2024

May

New King Coal? New-Generation Coal-Fired Power Stations

The Al-Attiyah Foundation

The Al-Attiyah Foundation is proudly supported by:

The prevailing belief is that the use of coal must cease to achieve net-zero emissions. However, new coal power plants, equipped with advanced ultra-supercritical, fuel cells, small supercritical, co-combustion, combined heat and power, and carbon capture, use and storage (CCUS) technologies offer enhanced thermal efficiency, reduced emissions, and increased flexibility in power generation.

What is the impact of these advanced technologies on the economics of coal generation? How are advanced designs being implemented? If coal power plants employ CCUS technologies on a large scale, what would be the implications for the power sector? Can they coexist with renewables in the power mix?

ENERGY RESEARCH PAPER

This research paper is part of a 12-month series published by the Al-Attiyah Foundation every year. Each in-depth research paper focuses on a current energy topic that is of interest to the Foundation's members and partners. The 12 technical papers are distributed to members, partners, and universities, as well as made available on the Foundation's website.

Introduction

- An average of 1.5 GW / year of new unabated (non-CCUS) coal plant capacity is expected to be developed by 2050, mainly in countries that have not committed to phasing out coal. The new capacity is primarily intended to replace ageing coal plants.
- 71% of emissions from coal in 2022 came from the power sector. In turn, coal power generation represented 32% of global carbon dioxide emissions[i].
- Coal generated 10,513 TWh of global electricity in 2023, 35% of the total and the largest single source[ii]. It was up 1.8% on 2022, although net-zero scenarios require a sharp fall in coal use by 2030.
- China accounted for 55% of this generation, India for 14% and the US for 7%. So trends for coal use and emissions in these countries are of crucial importance for global climate.
- There are five primary strategies to reduce emissions from existing coal power plants: 1) improve efficiency with advanced technologies and system designs, 2) retrofit for co-combustion with low-emission fuels like biomass or ammonia, 3) retrofit with CCUS technology, 4) repurpose to provide load balancing services instead of baseload power, and 5) retire the plants early.

Advanced Coal Generation Technologies and System Designs

- The global coal fleet currently has an estimated average efficiency of 33% on higher heating value (HHV)-basis or 35% on lower heating value (LHV)-basis, resulting in ~900 gCO_2 / kWh of emissions.
- Advanced ultra-supercritical coal power plants presently attain efficiencies of ~47% by operating at high temperatures and pressures. However, efforts are being made to exceed this threshold by creating advanced ultra-supercritical units that use nickel alloy instead of steel, which can boost efficiency to ~50% by raising steam temperatures further.
- Integrating fuel cell technology, such as solid oxide fuel cells and molten carbonate fuel cells, into integrated gasification combined cycle coal units can enhance the efficiency of low-emission coal generation.
- Supercritical CO_2 cycles, like the Allam-Fetvedt Cycle, offer the greatest potential for alternative coal generation. These technologies can achieve higher plant efficiency and nearly complete carbon capture at reduced costs.

Co-Generation and Carbon Capture, Use, and Storage Technologies

- Using biomass co-combustion with a conventional pulverised combustion process and a 90% CO_2 capture rate can be a cost-effective strategy for decarbonising coal-dependent power mixes, especially in the Asia-Pacific region.
- Modifying existing coal power plants to co-combust ammonia is relatively simple, requiring boiler adjustments and additional facilities like ammonia tanks and vaporisers. However, low carbon "blue" or "green" ammonia is expensive.

- Improving coal power plant efficiencies by adopting modern steam cycle conditions is crucial for reducing emissions. However, to decarbonise coal generation, CCUS is required. High-efficiency power plants are more suitable to be coupled with CCUS technologies.

Future of Advanced Coal Generation

- Advanced coal units as dispatchable generators (with ancillary services) can complement and facilitate the integration of variable renewable energy in a power system that responds to fluctuations in output.
- Whilst repurposing coal power projects for flexibility reduces emissions, it also poses financial challenges and accelerates plant deterioration. To incentivise plant operators, electricity supply contracts and system service provisions may need reshaping.

Coal power plants provide 35% of global electricity generation, accounting for 65% of global coal consumption, emitting 10.5 $GtCO_2$ (or 32% of energy-related CO_2 emissions)[iii]. However, it is possible to reduce reliance on unabated coal power generation only if alternatives are developed quickly enough to meet demand.

COP26 in Glasgow in 2021 secured a 190-member coalition of countries and organisations committing to phase out unabated coal power[iv]. At COP28 in Dubai in November 2023, 133 national governments committed to collaborate to triple global installed renewable energy capacity by 2030, which would put renewable power capacity development in line with the 2050 net-zero emissions scenario[v].

Under current policies and market conditions, global renewable capacity is projected to reach ~2.5 times its present level by 2030. However, by 2027, additions to renewable capacity are expected to decrease to just over 6 GW / year, much lower than any year in the past half-century[vi]. It is projected that an average of 1.5 GW of new unabated coal plant capacity will be developed each year through to 2050, particularly in countries that have not committed to phasing out its use, primarily intended to replace ageing coal plants[vii]. Coal power today is concentrated in North America, Europe, South Africa, Australia, Russia, China, India and south-east Asia (Figure 1), but most European and Australian and many North American plants are closing. Most new and under-construction plants are in Asia.

The limited role of unabated gas is a reflection of changing perceptions of the fuel due to recent market volatility and supply concerns stemming from Russia's invasion of Ukraine. By 2050, generation from existing unabated coal power plants is projected to be < 1,600 TWh, which is 85% lower than in 2023[viii]. Other technologies are expected to replace it in roughly the same proportions as in 2030, although the share of fossil fuels with carbon capture, use, and storage (CCUS) is expected to increase as well as the technology matures.

Solar and wind power generation capacities are projected to lead the transition away from coal due to their cost-effectiveness and robust policy support, with measures already in place across 174 countries. Capitalising on the rapid growth witnessed over the past decade, global capacity additions of solar are expected to triple by the end of this decade, which equates to an addition of 640 GW / year by 2030, up from 220 GW / year in 2022[ix]. Similarly, wind power deployment is also anticipated to more than triple, with an expected addition of 240 GW / year in 2030, compared to 75 GW / year in 2022[x].

