.

Moreover, HELE technology represents significant progress on the pathway towards carbon capture, use and storage (CCUS), which will be vital to achieving global climate objectives.

Recognising the above, many countries have included a role for HELE coal-based power generation in their INDCs. In order to support the transition away from older, less efficient subcritical technology, these countries will require international financial, technological and other kinds of support to accelerate deployment of this technology.

6.1 Efficiency Improvements – What Can Be Achieved?

HELE technologies are in existence and available ‘off-the-shelf’. They are currently being installed and used in many countries and provide efficiency gains and are financially viable. HELE coal-fuelled generation facilities, with modern emissions-control systems, emit 25–33% less CO_2 and significantly reduce or eliminate pollutant emissions, such as oxides of sulfur and nitrogen, and particulates compared to older, less-efficient subcritical technology.

The current average efficiency of coal-fired power plants around the world is 33%. This is well below the state-of-the-art rate of 45% and even ‘off-the-shelf’ rates of around 40%. Increasing the efficiency of coal-fired power plants by 1% reduces CO_2 emissions by between 2 and 3%. Moving the current average global efficiency rate of coal-fired power plants from 33% to 40% by deploying more advanced technology could cut 2 gigatonnes of CO_2 emissions.[50]

Recent trends suggest that the link between energy demand and economic growth is gradually becoming eroded. Indeed, the 2013 BP Energy Outlook forecasts energy intensity – the amount of energy required *per* unit of GDP – to decline by 36% (1.9% *p.a.*) between 2012 and 2035. This is a promising development and may in part be attributed to the number of countries that have committed to deploy HELE technologies, rather than older less-efficient subcritical coal-fired power stations.

Yet, there is a risk of complacency following the Paris Agreement. Over the coming decades, developing countries will have to balance environmental imperatives with the aims of universal access to energy, energy security and social and economic development. Without international financial, technological and other kinds of support to accelerate deployment of HELE technology, it is possible that the transition away from subcritical technologies will stall, weakening the recent gains in reducing energy intensity.

Analysis presented in the 2015 WCA study, *India’s Energy Trilemma*, provides compelling evidence on the emission-reduction benefits of deploying HELE technologies. This analysis shows that replacing the subcritical capacity currently in India’s development pipeline with supercritical or ultra-supercritical capacity could remove up to 11 billion tonnes of CO_2 emissions over the life of the power plants (see Figure 10). Adopting the most

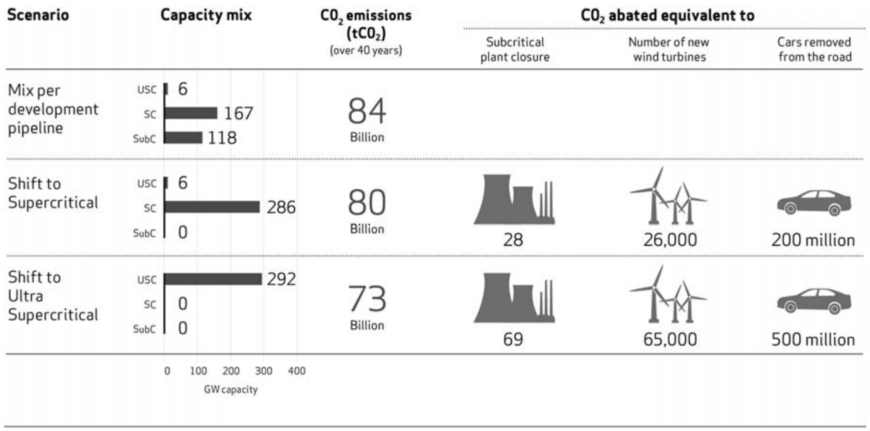
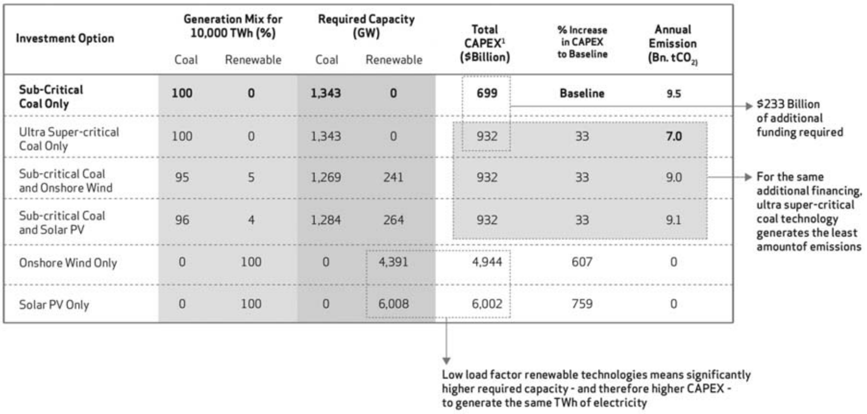


