

Phasing Out Unabated Coal

Current status and three case studies



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Abstract

Reducing global carbon dioxide (CO₂) emissions to net zero by 2050 is necessary to limit the long-term increase in average global temperatures to 1.5 °C. Today, coal-fired power generation is the largest single source of CO₂ emissions. Therefore, tackling emissions from this sector is critical to achieving our goal. National governments, subnational jurisdictions, coalitions and many large corporations have announced coal phase-out pledges and net zero targets. Ahead of COP 26 in November 2021, *Phasing Out Unabated Coal: Current Status and Three Case Studies* gathers all known national commitments to eventually stop using unabated coal-fired power generation announced to date and assesses their impact in terms of reducing emissions. In addition, the report analyses three jurisdictions in detail to extract recommendation. First, an early example of coal phase-out commitment and execution from the Canadian province of Ontario. Second, the case of the United Kingdom, where the industrial revolution started but which was one of the first countries to decide to phase out coal. Finally, Germany, where phasing out is particularly complex because it is the largest coal-fired power generator among those committing to a phase-out and has thousands of jobs that rely on lignite mining. This paper acknowledges that each country must tailor its approach based on its own specific circumstances, but that nonetheless there are instructive experiences from other jurisdictions undertaking similar measures.

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Vladimir Andrascik	Ministry of Economy, Slovak Republic
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Hans-Wilhelm Schiffer	RWE

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Comments and questions are welcome and should be addressed to the lead authors of the report:

Carlos Fernández Alvarez (Carlos.fernandezalvarez@iea.org)

Kieran McNamara (Kieran.McNamara@iea.org)

Gabriel Saive (Gabriel.Saive@iea.org)

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Executive summary

The recently published [World Energy Outlook 2021](#) highlights the need to end investment in new unabated coal-fired power plants, as well as strategies to retrofit, repurpose or retire existing ones. The Net Zero Emissions by 2050 Scenario (NZE) envisages that by 2030 advanced economies would end all power generation by unabated coal-fired plant. It also foresees the end of all unabated sub-critical coal generation in emerging markets and developing economies. Unabated coal generation would be phased out by 2040. This outlook coincides with commitments by a growing number of jurisdictions to phase out unabated coal in power generation. However, the contributions that these pledges will make to reducing global energy-related CO₂ emissions fall far short of what is required in the NZE scenario.

Since the Paris Agreement in 2015, 53 countries and the European Union have pledged to achieve net zero emissions. As of mid-2021, however, only 21 countries using unabated coal for electricity generation have committed to phase it out, between 2021 (Portugal) and 2040 (Chile). Among them, few countries have already done so, such as Austria (2020), Belgium (2016) and Sweden (2020). Collectively, these commitments cover just 4.1% of global coal-fired generation and 1.3% of global energy-related CO₂ emissions.

While the phase-out policies cover only a small share of coal generation capacity, and every country must tailor policies to its own circumstances, the experiences of jurisdictions in phasing out coal can be instructive for other countries. They can shed light on three main considerations: potential impacts on the local economy, the price of electricity and the security of electricity supply. These considerations depend in turn on factors such as the current share of coal in electricity generation; growth of electricity demand; reserve margin in the grid; availability of alternative sources of power generation; supporting network infrastructure, including interconnections; and whether local coal is supplying the power plants.

Of the 21 countries that have pledged to phase out coal, [in 14 countries less than 10% of the electricity supply came from coal](#). In countries where coal contributes little to the power supply and there is no domestic coal industry, phasing out coal is likely to be feasible without detriment to the economy, electricity prices or security of electricity supply.

In three of the 21 countries, by contrast, coal represents more than 20% of the electricity supply. Seven countries also have a domestic mining industry that supplies coal for power generation. In such countries, phasing out coal will be longer and more complex. This short report analyses the phase-out experiences of the Canadian province of Ontario, the United Kingdom and Germany. Based on their experiences, we present six recommendations:

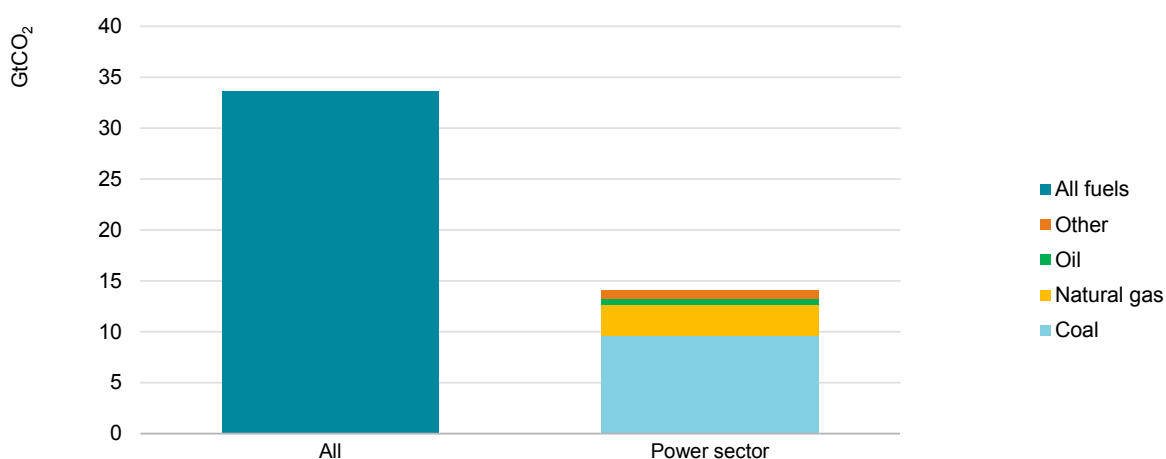
- 1. Allow sufficient time for consultation and implementation.** Phasing out coal may be a long and complex process. It may face political challenges and have numerous effects on communities, electricity prices, security of electricity supply and beyond. All these impacts need to be properly assessed and communicated to the public, together with the benefits involved.
- 2. Provide support for affected workers and communities.** When coal plants and coal mines close, communities lose jobs and revenue. As a result, workers need compensation and retraining, and both workers and capital need to be redeployed as part of comprehensive strategies.
- 3. Ensure that security of electricity supply is a cornerstone of phase-out policies.** Security of electricity supply should be paramount. Plant closures should only proceed if security of electricity supply can be maintained by combining supply, demand and storage technologies with interconnections to reliable sources.
- 4. Implement carbon pricing:** In many regions, a key way of reducing coal generation is to establish a CO₂ price or a similar instrument, such as a carbon tax, that encourages power plant operators to reduce the amount of CO₂ they emit. CO₂ prices can affect business competitiveness and affordability of energy supplies, so these economic impacts need to be considered.
- 5. Improve the climate for investment in clean electricity and the necessary infrastructure.** If there is to be a smooth transition away from coal-fired power generation, investment in energy efficiency, low-carbon generation and electricity transmission and distribution networks needs to accelerate. Mobilisation of investment in electricity networks is likely to be challenging. Long approval processes and frequent delays, often linked to public opposition concerns, can present major obstacles to development.
- 6. Consider conversion of coal generation assets.** Converting coal-fired plants to low-carbon uses not only helps to phase out coal but also reduces the need for new transmission investments. Plants can be retrofitted to enable carbon capture, utilisation and storage (CCUS) or to use low-carbon fuels such as biomass or ammonia. They can also be converted to provide the ancillary services necessary to support electricity transmission from generators to consumers, such as frequency control. This can be a useful means to obtain an adequate return from existing assets and reduce emissions while keeping jobs and wealth in local communities.

Overview

Introduction

Coal-fired power generation accounted for 37% of global electricity output in 2019, 72% of CO₂ emissions from the power sector and 30% of global energy-related CO₂ emissions. The IEA Stated Policies Scenario – which reflects the impact of existing policy frameworks and today’s announced policy intentions – projects that global power plant construction will shift from coal towards solar PV and wind over the coming decade. Construction of new coal-fired power plants will slow dramatically while [solar PV and wind deployment continues and increases](#).

Global energy-related CO₂ emissions from fuel combustion in 2019



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In the IEA Stated Policies Scenario, existing and planned regulatory or market measures are expected to contribute to over 430 GW of coal-fired capacity retirements by 2030 (20% of the 2020 global coal capacity). This includes close to 140 GW in the United States and 95 GW in the European Union, where [16 member states are committed or considering to phase out all unabated coal](#), out of the 18 with significant coal use in power today. In the United States, an ageing fleet of coal plants faces challenging market conditions as wind and solar PV capacity expands and low gas prices make gas-fired power plants very competitive. In July 2020, Japan announced that it intended to phase out less efficient coal-fired power plants by 2030. Since then, it has announced more ambitious climate targets. Despite these measures, global retirements of coal plants will be nearly offset by additions of new plants through to 2025. More than

200 GW of capacity is under construction, mostly in People's Republic of China ("China" hereafter), India and Southeast Asia.

The recent IEA publication [Net Zero by 2050 Roadmap](#) emphasised that if we are to achieve net zero emissions by 2050, no final investment decisions should be taken for new unabated coal plants, the least efficient coal plants must be phased out by 2030, and the remaining coal plants still in use by 2040 should either close down or be retrofitted to become low-emission plants. Since the Paris Agreement was adopted, 21 countries have pledged to fully phase out unabated coal use in the power sector.

Scope and structure

Many countries, companies, investors and other stakeholders have announced climate-related goals regarding emissions and use of fossil fuels. However, it is difficult to know how much these commitments will contribute to achieving the global climate goals.