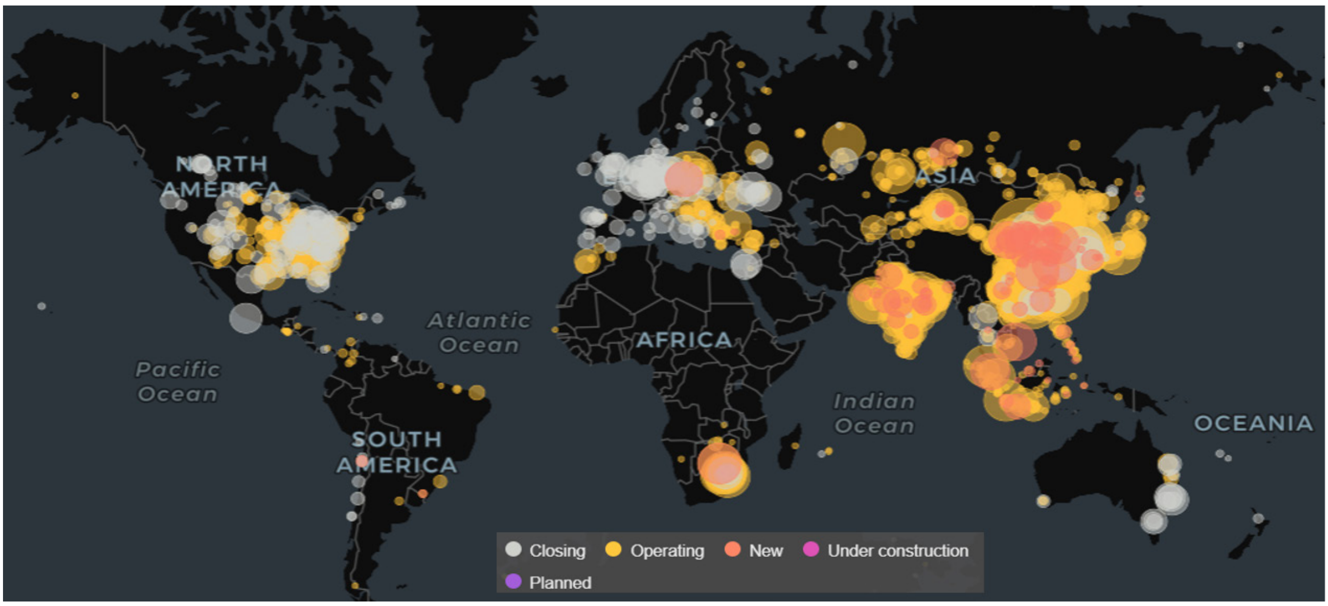
However, the increasing penetration of renewables necessitates a careful evaluation of the impact of variable power generation on the broader electricity system. In many instances, an enhancement in flexibility resources, including stronger grids, interconnections, demand-side measures, and dispatchable power and storage, will be required to ensure these power sources are effectively integrated into the power system.

Existing coal-fired generation assets can contribute to system adequacy and flexibility resources by remaining available to produce electricity when power demand peaks, even if they no longer serve as a source of baseload power.

There are five primary strategies for reducing emissions from existing coal power plants: 1) improving their efficiency through advanced technologies and systems designs, 2) retrofitting them to enable co-combustion with low-emission fuels such as biomass or ammonia, 3) retrofitting them with CCUS technology, 4) repurposing them to provide load balancing services instead of baseload power supply, or 5) retiring them early.

Regardless of the strategy employed, the concurrent development of adequate alternative power sources will be a prerequisite for reducing emissions from coal plants. If all the coal plants worldwide were to continue operating as they do today until the end of their normal operating lives, they would lock in cumulative emissions of approximately 250 $GtCO_2$ between 2023 – 2050. [xii]

Figure 1 Location and status of global coal power plants[xi]



Conventional coal plants operate by grinding coal to a fine powder (finer than talcum powder), then burning it to heat water to drive a steam turbine. In subcritical plants, the water remains below its critical point. In more modern supercritical and ultra-supercritical plants, the water is above its critical point of temperature and pressure, and behaves as a supercritical fluid, neither liquid nor gas. Beyond the supercritical point, no heat is required to vaporise the water, which therefore saves fuel and raises plant efficiency. Supercritical and ultra-supercritical plants require more sophisticated materials to contain the high temperatures and pressures.

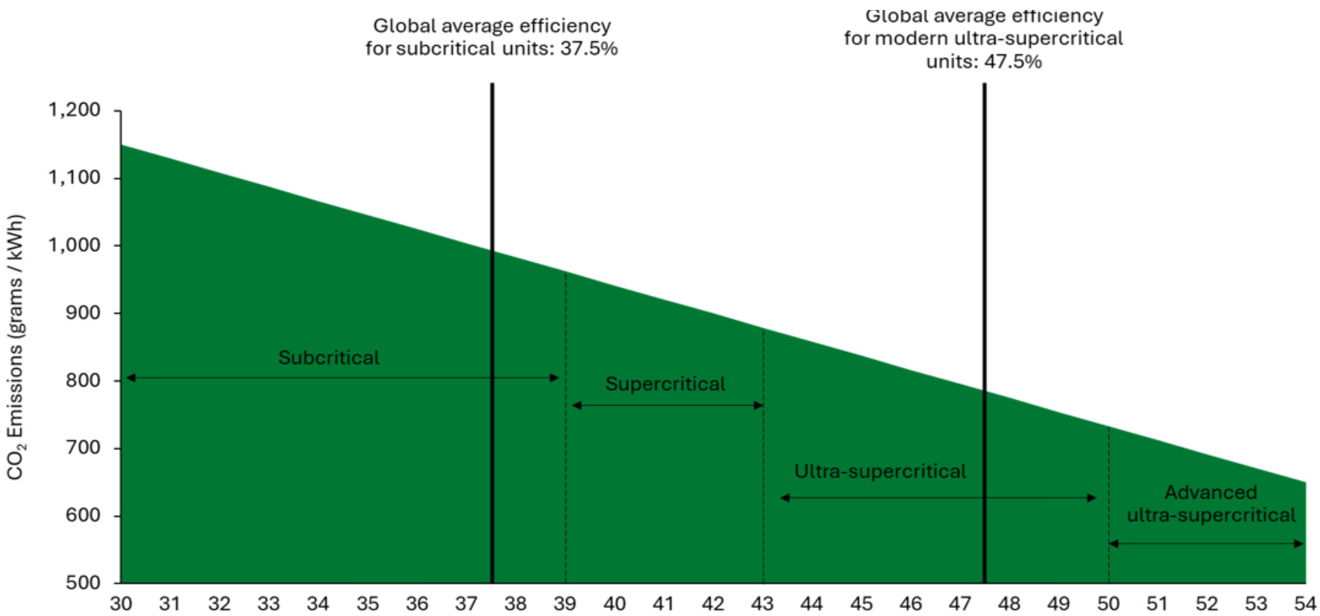
Efficiency improvements in thermal plants are inversely related to CO_2 emissions. Currently, the estimated average efficiency for the global coal fleet stands at 33% higher-heating value (HHV) basis or 35% lower-heating value (LHV) basis, which corresponds to ~900 gCO_2 / kWh of emissions[xiii]. However, as efficiencies approach 50%, particularly in future advanced ultra-supercritical units, emissions can be reduced to < 700 gCO_2 / kWh.

~75% of coal plants in operation today utilise subcritical steam cycles, resulting in efficiencies that fall short of modern standards[xiv].

A significant portion of this capacity is > 30 years old, which could potentially be phased out. Nevertheless, 240 GW of subcritical capacity been constructed since 2010 and is expected to remain operational for at least another 15 years[xv].

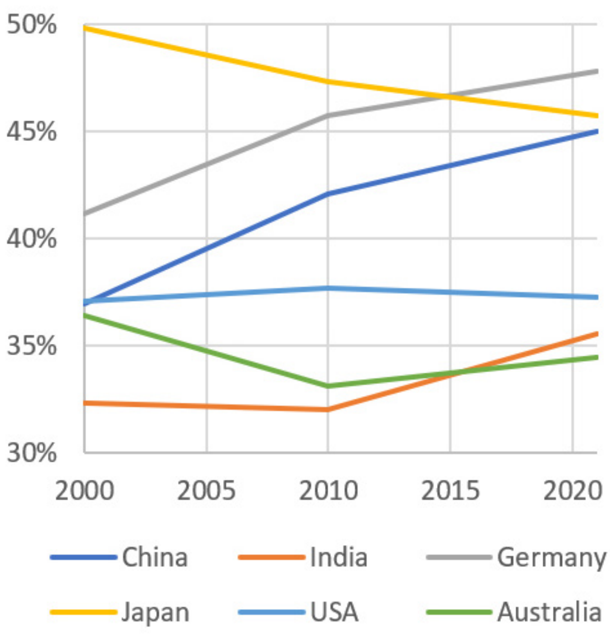
Average efficiency of coal power generation fleets varies widely (Figure 3), depending on the age and technology of plants, operational modes, the use of waste heat, and the coal type (lignite plants generally being less efficient than hard coal plants). The efficiency of Chinese plants has improved significantly over time and is now one of the best among major coal-using countries. Germany has also gained significantly, possibly due to the closure of older plants and to the increased use of combined

Figure 2 CO_2 Savings from Efficiency Improvements



heat-and-power. Japan had a highly efficient fleet in 2000 but levels have declined. Efficiency of plants in India has improved recently but remains relatively low.

