Coal combustion products worldwide: On the stretch from suitability to sustainability

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Coal is used worldwide for energy and heat production with pros and cons and restrictions or phase-out decision in parts of the world for environmental reasons. Based on published commitments from more than 90 % coal use in Annex I countries will be phased out by 2050.

During COP28 in December 2023, Dubai more than 200 parties confirmed the 1.5 degree celsius limit and agreed to triple the amount of renewable energy capacities, with priority market access. Throughout regions of the world markets for coal combustion products (CCPs) users are increasingly dealing with the consequences today, i.e. CCP quality issues arising from discontinuous operation and less available CCPs for construction.

In parallel to these developments the increased utilization of CCPs in Annex I countries is being driven by resource sustainability and lower carbon material demand, whereas in other parts of the world markets have not developed. Sustainability is becoming increasingly important driver for construction. In particular, construction materials have to prove their low carbon benefits or misfits in the form of Environmental Product Declarations which are becoming mandatory in some countries.

To serve construction markets 'harvesting' CCPs from long-term storage is increasingly being embraced as phase out of coal energy escalates throughout the world. Research into harvested CCPs, use of other types of coal ash with and without processing needs, and blends with other materials are developing. The developments are partly already covered in standards and guidelines. The report gives an update on the situation with CCPs worldwide, on partly necessary sustainability aspect and developments in standards.

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Introduction

Developments in Regulations - Conference of the Parties – COP 28 in Italy. From 30th November till 12th December World leaders, environmental activist and campaigners of nearly 200 countries met in Dubai/VAE for the 28th meeting of the Conference of the Parties (COP). The conference aims of keeping within reach the Paris Agreement target of limiting global warming to 1.5 °C. The International Energy Agency (IEA) concluded that "for the first time, governments recognised that to achieve this target, energy-related emissions need to reach net zero by 2050, and they set key goals to help meet this objective including tripling global renewable energy capacity and doubling global energy efficiency improvements by 2030, accelerating the transition away from fossil fuels, and deploying emerging technologies, such as low-emissions hydrogen and carbon capture [1].

The summary document provides an overview of the key outcomes of global climate action (Figure 1) across the four pillars set by the COP28 Presidency [2]:

- fast-tracking a just, orderly, and equitable energy transition;
- fixing climate finance;
- focusing on people, lives and livelihoods; and
- underpinning everything with full inclusivity.

The background information used in analysing the key outcomes is based on several sources. These include (but are not limited to) summary documents by the COP 28 Presidency on the thematic days, the World Climate Action Summit, as well as its Midpoint Summary report, daily newsletters (a.k.a. 'Top of the COP') published by the High-Level Champions, and the secretariat's work in collecting announcements made at COP28 through the Global Climate Action Portal, including the call for announcements to all participants throughout COP28. The full list of announcements and initiatives tracked can be found on the Portal's Event Tracking Page [2].

The IEA, in collaboration with UN Climate Change, is closely tracking progress towards the energy objectives established at COP28. At the request of governments, this work is to support the full and timely implementation of the energy promises made in Dubai by identifying pathways forwards and providing policy makers with advice on accelerating national and secure clean energy transitions. This assessment is based on the IEA's Net Zero Emissions by 2050 Scenario, as well as the latest data and analysis [3]. The global tracking indicators are:

- Triple renewable power capacity globally by 2030
- Double the global rate of energy efficiency improvement by 2030
- Accelerate efforts to phase down unabated coal power
- Accelerate efforts globally towards net zero emission energy systems well before or by around mid-century
- Transition away from fossil fuels in energy systems
- In a just, orderly and equitable manner

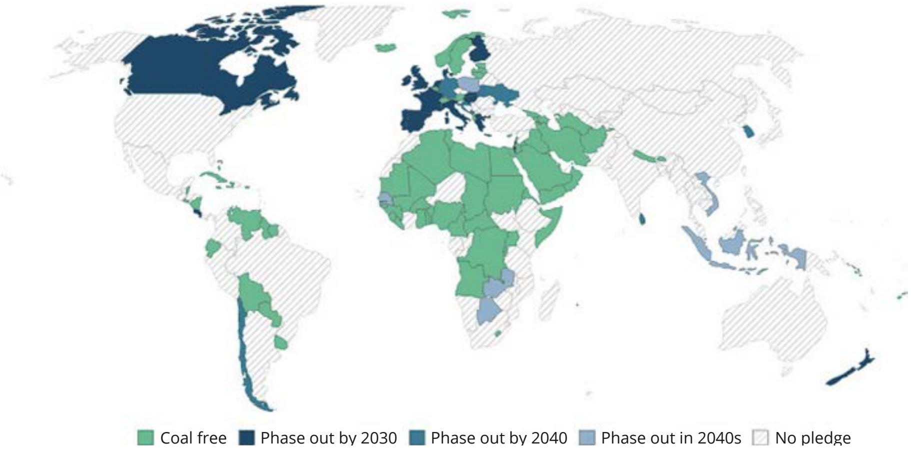

Fig. 1. Global coal phase out announcements and status [6].

- Accelerate zero and low-emissions technologies
- Substantially reduce methane emission by 2030
- Accelerate the reduction of emission from road transport
- Phase out inefficient fossil fuel subsidies

Negotiations at COP28 concluded with the "UAE Consensus". One notable element of which was the agreement on a global "transition away from fossil fuels in energy systems, in a just, orderly, and equitable manner, accelerating action in this critical decade, to achieve net zero by 2050 in keeping with the science." This is the first time that fossil fuels have been collectively mentioned in a COP agreement, although there was a commitment to "phase down unabated coal power" at COP26.