As the 2021 United Nations Climate Change Conference (COP26) approaches, this report assesses the global impact of countries' pledges and policies that aim to phase out the use of coal in power generation. Phase-out experiences in three jurisdictions have been analysed in greater depth to extract some wider lessons.

The report, which deals with a complex topic, is intentionally brief. It focuses on national coal phase-outs that have already been agreed and excludes related aspects relevant to the energy-climate debate, such as construction of new coal units or use of coal in the non-power sectors. It does not cover in detail policies such as carbon pricing, air pollution regulation or the revitalisation of impacted communities.

The report details [countries' coal phase-out pledges](#) and how much they will reduce global CO₂ emissions. It describes [policies and other instruments designed to reduce and eventually phase out coal](#) in power generation.

The report also analyses the [phase-out process in three jurisdictions](#) – the Canadian province of Ontario, the United Kingdom and Germany – from which some recommendations can be extracted. Ontario, despite being a subnational entity, has been selected as it was the world's first jurisdiction to decide and implement a phase-out policy.

Lastly, examples are given of [ways in which of coal power plants may be converted](#).

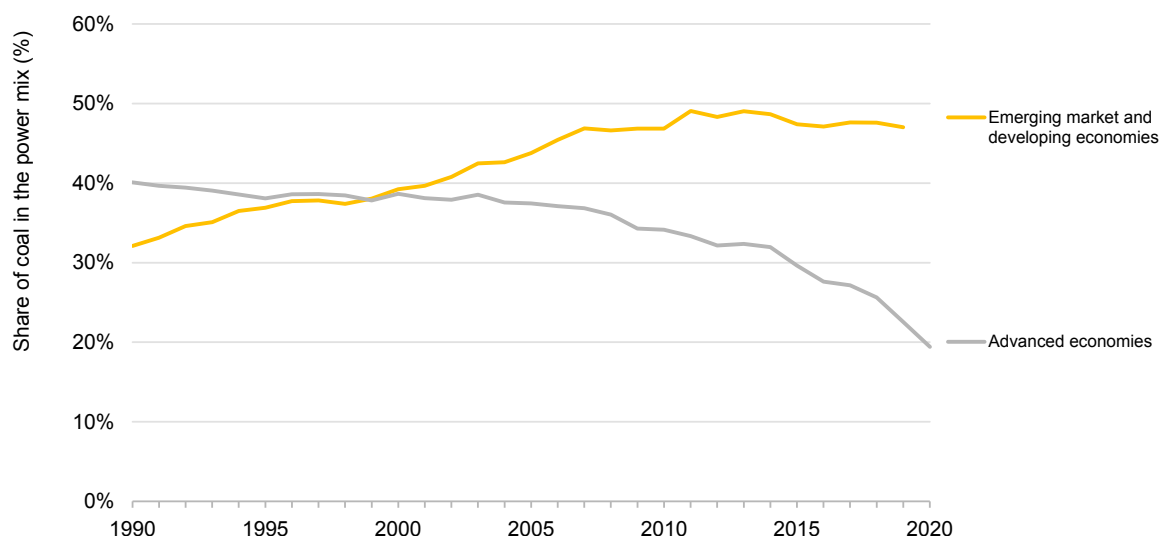
Current state of coal phase-out pledges

Since the Paris Agreement entered into force in November 2016, 21 countries have made a commitment to fully phase out coal within a fixed timeframe. Of the 21, all but Chile, Israel and New Zealand are members of the G20 group of countries or the European Union. EU climate policies have been instrumental in reducing coal's share of power generation, which has accelerated the transition from coal in the region.

Among G20 member countries, only five have a full coal phase-out target: Canada, France, Germany, Italy and the United Kingdom. Emissions from the coal-fired power sectors of these five countries represent less than 0.8% of global emissions, and the share of coal in national emissions ranges from 3.3% in the United Kingdom to 28% in Germany. In these countries, coal use has been in decline for some time. In the United Kingdom, for example, coal-fired power dropped from 65% of generation output in 1990 to 34% in 2005 and 2.0% in 2020.

By August 2021, only three countries had completed their phase-outs: Austria (2020), Belgium (2016) and Sweden (2020). Seven large countries with a net zero emissions (NZE) target remain without a coal phase-out plan: Brazil, China, Japan, Korea, South Africa and the United States. (The US Executive Order on Tackling the Climate Crisis at Home and Abroad, 27 January 2021, proposes net zero emissions, economy-wide, by no later than 2050.) Other countries from the G20 group, most notably, India and the Russian Federation, do not have a NZE target yet. Several countries made announcements in 2021 to retire their coal power plant fleet ahead of time, notably Chile, Hungary and the United Kingdom.

Share of coal in the power mix (%)



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Note: Countries qualified as advanced economies are OECD regional grouping and Bulgaria, Croatia, Cyprus¹, Malta and Romania. Emerging market and developing economies are all other countries not included in the advanced economies regional grouping.

Countries	Target date	IEA Net Zero by 2050 target	Coal's share in the national power supply (2020)	Share of coal in national CO ₂ emissions (2019)	Most power generation coal from domestic mines
Austria*	2020	2050	3%	8.6%	No
Belgium*	2017	No	3%	5.8%	No
Canada	2030	2050	5%	7.2%	Yes
Chile	2040	2050	31%	32.9%	No
Denmark	2028	2050	11%	11.2%	No
Finland	2029	2035	8%	27.6%	No
France	2022	2050	1%	3.6%	No
Germany	2038	2045	26%	28.0%	Yes
Greece	2028	No	13%	22.8%	Yes
Hungary	2025	2050	11%	11.9%	Yes
Ireland	2025	2050	5%	7.5%	No
Israel	2030	No	28%	32.2%	No
Italy	2025	2050	5%	7.1%	No
The Netherlands	2029	2050	8%	13.4%	No

¹ Note by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

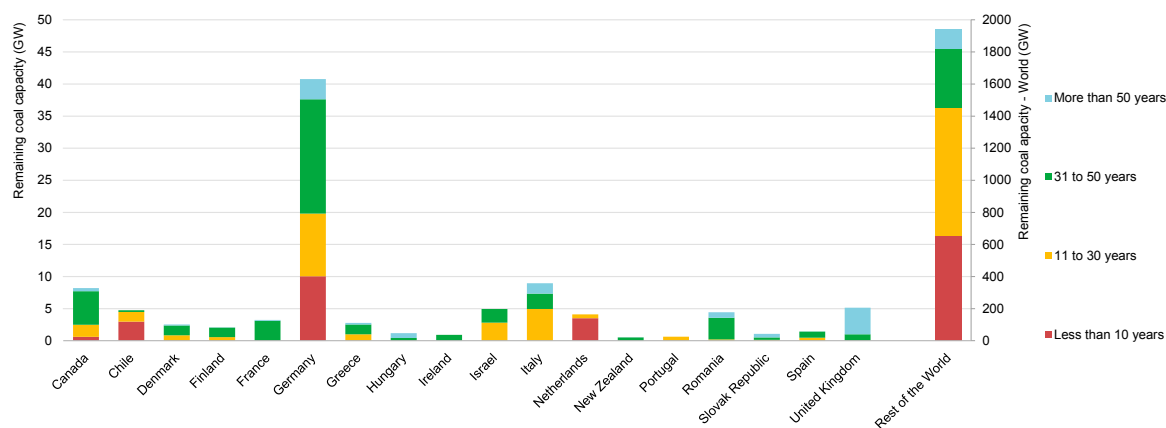
Note by all the European Union member states of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

Countries	Target date	IEA Net Zero by 2050 target	Coal's share in the national power supply (2020)	Share of coal in national CO ₂ emissions (2019)	Most power generation coal from domestic mines
New Zealand	2030	2050	5%	8.9%	Yes
Portugal	2021	2050	5%	11.6%	No
Romania	2032	No	17%	25.3%	Yes
Slovak Republic	2030	2050	7%	11.5%	Yes
Spain	2030	2050	2%	6.2%	No
Sweden*	2020	2045	1%	8.0%	No
United Kingdom	2024	2050	2%	3.3%	No

*Austria, Belgium and Sweden have completed their phase-outs except a few small boilers

Note: CO₂ emissions are from coal, peat and shale oil products used in the power sector only.

Remaining coal capacity distribution by age of plants still in operation (2021, GW)



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Source: S&P Global Market Intelligence LLC 2021.

The countries listed in the table accounted for 4.1% of global coal power generation in 2019, of which Germany weighed for 45%. In addition, the following countries have joined the [Powering Past Coal Alliance](#), whose members have committed to accelerate the transition from coal in power generation: Albania, Angola, Costa Rica, Croatia, El Salvador, Ethiopia, Fiji, Latvia, Liechtenstein, Lithuania, Luxembourg, Marshall Islands, Mexico, Niue, the Republic of North Macedonia (“North Macedonia” hereafter), Peru, Senegal, Switzerland, Tuvalu, Uruguay and Vanuatu. Among them, only Croatia, Mexico, North Macedonia, Peru and Senegal generate some electricity from coal. Poland has signed up to the EU climate law and is working to reduce its reliance on coal. In April 2021 the government of Poland and mining unions signed an agreement with the coal mining industry to phase out coal production by 2049.