Figure Average Efficiency of Coal Power Stations, Selected Countries[xxvi]



In addition, for less efficient supercritical units, it will be crucial to minimise CO_2 emissions intensity for the rest of their operational life, which can be accomplished by various measures to enhance their efficiency, especially as plant performance degrades over time. These include refurbishing the steam turbine, improving boiler heat recovery, implementing digitalisation and smart process control systems, reducing auxiliary power consumption, and increasing steam temperatures.

Additional efficiency can be gained by combined heat and power (CHP) systems that use the waste heat from coal combustion, typically to heat buildings. CHP can raise effective efficiency to 65-85%, depending on the demand for heat utilisation. Buildings are only likely to require all the heat produced during the winter.

Figure 4 Typical Operating Parameters for Coal Generation

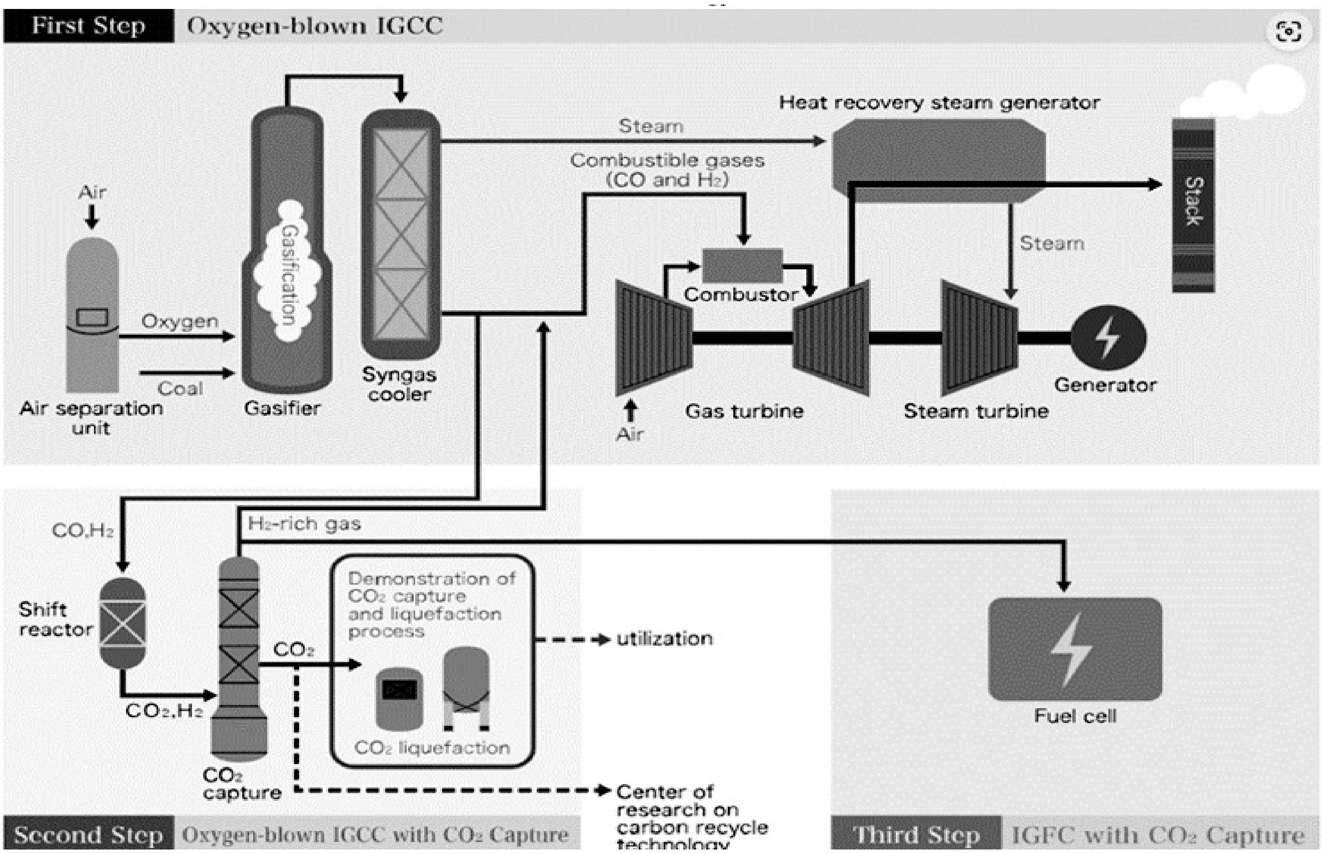
Operating Parameters	Subcritical	Supercritical	Ultra-supercritical
Main Stem Temperature	< 540ºC	538ºC – 566ºC	593ºC – 610º(
Steam Pressure	16 – 18 MPa	< 22 22 MPa	35 – 30 Mpa
Cycle Efficiency	30% - 39%	39% - 43%	< 47.5%
CO_2 Emissions Intensity	> 870 g / kWh	800 – 870 g / kWh	720 – 870 g / kWh

Advanced ultra-supercritical coal power plants presently attain efficiencies of ~47%.[xvii] However, efforts are being made to exceed this threshold by creating advanced ultra-supercritical units that use nickel alloy instead of steel, which can boost efficiency to ~50% by raising steam temperatures[xxviii].

Over the last two decades, research efforts have focused on creating a new generation of highly efficient advanced ultra-supercritical coal plants. The next phase of efficiency improvements necessitates the extensive use of nickel-based superalloys instead of advanced steel. These superalloys are used in the plant's hottest sections, including superheaters, headers, steam pipes, and turbines.

Advanced ultra-supercritical coal plant are designed to raise steam temperatures to at least 700°C in order to maximise the returns on costly high-performance materials[xix].

Figure 5 The Osaki CoolGen Integrated Gasification Combined Cycle and Integrated Gasification Fuel Cell Demonstration Project



Whilst nickel alloys are already used in gas turbines, their use in coal plants requires the development of modified alloys that can handle specific application challenges, including the fabrication of larger components and soldering with other materials.

Over the past decade, China has emerged as a significant contributor in the development of advanced ultra-supercritical technologies and operates a large-scale component test facility, where several domestically developed alloys are tested alongside new materials[xx]. However, a full-scale demonstration of advanced ultra-supercritical coal technology is not expected in China until the end of this decade.

Considering the high initial cost of commissioning a new advanced ultra-supercritical coal plant, there is some interest in using advanced materials for retrofit applications. In Japan, various designs have been proposed to retrofit existing coal plants with nickel alloys in key areas of the steam cycle to increase the main steam temperature to 700°C.[xxi]

Though international efforts to realise a 700°C plant based on nickel alloys have been relatively slow, the efficiency of modern ultra-supercritical plants continues incrementally to increase through development in materials used, particularly through the development of higher-performance steels that have emerged as a co-benefit of advanced ultra-supercritical coal research programs.

