Ash as an internationally traded commodity

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21.1 Introduction

Dramatic shifts in global patterns of supply and demand have increased interest in fly ash as an internationally traded commodity. Large volume production markets, led by China and India, are expected to have surplus supplies in the hundreds of millions of tons through 2030 and beyond. At the same time, the quantity and quality of supplies are diminishing in developed markets. Relative demand is high in geographies such as California, Western Europe, and the Middle East, where ash utilization techniques are advanced and construction material standards allow for high levels of substitution in cement, concrete and other applications. This chapter will focus on fly ash as the highest volume and most important coal combustion product, with the greatest potential for increased international trade. There may be opportunities for global trade in FGD gypsum, though markets are limited and supply/demand volumes are expected to be significantly less than fly ash. Bottom ash, due to its relatively low value, will likely see only small volumes in international trade, possibly across nearby borders or within consolidated bulk shipments.

Global fly ash sales are expected to reach $98 billion by 2020 with a five-year CAGR of 5.5%.[1] Performance, cost, and, increasingly the environmental benefits of fly ash are expected to continue driving demand in all markets, with Asia Pacific leading the growth in demand. Some of this demand may be offset by the increased use of alternative supplementary cementitious materials (SCM), such as ground granulated blast furnace slag (GGBFS). Ash and slag can work optimally as complimentary SCMs, but some substitution is possible in markets where certain SCM faces supply/quality limitations or prohibitive pricing.

Logistics costs and infrastructure are always critical cost considerations in bulk material trade. The Baltic Dry Index (BDI), an indication of global bulk commodity freight prices, currently sits at historic lows. This is expected to continue for the next three years at least, and it could keep total delivered costs in check if bulk commodity buyers can negotiate longer-term agreements or purchase their own ships during the down market.

Environmental concerns around loading and unloading will delay a full realization of international trade potential, as will limited infrastructure capacity. However, the

[1] http://www.bccresearch.com/pressroom/avm/uptick-in-global-construction-to-spur-growth-in-scm-market; BCC Research LLC, 49 Walnut Park, Building 2, Wellesley, MA 02481, Telephone: 866-285-7215; Email: editor@bccresearch.com.

Coal Combustion Products (CCP's). http://dx.doi.org/10.1016/B978-0-08-100945-1.00021-6

economics based on the price differential between SCMs and cement production prices, appear to justify an investment in port and transport capacity to meet the growing demand.

Other barriers to international trade include construction material standards that lag behind technology developments, as well as continued designation of CCPs as hazardous materials in some markets. Efforts are being made in developed and developing markets to adapt standards and regulatory frameworks to facilitate greater beneficial utilization and trade. Coordination around fly ash standards in different jurisdictions would also help to expand the global marketplace.

Additional sources of demand may come online should standards develop in a way that higher volumes are permitted for use in cement, concrete, and other mature applications. Emerging technologies present a wild card, which is that a number of technologies currently under development have the potential to significantly impact global fly ash demand. Should advances in aluminium extraction, geopolymers, industrial ceramics, or other applications prove commercially viable, they could represent hundreds of millions of tons per year in additional consumption. On the supply side, improvements in ash beneficiation techniques could produce marketable materials from the billions of tons of ash currently stockpiled in global landfills.

21.2 High-volume surplus markets

Growth in global fly ash supplies will be driven by coal-fired energy production China, India, and Southeast Asia. The economic advantages of coal power in these markets include lower financial costs per unit of power, a large and relatively young fleet of installed capacity, and a domestic industry highly geared to coal-power related equipment supply, fuel supply, and operations. Additionally, China and India rank third and fifth in the world by coal reserves, respectively, while the United States, Russia, and Australia rank first, second, and fourth, respectively. For both China and India, domestic coal reserves and installed capacity have strategic value in that they support national energy independence.

21.2.1 China

21.2.1.1 Production

Chinese fly ash production rates, as reported by officially recognized bodies, indicate 500 to 600 million tons of ash produced in 2015. China's growth in energy consumption has slowed since 2014, in line with the slowing of the overall domestic economy. Coal consumption has slowed from around six percent annual growth during the last decade and is now expected to grow at less than 0.5 percent each year through to 2025.[2] In absolute terms, however, growth in coal consumption and ash production volumes are substantial. With an average ash content of around 28 (Li, 2003), Chinese domestic coals rank amongst the highest in the world, trailing only India amongst the

[2] http://www.eia.gov/forecasts/ieo/world.cfm, http://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2016/bp-energy-outlook-2016-country-insights-china.pdf.

major coal producing countries. With 3.7 billion tons of coal consumed in 2015, an average of only 0.3% growth in coal consumption would mean 2.5–3 million tons of additional fly ash added to Chinese supplies each year.[3] This would add another 20–25 million tons to annual production figures by 2025.

Official Chinese fly ash production and utilization rates, as reported by institutes and departments recognised by the government, indicate 500–600 million tons of ash produced in 2016 (Cui, 2016) with a utilization rate of around 70%. Some observers question the accuracy of these official figures, and in particular question claims about utilization rates. Even with the best of intentions, calculating accurate total fly ash productions figures in China is complicated by a lack of both monitoring and transparency. While the guidelines and policies governing ash collection and ash disposal are reasonably clear in their content and comprehensive in their scope, monitoring and enforcement of regulations are lacking in some important production regions.