Policies and measures to accelerate coal phase-out

Coal has long been a low-cost source of baseload power. Its share of power generation has been declining, however, particularly in developed economies. Burning coal leads to greenhouse gas emissions, air pollution, and land and water contamination. At the same time, alternative generating technologies have emerged.

Regulators and governments have a variety of tools to phase out use of unabated coal. One way would be to remove subsidies for coal and accelerate electricity sector reforms to allow competition among generation sources. In many coal-intensive emerging and developing economies, competitive electricity markets do not exist. Electricity sector liberalisation and reform would go a long way towards accelerating a coal phase-out. The choice of policy mechanisms depends on the circumstances and policy landscape of each country.

Air pollution regulation

Emissions from fossil fuel combustion, notably coal, are major contributors to air pollution. Introducing air pollution regulations targeting coarse particulate matter, fine particulate matter, nitrogen oxides (NO_x) and sulphur oxides (SO_x) – and to a lesser extent mercury – has a significant impact on investments, costs and operation of coal-fired power plants. Air pollution regulations have affected coal power plants in very different ways across the world. In the European Union and the United States, more stringent standards combined with other factors – mainly climate policies in the European Union and cheap gas in the United States – have resulted in massive retirement of coal-fired plants. In China, by contrast, most coal power plants have been retrofitted to reduce air pollutant emissions by orders of magnitude and only small, old units have been retired. India and South Africa have delayed enforcing air pollution standards because utilities have encountered difficulties in retrofitting their plants and closure of coal plants would jeopardise the supply of electricity.

Restrictions on public financing

In some regions, coal-fired power plants receive government subsidies to maintain their viability, in order to support workforces and communities or to guarantee the

power supply. Some public finance and development institutions also support construction of coal power plants overseas. Countries have adopted contrasting approaches to coal power subsidies. France and Italy have banned domestic and international support for coal and Germany has introduced restrictions according to efficiency standards. Australia, on the other hand, still provides direct support and subsidies to its coal power generation companies and China finances coal power plants projects internationally. More recently, in May 2021, the G7 group (Canada, France, Germany, Italy, Japan, the United Kingdom and the United States) agreed to stop investment in unabated coal and support for overseas coal projects. In September 2021, President Xi pledged that China would not build more coal power plants abroad.

Over the past decade international organisations have announced a wave of restrictions on financing coal power. In 2013, the World Bank affirmed that it would “only in rare circumstances” provide financial support for new greenfield coal power generation projects, such as “meeting basic energy needs in countries with no feasible alternatives”. In 2016, OECD member countries introduced [stricter terms and conditions](#) that encourage both exporters and buyers of coal-fired power plants to move towards higher-efficiency technologies by limiting export credit support for coal-fired power plants. In December 2018, the European Bank for Reconstruction and Development confirmed that it would no longer finance new mining for thermal coal or coal-fired electricity generation, while in 2019 the European Investment Bank announced that it would finance no new fossil fuel energy projects after 2021. In the same year, the African Development Bank announced it would no longer finance coal projects. The Asian Development Bank stated in May 2021 that it would no longer finance new coal power plants. Also in 2021, the US government committed to “identify steps through which the United States can promote ending international financing of carbon-intensive fossil fuel-based energy while simultaneously advancing sustainable development and a green recovery”.

Financial agreements with power companies

Some governments compensate power companies for closing coal power plants before the end of their economic or technical life to comply with the new objectives of the government. Support can take the form of payments with agreed dates for closure, as is the case with lignite in Germany, or auctions in which power plant operators can compete for compensation for closing their plants early, as with hard coal in Germany.

In some markets, a capacity mechanism rewards power plants for the MWs available to produce if needed rather than the MWhs they actually generate. Another option is mothballing coal plants to use later in exceptional circumstances.

Subsidies and other fiscal and regulatory mechanisms can also be used to help companies switch from coal to other sources. In the United Kingdom, for example, some units at the Drax coal-fired power plant retain contracts to provide capacity until the end of the 2021-2022 winter, while four units have been converted to burn biomass, supported by a contract for difference (CfD) for renewable electricity. Many of these options may not be available in emerging markets and developing economies, however, for a variety of reasons, including budget constraints and the need for energy for development. If such measures were to be implemented, support from OECD countries might be required.

Carbon pricing

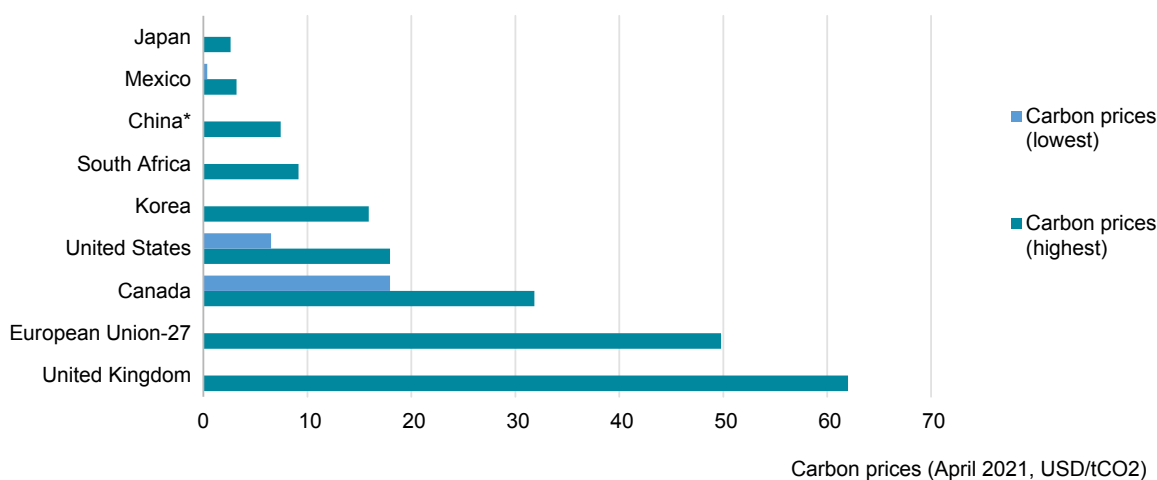
Pricing carbon – obliging operators to pay according to the amount of CO₂ their power plants emit – can lead to substitution of coal-fired power by less carbon-intensive sources of power and sometimes to lower demand for electricity. In the short term, carbon pricing raises the marginal cost of coal-fired powered plants, so it can induce a shift in the merit order, prioritising dispatchable sources with lower CO₂ emissions over coal. In the long term, as coal becomes less competitive and less financially attractive than lower-carbon energy sources, carbon pricing sends investors a signal to move from coal to natural gas or to low-carbon energy sources, such as solar and wind power.

Nonetheless, care must be taken to ensure carbon pricing is effective in decarbonising the power sector and to apply it across the fuel supply chain. Otherwise, the carbon pricing regime may penalise coal plants compared to gas plants if, for example, methane leakages are not taken into account. Where market structure and regulation allow, electricity producers will pass on the increase in production costs resulting from carbon prices to consumers of electricity, in the form of higher electricity prices.

More broadly, the stability, predictability and level of the carbon price – and the availability of substitutes for the energy source – determine by how much carbon prices reduce emissions. Larger price increases usually lead to larger emissions reductions. Where alternatives are expensive or not available, emissions may only be reduced when carbon prices are higher. Where substitutes are available at small additional cost, emissions reductions can be substantial, even when carbon prices are low. Many jurisdictions have introduced either a carbon tax or an

emissions trading system (ETS) for the power sector. Examples include the EU ETS, Korea-ETS, Canadian Framework and China, which has launched the world's largest ETS for its power sector – with prices ranging from USD 2.6/tCO₂ in Japan to USD 62/tCO₂ in the United Kingdom in Spring 2021. In May 2021, the EU CO₂ price surpassed USD 50/tCO₂ ahead of the launch of the EU Fit-for-55 Package, which includes a significant ETS reform to meet higher emissions reductions of 55% by 2030 compared with 1990 levels.

Carbon pricing levels on coal in selected countries (USD/tCO₂, 2021 average levels)



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* Results of the first auction of the China National ETS held in July 2021.

Note: Highest and lowest carbon prices are provided to give an overview of the range in prices where different pricing schemes are present.

Source: Data extracted from emissions trading systems and carbon taxes covering emissions from coal power plants. The prices can be found in the [World Bank Carbon Pricing Dashboard](#) and the [ICAP Allowance Price Explorer](#).

Emissions standards

Some jurisdictions have established CO₂ emissions standards for new or existing generation plants as a way to reduce CO₂ emissions by reducing coal power generation. Given that emissions from the most efficient coal plants are over 0.75 tCO₂/MWh, any standard well below that level makes it impossible to operate coal power plants, unless they use bioenergy co-firing, CCUS or other technology to reduce emissions. Emissions standards are less flexible than CO₂ pricing and only countries under specific circumstances can impose such standards, in particular for plants in operation.

Supporting alternative technologies

Supporting clean energy technologies as an alternative to coal power is another policy option to reduce reliance on coal for electricity supply before coal is phased

out. Declining costs of wind and solar are helping their deployment, but in countries where electricity demand is growing, such as China, India or Indonesia, deployment of clean energies rarely reduces dependency on coal. In emerging markets and developing economies, therefore, near-zero emissions capacity additions will require financial support such as low interest and concessional loans and blended finance, as well as contributions by advanced economies to funds that support such projects. Support for clean energy technologies is essential, therefore, to reduce and eventually phase out unabated coal power generation. Several clean energy technologies have very low operating costs, which give them a competitive advantage in electricity dispatching based on merit order.