Figure 10 The environmental benefits of deploying cleaner coal technology in India.

efficient HELE technology would abate the CO_2 emissions equivalent to removing 500 million cars from the road. While the environmental implications are clear, the report notes that, with limited financing options available from development banks, power plant developers may accept lower efficiency and poorer emissions rates due to cost differences. There is as much as a 40% price difference between the capital costs of an ultra-supercritical and a subcritical coal plant. Analysis suggests that if all coal plants built from 2020 onwards were ultra-supercritical, total capital expenditure would reach \$500 billion by 2040, compared to around \$387 billion if all coal plant built from 2020 onwards were subcritical.[51]

Complementary analysis presented in the WCA's 2016 report, *The Power of High Efficiency Coal*, found that in many scenarios HELE technologies represent the lowest cost CO_2 abatement alternative (on a \$ $tonne^{-1}$ basis). The report considered the implications of concentrating support on renewable technology and excluding support for HELE coal-fired generation. The study found the challenge with increasing funding for the deployment of renewable generation is that its low load factor means that *per* dollar of investment, intermittent energy technologies substitute much fewer MWh of subcritical generation than is the case with HELE coal-fired generation. Therefore, in practice, HELE coal-fired generation mitigates more CO_2 emissions than renewables *per* dollar of investment.[51]

To put this in context, the IEA projects a growth of approximately 10 000 TWh of electricity demand in non-OECD Asia between 2020 and 2040. The analysis in Figure 11 compares the up-front capital investment required for the different generation scenarios which could be used to meet this demand growth.



Investment Option	Generation Mix for 10,000 TWh (%)		Required Capacity (GW)		Total CAPEX[1] (\$Billion)	% Increase in CAPEX to Baseline	Annual Emission (Bn. tCO_2)
	Coal	Renewable	Coal	Renewable			
Sub-Critical Coal Only	**100**	**0**	**1,343**	**0**	**699**	**Baseline**	**9.5**
Ultra Super-critical Coal Only	100	0	1,343	0	932	33	**7.0**
Sub-critical Coal and Onshore Wind	95	5	1,269	241	932	33	9.0
Sub-critical Coal and Solar PV	96	4	1,284	264	932	33	9.1
Onshore Wind Only	0	100	0	4,391	4,944	607	0
Solar PV Only	0	100	0	6,008	6,002	759	0

\$233 Billion of additional funding required

For the same additional financing, ultra super-critical coal technology generates the least amountof emissions

Low load factor renewable technologies means significantly higher required capacity - and therefore higher CAPEX - to generate the same TWh of electricity

Notes:
1) Based on IEA's WEO 2014 New Policy Scenarios capital cost estimates for China in 2035 with construction costs spread equally over the construction period

Source: World Coal Association analysis, 2015

Figure 11 Compared to renewables, High Efficiency Low Emission (HELE) coal technologies can reduce more emissions for the same upfront investment.