The financial cost of installing and using ash collection systems is relatively high, with electrostatic precipitation systems estimated at 30–80 USD/kWe capital cost and 5 USD per kW per year for operation and maintenance. Ash transportation and disposal costs can add another 3–15 USD per ton, depending on regulations and the distance to be travelled. Given such high operating costs, power station operators in areas with weak regulation or enforcement may avoid proper collection and disposal. For example, by switching off collection systems (typically overnight), ash can be disposed of into the atmosphere with substantial a cost savings. The China Academy of Sciences has estimated that coal combustion is responsible for between 19% and 34% of PM2.5 in Beijing and the surrounding areas in Hebei province.[4] Researchers have found evidence of fly ash being a significant contributor to PM2.5 levels in the eastern metropolitan areas of Shanghai and Chengdu, the capital of the southwestern province of Sichuan (Tao et al., 2014). Modern ash collection systems are designed to collect more than 99.7% of the ash produced. With systems installed and deployed properly, these volumes of fly ash should not be present in the atmosphere. In a scenario where only 15% of power stations turn off their collection systems for 8 h a day, that would represent an additional 25–30 million tons of undocumented fly ash production each year.

Other irresponsible methods of disposal include dumping ash onto land or bodies of water without proper liners or containment systems. These disposal practices are not officially reported, but again as a scenario, if only 10% of power stations were collecting and dumping 20% of their ash ‘off the record’, it would represent millions of tons of production for which it is currently unaccounted.

China’s recent history of recognizing and creating policy to address environmental challenges suggests that the scope for this type of negligence will decrease. Laws and policies related to air, water, and soil pollution are improving in their scope, though monitoring and enforcement naturally lag behind central and provincial government level edicts. Policies place clear responsibility for ash collection on producers and

[3] 3.7 Billion $\times$ 0.3% growth = 11.1 million tons $\times$ 25% ash content = 2.78 million tons of fly ash.

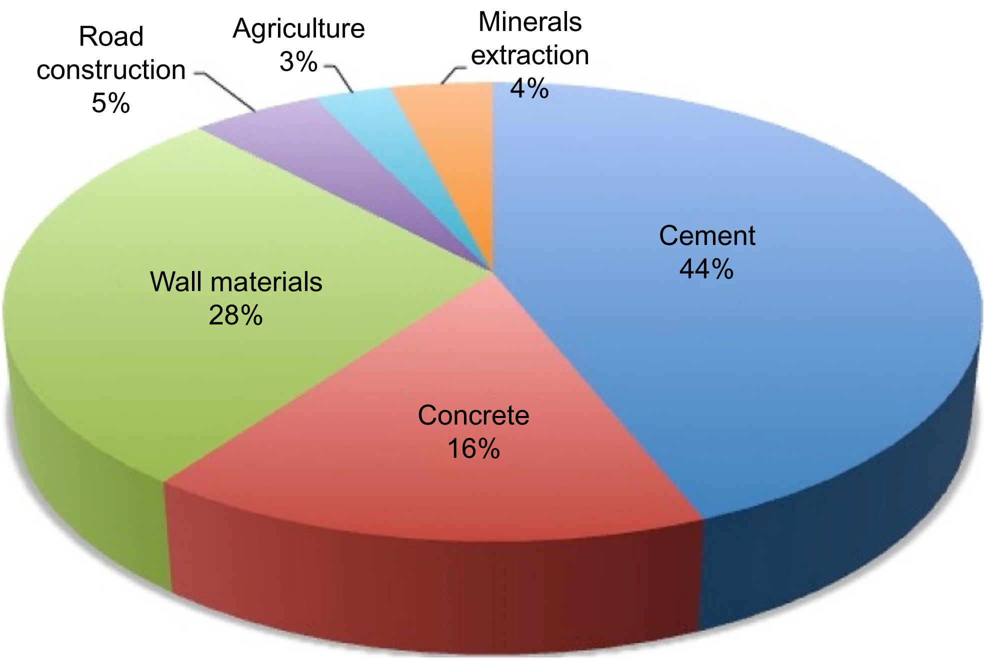
[4] Institute of Atmospheric Physics, Chinese Academy of Sciences.

clearly indicate that commercial benefits should go to the consumers. Implementation is not without its challenges, but overall it is expected that China will continue to strengthen regulations, increase the monitoring of emissions at power stations, and enforce responsible disposal. These measures should serve to increase the amount of ash collected by power stations, adding to total supplies. The added costs incurred by power stations may stimulate investments in ash reduction techniques, such as coal washing, or the pursuit of alternative utilization methods.

Penalties for noncompliance should be both deterrent (i.e., designed to dissuade others from non-compliance) and punitive. Punitive penalties should reflect the degree to which society may be harmed by the negligent or purposeful release of pollutants into the atmosphere or contamination of soil, groundwater, or marine environments. Policy makers and regulators should also encourage the development of beneficial utilization so that the costs of adopting beneficial-use methods and technologies are preferable to the risks and costs of noncompliance.