Coal and the just transition

As countries seek to shift from fossil fuels to clean energy technologies, the success of these efforts also rests on enabling citizens to benefit from opportunities and navigate changes. Any reduction in domestic coal use or of coal exports is likely to have a significant social and economic effect on the communities where coal mines and plants are located, including losses of jobs and tax revenues. The impact will be larger in coal-producing regions, as coal production is labour intensive. Overall, about 140 thousands jobs are expected to be lost through the listed coal phase-out plans (IEA estimates).

Managing the expected job losses during the energy transition presents a policy challenge. Many coal-producing and/or coal-consuming regions will need to restructure and/or diversify their economies, maintain social cohesion, and retrain the affected workers and job seekers to prepare them for future jobs. As with the other coal reduction policies and measures highlighted here, there is considerable international experience in targeting economic restructuring aid to coal regions. There is no silver bullet to avoid the impact of coal phase-out on communities, however. On 26 January 2021, the IEA established a high-level Global Commission on People-Centred Clean Energy Transitions, which will produce recommendations ahead of COP26.

Conversion of coal power plants

The conversion of coal power plants should be seriously considered before their closure is planned, as it enables the owner to retain some of the value of the existing assets and the community to maintain a source of jobs and taxes. Conversion can also aid the smooth functioning of the electricity system. Policy

makers, regulators and other stakeholders should be aware of that potential and set up the legal and social framework necessary to extract ongoing value from existing coal power plants.

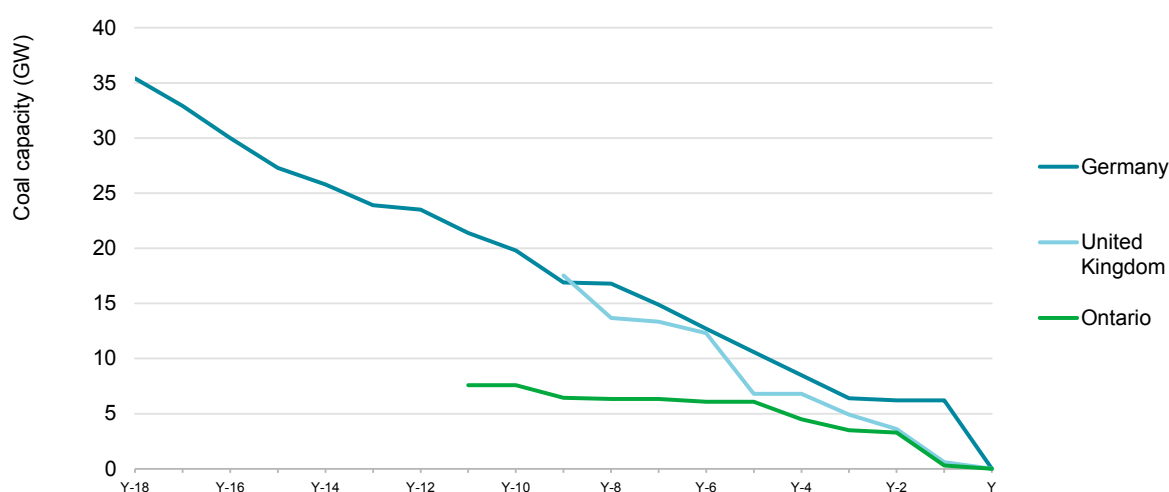
A coal power plant includes many assets that could continue to be used to generate power, such as the boiler, the water/steam system, the cooling system and the turbine/generator, as well as equipment for handling materials. The physical space where the plant is located and the grid connection are also valuable assets. Other less tangible but equally valuable assets are the plant's group of skilled workers, auxiliary industry and services developed around the plant, and the licence to operate, including the "social licence", or support of the community.

The grid connection, the physical space and the water availability make coal plant sites valuable for many electricity uses or even industrial uses. The United States, where the world's largest amount of coal capacity has been closed during the last decade, offers useful experiences on conversion, mostly to gas power plants. Low-carbon conversion options will become more frequent. The last section of this report presents some examples of coal power plant conversion.

Case studies: Ontario, the United Kingdom and Germany

Many different approaches have been adopted to reduce the use of coal and facilitate its removal from the power sector. This section summarises three contrasting approaches adopted in Ontario, the United Kingdom and Germany.

Installed capacity in coal: from the announcement of the phase-out to its completion



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Note: For Germany, 2038 is assumed as the completion date, but completion could occur earlier.

Sources: [German Federal Network Agency](#), [Independent Electricity System Operator](#), [UK Government](#).

Coal phase-out in Ontario, Canada: Closing government-owned plants

In 2003, the government of Ontario pledged to close all the coal power plants in the province by 2007. When technical challenges were encountered in replacing generation capacity and upgrading the grid, the deadline was pushed back to 2009. In 2007, the province passed legislation calling for the cessation of coal use by 2014, which was the year the last unit closed.

In 2003, coal represented [a quarter of Ontario's generating capacity \(7 560 MW\) and of its electricity supply \(36.6 TWh\)](#). Most of the existing coal capacity had been built in the 1960s and 1970s and had an economic life of about 40 years. Phasing out coal was a major structural policy reform that required a [set of complementary policies](#) to soften the detrimental effects of the transition and provide alternative

energy solutions. Grid planning was necessary to accommodate capacity replacement, as well as provision of ancillary services.

The elimination of coal-fired electricity was a shared effort by the provincial government, Ontario Power Generation (the largest power generator), and the Independent Electricity System Operator (IESO), the Crown corporation responsible for operating the electricity market and directing the operation of the bulk electrical system in Ontario. The province adopted a phased approach with capacity reduced in stages between 2003 and 2014 to maintain system reliability and operational efficiency. The Cessation of Coal Use Regulation (2007), which set an end date of 31 December 2014, was the key legal instrument for the later stages of the phase-out.

Timing of coal-fired plant closures in Ontario, 2003-2014

Remaining capacity (MW)	2003	2005	2010	2011	2012	2013	2014
Lakeview	1 150	-	-	-	-	-	-
Nanticoke	3 940	3 940	2 960	1 980	1 980	-	-
Lambton	1 980	1 980	1 010	1 010	1 010	-	-
Thunder Bay	306	306	306	306	306	306	(April)
Atikokan	211	211	211	211	-	-	-
Total	7 587	6 437	4 487	3 507	3 296	306	0

Source: Ontario state government (2021), [The end of coal](#).

Thunder Bay and Atikokan plants were converted to run on biomass. Owing to high costs, Thunder Bay was subsequently closed. Atikokan operates as a peaking plant and uses locally supplied biomass. The other three plants were closed and demolished. The site of the largest, Nanticoke, which now has a solar farm, has a good transmission link and is being considered for a connection to the United States that passes under Lake Erie (Lake Erie Connector).

Framework strategy

Several gas-fired power plants were built to replace most of the coal capacity that was being retired. Before the system operator (IESO) would allow the controlled shutdown of the coal-fired generating fleet, these gas plants had to demonstrate consistent, reliable performance. There was substantial investment in new non-hydro renewables, mainly wind and solar power. Coal-fired electricity was replaced by a mix of baseload, shoulder and peaking capacity, with a strong conservation and demand management approach:

- Nuclear: Two units at Bruce Power were refurbished and returned to service in 2012, adding 1 500 MW.
- Natural gas: New combined-cycle facilities, a peaking plant and combined heat and power facilities together added 5 500 MW.
- Non-hydro renewables: Added generation under procurements came to 5 500 MW.

By 2019, 94% of the electricity generated in Ontario was low-carbon.

Output by generation technology in Ontario, 2003 and 2014

Energy source	% of total generation 2003	% of total generation in 2014
Nuclear	42%	60%
Gas	11%	9%
Hydro	23%	24%
Coal	25%	0%
Non-hydro renewables	0%	7%

Source: IESO (2021), [Transmission Connected Generation](#).

The provincial government passed on the cost of the phase-out to customers as a charge on the bill (part of what is known as “global adjustment”) while transmission upgrades were included in regulated transmission rates. There was also an additional charge on customers during the transition to compensate Ontario Power Generation for above-market costs of the larger coal plants as output from the plants was curtailed (also recovered by means of the global adjustment).

Although costs were significant, [several factors made the phase-out simpler to achieve](#). As Ontario was not a coal producer, few jobs were lost. The falling cost of natural gas also made coal generation more expensive than gas generation. By the time phase-out was completed, it had ceased to be politically controversial.

Coal phase-out in the United Kingdom

In the United Kingdom, coal generation’s share of electricity output fell from 65% in 1990 to 34% in 2005, 23% in 2015 and 2% in 2020. The complete phase-out of coal is expected by 1 October 2024.

In November 2015, the government announced that it intended to consult on proposals to end unabated coal generation in Great Britain (England, Scotland and Wales, excluding Northern Ireland) by 2025. The date was chosen to balance the demands of affordability, security of energy supply and decarbonisation. The

overall objectives of the phase-out were not only to reduce emissions of CO₂ and other harmful pollutants from the power sector but also to increase revenue certainty for investment in new lower-carbon, flexible generation capacity.

As of mid-2017, the government estimated that 2 500 to 3 000 people were employed in coal mining and coal-fired power generation and that most would be able to find other jobs when plants closed. The government also estimated that coal plants would lose around GBP 250 million in profits by closing early. Profits would increase for other forms of power generation, however, which in some cases would be owned by the same companies that own coal plants. In other words, much of the resulting change in profitability would amount to a transfer between businesses.