The integration of fuel cell technology specifically solid oxide fuel cells and molten carbonate fuel cells, into integrated gasification combined cycle (IGCC) coal units has the potential to improve the efficiency of low emission coal generation.

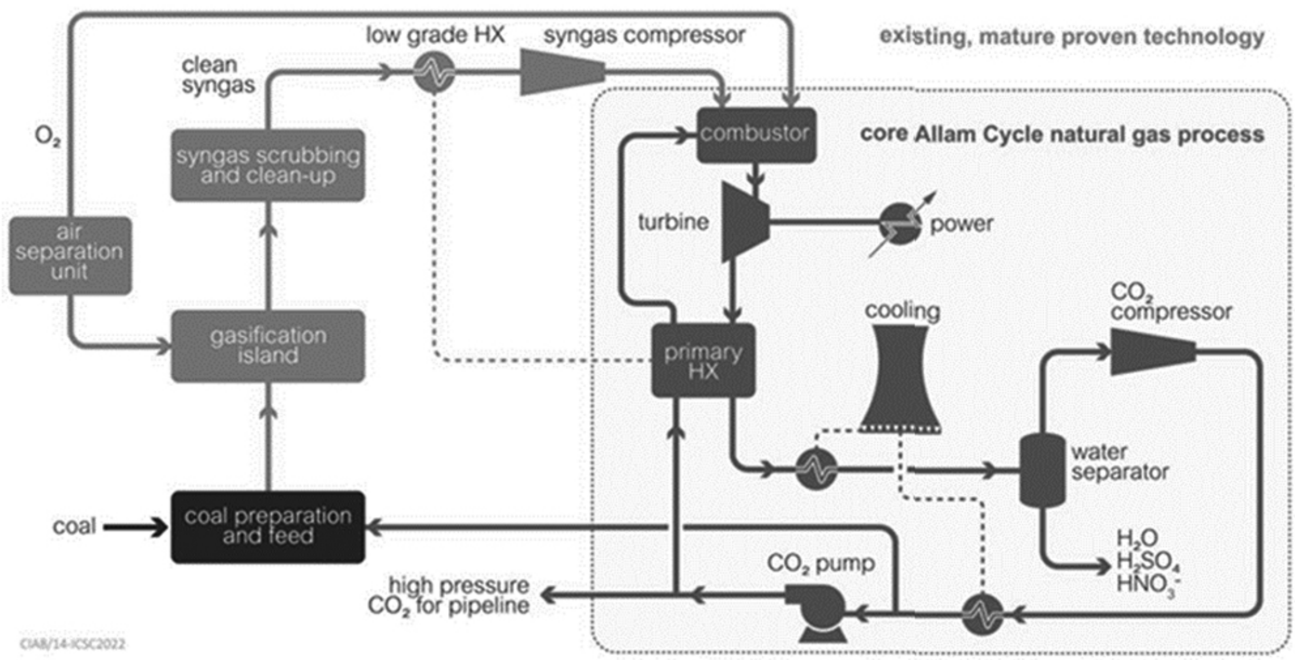
Solid oxide fuel cells are commonly-used fuel cells that operate at high temperatures and can be fuelled by gas, which is steam-reformed to hydrogen and CO_2 on-site or through coal-derived syngas from an integrated gasification combined cycle unit.

The 166 MW Osaki CoolGen Project in Japan is one of the first projects to produce coal-derived hydrogen from solid oxide fuel cells.[xxii] The project uses oxygen-blown gasification technology and includes an IGCC component, an integrated gasification fuel cell, and a pre-combustion CO_2 capture pilot. The entire plant is designed to achieve 40.8% efficiency (on an HHV-basis, or about 38.5% LHV), including CO_2 capture, with the fuel cell component aiming for an efficiency of 55%[xxiii]. The IGCC unit was commissioned in 2017, the CO_2 capture process in 2019, and the fuel cell was commissioned in 2021[xxiv].

Furthermore, molten carbonate fuel cells and direct carbon fuel cells offer high electrical efficiencies of 70% and combined heat and power efficiency of 90%[xxv]. There is no requirement for water usage in the process, which is beneficial for water-scarce areas. However, despite the significant potential of both fuel cells, the development of these systems is still in the early stages of technological readiness.

Supercritical CO_2 cycles, such as the Allam-Fetvedt Cycle, hold the greatest potential for alternative coal generation. These technologies can achieve superior plant efficiency and almost fully capture carbon at reduced costs.

Figure 6 Simplified Allam-Fetvedt Cycle Integrated with a Coal Gasification System



Various coal-based power generation cycles have been developed that drive turbines with supercritical CO_2. The most advanced supercritical CO_2 technology is the Allam-Fetvedt Cycle process, developed by 8 Rivers Capital and demonstrated at the NET Power Plant in Texas, United States[xxvi]. Whilst the plant is fuelled by gas, the company has also developed a design for a process based on coal-derived syngas, which achieves a maximum efficiency of 48% (on a LHV-basis) and inherently produces a pure stream of CO_2 ready for storage or sequestration.

The Allam-Fetvedt Cycle uses gas or syngas from the gasification of coal and has inherent CO_2 capture. It involves oxyfuel combustion, with the CO_2 produced used as the working fluid. The core process is a gas-fired and high-pressure, and operated with a single turbine. The cycle uses a turbine running on supercritical CO_2 instead of the steam used in conventional power generation units. The high energy density of supercritical CO_2 means the components are relatively small, leading to reductions in capital and fuel costs and reduced emissions from coal generation.

United States-based NET Power is currently commercialising the Allam-Fetvedt Cycle in the gas industry, whilst 8 Rivers Capital is leading an industrial consortium in North Dakota and Minnesota, United States to apply the Allam-Fetvedt Cycle to produce syngas from coal, biomass, and petroleum coke gasification[xxvii].

Apart from enhancing efficiency through advanced technologies, another strategy to achieve low emissions in coal generation involves co-combusting coal with carbon-neutral fuels such as biomass or carbon-free fuels like ammonia. This method provides a relatively swift and cost-effective solution for partially decarbonising power generated from coal in the short-to-medium term and also has the potential to extend the operational life of coal units in the transition to net-zero emissions.

Utilising biomass co-combustion in tandem with a conventional pulverised combustion process with a 90% CO_2 capture rate could be an economical strategy for decarbonising power mixes that heavily rely on coal, especially in the Asia-Pacific region.

The majority of direct biomass co-fired coal power units employ pulverised combustion. Some of these are large, modern ultra-supercritical plants, such as Uniper's 1.1 GW Maasvlakte MPP 3 plant[xxviii]. However, in general, fluidised bed boilers can co-fire higher biomass levels than pulverised combustion boilers.

Globally, 43% of thermal power projects are equipped with fluidised bed combustor co-fired units, most of these are < 300 MW and operate under subcritical steam conditions with efficiencies of ~38% – 40%[xxix]. The largest ultra-supercritical fluidised bed power plant is KOSPO's 2 x 1100 MW Green Power Plant in Samcheok, South Korea, which is designed to use up to 5% biomass by heat input, with the potential to increase the biomass ratio[xxx]. The 112 MW + 256 MW Kushiro power plant in Japan is designed to co-fire 30% wood pellets and palm kernel shells in a fluidised bed boiler[xxxi].

Parallel co-combustion requires the installation of a separate system for handling and combusting biomass. The steam produced from the biomass-fired boiler is mixed with steam from the coal-fired boiler. The system design typically has a low operational risk and allows a high ratio of biomass co-combustion.