21.2.1.2 Utilization

The officially recognized fly ash utilization rate is 70% (Cui, 2016), implying that an unutilized portion of 150–180 million tons from the 500 to 6000 million tons of total production. Utilization is concentrated in cement (44%), concrete walling products (28%), and ready-mix concrete (16%), with other low-value applications making up the road base and mine shaft fill making up the balance (12%).



Incentives for the utilization of ash, such as VAT exemption for achieving recycled content thresholds in some construction products, are designed to further support utilization. Carbon trading markets, implemented on an experimental scale in 2015, have yet to create clear demand-side stimulation for lower-carbon material technologies. The central government has recently announced environmental sustainability guidelines focused on soil, following earlier proclamations focused on air and water sustainability. When these are implemented at local levels, they should improve the monitoring of landfill management by increasing the costs of landfilling, which should increase incentives for the beneficial usage of more material.

As with policies governing collection and disposal, practical implementation of policies intended to stimulate demand is often slow. Navigating the required pathways to gain formal approvals and then actually receiving the defined benefits is often a significant challenge for private entrepreneurs and state-owned enterprises alike. Some of the policies face conflicting government goals. For example, adjusting building material standards to allow for higher amounts of fly ash in cement and concrete production would reduce demand for Portland cement at a time when the Chinese government is working to eliminate serious overcapacity in the sector.

Despite the difficulties in enforcement, the intention and direction of government policies strengthening fly ash collection, disposal and utilization regulations is clear. Efficacy of policies and regulations in China tend to improve over time, perhaps even improving to the extent that they will have a measurable impact on fly ash demand. However, unless these policies drive substantial breakthroughs in higher ash substitution in cement and concrete or support commercialization of new high-volume applications, the increases in demand will not significantly alter expected surpluses.

21.2.1.3 Declines in domestic cement and concrete consumption

Chinese domestic demand for cement and concrete are expected to remain flat through 2020, trailing the global average. Demand will likely see declines thereafter as the country's development shifts away from investment-led growth, despite recent efforts to support distressed property and construction material industries.

In mid-2016, in response to the slowest growth in 25 years the central government began acting to support the property and construction sectors. Infrastructure investments remains key in cushioning the hard-hit steel and cement industries, though recent stimulus measures to support infrastructure and housing construction are believed to be unsustainable. In early October 2016, the International Monetary Fund (IMF) indicated that Chinese total debt levels were becoming dangerously high, noting that the Chinese "economy's dependence on credit is increasing at a dangerous pace, intermediated through an increasingly opaque and complex financial sector." The IMF further suggested that China should rein in the credit growth and cut off support to "unviable" state-owned enterprises, "accepting the associated slower GDP growth… By maintaining high near-term growth momentum in this manner, the economy faces a growing misallocation of resources and risks an eventual disruptive adjustment" (World Economic Outlook, 2016).

While there is support for downstream industries that may sustain fly ash demand in China in the short term (i.e., cement and concrete producers vis-a-vis property and infrastructure spending), demand is expected to remain flat in the mid term (2–5 years) and decline over the long term (>5 years).

21.2.1.4 Surplus ash

The effects of sustained total coal power production levels, the likely increase in total ash collection volumes (through greater monitoring and enforcement of collection), and the fall in traditional demand suggests that existing annual surpluses will continue and likely grow. Based on two scenarios published by the Asian Coal Ash Association in December 2016, surplus fly ash volumes in China are expected to remain between 144 million and 243 million tons per year through 2025. At this range of projected accumulation, the current stockpile of two billion tons of fly ash in landfills may double to four billion during this period.

The below table illustrates two simplified scenarios that provide an estimated range for Chinese fly ash surplus through 2030. In the first scenario, production is kept at the same level through 2030. Coal will remain an important part of China's energy mix for the next 30–40 years, and while some models estimate moderate growth in absolute coal power production in China, others predict that the total coal production volumes have plateaued. Utilization predicts total fly ash consumption to remain in line with total cement production, using this figure as a proxy based on cement volumes being indicative of the demand for total construction materials.

The second scenario maintains the utilization growth figures while adjusting the production figures moderately upward (from 0.07% to 2% annual growth). The factors that may result in this larger growth in fly ash production include: (a) improvements in regulations and enforcement, such that a greater percentage of fly ash produced is captured and accounted for, as opposed to being, rather than released into the atmosphere or dumped in unregistered landfills; (b) coal power maintains its share of the energy mix, due to higher oil prices or the failure of renewables to meet expectations.

The models are highly simplified and could be sensitized to many variables not considered here. Total fly ash consumption and production during this period may be affected, for example, by emerging technologies, a surge in regional infrastructure development, a change in standards that allow for greater fly ash additions to cement or concrete, or unpredictable shifts in global energy markets. Overall, however, the projected ranges should provide a reasonable framework for estimating surplus volumes based on current knowledge.

21.2.1.5 International trade: Opportunities

Considering geographic location, supply-and-demand patterns, and total delivered logistics costs, Chinese ash producers have a number of potential export markets, including:

1. Australia
2. United States (West Coast)
3. Western Europe
4. South Korea
5. Southeast Asia

While there have been Chinese ash exports to these and other markets over the last 10 years, the trade has been largely limited to containerized bulk bags. Total exports are estimated to be less than three million tons per year.