Framework strategy

Several policies introduced after 2006 constrained the outlook for coal well before the government announced in 2015 its intention to phase out unabated coal. These policies included the introduction of a carbon price floor in 2013, the Renewables Obligation, the Emissions Performance Standard, along with the Climate Change Act, carbon budgets and EU pollution control regulations. As a result, the economics of coal-fired power deteriorated significantly. Falling gas prices, cheaper renewables and higher carbon taxes combined to leave coal generators facing increasing losses.

The government decided that the best way to ensure the phasing out of unabated coal by 2025 was to set a new emissions intensity limit of 450 gCO₂ per kWh of electricity generated. This level, broadly equivalent to the emissions intensity of an unabated gas-fired plant, was in line with the existing Emissions Performance Standard for new fossil fuel-fired power plants. This limit was to be applied on a unit-by-unit basis. Units could achieve this standard by investing in technologies that would reduce CO₂ emissions significantly.

By 2019, only three coal-fired plants remained on the system in Great Britain: Drax, Ratcliffe and West Burton. (One plant, in Kilroot, remained on the Northern Ireland system, which is part of the all-island Single Electricity Market in Ireland. It plans to convert to natural gas by 2023.) Drax units were over 30 years old and the rest over 40 years old. Since then, Drax has announced that its coal-fired units would close after September 2022. West Burton announced plans to close its remaining coal units in 2022 while the final remaining plant at Radcliffe recently secured a capacity contract for one unit for the winter of 2021/22.

Coal phase-out in Germany: structural planning and auctions mechanism

Coal phase-out in Germany is part of the Energiewende, a major government policy shift from nuclear power and fossil fuels to renewables. Coal-fired power accounts for just over a quarter of Germany's electricity output. In 2019, the coal-fired generation fleet accounted for around 28% of total emissions and more than 75% of emissions from the power sector. Unlike Ontario or the United Kingdom, in Germany coal mining and generation is a major employer, notably in Central Germany, Lusatia and the Rhineland. These regions are expected to receive billions of euros in economic support to adapt to the phase-out of coal. A major challenge identified before the coal phase-out was a slowdown in the development of power grids in the face of strong public resistance, in particular the north-to-south power corridor bringing electricity from renewables producing to consuming regions. Some authorities, such as the Court of Auditors, have warned that security of energy supply could be jeopardised.

Framework strategy

In 2020, the [Act to Reduce and End Coal-Powered Energy and Amend Other Laws](#) came into force. Known as the Coal Phase-Out Act, it aims to gradually reduce coal-fired power and end its use by 2038 at the latest to “reduce emissions and provide the public with a safe, a cost-effective, an efficient, and a climate-compatible energy supply”. Some more recent developments, like Germany's adoption of the objective of reaching net zero emissions by 2045, the new European Commission climate package or G7 agreement have raised expectations that there might be an earlier phase-out.

The Coal Phase-Out Act provides that no new coal power plants will be built in Germany. It also determines that coal generation capacity will be reduced to 30 GW by 2022 (15 GW from hard coal and 15 GW from lignite) and to 17 GW by 2030 (8 GW from hard coal and 9 GW from lignite), with reduction of the remaining capacity by 2038 at the latest.

The Act treats hard coal and large lignite power plants differently. A closing schedule has been agreed between the government and companies owning the lignite power plants and open pit mines to phase out large lignite power plants progressively. Mechanisms for the early retirement of power plants before 2030 have also been introduced to compensate companies for the potential losses they may face. In addition, older workers losing their jobs as a result of the closure of the plant will receive compensation payments.

A separate auction mechanism was adopted for hard coal and small lignite-fired power plants. A shutdown premium was awarded by means of a competitive tender process: the coal plant operators receive a “hard coal premium” for the capacity they take offline. The most cost-efficient bids are the first ones to be selected. Bids are ranked through an index dividing the bid value (EUR/MW) with the average annual historical emissions of CO₂ per megawatt of net nominal output of the hard coal plant in the three years before the auction takes place. For rounds two to seven (2021-2026), this index incorporates a “grid factor”, which takes into account the maintenance costs that might arise if there is a need to keep the plant in the network for energy security reasons; it is added to the bidding price before obtaining the ratio.

The bids are ranked so that the lowest number of the index comes first and the highest number comes last. The bids are awarded in the order in which they are placed until the tender volume is reached (Federal Network Agency, 2020).

Price bids are to be submitted by power plant operators in euros per megawatt capacity; this equals the compensation payment for winning bids (pay-as-bid). The highest price is regulated, decreasing from the first auction (EUR 165 000/MW) to the last (EUR 89 000/MW). For the award decision, however, bids were not ranked directly by the bid parameter. Instead, the bids were converted into euros per tonne of CO₂, based on the average annual CO₂ emissions per MWh observed for each plant over the previous three years. As the modern power plant units are more efficient (and emit less CO₂ per megawatt hour of electricity generated), they were operated more frequently than older and less efficient units. As a consequence, the bids of younger units were divided by a higher total amount of CO₂, which moved them up the bid ranking compared with older units. This allows more coal power generation to be reduced from the same capacity than without the conversion to euros per tonne of CO₂.

Compensation mechanisms

To compensate lignite power plant companies, EUR 4.35 billion will be awarded to plants in order to compensate them for their earlier investments and to close down the plants. RWE Power AG is entitled to compensation of EUR 2.6 billion, to be paid in 15 annual instalments from 2020, for its lignite plants in the Rhineland. Lausitz Energie Kraft-werk AG is entitled to compensation of EUR 1.75 billion, to be paid in 15 annual instalments from 2025, for its lignite plants in Lusatia. The compensation is currently audited by the European Commission.

As amended in the combined heat and power (CHP) law, plant operators that replace a CHP (cogeneration) plant that generates electricity from lignite or hard

coal with one that generates electricity from waste, waste heat, biomass or gaseous or liquid fuels will receive a one-off payment of EUR 5 to EUR 390 per kilowatt of capacity, depending on their operational start date.

The government aims to reduce hard coal generation capacity by 7 GW by 2022 and by a further 7 GW by 2030. To reach these levels, the first auction round in December 2020 targeted a reduction of 4 GW by January 2021. The law settled a maximum auctioning price of EUR 165 000 (Federal Network Agency, 2021). Overall, 11 bids for a total value of 4 788 MW were accepted, including bids from Vattenfall and RWE. The values of the successful bids range from EUR 6 047/MW to EUR 150 000/MW. The total amount resulting from the bids is around EUR 317 million. From 1 January 2021, the plants that were awarded the contract may no longer market their power output.

The most recent bid, settled in July 2021, aimed to close down 2.5 GW of coal installations. For the first time, the auction was undersubscribed. Eleven bidders won awards for 2.1 GW at an average price of EUR 102 799/MW, with bids ranging from EUR 0 (meaning no compensation was asked from the power plant closure) to EUR 155 000/MW. The undersubscription and the fairly higher price paid may indicate that the plants most eager to close early were selected during the first two tenders and that closing the remaining plants will require a higher level of funding. Different auction designs and sizing might increase competition for funding and yield more optimal results than the current single bid format.

The next tender will aim to close 433 MW of hard coal-fired generation capacity in 2023, with a bid deadline of 1 October 2021.

Timeline and objectives of the auctioning mechanism

Bid deadline	Tender volume	Actual traded volume	Max. bid price (EUR)	Lowest and highest bid (EUR)	Closing date
01-09-2020	4 GW	4.788 GW	165 000	6 000-150 000	01-01-2021
04-01-2021	1.5 GW	1.514 GW	155 000	0-59 000	08-12-2021
30-04-2021	2.481 GW	2.133 GW	155 000	0 -155 000	31-10-2022
01-10-2021	0.433 GW	n.a	116 000	n.a	2023
01-03-2022	n.a	n.a	107 000	n.a	2024
01-08-2022	n.a	n.a	98 000	n.a	2025
01-06-2023	n.a	n.a	89 000	n.a	2026
03-06-2024	n.a	n.a	89 000	n.a	2027

Coal plant conversion

Converting coal-fired plants to low-carbon not only avoids CO₂ emissions, but it also reduces the need to invest in new transmission infrastructure. Coal power plants can be modified by reusing the assets of the plant, such as retrofitting them with carbon capture, utilisation and storage; converting them to use other fuels (natural gas, biomass and ammonia); and reutilising them as small nuclear reactors, thermal energy storage and synchronous condensers.

Other low-carbon reutilisation options, not examined here, use only the former coal plant's physical space and/or connection with the grid. These options include batteries, solar PV and wind generation facilities, sometimes associated with hydrogen and/or ammonia production.