There are three leading co-combustion units in China. The 660 MW Unit at the Guodian Jingmen Coal Power Plant has been connected to a 10.8 MW gasifier to gasify straw for co-combustion[xxxii]. The Huadian Shiliquan Power Plant has a 140 MW unit with x2 30 MW straw combustors to co-combust less than 20% biomass[xxxiii]. The 660 MW SC Unit I at the Datang Changshan Power Plant has also been coupled with a 20 MW gasifier produced by Haerbin Power Limited to co-combust locally grown straw[xxxiv].

However, using biomass for power generation presents certain challenges, mainly relating to the cost and availability of a sustainable biomass supply. Agricultural and forestry residues, which might otherwise be burned without any benefit, provide a practical solution. The large size of a typical coal plant can make it challenging to source the necessary quantities of sustainable biomass nearby for high blending rates or full biomass conversion. Biomass transport is relatively expensive because of its lower energy content.

The Drax coal power station in the United Kingdom, which started co-firing biomass in 2003, serves as a prime example. Over time, the proportion of biomass in the fuel mix has increased, with coal burning completely stopped in 2023. There are plans to transform the plant into a bioenergy facility with CCUS (BECCS) to generate negative emissions by permanently removing CO_2 from the atmosphere.

The economic feasibility of biomass or ammonia co-combustion largely depends on cost, which in turn relies on carbon pricing, relative fuel costs, retrofit costs, and the success of cost-reducing innovations. Ammonia and, in some instances, biomass can be significantly more expensive than coal. However, in some cases, carbon penalties may be high enough to offset the higher fuel cost and provide a return on investment in plant modifications. In reality, uncertainty about future fuel costs and carbon penalties may hinder financing.

Modifying existing coal power plants to co-combust ammonia is a relatively simple process, which involves making changes to the boilers and investing in additional facilities such as ammonia tanks and vaporisers.

The Ministry of Economy, Trade, and Industry in Japan has set a new target to develop a coal generation unit capable of co-combusting ammonia at 50% in the fuel mix and a fully ammonia-fired gas turbine by 2030[xxxv]. In order to reach the goal, the Japan-based utility JERA in partnership with IHI, has begun testing a small quantity of ammonia in Unit IV of the Hekinan Thermal Power Station, developed by Chubu Electric and TEPCO Fuel and Power[xxxvi].

The ultimate aim of the test is to develop co-combustion burners that can be used at 20% co-combustion ratio[xxxvii]. JERA is responsible for procuring ammonia and constructing related facilities, such as the storage tank and vaporiser, whereas IHI's role is to develop the burners for use in the demonstration. The project is the first of its kind in the world, where a large quantity of ammonia will be co-combusted in a large-scale commercial coal power plant.

Japan has also established a stable, low-cost, and flexible low-emissions ammonia supply chain with Australia and Saudi Arabia. In response to strong market signals from Japan, the Energy Council of the Australian government published the National Hydrogen Strategy in 2019[xxxviii].

Coal power plant efficiency improvements through the adoption of modern steam cycle conditions are important to reduce CO_2 emissions, but to deliver emissions consistent with net-zero, they should be used in conjunction with CCUS technologies. Leading examples of CCUS applied to coal generation plants include Boundary Dam in Saskatchewan, Canada, Petra Nova in Texas, USA, and the Jinjie and Taizhou plants in China, and the Huaneng Multi-Energy under construction in China.

Improving the efficiency of coal power plants by adopting modern steam cycle conditions is a crucial step in reducing CO_2 emissions, but to achieve emissions levels that align with net-zero, these improvements should be paired with CCUS technologies.

Retrofitting coal plants with CCUS helps preserve existing assets, supply dispatchable electricity, and maintain grid stability while reducing coal use emissions. CCUS can be applied to the entire facility or just part of it. The simplest retrofit is via post-combustion capture, which reroutes flue gas from a unit boiler through a CO_2 capture facility, powered by heat from the steam cycle or an external source. More extensive modifications include converting the boiler to oxy-fuel combustion.

Coal plants chosen for CCUS retrofits must have space for additional equipment and solid transport links for managing captured CO_2.

To date, only four commercial coal power plants have been retrofitted with CCUS on a large scale: the Boundary Dam facility in Saskatchewan, Canada, the Petra Nova plant in Texas, United States, and the two mentioned coal plants in China. There are plans for about 15 new projects worldwide, with all but one being retrofits of existing coal plants[xxxix]. Nearly three-quarters of these projects are in China or the United States, where tax credits offer up to US$ 85 / tonne of CO_2 stored[xl]. If all planned projects proceed, global capture capacity from coal plants could reach ~28 $MtCO_2$ by 2030[xli].

The Boundary Dam 3 project, located in Saskatchewan, Canada, holds the distinction of being the world's first fully integrated CCUS facility at a coal power plant. The facility has a nominal capture rate of 1 $MtCO_2$ / year[xlii]. The CCUS facility supplies all the steam and power needed for its operations, and the primary product of the facility is CO_2, which is mainly used for enhanced oil recovery, in addition to re-injection and permanent geological storage.

The Petra Nova facility in Texas, United States, started operating in 2016 and has a capacity of 1.4 $MtCO_2$ / year[xliii]. It was suspended in 2020 because of a fall in oil prices, as its captured CO_2 is used for enhanced oil recovery, but restarted in September 2023.

Jinjie Energy's CCUS project, which has a capacity of 0.15 $MtCO_2$ / year, is a national research and development initiative in China and a key project in Shaanxi Province in China[xliv]. The project's goal is to research retrofitted CO_2 capture technology on one of the four 600 MW coal units at Shenhua Guohua Jinjie power station, conduct industrial demonstrations, and establish an innovative, efficient, and low-energy technology system for Chinese coal power plants to capture CO_2 from flue gas[xlv].

Figure 7 Parameters of Boundary Dam CCUS Project, Canada

Operating Parameters	Project Details
Location	Saskatchewan, Canada
New Build / Retrofit	Retrofit
Gross Capacity	160 MW
Net Capacity	100 MW
Form of Coal	Lignite
Design Capture Rate	85% - 90%
CO_2 Use	Enhanced Oil Recovery
CO_2 Capture Capacity	1 $MtCO_2$ / year
Solvent	Cansolv
Regeneration Energy	Steam Cycle from Coal Unit
Project Capital Cost	US$ 1,300 – US$ 1,500 (US$ 800 for CCUS Unit)