China fly ash production and utilization projections							Millions of tons				
Scenario 1	**Growth**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Production	1.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00	565.00
Utilization	1.01	395.50	398.27	401.06	403.86	406.69	409.54	412.40	415.29	418.20	421.13
Surplus		169.50	166.73	163.94	161.14	158.31	155.46	152.60	149.71	146.80	143.87
Notes:	• Production assumes coal consumption has plateaued and will remain at current consumption rates through 2040; based on WEO2015 • Utilization assumes ash consumption will grow at same rate as cement consumption, based on CW Group forecast of 0.07% growth										
Scenario 2	**Growth**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Production	1.02	565.00	576.30	587.83	599.58	611.57	623.81	636.28	649.01	661.99	675.23
Utilization	1.01	395.50	399.46	403.45	407.48	411.56	415.67	419.83	424.03	428.27	432.55
Surplus		169.50	176.85	184.38	192.10	200.02	208.13	216.45	224.98	233.72	242.67
Notes:	• Growth in production assumes uniform energy demand growth (two percent) and that coal will remain as the same percentage of energy mix • Utilization assumes ash consumption will grow at same rate as cement consumption, based on CW Group forecast of 0.07% growth										

Producers and prospective export customers are currently investigating infrastructure, as wella as the regulatory and financial requirements for bulk powder exports and imports. Some details regarding the demand in these markets, as well as considerations and challenges around bulk fly ash powder exports/imports, are discussed below.

21.2.2 India

21.2.2.1 Production

Coal is expected to remain central to Indian power generation for the next 40–50 years.[5] At 152 watts per person (2014), per capita annual domestic electricity consumption in India is less than half the worldwide average (385 watts) and less than 1/3rd of China's per person consumption (474 watts per person).[6] Strong growth in manufacturing and an additional 580 million consumers are boosting electricity demand by 4.9% per year in India. Total energy consumption is expected to reach nearly 3300 TW h in 2040, with the installed capacity growing from 290 GW in 2015 to nearly 1100 GW in 2040. Half of the net increase in coal-fired power generation capacity worldwide will occur in India.

There is an overwhelming dependence on domestic high-ash coal for power generation in India.[7] According to the latest report of the Central Electricity Authority, between April and September 2015, 132 thermal power plants (TPPs) of 58 utility companies having an installed capacity of 130,428 MW consumed 251.69 million tonnes of coal with an average ash content of 33.23%. This led to the generation of 83.64 million tonnes of coal ash during a sixth-month period, out of which only 46.87 million tonnes (or 56.04%) was beneficially utilized. The total installed capacity of coal based TPSs in India is 186,492.88 MW as of October 31, 2016. Annual figures are roughly double the sixth-month figures, and the increased capacity suggests total ash production of approximately 240 million tonnes at present.[8]

21.2.2.2 Utilization

Current utilization in India is concentrated in cement 42%; bricks and tiles 13%; mine filling 11%; kand reclamation 11%; roads and fly-overs 5%; agriculture 2%; ash dyke raising 7.5%; concrete 1%; and miscellaneous 7.5%. This pattern of use has been in practice for the last several years, and the overall utilization of fly ash has been in the range of 55%–62%.

India is expected to post the fastest growth in cement demand of any major national market, advancing 8.0% per year through 2019. The growth drivers, in addition to

[5] http://www.worldenergyoutlook.org/media/weowebsite/2015/FactsheetIndia.pdf.

[6] http://www.askci.com/finance/2015/01/20/1013378nyi.shtml (China); Ministry of Statistics and Programme Implementation, India "Energy statistics 2015"—page 48, 57 (India).

[7] https://www.pwc.in/assets/pdfs/industries/power-mining/icc-coal-report.pdf.

[8] Notes from Dr. Anjan Chatterjee, Nov. 12th, 2016.

growing incomes, include: reduction in the average size of the household (due to increased nuclearization of families), reduction in the average age of homeowners, increased availability of housing finance, and a favorable tax regime.[9] Growth in other ash consumption areas is expected to maintain a similar growth pattern to cement.

While these applications will certainly add some demand for fly ash, it is not likely to offset the increased supplies described above. Increased demand for exports may improve utilization rates, but it will be difficult to gain any meaningful volumes outside of their traditional markets.

21.2.2.3 Surplus ash

Growth in total ash supplies in India will be offset to some degree by an anticipated growth in cement and other construction materials consumption. The Asian Coal Ash Association produced two scenarios that estimate the surplus fly ash volumes in India will remain between 81 million and 114 million tons per year through 2025.

The two simplified scenarios provide an estimated range for Indian fly ash surplus through 2025. The first model assumes steady growth in coal power production at 4.9% per year through 2025 production, based on the World Energy Outlook 2015 paper.[10] The first scenario further models fly ash consumption growth at 9% through 2025, tracking projected cement demand growth as a proxy for total fly ash demand. Coal will remain an important part of China's energy mix for the next 30–40 years. While some models estimate moderate growth in absolute coal power production in China, others predict that the total coal production volumes have plateaued. Utilization predicts total fly ash consumption to remain in line with total cement production, using this figure as a proxy based on cement volumes being indicative of total construction materials demand.