Carbon capture, utilisation and storage

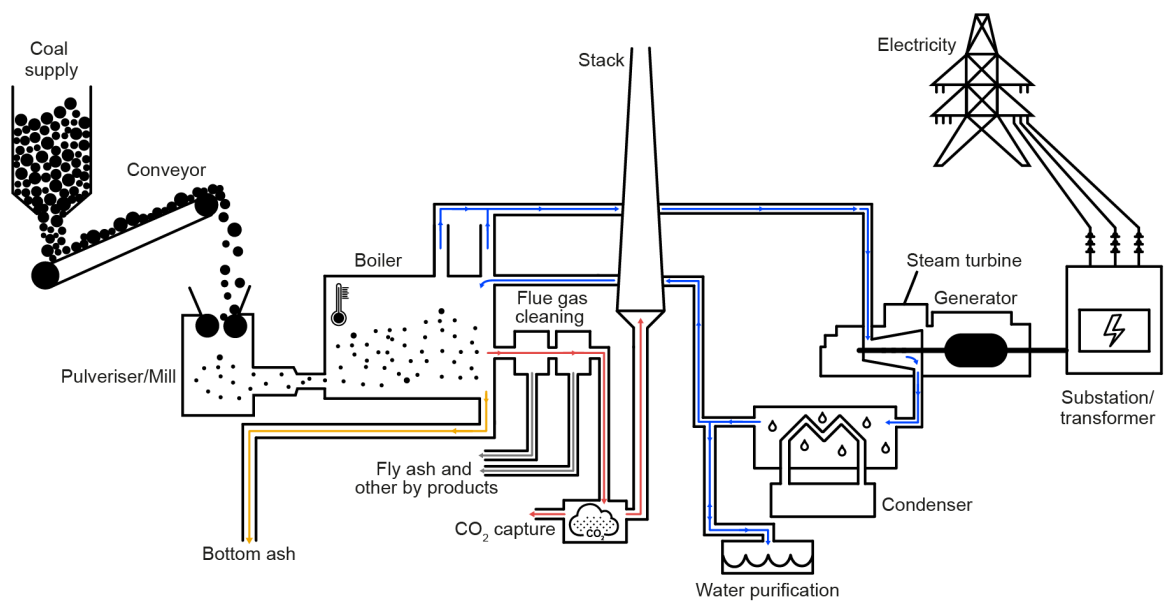
Retrofitting coal plants with carbon capture, utilisation and storage (CCUS) preserves existing assets and enables the plants to continue providing dispatchable electricity, grid stability and energy storage, in the form of coal. In “mine mouth” plants, built close to mines and fuelled with cheap coal, CCUS may be an attractive option to keep the plant in operation, maintaining mining jobs and helping the community. In the case of young plants, with a long lifetime ahead, retrofitting with CCUS can be a reasonable compromise to avoid the otherwise almost full depreciation of the plant. If the capture system allows energy to be stored (for example by adapting oxygen production to the required power output), the capture retrofit can augment the flexibility of the system, facilitating high penetration of variable renewable energy.

CCUS technologies for coal power plants include pre-combustion, oxy-combustion and post-combustion. A recent development is the Allam cycle, an oxy-fuelled semi-closed cycle using supercritical CO₂ at high pressure as the working fluid. Chemical looping, in which a metal acts as an oxygen carrier to produce CO₂ and water, is under development. Both are promising technologies, but for plants in operation, in which existing assets are to be preserved, the most suitable option is post-combustion, in which the CO₂ contained in the flue gas is adsorbed, or absorbed usually by amines, which are later regenerated. This is the approach followed by the two coal power plants retrofitted with CCUS at commercial scale so far in the world: Boundary Dam (Canada) and Petra Nova (United States). The Saskpower Boundary Dam CCUS facility in Saskatchewan

started operation in 2014, capturing around 1 MtCO₂ per year and becoming the world's first large-scale CCUS in a coal power plant. It was followed in 2017 by the Petra Nova facility in Texas, capturing around 1.4 Mt CO₂ per year. The CO₂ captured in those facilities is used for enhanced oil recovery.

A few years ago, expectations were high that CCUS in coal power plants would make a significant contribution to reducing emissions, but these hopes never materialised. Energy losses in the CCUS process, the capital expenditure required and lukewarm policy support all played a role. Enhanced policy support in the United States in 2018 created new momentum, however. Four coal power plants are considering CCUS.

Coal power plant retrofitted with post-combustion CCUS



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Gas boilers

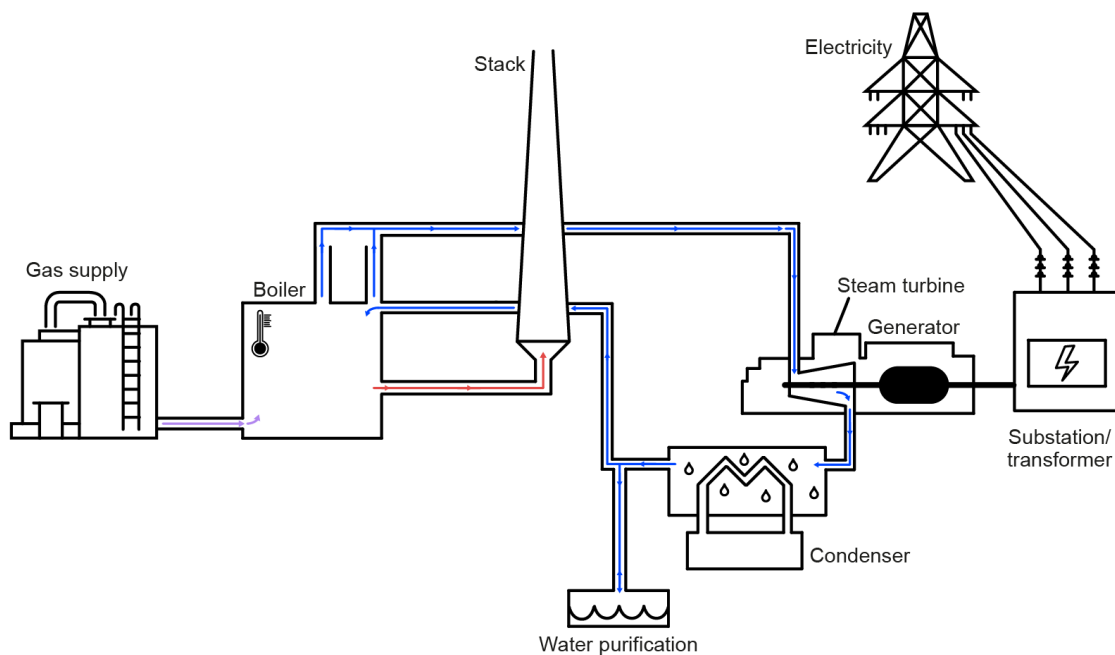
The United States has accumulated much experience on how to deal with retired coal power plants. From 2011 to 2019, 50 GW of coal capacity was retired, with most plants modified to burn another fuel. Eighty-six old coal power plants representing 14.3 GW of capacity converted their boilers to burn natural gas, driven by more stringent emission standards and lower natural gas prices. Investments required are small. Each boiler requires different changes, depending on its physical geometry, materials of construction, steam conditions required for the turbine and other factors. The plant load factor is another important consideration. In general, a gas boiler is a retrofit option for coal plants that expect

low load factors. It is also notable that gas plants require fewer workers than coal plants, which require extra personnel to handle fuel, ash and by-products from flue gas cleaning.

Retrofitting coal plants as gas boilers uses most of the existing infrastructure downstream and frees up the space that was dedicated to coal supply, but it requires infrastructure to supply gas through a gas pipeline. If a gas pipeline close to the site exists, this is straightforward. If no pipeline is close, permits and expenses from a new gas natural corridor can threaten profitability.

From a climate perspective, a gas boiler emits less CO₂ (just over 500 kgCO₂/MWh) than a comparable coal plant (900 kgCO₂/MWh). Such a conversion does not represent a real low-carbon alternative to coal, however, just a temporary, low capital option to maintain the electricity supply while further reutilisation or closure is undertaken.

Coal power plant converted into a gas power plant (boiler)



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Natural gas combined-cycle plants

As already mentioned, the United States has led the way in converting coal power plants in the 2010s. Between 2011 and 2019, 17 coal power plants with total capacity of 7.9 GW were converted into combined-cycle gas-fired plants (combined-cycle gas turbines [CCGT]) with capacity of 15.3 GW. Major

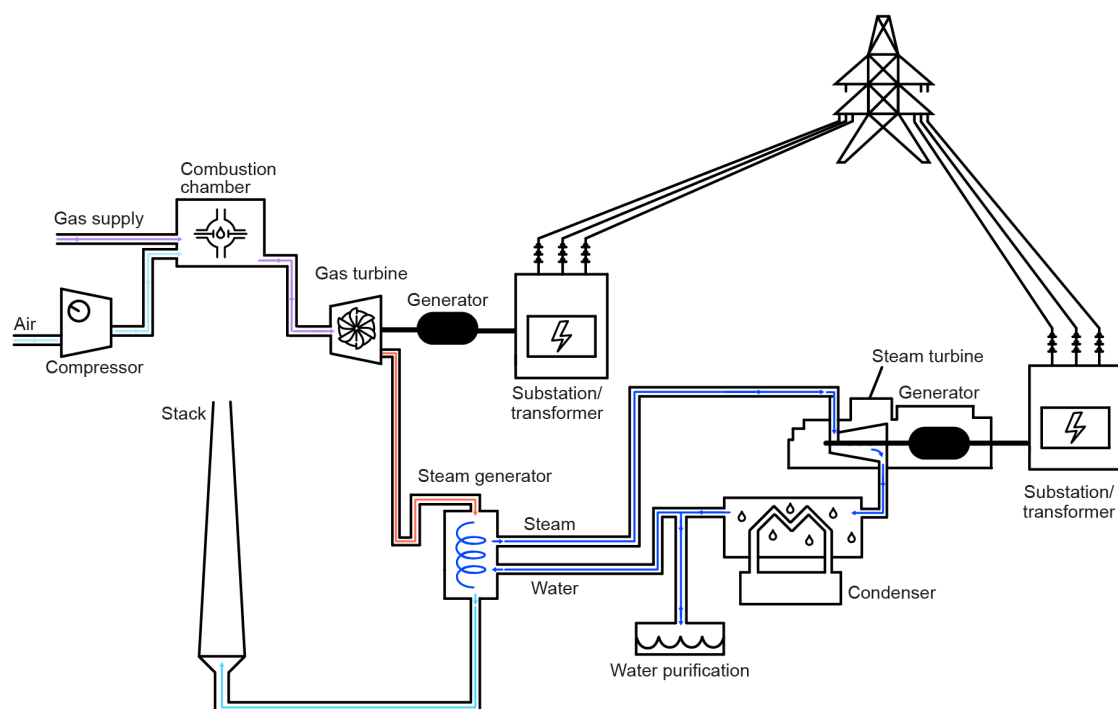
refurbishment was required: the fuel, ash and by-product handling infrastructure, the boiler and the balance of the plant all need replacement, as do the electrical parts, including generators and transformers. This major transformation and replacement requires much higher investment than in the case of gas boilers.