As with other COP outcomes, the agreement is non-binding, and the mechanisms for implementing this commitment will be critical. However, including this language in the COP agreement is expected to trigger initiatives and actions at future COPs, and intended to spur "real-world" action by companies and other stakeholders [4].

Similar agreements have already been reached within a meeting of Group of Seven (G7) which is an informal forum that brings together Italy, Canada, France, Germany, Japan, the United Kingdom, and the United States of America. The European Union also participates in the Group and is represented at the summits by the President of the European Council and the President of the European Commission. From 28-30 April, the G7 Minister's on Climate, Energy and Environment met in Turin, Italy. Considering the outcome of COP28 regarding a pathway to a reduction of fossil fuels in the energy sector to achieve net-zero by 2050 and identified measures to limit the rise in temperature to within 1.5° compared to pre-industrial levels. The G7 ministers committed to [5]:

- phase out existing unabated coal power generation in our energy systems during the first half of 2030s or in a timeline consistent with keeping a limit of 1.5 °C temperature rise within reach, in line with countries' net-zero pathways;
- reduce as much as possible, in the meanwhile, the utilization of unabated coal power generation plants in our energy systems to a level consistent with keeping the limit of 1.5 °C temperature rise within reach;
- take concrete and timely steps in this regard as part of the policies that inform and implement the next NDC;
- promote cooperation with countries and international partners including the financial sector towards the end of the approval of new unabated coal-fired power plants globally as soon as possible;
- call on private finance institutions to continue working with governments to enable the transitioning away from unabated coal power and end support for new unabated coal power.

Trends in coal production and use

The data includes commercial solid fuels only, i.e. bituminous coal and anthracite (hard coal), and lignite and brown (sub-bituminous) coal, and other commercial solid fuels. Includes coal produced for Coal-to-Liquids and Coal-to-Gas transformations.

Apparently, based on the Figure 2, China has become the largest coal production and use country after 1990 and had more than 50 % production globally in recent years. India is also catching up as the second large coal production and use country now as also other Asian countries which are not listed [7].

Ember's reported in its recent Global Electricity Review [8] that coal generation fell a record 4 % (-346 TWh) in 2020. Coal however remains the world's single largest power source, generating 34 % of global electricity in 2020 (8736 TWh). China has more than 50 % coal power capacity globally as shown in Figure 3.

Electricity from coal would needs to fall by 14 % every year this decade to put the world on course for net zero by 2050 as reported by Ember. OECD countries are expected to do the heavy lifting by exiting coal for power by 2030 and the rest of the world by 2040 [8].

The top 25 countries by the total terawatt-hours (TWh) of coal-fired electricity are rank in the above figure for 2020. The top four (4) countries are China, India, the United States and Japan – are responsible for over three-quarters of the world's coal-fired electricity (76 %, 6,626 TWh). Whereas South Africa, India, Sebria, Poland and Kazakhstan make up the top five countries with the largest reliance on coal electricity. China, Indonesia, Vietnam, Kazakhstan and Serbia are continuing to increase total coal generation capacity.

Global coal demand reached a record high in 2022 amid the global energy crisis, rising by 4 % year-on-year to 8.42 billion tonnes. 2023 however coal demand is expected to fall in advanced economies, with the largest declines in EU and USA of around 20 %. Reduc-

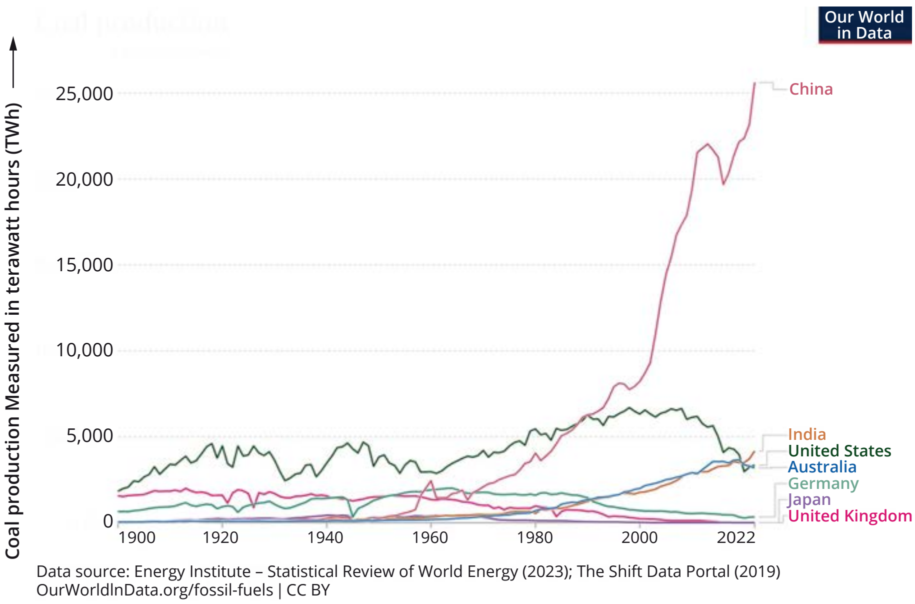

Fig. 2. Coal Production by selected countries [7].

Ranking of countries by coal generation (TWh) in 2020

Rank	2019-2020	Country	Coal generation (TWh)	Percentage of electricity production	Change 2015-2020 (TWh)
1		China	4631	61	
2		India	947	71	
3		United States	774	19	
4		Japan	274	29	
5		South Korea	192	36	
6		South Africa	191	86	
7	▲*	Indonesia*	168	60	
8		Russia	155	15	
9	▲	Vietnam	141	53	
10		Australia	135	54	
11	▼	Germany	134	24	
12	▲	Taiwan	117	44	
13	▼	Poland	110	70	
14		Turkey	99	34	
15		Kazakhstan	72	70	
16		Malaysia*	67	41	
17		Philippines	49	50	
18		Canada	45		
19		Ukraine	38	28	
20	▲	Thailand	35	20	
21	▼	Czechia	32	40	
22		Pakistan	29	20	
23	▲	Serbia	25	70	
24	▼	Brazil	22		
25		Israel*	22	33	

Source: Ember Global Electricity Review 2021 · *For Indonesia, Malaysia and Israel, 2019 is used as no 2020 data exists.