The second scenario maintains the utilization growth figures while adjusting the production figures moderately upward (from 0.07% annual growth to 2% annual growth). The factors that may result in this larger growth in fly ash production include: (a) improvements in regulations and enforcement, such that a greater percentage of fly ash produced is captured and accounted for, as opposed to being released into the atmosphere or dumped in unregistered landfills; (b) coal power maintaining its share of the energy mix due to higher oil prices or failure of renewables to meet expectations.

The models are by definition simplifications that could be sensitized to many variables not considered herein. Total fly ash consumption and production during this period may be affected, for example, by emerging technologies, a surge in regional infrastructure development, a change in standards that allow for greater fly ash

[9] http://www.ijemr.net/April2014Issue/AStudyOnFutureMarketingTrendsIndianCementIndustry(154-156).pdf.

[10] http://www.worldenergyoutlook.org/media/weowebsite/2015/FactsheetIndia.pdf.

	Growth	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Production	1.05	240.00	251.76	264.35	277.57	291.44	306.02	321.32	337.38	354.25	371.96
Utilization	1.08	134.00	144.72	156.30	168.80	182.31	196.89	212.64	229.65	248.02	267.87
Surplus		106.00	107.04	108.05	108.76	109.14	109.13	108.68	107.73	106.23	104.10
Notes:	Growth in production assumes uniform energy demand growth (4.9%) and that coal will remain the same percentage of energy mix Utilization assumes ash consumption will grow at same rate as growth in cement consumption										

	Growth	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Production	1.05	240.00	251.76	264.35	277.57	291.44	306.02	321.32	337.38	354.25	371.96
Utilization	1.08*	134.00	144.72	156.30	168.80	182.31	196.89	210.67	225.42	238.94	253.28
Surplus		106.00	107.04	108.05	108.76	109.14	109.13	110.64	111.96	115.31	118.68
Notes:	Growth in production assumes that uniform energy demand growth (4.9%) and that coal will remain the same percentage of the energy mix.										

*Utilization assumes a gradual decline in cement/construction materials consumption from 8% to 5% per year, starting in 2022 through 2030.

additions to cement or concrete, or unpredictable shifts in global energy markets. Overall, however, the projected ranges should provide a reasonable framework for estimating surplus volumes based on current knowledge.

21.2.2.4 Policies

Policy regarding the use and disposal of fly ash are handled by the Ministry of Environment, Power and Climate Change (MOEFCC). The current regulation is dated January 2016 and stipulates that cost of transportation of fly ash up to 100 km from the power station needs to be borne by the concerned generator. Transportation cost from 100 to 300 km is to be shared between the generator and the consumer. The regulation requires mandatory use of fly ash products in all government schemes and monthly reporting of fly ash stocks.

Again, the problem with the policies has been implementation. Although there are state-level monitoring committees, the speed of implementation has been slow.[11]

21.2.2.5 International trade: Opportunities

Although Indian traders have exported fly ash in small consignments, ash as an international commodity has not received much attention in the domestic industry. The sales cycle can be lengthy, starting with laboratory sample approvals and often requiring additional field trials, making the market less desirable for ash traders. Consignment sizes range from a few hundred to a few thousand tonnes each. While export-import data services provide some insight into international trade, reliable export statistics are difficult to determine, as several ash-based products are often shipped under the 26219000 HS code number. A reasonable estimate based on the trade data is that exports may not exceed a couple of million tonnes per year. Main ports for export include Mundra in Gujrat, Tuticorin in Tamil Nadu, Sabarmati, Nhava Shiva, Kolkata, and some others. The importing countries are Qatar, Kenya, UAE, Japan, and Sri Lanka. Cenospheres are also exported from India in consignment sizes of kilogram quantities, typically by air cargo from various parts of the country. Export to Bangladesh from Kolkata port in small barges is a regular trade from the coastal TPSs in West Bengal. It is reported that Tata Power has done some ground work to export up to 90,000 tonnes of fly ash per year to Middle East from the western ports.

Potential export markets for Indian ash include:

1. Middle East
2. Australia
3. Africa
4. Western Europe
5. United States (West Coast)

[11] Notes from Dr. Anjan Chatterjee, Nov. 12th, 2016.

21.2.3 Southeast Asia

Coal-fired generating capacity has grown in the region over the past decade, with significant additional capacity already in the pipeline in Vietnam, Malaysia, Indonesia, and Taiwan. In the IEO2016 reference case, the coal-fired generating capacity in non-OECD Asia (excluding China and India) nearly doubles from 2012 to 2040.[12]

Many countries in the Asia/Pacific region will post strong growth in cement consumption, including Vietnam, Indonesia, and Pakistan.

In Vietnam, where electricity demand has been increasing at a rapid pace in recent years, there are ambitious plans to increase the coal-fired generating capacity. As of January 2016, more than 12 GW of coal-fired capacity was under construction, and there are plans to add an additional 60 GW of new coal-fired generating capacity by 2030. The majority of the coal will by imported from Australia and Indonesia.[13]

21.3 International trade: Challenges

Major barriers for export include the cost of inland transport, port expenses, and shipping costs for relatively small consignments and lengthy approval procedures for export, import, and transport permits. For ash traders, all of these barriers result in export being less attractive than the domestic sales. As supply constraints hit key markets, upward price pressure on SCMs will push buyers and suppliers to tackle these and other challenges to developing new international supply chains.