In the first instance, this could be met at an investment cost of \$699 billion, with subcritical coal-fired generation capacity resulting in 9.5 billion tonnes of CO_2 *per* annum. However, with an extra \$233 billion of funding, ultra-supercritical coal-fired capacity could replace all the subcritical capacity, produce the same 10 000 TWh, but emit 2.5 billion tonnes less CO_2 each year.

In contrast, with the same funding, onshore wind or large-scale solar PV cannot displace subcritical coal-fired capacity to the same extent, while also delivering the 10 000 TWh. As a result, the residual energy demand not met by renewable sources may be met by subcritical generation capacity and, as a consequence, onshore wind or large-scale solar photovoltaics (PV) does not reduce emissions by the same amount as ultra-supercritical coal capacity. In other words, no other low-emission generation technology can provide the same high level of generation and low cost as HELE coal-fired power generation.

6.2 Carbon Capture, Utilisation and Storage (CCUS) Development Vital to Meeting Climate Goals

Given society's on-going reliance on fossil fuels, CCUS is vital to achieve the required level of emissions reduction. CCUS will be required not only for coal, but also natural gas and industrial sources to ensure global temperature increases are to be kept below 2 °C.

Yet, the current rate of CCUS deployment is too slow to enable the necessary emissions reductions goals to be achieved. Accordingly, it cannot be expected that developing countries or emerging economies should be the first movers for its deployment. Instead, the international community must concentrate on the following three key areas to support the deployment of CCUS.

6.2.1 International Financing for Carbon Capture, Utilisation and Storage (CCUS). One of the key barriers to the increased deployment of CCUS is the availability of commercial finance. CCUS is currently highly capital-intensive and has associated risks that tend to restrict sources of private finance. While several projects have engaged with debt-finance providers, the Global CCS Institute (GCCSI) suggests that the appetite for, and understanding of, CCS in the financial sector has not been widely tested.

International financing can provide much-needed support in these circumstances. A number of multilateral funding bodies support the development of CCUS projects, including the GCCSI, the World Bank CCS Capacity Building Fund, the Green Climate Fund, the Asian Development Bank CCUS Fund and the UNFCCC Clean Development Mechanism. Existing programmes, however, can only provide some of the capital investment required. More ambitious funding is required by multilateral schemes to improve the financial viability of CCUS projects.

The Low Carbon Technology Partnerships Initiative (LCTPI) launched by the World Business Council for Sustainable Development, together with the Sustainable Development Solutions Network (SDSN) and the IEA offers a particularly promising potential funding model. The platform offers a forum for the diffusion of CCUS by removing barriers and introducing required policy and financial instruments, while promoting Public Private Partnerships (PPPs) on research and development.

6.2.2 Policy Parity. Strong policy drives strong action. Growth in renewable energy technology has been driven by policy that provides \$100 billion in subsidies every year.[52] The cumulative value of government policy support provided to CCUS to date is approximately 1% of the cumulative value of policy support provided to renewable technologies. Policy tools available for renewables are not generally made available for CCUS, which has a dampening effect on investment. With strong policy support for CCUS, including parity with other low emissions technologies, the necessary investment will occur. This will make further strides possible in the wider demonstration and deployment of CCUS, which will in turn drive down costs.

6.2.3 Carbon Capture, Utilisation and Storage (CCUS) Deployment Requires International Incentives. Climate solutions require international action. It is imperative that lessons learnt in CCUS projects are shared in international fora, such as the newly developed USA-China Clean Energy Research Centre. In addition, development banks and donors should develop funding mechanisms for CCUS research and development.

7 Coal and Our Energy Future

The global energy system faces many challenges in this century. It will have to continue to supply secure and affordable energy in the face of growing demand. At the same time society expects cleaner energy and fewer emissions, with an increasing emphasis on environmental sustainability.

Alleviating poverty, maintaining secure supplies of energy, and protecting the natural environment are some of the biggest challenges facing our world today. The production and use of coal is linked to each of these challenges.

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