Fig. 3. Top 25 countries using coal for energy generation [8].

tions in USA and especially EU are being driven by Green Deal – Carbon neutral by 2050 and closure of coal-fired power stations.

Other advanced economies like Korea, Japan, Canada and Australia will have more modest declines. Growth is forecast across China (~5 %), India (~8 %), Indonesia, Vietnam and Philippines which together represent more than 70 % of global coal demand offsets declines in other countries [9].

Coal combustion products – Roles and options in a circular economy

The changing regulatory environments and international agreements to reduce reliance on coal energy as discuss above impact on operating conditions for coal fired power plants can lead to adverse effects on quality, consistency and availability as the beneficial use of CCPs as raw materials in construction materials.

Globally, various terms continue to proliferate to describe CCPs. Terms including coal ash, pulverized fuel ash, coal utilization by-products (CUBs), coal combustion by-products (CCBs), coal combustion residues (CCRs), coal combustion wastes (CWRs) and others are used to describe what are basically the same materials.

Precise understanding and consistent definitions are important in drafting effective regulations and standards. In an attempt to facilitate precision and consistency the members of the World Wide Coal Combustion Products Network (‘WWCCPN’ [10] or ‘Network’) have collaborated to harmonize terminology and to promote CCPs as the consistent nomenclature.

This terminology is a more positive view and is in keeping with the concept of industrial ecology and circular economy principles being an approach which seeks to reuse one industry’s by-products as another industry’s raw material. The WWCCPN global definitions for coal combustion products are given in Table 1.

Building upon these consistent definitions, unambiguous regulatory classifications can be developed which create important understanding about the positive experiences regarding utilization and transport.

Table 2 gives an update on the classification status of CCPs in countries reported by the WWCCPN. Generally, no major changes in classification have been observed other than a recent change in classification for Indonesia where the Government has deregulated several industrial by-products from the list of hazardous and toxic (B3) waste including fly ash and bottom ash from coal burning to industrial resource.

Global production and utilisation

WWCCPN members share published production and utilization data from publicly available, proven sources or based on coal consumption data. Based on collated data 1.22 billion metric tonnes of coal combustion products were produced in 2022.

Table 3 reports on Annual Production, Utilization Rates by Country in 2022. The largest coal combustion product producing countries continue to be China, India, Europe, other Asia and the USA.

Global CCP production totaled 1.1 [2019]. 1.2 [2017] and 0.78 [2010] billion metric tonnes which shows very little global growth in CCP production.

The utilization varies widely in the countries discussed in this paper depending on the type of coal and the combustion technology resulting in respective properties decisive for use. Utilisation rates, where use is report-

Tab. 1. WWCPN global definitions for coal combustion products [10].

Term	Definition
Coal Combustion Products	Coal combustion products (CCPs) include fly ash, bottom ash, boiler slag, fluidized-bed combustion (FBC) ash, or flue gas desulfurization (FGD) material produced primarily from the combustion of coal or the cleaning of the stack gases of coal fired power stations. The term coal ash is used interchangeable for the different ash types.
Fly ash	The finer ash produced in a coal fired power station, which is collected using electro-static precipitators. This is also known as Pulverised Fuel Ash (PFA) in some countries. About 85+ % of the ash produced is fly ash.
Furnace Bottom Ash (FBA)	The coarse ash that falls to the bottom of a furnace. The molten ash adheres to the boiler tubes, eventually falling to the base of the furnace. ..... Usually <15 % of the ash produced is FBA
Cenospheres	Hollow ash particles that form in the furnace gas stream. They float on water and are usually collected from lagoons, where ash/water disposal systems are being used.
Conditioned ash	Where fly ash is mixed with a proportion of water (10 to 20 % by dry mass typically) in order that it can be transported in normal tipping vehicles without problems with dust for sale or disposal.
Flue Gas De-sulfurisation	Where a source of calcium is injected into the furnace gas stream to remove sulfur compounds. The sulfur compounds convert the calcium carbonate to calcium sulfate, or gypsum, which is used in the wallboard industry for general construction
Harvested CCPs	The removal, or reclamation, of CCPs from an active or inactive storage area for the purpose of beneficial use.

Tab. 2. Environmental Classification Systems adopted by Country [10].

Countries	Defined as Waste	Defined as haz.waste	Basel Convention adopted	REACH adopted	IInt'L Treaty on Mercury[3]	Utilis. Env. Condit.
United States	Yes	No	Yes	No	Yes	Yes
Australia	Yes	No	Yes	No	No4	Yes
Canada	Yes	No	Yes	Ref	Yes	Yes
China	Yes	No	Yes	Yes[2]	Yes	Yes
Europe	Yes[1]	No	Yes	Yes	Yes[4]	Yes
India	Yes	No	Yes	No	Yes	Yes
Indonesia	Yes	No	Yes	No	Yes	Yes
Israel	No	No	Yes	No	No	Yes
Japan	Yes	No	Yes	No	Yes	Yes
Russia	Yes	No	Yes	No	Yes4	Yes
South Africa	Yes	No	Yes	No	Yes4	Yes

1 – in some member states defined as by-products or products
2 – China REACH is similar to EU REACH
3 – International Treaty on Hg, under UN Environment Program;
4 – partly not ratified yet

Tab. 3. Production and Utilisation Rates of CCPs by Country 2022-[10].