21.3.1 High-quality coastal supplies already contracted

Coastal power stations, due to their proximity to major urban areas, tend to be better managed in terms of production consistency and environmental standards. In China and India in particular, coastal power stations tend to mill coal more finely, use superior emissions to control technologies, and have a tendency to use higher-quality coal blends. The result is higher quality and greater consistency in fly ash chemical and physical properties, to the extent that the material is more desirable to local cement manufacturers and those in other domestic markets along the coast. This material is typically allocated in multiyear contracts.

Adding to this, coastal urban areas usually have high volume demand for construction materials. Coastal power stations are often fully contracted to supply cement-grade fly ash, as well as the run of station ash and bottom ash to serve this demand. This is particularly clear in China, where coastal cities such as Shanghai and Shenzhen have seen dramatic urban development over the last 20 years. During this period, both cities have been net importers of fly ash, drawing from both inland and domestic coastal sources.

[12] http://www.eia.gov/forecasts/ieo/coal.cfm.

[13] http://www.eia.gov/forecasts/ieo/coal.cfm.

The cost of loading material onto vessels, whether in containers or bulk, is much lower at coastal power stations due to lower local land transport costs. As a result, coastal power stations have been logical first choices for exporters/importers, and many have already developed either domestic coastal markets for their ash or export markets.

21.3.2 Production moving away from the coast

In earlier stages of economic development, coal power stations are often located along the coasts to take advantage of access to coal resources (through coastal trade and imports) and proximity to energy consumers. As economies develop, coal power production typically moves away from coastal areas. This trend is notable in China, where over the last decade the central government has specifically focused on relocating coal power production away from the coast. China's coal power production base has shifted towards the central, west, and northern regions of the country, where domestic coal resources are most abundant. In the United States the majority of coal power stations are located more than 100 km from the coast. In California, coal-fired generation is projected to serve about three percent of California's electricity consumption by 2024; this generation is expected to decline to zero by 2026.[14] The Californian market already suffers from severe ash shortages, with expensive synthetic alternatives currently under development. In the United Kingdom, there is no coal power in Scotland, and all ash is currently being imported from Germany. In England and Wales, all remaining coal power stations are mandated to close by 2025, though they are likely to close earlier.

The relocation of ash production away from seaports brings increased transportation costs when moving the material from source to port, raising the FOB cost and limiting the number of addressable export markets. It also raises delivered costs to the high-demand domestic coastal markets.

21.3.3 Road and rail infrastructure

China's rail and road infrastructure is well developed, though transport costs from main fly ash production regions (Shanxi, Inner Mongolia) to the coast still add 10–20 USD per ton.

In India, inadequate rail infrastructure and a lack of dedicated freight infrastructure limit the ability for exports to bring supplies to the coast from the interior. "Decades-long projects including dedicated freight lines have yet to be completed, and several rail projects have stalled, including the 93-km Tori-Shivpur-Kathautia line to provide access to coal mines in Jharkhand, which was begun in 1999 and scheduled to be completed in 2005, but was only half complete as of 2015."[15]

[14] http://www.energy.ca.gov/renewables/tracking_progress/documents/current_expected_energy_from_coal.pdf.

[15] http://www.eia.gov/forecasts/ieo/footnotes.cfm#138.

21.3.4 Export infrastructure

China has spent nearly three decades investing in infrastructure to support raw material imports and exports. Infrastructure has also been developed to support a vibrant domestic coastal trade in raw construction materials. As a result, the country has a large bulk powder export capacity with storage facilities and ports that can accommodate large bulk vessels. Much of this capacity is currently underutilized due to a decline in domestic demand, resulting in competitive port charges that should reduce overall export costs. In addition, there is abundant capacity to export powders in bulk bags. This is a higher cost option, but may be viable in markets where cement prices justify the added cost.

In India, export facilities for bulk powder are more limited. Most of the ash being exported currently is done so in bulk bags, with volumes typically a few hundred to a few thousand tons per shipment. It is reported that Tata Power has done some groundwork to export up to 90,000 tons of ash per year to the Middle East. Such volumes are not likely to yet justify major infrastructure investment, but may be an indicator of things to come. Indian export volumes could grow substantially and justify investments in bulk shipment capabilities if exporters are able to secure purchase agreements to fulfill some of the growing demand described in this chapter.

21.3.5 Import infrastructure

21.3.5.1 Bulk powder

Bulk powder unloading of fly ash can be done at import terminals that currently handle bulk cement and GGBS. Capacity issues at import facilities create a bottleneck for importers, and the approvals process to allow nonpneumatic vessels can be lengthy, costly, and uncertain. Many ports within reasonable distance to the main markets have a preference for container ships or at best pneumatic vessels due to the risk of dust emissions during unloading and unwanted discharge during cleaning. Naturally, importers want to get their material as close as possible by sea freight to the end-use location in order to reduce more expensive land transport costs.

Building an additional import capacity requires substantial investment in shore-based offloading equipment and warehousing. To justify these expenditures, importers need to develop confidence that they have access to long-term, reliable, quality supplies from at least one resource, with additional options preferable so as to reduce risk.