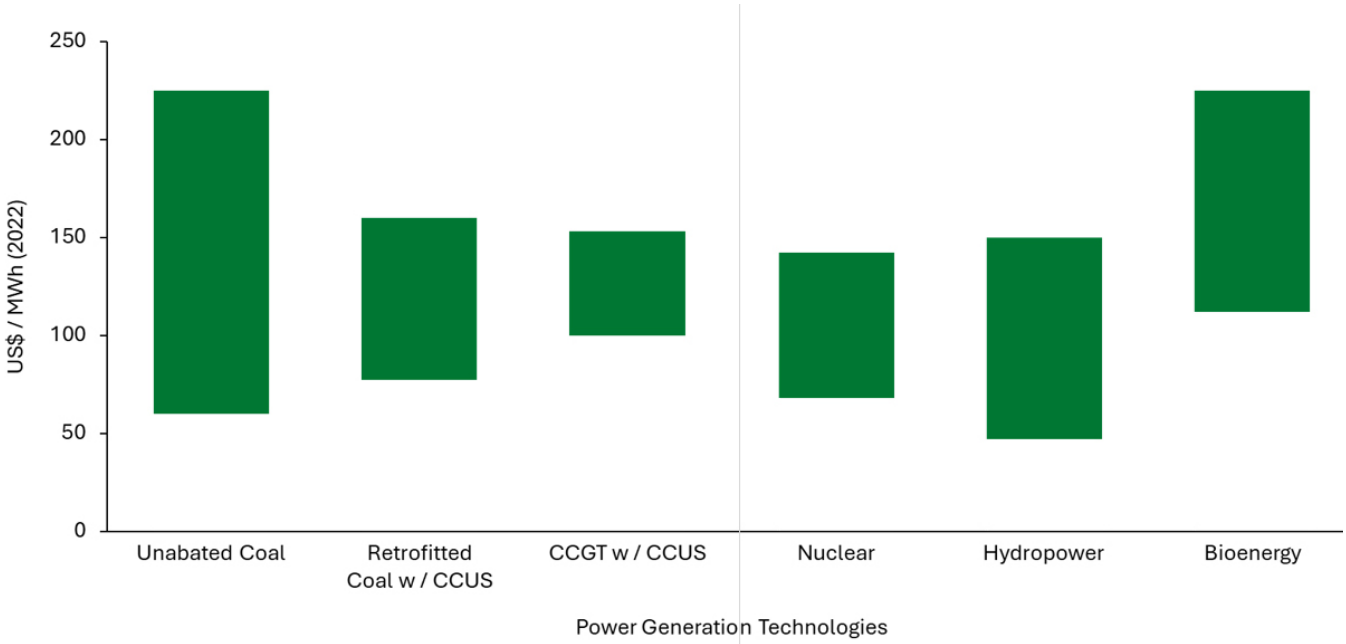
The CCUS project employs chemical absorption to research carbon capture technologies for coal-fired power plants. The facility is equipped with several efficient and energy-saving components, including inter-stage cooling, efficient heat exchangers with low terminal difference, a high gravity reactor, and modified plastic fillers. The captured CO_2 is injected into an existing CO_2 injection site in the Chenjiacun field in Inner Mongolia for dedicated geological storage[xlvi]. The Jinjie Energy project the first post-combustion CCUS full-chain demonstration facility applied to a coal power plant in China.

Last year, the China Energy Investment Corporation commenced operations at Asia's largest coal-linked CCUS facility. The facility is attached to the group's Taizhou thermal coal power plant in the eastern Jiangsu province of China[xlvii]. The project has an annual capacity to store 0.5 $MtCO_2$ / year. The captured CO_2 is primarily used for dry-ice manufacturing and the production of shielding gases for welding[xlviii].

The future of CCUS hinges heavily on its costs. Currently, capital costs constitute the majority of capital deployment for the first-generation CCUS retrofits at operational coal plants. However, as CCUS deployment increases, these costs are projected to decrease to US$ 1 – US$ 3 million / MW by 2030[xlix]. This reduction would result in a levelised cost of electricity between US$ 80 – US$ 160 / MWh, inclusive of the efficiency penalty[l]. At this price point, coal plants equipped with CCUS could compete with other low-emission, dispatchable sources like bioenergy or nuclear power in various markets. For newly built plants, retrofitting with CCUS might be a viable alternative to prevent plant closure and nearly complete asset write-off. It is preferable to equip new, highly efficient coal power plants with CCUS, rather than older plants, because the volume of CO_2 per unit of electricity to be captured is less.

Applying CCUS to coal power plants with biomass co-firing can generate negative emissions if the level of capture is higher than the percentage of coal burnt (for example, 20% biomass co-firing with a 90% capture rate).

Figure 8 Levelised Cost of Electricity for Selected Large-Scale Dispatchable Low



Advanced coal generation units as dispatchable technologies (with ancillary services) can facilitate the integration of variable renewable energy in a power system that needs to respond to fluctuations in output.

Advanced coal generation technologies provide flexible operation characteristics including faster ramp rates and start-up times, lower minimum loads, and the ability to maximise the efficiency of both power generation and emissions control measures.

Coal power plants play a crucial role during winter seasons that coincide with meteorological conditions resulting in higher electricity demand with limited output from solar and wind projects, i.e. cold, dark and still conditions. Their role in providing seasonal flexibility is increasingly important as the share of renewables grows. For example, a study on cold winter spells lasting one to three days in Germany, a country with a relatively high level of renewables, found that coal power plants generate twice as much power on an average day if the renewable energy share is 50%, and three times more power if the renewable energy share is 70%.[li] This effect is increased for CHP projects, where heat is required for buildings in winter.

Repurposing coal power plants involves reducing operations to focus on providing system adequacy (reserve capacity) or flexibility services. Although an unabated coal plant produces less electricity over time, it remains available during peak demand, contributing to power system reliability. For coal plant owners, electricity consumers, and policymakers, this approach may be preferable to outright closure.

Many plants currently operate in a stable baseload mode, running at near full capacity most of the time due to coal's lower cost compared to gas or oil. In China, coal generation has shifted toward flexibility, resulting in a decreased average utilisation rate for coal fleets. Repurposing coal plants for flexibility typically requires minor equipment upgrades, adjustments to market designs and operations, and updates to power purchase agreements. These plants can run at partial load, adjusting output within minutes or hours.

Whilst repurposing existing plants for flexibility reduces emissions, it also poses financial challenges and accelerates plant deterioration. To incentivise plant operators, electricity supply contracts and system service provisions may need reshaping. Adjusting contracts ensures that asset owners aren't obligated to generate coal-fired power when cheaper, low-emission alternatives are available.

Larger targeted investments can further enhance the flexibility of coal plants. For instance, retrofitting boilers can reduce the plant's minimum stable load. Upgrading control systems and components can increase ramping speeds and allow plants to operate above their rated capacity for short periods. Other retrofits, like adding battery storage, can enhance flexibility and enable the plant to provide services like fast frequency response or supplementary spinning reserves without burning extra fuel. Adding heat storage can also increase the flexibility of coal co-combustion plants.

There are many successful examples of coal plants being repurposed for flexibility, leading to reduced coal use and emissions. For example, in Denmark, the rise of wind power has increased the need for flexibility and reduced the need for baseload coal generation. As a result, several co-generation plants have been modified to decouple heat and electricity output by reducing minimum load and increasing maximum heat supply. In 2016, China launched a major retrofit program involving 22 pilot projects. This was expanded in the 14th Five-Year Plan for energy, with increased investments in flexibility from coal power plants, battery storage, and other dispatchable power sources.

However, the transition away from coal power, including the repurposing of coal plants for flexibility, can impact the financial stability of power companies and the security of electricity supplies. There is a significant amount of unrecovered capital in existing coal power plants, particularly in emerging economies. Given government commitments to reduce coal burning and emissions, there is a risk that some of this capital may not be recovered, threatening the financial stability of power companies and their ability to meet electricity needs.

CONCLUSION

Many believe that to decarbonise our power systems, we must stop using coal. Coal power plants contribute nearly one-third of all global energy-related CO_2 emissions. However, coal remains a key energy source in much of Asia due to its affordability and availability. Asian countries import the majority of their gas, which is relatively expensive. The experience of 2022, with very expensive and volatile liquefied natural gas (LNG) prices has made countries such as Pakistan and Bangladesh rethink growing dependence on imported gas. Coal is perceived as a secure, domestic source, which contributes to local employment, and is often important to local governments, miners' unions and railways.

Enhancing the efficiency of these coal plants can significantly cut CO_2 emissions. A percentage point increase in a coal power plant's efficiency can reduce emissions by 2% - 3%. Advanced high-efficiency, low-emission power plants are also more compatible with CCUS technologies.