Country/Region	Production (Mt)	Utilisation (Mt)	Utilisation Rate %
Australia	10.6	6.6	62 %
Asia	724.5		
– China	650.0	388.0	60 %
– Korea	7.5	6.2	83 %
– Other Asia	67.0		0 %
Canada	3.4		0 %
Europe	75.0		
– EU15	15.0	18.0	120 %
India	282.8	282.7	100 %
Japan	12.1	11.7	97 %
Middle East & Africa	34.5	2.4	7 %
Israel	0.5	0.5	100 %
United States of America	45.5	29.3	64 %
South America	8.6		0 %
Russian Federation	17.4	5.0	29 %
Total	1215.4	750.8	62 %

ed range from 7 % [Middle East & Africa] to more than 120 % in Europe resulting from harvesting CCPs from long-term storage.

The countries with a high utilization rate also demonstrate an existing market where CCPs are used regularly according to existing regulations and can easily be put into the market. CCPs are mostly used in cement and concrete applications, especially those with siliceous properties (or class F). Furthermore, they are used in road construction, especially when stocks are available, and for filling applications.

Calcareous coal ashes are mostly used for reclamation or, due to their hydraulic properties, as binders. FGD gypsum is predominantly used as raw material for the gypsum industry in different applications including manufacture of wallboard and plaster, in the cement industry as a setting regulator as well as a fertilizer in agricultural applications. With their use CCPs replace natural materials and grant energy savings for their production. They also contribute to the sustainability of construction products and construction as climate neutrality has also to be considered by them.

Selected production, utilisation, by country / region

United States of America -- American Coal Ash Association (ACAA) most recent production and use data is for 2022. In addition to production in power plants, the ACAA are estimating harvested ash use in concrete products of approximately 1.8 million tons. Data on the quantity of harvested ash use in the production of portland cement is not currently captured.

ACAA reports Standards (ASTM's) continue to be important tools to facilitate CCP use. There are some issues in the balloting process at ASTM currently. They will not be resolved prior to WOCA. There is some mild interest in getting further information on fluidized bed combustion ash performance in concrete mixtures, but no one has stepped forward with the funds and the time for doing the research.

Considerable time and money is being spent by the U.S. Federal Government on PCRs and EPDs. The General Services Administration, Federal Highway Administration, and the EPA are leading the charge. They are aiming at having a robust labeling program operating in late 2024. The labels will present information on the embodied carbon in construction materials to assist the potential user in selecting the best source for their project. At this time, the focus is on asphalt, concrete, glass, and steel only.

Australia -- Based on the published Ash Development Association of Australia (ADAA) membership survey results the beneficial use of coal combustion products (CCPs) during 2022 resulted in 6.59 million tonnes or 62 % being beneficially used, resulting in the conservation of energy finite natural resources, and the reduction of carbon emissions through the recovery of CCPs being mineral by-product resources.

The survey results for CCP production and end uses for the period January to December 2022 discussed in this report are shown in Table 3. Over the survey period more than 79 million tonnes of thermal coal was consumed to generate vital energy to support the Australian economy. Some 10.3 million tonnes of all CCPs were produced with 62 % being effectively utilised within various civil and construction applications throughout Australia.

Total CCPs produced reduced over the reporting period by 0.8 million tonnes, with the longer-term trend of coal powered energy continuing to decrease. This decline is consistent with ongoing planned closures of coal fired power stations and reduced demand for thermal coal as an energy source, coupled with ongoing energy reforms, renewable energy targets (RET) and state government privatisation agenda for electricity over the past several years.

Early, 2023 the NSW Government have made a $ 3.25 million commitment to future investment to support construction material industry efforts to explore and identify investment opportunities pathways for harvesting of stored coal combustion products within NSW into existing and new markets to further reduce carbon emissions and mitigate climate change in NSW. Within NSW the energy economy is forecast to transition out of coal fired power stations by the end of 2040 as shown in Figure 4.

Nationally, the Australian Energy Market Operator [11] has reported the most likely scenario is about 90 % of the current 21 gigawatts of coal capacity would retire by 2034-35 and all by 2038. Even in its "pro-

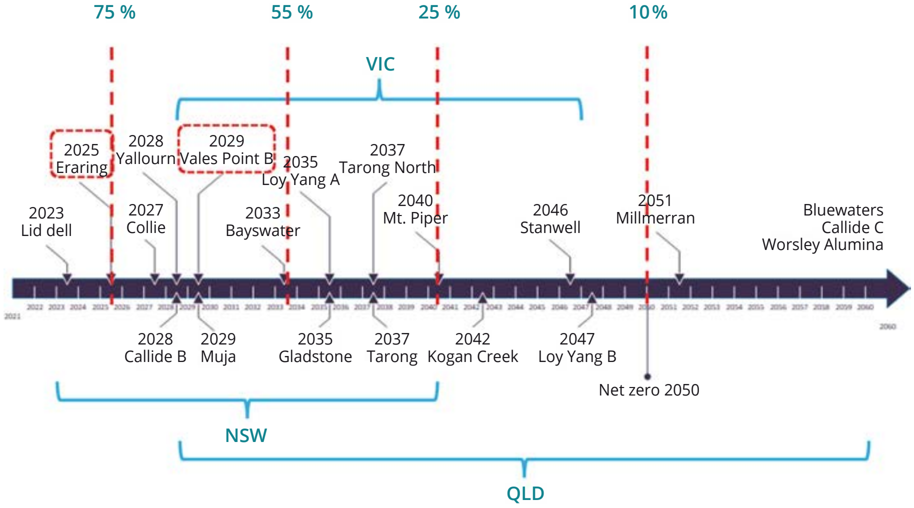

Fig. 4. Planned staged closure of Australian coal-fired power stations [11].

gressive change" path, only 4GW of coal generation would remain in 2034-35. Should the forecasts materialize, harvesting of the existing stored CCPs will need to further accelerate.