21.3.5.2 Bulk bags

Bulk bags can be used to pack and transport fly ash, eliminating the need for specialized shore- or vessel-based offloading equipment. Environmental concerns with dust emissions are also less of a concern. The 1 or 1.5 ton bulk bags can be packed in the cargo hold of the vessel and removed with a standard gantry crane. While avoiding the capital costs or capacity restrictions of bulk powder imports, shipping by bulk bag incurs additional costs due to the cost of the bag, the cost of filling the bag, and the cost of emptying the bag by the customer. The debagging process can also be messy, with expensive equipment often necessary to contain fugitive dust. While this method of delivery works in markets where local cement or SCM supplies are relatively expensive, the added cost and additional processing required in debagging make this a less desirable or unviable option for large-volume trading in established markets.

21.3.5.3 Pneumatic vessels

Pneumatic vessels avoid many of the environmental concerns that port authorities have during both export and import. Pneumatic vessels also eliminate the need for offloading equipment at the port of destination, reducing capital expenditure requirements for importers. However, the global fleet of pneumatic vessels is limited, with a relatively small cargo capacity on an average vessel. As of 2013, there were only 11 self-discharging vessels globally with a capacity greater than 19,000dwt.[16] Current ocean freight costs for chartering pneumatic vessels are considerably higher, with current rates two to three times higher than standard bulk ships.

Importers will need to compare total costs of chartering or acquiring and operating bulk vessels with the total costs of chartering or acquiring and operating pneumatic vessels. Bulk vessels require additional investment in import infrastructure for offloading and have greater regulatory restrictions. Pneumatic vessels are more expensive to purchase or operate, but require less import infrastructure and are typically less of an environmental concern to port authorities.

21.3.6 Environmental and regulatory challenges

Bulk powder vessels face restrictions at many ports due to environmental regulations. Primary concern is fugitive dust emissions during loading and unloading. Pneumatic vessels face fewer restrictions at ports, as they tend to provide better containment of dust.

Other regulatory challenges include restrictions on transporting or importing material designated as hazardous waste in some countries. After a long regulatory process, the US EPA in 2014 determined that fly ash would be classified under a subcategory of hazardous waste. This designation allows for relative ease of transport and beneficial use in cement, concrete, and other applications. Other countries, such as Indonesia, classify fly ash as hazardous waste. While responsible material handling should be practiced with any bulk powder material, the hazardous waste designation adds substantial cost and complexity to transporting and utilizing ash.

21.3.7 Quality and standards

Only a small percentage of power stations or ash managers in China, India, and other surplus markets are presently equipped with sufficient facilities or expertise to provide fly ash that meet specifications for cement in the United States, Australia, and Europe. The main challenges are the ability to supply ash over sustained periods with

[16] http://ashtrans.eu/2013%2008%2026%20KGJ%20Cement%20Presentationx.pdf.

consistent chemical and physical properties. Consumers of fly ash need to adjust their supply chains and mix designs around specific ash profiles; fluctuations outside of tolerable limits can cause unacceptable disruption to their supply chains. Maintaining consistently low levels of LOI and consistent fineness are the main challenges. Proven methods to control for these parameters are well understood in the industry, but justifying the investments in equipment, training, and quality control and monitoring require credible long-term sales prospects.

Part of the difficulty in building consistent quality ash supplies is a lack of coordination in international standards. There is evidence that increased coordination around fly ash standards in different jurisdictions would help to create a broader global marketplace. Prior to standardization, some EU members utilized 100% of the coal combustion products produced in their country, while others only utilized 10% due to differing regulations. The EU laws that have harmonized differing standards take precedent over national laws and have benefitted the fly ash industry by requiring fly ash to be utilized more widely throughout the EU (Hans-Joachim, 2005).

21.4 International trade: Opportunities

Decreasing local demand and increasing costs of disposal in high-volume surplus markets may combine to justify the costs of investing in the quality production and logistics required to export fly ash to high value markets. A "first-mover" opportunity exists for those producers willing to make the investments in infrastructure and put in place quality control programs that satisfy sophisticated and demanding international customers.

At the time of writing, ocean freight rates are at historical lows and are expected to remain depressed for the next 2–3 years due to vessel oversupply and a slowdown in global commodity markets. Early movers are in a position to lock in competitive pricing for near to mid-term contracts while ship owners are desperate for business. The price of bulk vessels is also at historical lows, with many shipbuilders struggling for new orders. This may motivate some large-volume customers to invest in their own fleets and secure long-term purchase agreements as part of a strategic raw material procurement program.

21.4.1 Diminishing supplies in key markets

A number of key markets have seen steady declines in fly ash supplies over the last decade, including the United States, Western Europe, and Australia. Fly ash production in these markets has declined primarily as a result of the retiring of coal power capacity and an infrastructure investment shift towards nuclear, gas, and renewable energy.

The American Coal Ash Association publishes fly ash production and utilization figures from 2000. According to the published figures, production has seen a steady decline from around 72 million tons in 2006 to 45 million tons in 2015.[17] Utilization

[17] https://www.acaa-usa.org/Portals/9/Files/PDFs/2015-Survey_Results_Charts.pdf.

has remained between 20 and 30 million tons during the same period. Coal power stations in the United States are being retired at a rapid rate, with nearly 5% of installed capacity retired in 2015 alone.[18] Policy changes in the new Trump administration aimed at reviving the coal industry may result in increased fly ash production volumes in the near term, but price competition from natural gas and the improving economics of renewables suggest that the long-term trend for American coal and fly ash production will be a steady decline.