The advantage of CCGTs versus gas boilers is the higher efficiency of the cycle, which is typically over 50% and can be over 60% using advanced turbine technology. In boilers, by comparison, typical efficiency is 35%. This higher efficiency significantly reduces both fuel generation costs and CO₂ emissions, by more than 40% in each case.

The pros and cons mentioned above in converting coal plants to gas boilers are also relevant for CCGTs. The need for gas receiving infrastructure and associated permits can delay construction and increase costs. If investments for a CCGT are decided, a certain plant load factor is expected and gas supply must be somehow guaranteed. In terms of jobs, CCGTs like gas boilers use a smaller workforce than a coal plant, as the personnel in charge of coal and ash handling are no longer required.

CCGTs emit less than 350 kg CO₂/MWh, much less than gas boilers or, even more, coal power plants. Even this level of emissions is unacceptable, however, in a net zero emissions world. Like gas boilers, CCGTs can only be a transition option.

Coal power plant converted into a CCGT



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Biomass power plants

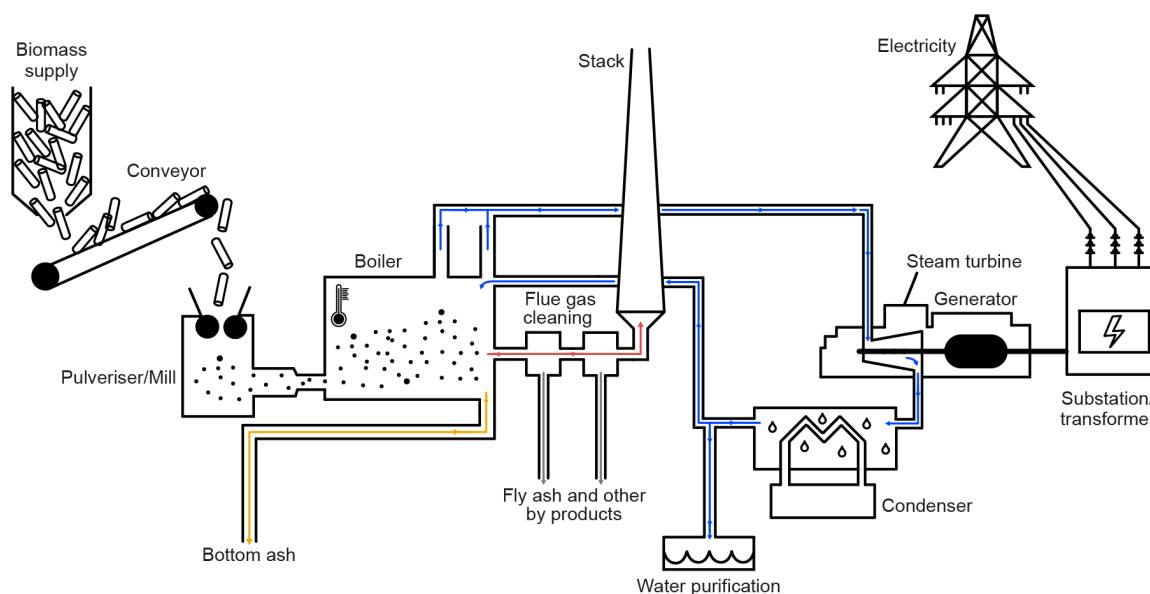
Converting a coal power plant to use biomass can become a negative emissions solution when combined with CCUS.

Some US coal plants have been converted to use biomass, but one global reference is the Drax power plant (3 960 MW), which was the United Kingdom's biggest coal plant and the second-largest in Europe. Since 2013, four out of six units have been converted to run on biomass, with the remaining two due to be converted in the coming years. Drax will become the world's largest biomass-fuelled power facility.

Unless the original fuel is lignite, the main changes when converting a coal plant into biomass are that wood has a lower energy density than coal, because its moisture content is higher, and the mass of biomass fuel is approximately double that of coal. If, as in the case of Drax, wood pellets are imported, the complex logistics of importing, transporting and storing the pellets need to be managed. Biomass also generally releases more particulate matter than coal. To avoid challenges arising from the density difference, a technology under development can produce pellets that can mimic coal, removing the need to modify the boiler or the fuel handling facilities, and therefore improving the economics of plant conversion.

The sustainability of biomass, including its traceability and accountability, always needs to be taken into account. "No-regret options" include agricultural and forestry residues that otherwise would be burned without any benefit. Given the size of typical coal plants, availability of that kind of biomass at the scale required may be an issue. Emissions in the supply chain (collection, processing and transport) and indirect land use change also need to be addressed.

Coal power plant converted into a biomass power plant



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Ammonia-fuelled power plant

There is growing interest in using hydrogen-based ammonia to replace fossil fuels in some applications. If the hydrogen used is low-carbon – produced either through electrolyzers from renewable electricity or from fossil fuel hydrogen with CCUS, ammonia can be considered a low-carbon fuel (or rather, an energy carrier).

Ammonia has a variety of uses, so a distribution network has already been established. It is a liquid and hence stable for long-term storage and transportation, a great advantage over hydrogen, the other energy carrier with potential to become a pivotal player in clean energy transitions.

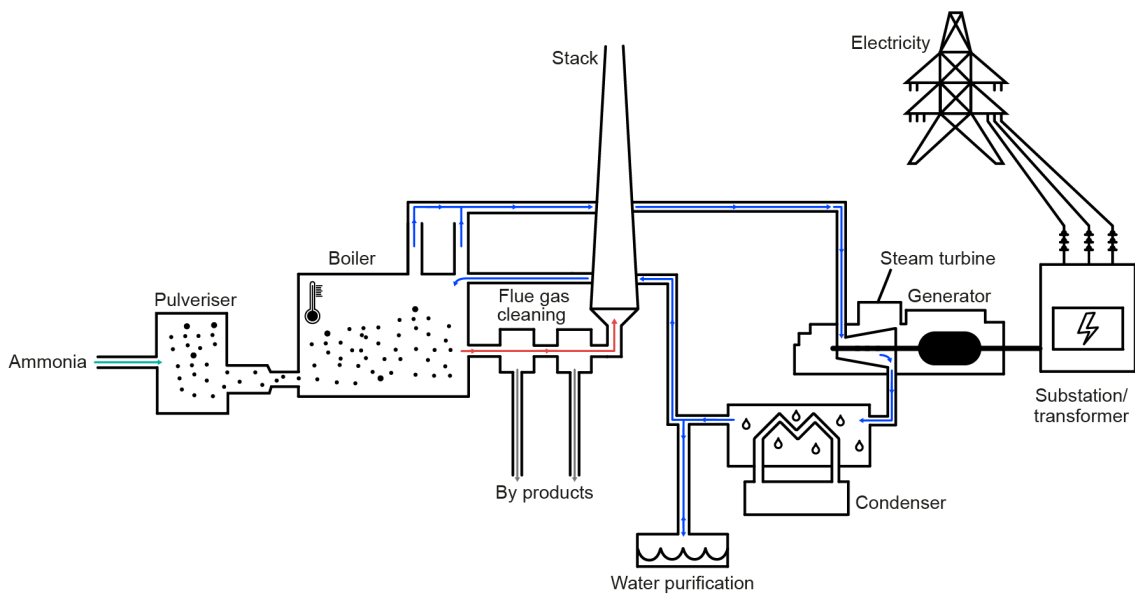
In Japan, co-firing with ammonia in coal plants has been already demonstrated, using up to 20% ammonia in ultra-supercritical plants, where efficiency is well over 40%. Efficiency is important not only from an economic perspective but also to minimise energy losses across the whole supply chain.

As well as improving the technology to allow higher shares of ammonia until the complete substitution of coal, several other issues need to be overcome. More than 80% of the ammonia mass is nitrogen, and therefore, NO_x emissions have to be properly addressed if ammonia is going to be used on a large scale. One plant co-firing ammonia at 20% share can consume 500 000 tonnes of ammonia per year, twice the annual Japanese imports, so extended use of ammonia will pose logistics challenges. Using ammonia for energy will compete with its use to

produce fertilisers, which could jeopardise food supply. Other energy uses, such as shipping fuel, could be more appropriate for ammonia, given that shipping is considered one of the hard-to-abate sectors. For electricity production, using ammonia in fuel cells or turbines can offer more efficiency than burning it in a boiler, but bigger investments would be required to use these technologies.