Europe -- For Europe, the phase-out is nothing new (Figure 5) and the update of the phase-out date will only cause confusion as France has announced the phase-out first for 2022 and has corrected to 2027 as also Italy. Germany was with 2038 but announced already earlier a target of 2030, and the UK has anyway reduced already a lot and announced the complete phase-out within this year. Beside the permits to operate coal-fired power plants also the operational time of such plants and the way of operation has to be considered. Therefore, beside availability, plants operators have to consider also the economics.

Consequently, the production of CCPs has decreased in Europe, especially in some Western European countries (out of EU15). The CCP production in coal-fired power plants in Europe still totals to about 75 million tonnes with decreasing tendency. Beside fresh production in power plants, especially fly ash is re-used from stocks and stocks with fly ash and bottom ash are under investigation. The experience with re-use from stock for filling applications is already since more than 50 years, with re-drying for cementitious application about 30 years.

Contrary to the development in CCPs production the demand for low or carbon neutral raw materials and especially additions in the cement and concrete industry is growing as also the construction industry and the constructions have to become carbon neutral. The preparation of Environmental Product Declaration (EPD) is increasingly important. In Europe, EN 15804 [12] provides the core rules for the preparation of EPDs which are precise in product specific documentations (product category rules – PCR). The content of the EPDs will become part of the new harmonised product standards when revised based on new mandates.

China -- China has more than 50 % coal production and coal-fired power capacity and generation globally, producing more than 50 % CCP worldwide, in recent years. In terms of carbon emission, China also sets to reach carbon peak in 2030 and carbon neutral in 2060. Starting from 2013, more new renewable energy capacity was installed each year than new coal power capacity in China. At the end of 2023, the total installed renewable energy capacity exceeded the total installed coal power capacity the first time in the history.

In terms of CCP utilization, China still has more than 85 % in building and construction, particularly for cement, concrete, and wall materials. However, most of newly established large coal-fired power plants are located in the remote area and very close to the local coal mining area. Each of them typically produces more than 1 million tons of CCP annually, far exceeding local building and construction market needs. Therefore, local road construction, coal mine underground back-filling, and coal mine subsidence area refilling are three important applications for their CCP utilization. The relevant implementation and pollution control standards are also needed to support these three applications for the large quantity utilization to increase the utilization rate.

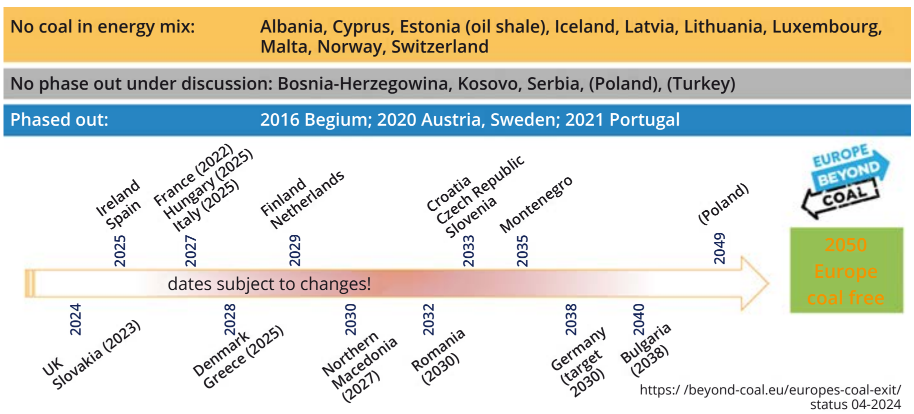

Fig. 5. Coal-phase out announcement in Europe.

Updates on international standards

Fly ashes are used worldwide for the production of cement and concrete and other construction. Already in 2019, the WWC-CPN has compiled international standard for fly ash in cement and concrete to inform about similarities and major differences. Table 4 provides the basic information about scope and definition in international standards. The definition cover fly ash from hard coal and lignite resulting in siliceous (class F) or calcareous (class C) fly ash. In some definitions a limit for calciumoxide of 10 % is given. This is to highlight the changes in ASTM C 618 where in 2019 the limit was defined to 18 %. Only the European standard EN 450-1 provides details for co-combustion. In the most recent revision the title of ASTM C 618 was modified to "coal ash" to address also the use of harvested ash and ground bottom ash.

In Table 5, the chemical and physical requirements of the international standards are compiled. For harvested fly ash and fly ash with ground bottom ash an additional fineness criterion on the 150 µ sieve was introduced. This followed the example of the Canadian standard which will be incorporated in the next update of this compilation. In India, part 2 of IS 3812 provides the requirements for bottom ash, mound ash and pond ash.

The recent changes in the standard comparison of fly ash used for cement and concrete is the most important and popular one for international interest. Other important application standards for CCPs utilization established in different countries or regions may be further explored and shared in the future.

Net zero accelerating circular economy

In recent years, there has been a growing recognition of the need to shift towards a circular economy, where waste is minimized and resources are reused and recycled. This shift is particularly relevant in the context of

Tab. 4. Fly ash used for concrete from standards of selected countries and regions [10].