Efficiencies could potentially be increased to ~50% in the medium-term, further reducing emissions by ~10%. Therefore, all new, large coal units should employ ultra-supercritical conditions with high efficiency, low emissions, and the best available pollutant controls. In the long-term, all coal-fired units will need to be equipped with CCUS.

Several high-efficiency alternatives provide added advantages such as fuel adaptability, production of valuable products, and compatibility with CCUS technologies. Incorporating fuel cell technologies, especially solid oxide fuel cells and molten carbonate fuel cells, into integrated gasification combined cycle plants could boost the efficiency of low-emission coal technologies.

In the long-term, these power plants are projected to achieve efficiencies of ~60% (LHV-basis). Supercritical CO_2 cycles, like the Allam-Fetvedt Cycle, offer significant potential, provide advanced power generation systems with high efficiencies and close to full carbon capture at full costs.

Co-combusting coal with biomass (or agricultural waste), as well as low-carbon hydrogen and ammonia could provide a more cost-effective way to decarbonise the power system. The practice of co-combustion is gaining traction in Asia, with countries like China and Japan implementing specific policies to encourage biomass co-firing.

In countries where coal dominates the power mix, dispatchable coal generation becomes crucial as the share of variable renewable output into the grid increases. Coal power plants can increase their output to ensure a steady electricity supply when there's little wind or sunlight.

Coal power will continue to be essential for maintaining a reliable power supply. An increase in renewable generation capacity reduces the output from coal plants, but it doesn't necessarily lead to their closure. Coal power plants don't compete with renewable generators; instead, they support the integration of more variable power in the network by maintaining grid stability and produce low-emission power when needed.

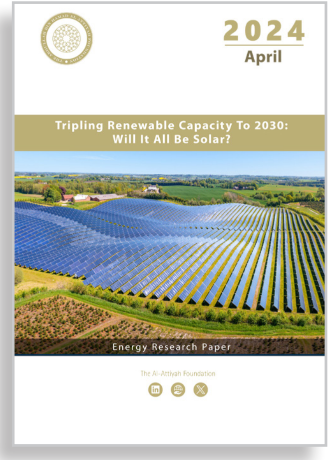
Despite the focus on variable renewable generation in power sector, with policies focused on power sector transformation and investments, inefficient coal power plants continue to operate, instead of being replaced by high-efficiency, low-emission plants equipped with CCUS technologies, which is worsened by the withdrawal of international finance and technology providers from the coal sector.

Coal remains a key component of many power grids in areas such as Asia, South Africa and Poland. To ensure a swift transition to advanced high-efficiency and low-emission system designs, coal generation needs support, which includes appropriate valuation of dispatchable capacity for grid reliability, ongoing research and development, and increased international collaboration.

i. World Energy Outlook 2032, International Energy Agency (https://iea.blob.core.windows.net/assets/26ca51d0-4a42-4649-a7c0-552d75ddf9b2/WorldEnergyOutlook2023.pdf)
ii. Statistical Review of World Energy, 2024, Energy Institute (Home | Energy Institute)
iii. Statistical Review of World Energy, 2024, Energy Institute (Home | Energy Institute)
iv. End of coal in sight as UK secures ambitious commitments at COP26 summit, 3 November 2021, UK Government (https://www.gov.uk/government/news/end-of-coal-in-sight-as-uk-secures-ambitious-commitments-at-cop26-summit)
v. 130 National Governments Committed to Collaborate to Triple Global Installed Renewable Energy Capacity by 2030, COP28 United Arab Emirates (COP28: Global Renewables And Energy Efficiency Pledge)
vi. Renewables 2023, International Energy Agency (Renewables_2023.pdf (iea.blob.core.windows.net))
vii. Accelerating Just Transitions for the Coal Sector, 2024, International Energy Agency (AcceleratingJustTransitionsfortheCoalSector-WEOSpecialReport.pdf (iea.blob.core.windows.net))
viii. Accelerating Just Transitions for the Coal Sector, 2024, International Energy Agency (AcceleratingJustTransitionsfortheCoalSector-WEOSpecialReport.pdf (iea.blob.core.windows.net))
ix. Renewables 2023, International Energy Agency (Renewables_2023.pdf (iea.blob.core.windows.net))
x. Renewables 2023, International Energy Agency (Renewables_2023.pdf (iea.blob.core.windows.net))
xi. Carbon Brief (https://www.carbonbrief.org/mapped-worlds-coal-power-plants/)
xii. Accelerating Just Transitions for the Coal Sector, 2024, International Energy Agency (AcceleratingJustTransitionsfortheCoalSector-WEOSpecialReport.pdf (iea.blob.core.windows.net))
xiii. The World's Most Efficient Coal-Fired Power Plants, 2015, Only Natural Energy (ONE Only Natural Energy – Magazine on sustainable energy, climate change, innovation and environment)
xiv. The Future of Coal: Options for a Carbon-Constrained World, 2007, Massachusetts Institute of Technology (The_Future_of_Coal.pdf (mit.edu))
xv. Coal 2020: Analysis and forecast to 2025, International Energy Agency (Coal 2020.pdf (iea.blob.core.windows.net)
xvi. Data from International Energy Agency. Excludes coal-derived gases; includes utilised heat
xvii. Ultra Supercritical Thermal Power Plant Material Advancements: A Review, 2023, Journal of Alloys and Metallurgical Systems (Ultra supercritical thermal power plant material advancements: A review - ScienceDirect)
xviii. Ultra Supercritical Thermal Power Plant Material Advancements: A Review, 2023, Journal of Alloys and Metallurgical Systems (Ultra supercritical thermal power plant material advancements: A review - ScienceDirect)
xix. Ultra Supercritical Thermal Power Plant Material Advancements: A Review, 2023, Journal of Alloys and Metallurgical Systems (Ultra supercritical thermal power plant material advancements: A review - ScienceDirect)
xx. China's R&D of Advanced Ultra-Supercritical Coal-Fired Power Generation for Addressing Climate Change, 2018, Thermal Science and Engineering Progress (China's R&D of advanced ultra-supercritical coal-fired power generation for addressing climate change - ScienceDirect)
xxi. Development of Advanced Ultra Supercritical Fossil Power Plants in Japan: Materials and High Temperature Corrosion Properties, 2011, Materials Science Forum ((PDF) Development of Advanced Ultra Supercritical Fossil Power Plants in Japan: Materials and High Temperature Corrosion Properties (researchgate.net))
xxii. Commissioning commences at Japan's Osaki CoolGen Capture Plant, 2019, Global CCS Institute (Commissioning commences at Japan's Osaki CoolGen Capture Plant - Global CCS Institute)
xxiii. Commissioning commences at Japan's Osaki CoolGen Capture Plant, 2019, Global CCS Institute (Commissioning commences at Japan's Osaki CoolGen Capture Plant - Global CCS Institute)
xxiv. Demonstration: First Step / Oxygen-Blown IGCC: Project Overview, Osaki CoolGen Corporation (Demonstration: First Step | Oxygen-blown IGC | Project Overview - Osaki CoolGen Corporation (osaki-coolgen.jp))
xxv. Molten Carbonate Fuel Cells for 90% Post Combustion CO2 Capture From a New Build CCGT, 2021, Frontiers (Frontiers | Molten Carbonate Fuel Cells for 90% Post Combustion CO2 Capture From a New Build CCGT (frontiersin.org))
xxvi. NET Power's First Allam Cycle 300-MW Gas-Fired Project Will Be Built in Texas, 2022, Power Magazine (NET Power's First Allam Cycle 300-MW Gas-Fired Project Will Be Built in Texas (powermag.com))
xxvii. The Allam-Fetvedt Cycle, 8Rivers (The Allam-Fetvedt Cycle - 8 Rivers)
xxviii. Maasvlakte Energy Hub, Uniper (Maasvlakte Energy Hub | Uniper)
xxix. Circulating Fluidized Bed Combustion, 2021, Construction and Building Materials (Circulating Fluidized Bed Combustion - an overview | ScienceDirect Topics)
xxx. Power Generation, KOSPO (Power Generation (kospo.co.kr))