From the health and safety perspective, ammonia is toxic and flammable. It has been used for many years so there is ample knowledge about how to handle it, but expanding its use to other sectors and regions would increase the risk of accidents.

Coal power plant modified to use ammonia as fuel



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Small modular nuclear reactors

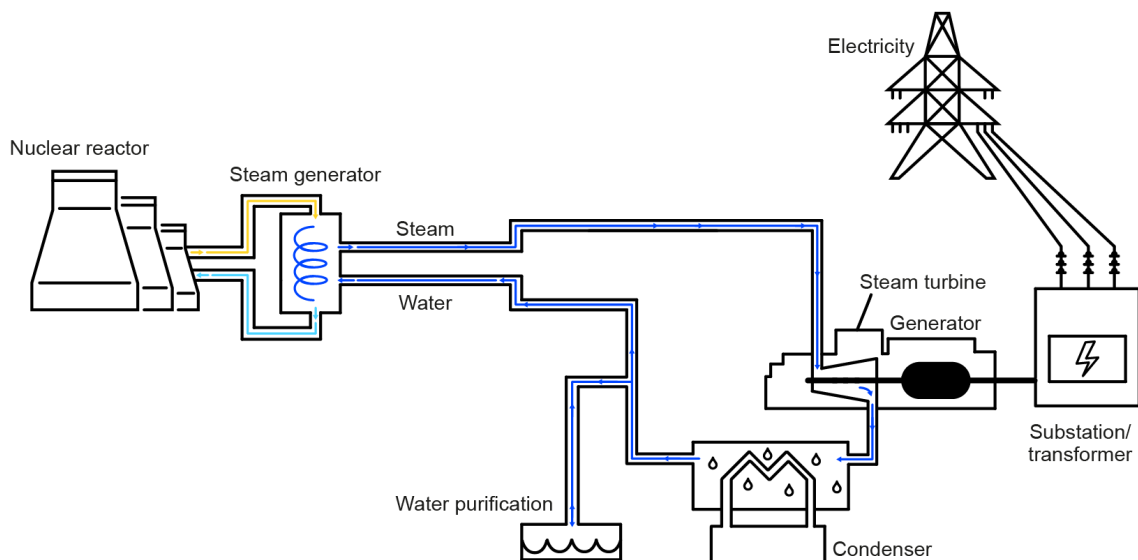
In jurisdictions where nuclear energy is acceptable, transforming a coal power plant into a nuclear plant can be a way to generate low-carbon electricity, while making good use of the transmission grid, cooling water, land and other assets. The nuclear plant can also provide dispatchability and ancillary services for the grid that are similar to those of other thermal plants. Nuclear power can pose some additional challenges, however. The pre-existence of a power plant can facilitate social acceptance of the new design, but this is not guaranteed in the case of nuclear power, an especially sensitive matter in most places. Likewise, licensing and regulatory aspects can be barriers, as geology, seismic conditions and other

factors need to be addressed before a licence for a nuclear facility is awarded. This can delay permits and approvals, increasing the financial burden and the level of risk.

Small modular reactors can replace coal power plants of up to 300 MW that lack a nearby gas supply or when the owner wants to eliminate CO₂ emissions rather than just reduce them. Small modular reactors have some advantages over traditional nuclear power plants. They generate less waste, have longer discharge cycles and provide more flexibility than typical nuclear units of 1 000 MW or more. Small modular reactors do not take advantage of the extensive experience developed in operating the technologies used in larger reactors, however. Developing and licensing new designs requires a significant upfront investment and therefore represents a certain economic risk.

Despite all the challenges, TerraPower and PacifiCorp have announced the construction a demonstration plant on the site of a retired coal plant in Wyoming, the largest coal-producing state in the United States. The plant plans to use the Natrium technology, which is a sodium-cooled reactor. It will incorporate thermal storage to provide more flexibility, enabling the reactor to supply power from 345 MW to 500 MW if required.

Coal power plant reutilised as a small modular reactor



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Thermal energy storage

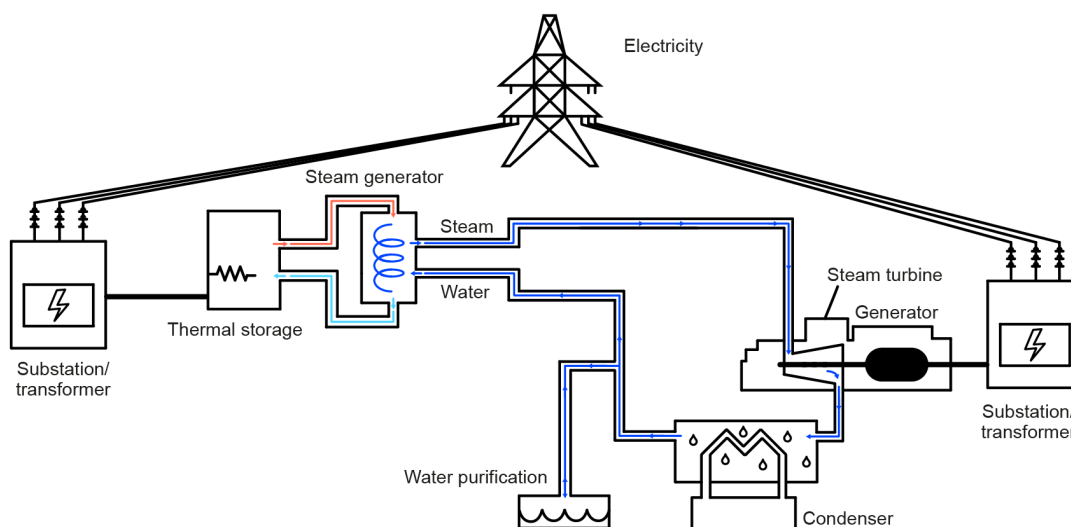
The increasing share of weather-dependent renewable generation will require energy storage capacity at different scales and response times. Replace coal boilers with thermal energy storage is a way not only to make use of existing assets but also to reduce job losses in the community when a coal plant closes.

When electricity generated from wind and solar power is abundant and there is an electricity surplus in the system, some electricity can be sent to a thermal storage plant where is used to heat a material that will store the energy. When there is an electricity generation shortage in the system, for example when wind and solar output decrease, the heat stored is transferred to the water in the steam generators. Such change enables the existing balance of the plant to be used while the steam turbine and generator provide ancillary services that will be very much needed in the future to guarantee grid stability.

Molten salt is a feasible storage material, as there is extensive experience in using it in thermal solar units to increase its dispatchability. Electric heaters, cold and hot molten salt tanks and steam generators are the elements required. Such a transformation is straightforward and requires low capital expenditure, so its economic feasibility is reasonable. In addition, it can store significant quantities of energy and offer high energy density,

Other materials for thermal energy storage are under development. One promising technology consists of producing a composite made from aluminium and graphite. As the aluminium has a melting point of 660 C, the latent heat of the phase change increases the amount of heat stored. This increases the energy density and reduces the materials and space needed, saving money and resources. Graphite's melting point is over 3 000°C, much higher than the working temperature. In this way, the graphite ensures that the physical structure of the storage is maintained throughout the whole cycle of charge and discharge.

Coal power plant reutilised as thermal energy storage



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Synchronous condenser

Coal power plants can also be transformed into synchronous condensers, providing ancillary services that help control the electricity system as well as some return to the owner of the plant.

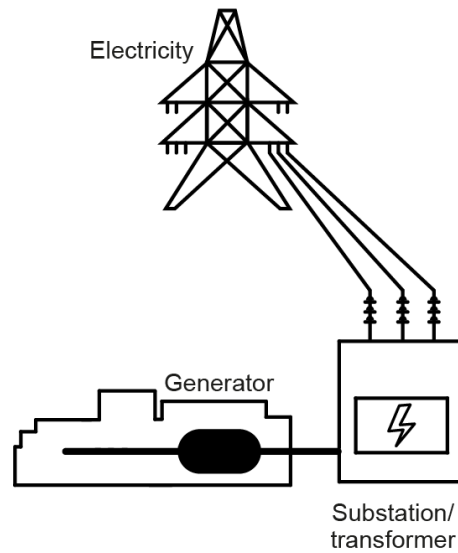
Ancillary services are mostly by-products from the turbines and generators of conventional thermal plants rotating in synchrony: inertia to stabilise frequency, reactive power to control voltage, and system strength to manage faults and maintain voltage stability. Traditionally, they were provided by the generators as required by the system operator and remuneration was not needed. When conventional generators are replaced by wind and solar – electricity generators connected through power electronics – these services need to be provided differently and remunerated accordingly.

A good example is South Australia, where renewable penetration is over 50% and over 100% in some instances. After the market operator warned about a lack of inertia and system strength, an analysis concluded that synchronous condensers fitted with flywheels were the most cost-effective way to provide the required ancillary services. Two synchronous condensers are being put into operation in the Davenport substation in 2021 and two in the Robertson substation.

As wind and solar PV penetration increase and thermal power plants are retired, one option to provide the necessary ancillary services is to transform coal power plants into synchronous condensers by removing the boiler and steam-related equipment and leaving the generator spinning free. In this way, the synchronous

condenser can add inertia to the system, improving the frequency control; absorb or inject reactive power, improving the voltage control; and supply fault current to support system strength.

Coal power plant reutilised as synchronous condenser



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