	Europe	USA	Australia/ New Zealand	Japan	India	China	Russia
	EN 450-1	ASTM C 618	AZ/NZS 3582	JIS 6201	IS 3812-1	GB/T 1596	GOST 25818
type of coal	coal	coal	coal	coal	anthracite, bituminous, subbituminuous, lignite	anthracite, bituminous, subbituminuous, lignite	
	co-combustion materials; -max 40 or 50 % by mass in case of green wood; -ash amount from CCM				from burning of ground or pulverized or crushed coal or lignite		
	covers processing (of FA from fresh prodution)	covers fly ash and bottom ash from fresh production and from stock	covers "conditioned" ash (humidity for handling)		covers processing to modify physical or chemical characteristics		
definition	fine powder of mainly spherical, glassy particles, derived from burning of pulverised coal, with or without cocombustion materials, which has pozzolanic properties and consists essentially of SiO_2 and Al_2O_3	class F - coal ash that meets appl. requirements... This type of ash has pozzolanic properties class C- coal ash that meets appl. requirements... Pozzolanic and some cementitious properties	solid material extracted from the flue gases of boiler fired with pulverized coal	ash collected by the dust collector from the flue gas of the pulverized coal combustion boiler	siliceous pulverized fuel ash for use with $CaO_{react.}$ less than 10 %; from anthrazit or bituminous coal / calcareous pulverized fuel ash for use with $CaO_{react.}$ Not less than 10 %; from lignite or sub-bituminous coal	class F fly ash from combustion of anthracite or bituminous coal; Class C fly ash from combustion of lignite of sub-bituminous coal, CaO ≥ 10 %	siliceous fly ash from pulverized coal with $CaO_{react.}$ less than 10 %; calcareous fly ash for use with CaO_{react} with more than 10 %
excluded	municipal and industrial waste incineration ashes do not conform to the definition		fly ash from fluidised bed combustion			ashes from municipal and industrial waste incineration; ashes from fluidised bed combustion	
comment	also used in Israel (SI1209); deviating for fuel and conformity control				requirement for bottom ash, pond ash and mound ash are given in IS 3812-2		ashes are subdivided by types of coal resulting in siliceous and calcareous ash, as well as for use in 4 differnt applciations:

coal combustion products (CCPs), which are generated as a byproduct of coal-fired power plants and have traditionally been treated as waste.

However, there is now increasing interest in harvesting CCPs for use in various applications, including construction materials, agriculture, and even cosmetics. This emerging trend is driven by several factors, including the need to reduce waste, the desire to conserve resources, and the recognition of the potential economic benefits of CCPs.

One example of the use of CCPs in the circular economy is their incorporation into concrete. Fly ash, a CCP, can be used as a replacement for cement in concrete, reducing the need for virgin materials and lowering the carbon footprint of the concrete. Other CCPs, such as gypsum, can be used in the production of drywall and other construction materials.

In addition to construction materials, CCPs can also be used in agriculture. For example, some CCPs contain nutrients that are beneficial for plant growth, and can be used as a fertilizer. Other CCPs, such as flue gas desulfurization gypsum, can be used to improve soil quality and reduce soil acidity.

Overall, the shift towards the harvesting of CCPs for the circular economy represents a significant opportunity to reduce waste, conserve resources, and create economic value. However, it also requires careful consideration of the potential environmental and health impacts of CCPs, as well as the need for appropriate regulation and management of these materials.

PCR's and EPD's just another cost to business?

PCR's and EPD's are being touted as the silver bullet required to validate industry claims as we drive towards Net Zero goals. For example, the U.S. federal government has committed significant fiscal resources through the Inflation Reduction Act (IRA) and agencies like the U.S. Environmental Protection Agency (EPA) to influence federal procurement, drive significant emissions reductions over the next decade, and lay the groundwork for long-term decarbonization of manufacturing sectors. In particular, the development and adoption of more environmentally preferable construction materials necessary to build the infrastructure of the future [13].

Environmental Product Declarations (EPDs) provide information about the environmental impact of a product throughout its lifecycle, from raw material extraction to disposal. As the construction industry becomes increasingly focused on sustainability, EPDs are likely to have a significant impact on the industry. Some thoughts about the potential impacts that the emergence of EPDs may have on the construction industry:

- **Improved Environmental Performance:** EPDs can help construction companies make more informed decisions about the environmental impact of the materials they use. By providing transparent data on a product's environmental impact, EPDs can incentivize manufacturers to develop more sustainable products, and construction companies to select more environmentally friendly materials.
- **Increased Transparency:** EPDs can help increase transparency in the construction

Tab. 5. Classification and specification of fly ash used for concrete from standards of selected countries and regions (compiled by [10]).