xxxi. JFE Engineering Hands Over One of Japan's Largest CFB Boiler Power Plants, 2020, JFE Engineering (JFE Engineering hands over one of Japan's largest CFB boiler power plants | News | JFE Engineering Corporation (jfe-eng.co.jp))
xxxii. Technology Developments in the Co-firing of Biomass, 2021, International Energy Agency Clean Coal Centre ((PDF) TECHNOLOGY DEVELOPMENTS IN THE COFIRING OF BIOMASS (researchgate.net))
xxxiii. Technology Developments in the Co-firing of Biomass, 2021, International Energy Agency Clean Coal Centre ((PDF) TECHNOLOGY DEVELOPMENTS IN THE COFIRING OF BIOMASS (researchgate.net))
xxxiv. Technology Developments in the Co-firing of Biomass, 2021, International Energy Agency Clean Coal Centre ((PDF) TECHNOLOGY DEVELOPMENTS IN THE COFIRING OF BIOMASS (researchgate.net))
xxxv. Japan's Fuel Ammonia Strategy, 2023, International Energy Agency (Japans fuel ammonia strategy – Policies - IEA)
xxxvi. Start of Demonstration Testing of Fuel Ammonia Substitution at JERA's Hekinan Thermal Power Station: The World's First Demonstration Testing of 20% Ammonia Substitution at a Large-Scale Commercial Coal-Fired Thermal Power Plant, 2024, JERA (Start of Demonstration Testing of Fuel Ammonia Substitution at JERA's Hekinan Thermal Power Station: The World's First Demonstration Testing of 20% Ammonia Substitution at a Large-Scale Commercial Coal-Fired Thermal Power Plant | 2024FY | News Articles | IHI Corporation)
xxxvii. Start of Demonstration Testing of Fuel Ammonia Substitution at JERA's Hekinan Thermal Power Station: The World's First Demonstration Testing of 20% Ammonia Substitution at a Large-Scale Commercial Coal-Fired Thermal Power Plant, 2024, JERA (Start of Demonstration Testing of Fuel Ammonia Substitution at JERA's Hekinan Thermal Power Station: The World's First Demonstration Testing of 20% Ammonia Substitution at a Large-Scale Commercial Coal-Fired Thermal Power Plant | 2024FY | News Articles | IHI Corporation)
xxxviii. Australia's National Hydrogen Strategy, Australian Government's Department of Climate Change, Energy, the Environment, and Water (Australia's National Hydrogen Strategy - DCCEEW)
xxxix. CCS Facilities Database, Global CCS Institute (CCS Facilities Database - Global CCS Institute)
xl. Inflation Reduction Act 2022: Sec. 13104 Extension and Modification of Credit for Carbon Oxide Sequestration, International Energy Agency (Inflation Reduction Act 2022: Sec. 13104 Extension and Modification of Credit for Carbon Oxide Sequestration – Policies - IEA)
xli. Accelerating Just Transitions for the Coal Sector, 2024, International Energy Agency (AcceleratingJustTransitions-fortheCoalSector-WEOSpecialReport.pdf (iea.blob.core.windows.net)
xlii. Boundary Dam Carbon Capture and Storage Project – Canada, United Nations Framework Convention on Climate Change (Boundary Dam Carbon Capture and Storage Project - Canada | UNFCCC)
xliii. Petra Nova Carbon Capture Project Details, University of Edinburgh Scotland (Petra Nova Carbon Capture Project Details (ed.ac.uk))
xliv. China's Largest CCS Pilot Project Completed, 2021, CHN Energy (China's Largest CCS Pilot Project Completed (ceic.com))
xlv. Jinjie Power Plant CCS Demonstration Project Details, University of Edinburgh Scotland (Jinjie Power Plant CCS Demonstration Project Details (ed.ac.uk))
xlvi. New CCS Facilities added to Global CCS Institute Database, 2018, Global CCS Institute (New CCS Facilities added to Global CCS Institute database - Global CCS Institute)
xlvii. China Energy Starts Operations at Asia's Largest Coal Carbon Capture Facility, 2023, Reuters (China Energy starts operations at Asia's largest coal carbon capture facility | Reuters)
xlviii. China Launches Asia's Largest Carbon Capture Project for Coal-Fired Power Sector, 2023, State Council Information Office of the Peoples Republic of China (China launches Asia's largest carbon capture project for coal-fired power sector | english.scio.gov.cn)
xlix. Accelerating Just Transitions for the Coal Sector, 2024, International Energy Agency (AcceleratingJustTransitions-fortheCoalSector-WEOSpecialReport.pdf (iea.blob.core.windows.net)
l. Accelerating Just Transitions for the Coal Sector, 2024, International Energy Agency (AcceleratingJustTransitions-fortheCoalSector-WEOSpecialReport.pdf (iea.blob.core.windows.net)
li. Assessing the Flexibility of Coal-Fired Power Plants for the Integration of Renewable Energy in Germany, 2019, Deloitte (deloitte_assessing-flexibility-coal-fired-power-plants.pdf)

Have you missed a previous issue? All past issues of The Al-Attiyah Foundation's Research Series, both Energy and Sustainability Development, can be found on the Foundation's website at www.abhafoundation.org/publications



April – 2024

Tripling Renewable Capacity To 2030:Will It All Be Solar?

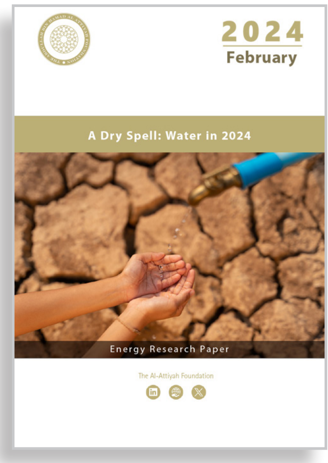
The 2023 United Nations Climate Change Conference (COP28) united parties around a pledge to triple current global renewable capacity from about 3.8 GW currently to reach 11 TW by 2030, placing renewables at the center of achieving global climate commitments.

March – 2024

Russia – China Energy Nexus

China has leveraged Russia's shift in energy trade focus from Europe to Asia, in the wake of Western sanctions imposed over the invasion of Ukraine. Chinese companies have seized the opportunity presented by discounted prices, increasing purchases of Russian energy.

(QRCODE)



February – 2023

A Dry Spell: Water in 2024

This research paper is part of a 12-month series published by the Al-Attiyah Foundation every year. Each in-depth research paper focuses on a current energy topic that is of interest to the Foundation's members and partners.

(QRCODE)

Our partners collaborate with The Al-Attiyah Foundation on various projects and research within the themes of energy and sustainable development.

The Al-Attiyah Foundation

Tel: +(974) 4042 8000,
Fax: +(974) 4042 8099
www.abhafoundation.org

Barzan Tower, 4th Floor,
West Bay.
PO Box 1916 Doha, Qatar

AlAttiyahFndn
The Al-Attiyah Foundation
Al-Attiyah Foundation