COUNTRY	Europe		USA		India		Australia			China		Russia		Japan			
Standard	EN 450-1		ASTM C 618		IS 3812-1		AS 3582.1			GB/T 1596		GOST 25818		JIS 6201			
Classification	Cat N	Cat S	Class F	ClassC	siliceous	calcareous	spec.grade	grade1	grade2	Class F	ClassC	siliceous	calcareous	type I	type II	type III	type IV
							fine	medium	coarse								
Loss on ignition, max,%	<5; <7; <9 (cat A;B;C)		6.0 (12.0)	6	5.0 (7.0[2)])		3	4	6	≤5; ≤8[1)]; ≤10 (class I; II; III)		<10;<15 (type I;II)[1)]	<3;<5 (type I;II)	≤ 3	≤ 5	≤ 8	≤ 5
CaOfree, max,%	1.5 (>1.5)									≤ 1.0	≤ 4.0		<5 (type I;II)				
SO3, max,%	3.0		5.0		3.0 (5.0[2)])		3			≤ 3.0 (≤ 3.5[1)])		<3;<5 (type I;II)	<5 (type I;II)				
Cl, max, %	0.1				0.05												
CaO, %			≤ 18	> 18			<10 (AS) / <25 (NZS)				2)						
Reactive CaO, max,%	10				< 10	> 10						< 10	> 10				
Reactive SiO2, min,%	25				20												
SiO2, min %					35	25								≥ 45			
SiO2 + Al2O3 + Fe2O3 min,%	70		70	50	70	50	70 (AS) / 60 (NZS)			≥ 70	≥ 50	≥ 70					
Na2O equ., max,%	5				1.5							< 3	< 1,5 (type I;II)				
MgO, max,%	4				5							< 5					
P2O5 sol., max, mg/kg	100																
P2O5 %	5																
Moisture %			3.0		2.0		0.5			≤ 1.0		≤ 1.0		≤ 1			
Amount retained on 45µm, max,%	40 (+/-10%)	12	34 (+/-5%)		34 (50[2)])		15	25	45	≤12; ≤30; ≤45 (class I; II; III)				≤ 10	≤ 40	≤ 40	≤ 70
Amount retained on 80µm, max,%												<20;<30 (type I;II)	<20 (type I;II)				
Amount retained on 150µm, max.%			10[1)]														
Fineness: specific surf. area cm²/g					min. 3200[1)] (2000[2)])							>2500/1500 (type I/II)	>2500/2000 (type I/II)	≥ 5000	≥ 2500	≥ 2500	≥ 1500
Particle density, kg/m3	+/- 2001)		5%[1)]							≤ 2.6							
Specific gravity, min														≥ 1.95			
Soundness, max	10 mm[2)]		0.8%[2)]		0.8%					≤ 5 mm							
Setting time, max minutes to ref.	120[3)]																
Strength (Activity) Index ß7d min,%			75[3)]														
Strength (Activity) Index ß28d min,%	75[4)]		75[3)]		80					≥ 70				≥ 90	≥ 80	≥ 80	≥ 60
Strength (Activity) Index ß90d min,%	85[4)]																
Strength (Activity) Index ß91d min,%														≥ 100	≥ 90	≥ 90	≥ 70
Relative Strength, Mpa min							105%[1)]	75%[1)]									
Lime reactivity Mpa					4.5												
Water requirement, max, % of control	95[5)]		105		105					≤95; ≤105; ≤115 (class I;II;III)				≥ 105	≥ 95	≥ 85	≥ 75
	[1)] max. deviation from declared value		[1)] for coal ash that is harvested or containing bottom ash		1) fly ash of fineness 2500 cm²/g can be used by intergrinding with clinker		1) Relative strength not a measure of performance but for reactivity in a given blend (blend by trials)			1) for fly ash for cement use		Type I: for reinforced concrete acc. GOST 26633: Type II concrete structures and lighweight concrete					
	[2)] only when CaOfree content is >1.6%		[2)] max. deviation form average value		2) for ashes according IS 3812-2 (bottom ash: mound ash, pond ash, ...)					[2)] for class C CaO ≥ 10 % based on definition and coal type		1) for fly ash from hard coal <20;<25 (type I;II) for fly ash from anthrazite					
	[3)] to be tested with mix of 25% flyash:75% cement		[3)] According to ASTM C-1012. Flyash/Cement: 20/80. equal slump														
	[4)] according to EN 196. no fixed fly ash /cement ratio. W/C:0.5		[4)] According to ASTM C-311. Flyash/Cement: 20/80. equal slump														
	[5)] Only for fineness category S																

industry by providing clear and comparable information on the environmental impact of different products. This can make it easier for construction companies to evaluate and compare the environmental impact of different products and make more informed decisions.

- **Changes in Procurement:** The use of EPDs may drive changes in procurement practices, with more emphasis placed on selecting products with lower environmental impacts. This could lead to a shift in the types of materials and products that are commonly used in the construction industry, as well as changes in the sourcing and supply chains for these materials.
- **Compliance and Regulation:** As governments around the world introduce new regulations aimed at reducing carbon emissions and promoting sustainability, the use of EPDs may become more widespread and even mandatory. This could drive widespread changes in the construction industry as companies adapt to meet these new requirements.

Overall, the emergence of EPDs is likely to have a significant impact on the construction industry, driving increased sustainability and environmental responsibility. As companies increasingly prioritize sustainability, the use of EPDs will likely become more widespread, leading to significant changes in the types of materials and products used in the construction industry.

Having said the above, Product Category Rules (PCR) are of great importance in the development of Environmental Product Declarations (EPD) for the construction industry. That is, PCR's are essential in the development of EPDs as it provides a standardized approach to environmental assessment, which ensures that the results obtained are reliable, consistent, and comparable. A PCR helps to ensure that the environmental performance of products is assessed using a consistent methodology, which allows for accurate comparisons of products and materials within the same category.

Product Category Rules (PCR) can be thought of as the "grammar" of Environmental Product Declarations (EPD) for the construction industry. Just as grammar provides a set of rules for constructing sentences and communicating effectively, PCR provides a standardized approach to environmental assessment and reporting.

In the same way that good grammar ensures that a message is clear, concise, and easily understood, PCR ensures that the environmental performance of construction products is assessed using a consistent methodology, making the results reliable, consistent, and comparable. This allows designers, contractors, and consumers to make informed decisions based on accurate and transparent information.

Just as grammar evolves over time to reflect changes in language and usage, PCR also evolves to reflect changes in technology, knowledge, and best practices. By providing a clear framework for environmental assessment and reporting, PCR can drive innovation and encourage the development of more sustainable products and processes in the construction industry.

Conclusions

Coal is used worldwide for energy and heat production with pros and cons and restrictions or phase-out decision in parts of the world for environmental reasons. Based on published commitments from more than 90 % coal use in Annex I countries will be phased out by 2050.

The worldwide production of CCPs is greater than 1.2 billion tonnes with utilization rates from 7 to more than 120 %. For the utilization of CCPs legal and technical requirements have to be considered. The dislocation between markets and jurisdictions across the globe continues with some continuing to refer to CCPs either as waste or resources, by-products or products and used widely in construction applications.

In recent years, there has been a growing recognition of the need to shift towards a circular economy, where waste is minimized and resources are reused and recycled. This shift is particularly relevant in the context of coal combustion products (CCPs), which are generated as a byproduct of coal-fired power plants and have traditionally been treated as waste.

However, there is now increasing interest in harvesting CCPs for use in various applications, including construction materials, agriculture, and even cosmetics. This emerging trend is driven by several factors, including the need to reduce waste, the desire to conserve resources, and the recognition of the potential economic benefits of CCPs.

Through the WWCCPN we continue to promote consistent terminology and classification of by-products from coal combustion as coal combustion 'products' (CCPs) – which contribute significantly as raw material in construction applications considering their properties.

CCPs contribute to the circularity and finally also the sustainability of products and constructions. The members of the World-Wide Coal Combustion Products Network will continue to promote, coordinate and inform the public, industry and governmental entities about the beneficial environmental, technical and commercial uses of Coal Combustion Products.

References

[1] UNFCC: Summary of Global Climate Action at COP 28; https://unfccc.int/sites/default /files/ resource/SummaryGCA_COP28.pdf

[2] UNFCC: Global Climate Action, Event tracking; https://climateaction.unfccc.int/Events/COP28

[3] International Energy Agency (IEA): COP 28: Tracking the Energy Outcomes; https://www.iea.org/topics/cop28-tracking-the-energy-outcomes

[4] McKinsey: Outcomes from COP28: What next to accelerate climate action; https://www.mckinsey.com/capabilities/sustainability/our-insights/outcomes-from-cop28-what-next-to-accelerate-climate-action

[5] G7 Italia 2024: Climate, energy and Environment Ministers' Meeting Communique; https://www.g7italy.it/wp-content/uploads/G7-Climate-Energy-Environment-Ministerial-Communique_Final.pdf

[6] Our World in Data: When will countries phase out coal power? https://ourworldindata.org/grapher/coal-phase-out-timeline

[7] Our World in Data: Data - Coal production; https://ourworldindata.org/grapher/coal-production-by-country

[8] EMBER: Top 25 Coal Power Countries; Ranking of the countries geeration most coal-fired generation electricity in 2020; https://ember-climate.org/insights/research/top-25-coal-power-countries-in-2020/

[9] International Energy Agency (IEA): Latest findings: Global Coal Consumption 2000-2025, https://www.iea.org/energy-system/fossil-fuels/coal

[10] World-Wide Coal Production Products Network (WWCCPN): http://www.wwccpn.org/

[11] Australian Energy Market Operator, staged closure of CFPS, compiled by the ADAA

[12] EN 15804:Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products; 2022-03 (EN 15804:2012+A2:2019 + AC:2021)

[13] US Environmental Protection Agency (US EPA): news release 19th January 2023: EPA Seeks Input on Inflation Reduction Act Programs to Reduce Greenhouse Gas Emissions Associated with Construction Materials and Products https://www.epa.gov/newsreleases/epa-seeks-input-inflation-reduction-act-programs-reduce-greenhouse-gas-emissions

Kurzfassung

Kraftwerksnebenprodukte weltweit: Auf dem Weg von der Eignung zur Nachhaltigkeit

Kohle wird weltweit zur Energie- und Wärmeerzeugung genutzt, mit Vor- und Nachteilen sowie Einschränkungen oder Ausstiegsbeschlüssen in Teilen der Welt aus Umweltgründen. Basierend auf veröffentlichten Verpflichtungen zum Kyoto-/Paris-Protokoll wird die Kohlenutzung in mehr als 90 % der Länder des Anhangs I bis 2050 auslaufen.

Auf der COP28 im Dezember 2023 in Dubai bestätigten mehr als 200 Parteien das 1,5-Grad-Celsius-Limit und einigten sich darauf, die Kapazitäten für erneuerbare Energien zu verdreifachen und ihnen einen bevorzugten Marktzugang zu gewähren. In allen Regionen der Welt haben die Nutzer von Kraftwerksnebenprodukten der Kohle (CCPs) zunehmend Folgen zu bewältigen, d.h. mit Qualitätsproblemen bei CCPs, die durch den diskontinuierlichen Betrieb entstehen, und mit weniger verfügbaren CCPs für den Bausektor.

Parallel zu diesen Entwicklungen wird die verstärkte Nutzung von CCPs in Ländern des Anhangs I durch Ressourcennachhaltigkeit und eine geringere Nachfrage nach kohlenstoffarmen Materialien vorangetrieben, während sich in anderen Teilen der Welt die Märkte nicht entwickelt haben. Nachhaltigkeit wird zu einem immer wichtigeren Faktor im Bauwesen. Insbesondere Baumaterialien müssen ihre kohlenstoffarmen Vorteile oder Nachteile in Form von Umweltproduktdeklarationen nachweisen, die in einigen Ländern bereits vorgeschrieben sind.

Um den Bedarf des Bausektors zu decken, nimmt der Rückgriff von CCPs aus Langzeitlagern zu, da der Ausstieg aus der Kohleenergie weltweit voranschreitet. Die Forschung zu diesen CCPs, zur Verwendung anderer Arten von Kohleasche mit und ohne Verarbeitungsbedarf und zu Mischungen mit anderen Materialien entwickelt sich weiter. Die Entwicklungen sind teilweise bereits in Normen und Richtlinien enthalten. Der Bericht gibt einen aktuellen Überblick über die Situation mit CCPs weltweit, über teilweise notwendige Nachhaltigkeitsaspekte und Entwicklungen bei Normen.

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