In Europe (EU15[19]), there has been a steady overall decline in coal consumption since 1995,[20] with corresponding decreases in fly ash production tracked by the European Coal Combustion Products Association. Some of this decline can be attributed to the slowdown in industrial demand due to the 2008 financial crisis, but more meaningful longer-term impact is likely caused by political decisions relative to CO2 reduction and an increased focus on energy production through renewables. Air-quality regulations are likely to continue forcing plant closures, and renewable energy will continue to surge, while European energy demand will be weak in general. Currently, production (2015) is 32 million tons, of which approximately 92% is used. As supplies continue to diminish in these markets, demand will quickly outstrip supplies.

In contrast to the EU15, the total amount of CCPs in EU-28 did not decrease substantially, as EU12[21] countries generate a larger share of their energy from coal-fired power plants. ECOBA estimates total CCPs for the EU28 countries at $>$ 105 million tons (2015), implying EU12 countries were producing $>$73 million tons in 2015. ECOBA has not published figures on utilization rates, but due to less development in these markets, it is expected to be considerably lower. Ash trading within the EU is already established and will likely increase, given the asymmetrical supply and demand. The high costs of land transport, however, will restrict much of this trade, and exporters from the East Coast of America or Asia may emerge to meet Western European fly ash demand.

The supply problems in the United Kingdom have emerged quickly. At the end of 2015, the UK had adequate amounts of fly ash to meet domestic demand. It is now expected that there will be a 200,000–300,000 ton shortfall to supply current demand. The UK withdrawal from the EU may further complicate imports and increase the price of European ash. The price of fly ash increased from 10 euros per ton (delivered) to 20–30 Euros per ton in a six-month period in 2016. Fly ash stockpiles that existed in Germany and the Netherlands just last year have already been consumed. The impact on global trade has been rapid for other countries too. Trade flows of fly ash from northern Europe to the United States, accounting for sizeable volumes in 2015, have all but stopped.

[18] http://www.ibtimes.com/coal-power-waning-nearly-5-us-capacity-retired-2015-aging-plants-lose-ground-2333207.

[19] Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, United Kingdom, Austria, Finland, Sweden.

[20] http://www.eiu.com/industry/article/741997658/coals-last-gasp-in-europe/2014-07-09.

[21] Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, United Kingdom.

21.4.2 Quality declines

Average ash quality in many markets has also seen a decline in the last decade. Low NOx burners, widely adopted in new power station designs following the 1970 Clean Air Act Amendment in the United States, are designed to reduce the amount of nitrogen oxides emitted during coal combustion. The process typically involves lower combustion temperatures and results in higher levels of unburned carbon (LOI) in fly ash. In most cement standards, LOI is a critical specification that requires a certain percentage, typically below 5% in most standards and below 2% in more stringent specifications. While a number of postcombustion processes have been developed to address this higher LOI from low-NOx burners, the added capital and operating costs have often been unviable for ash producers. Rising cement costs and an increasing scarcity of local fly ash supplies in some markets may cause wider-spread adoption of carbon removal technologies, but the overall costs and quality will need to compete with total delivered cost of imports from more distant markets.

The changing role of renewables in the overall energy mix also impacts fly ash quality. Daytime demand in markets such as Australia is being met by solar power. Coal power, previously the base load power supplier, now shut down in the morning and need to be reignited in the evening. The re-ignition process involves using kerosene as the initial fuel to fire up the boiler. Coal is then slowly added until coal is the sole fuel source. The ash during the period where kerosene is being employed is much higher LOI than the pure coal burn. Quality ash supply volumes from these power stations are therefore reduced substantially, and the process of separating the lower LOI ash from the higher LOI ash introduces additional management and operating costs.

21.4.3 Increased demand for supplementary cementitious materials (SCMs) globally

Demand for supplementary cementitious materials (SCM) depends heavily on the global construction industry. Global infrastructure development, particularly in Asia Pacific, Latin America, Africa, and the Middle East, should drive demand for SCMs through 2020.

Global fly ash sales totalled an estimated $75 billion in 2015, account for over 70% of the volume and almost 95% of the revenue in the global SCM market.[22] Fly ash revenue is expected to reach $98 billion by 2020 with a five-year CAGR of 5.5%.[23] Comparatively accommodative regulations governing the use of fly ash in

[22] http://www.bccresearch.com/pressroom/avm/uptick-in-global-construction-to-spur-growth-in-scm-market; BCC Research LLC, 49 Walnut Park, Building 2, Wellesley, MA 02481, Telephone: 866-285-7215; Email: editor@bccresearch.com.

[23] http://www.bccresearch.com/pressroom/avm/uptick-in-global-construction-to-spur-growth-in-scm-market; BCC Research LLC, 49 Walnut Park, Building 2, Wellesley, MA 02481, Telephone: 866-285-7215; Email: editor@bccresearch.com.

Asia Pacific supported high consumption, with the region accounting for the majority of global trade, followed by North America.

Demand for supplementary cementitious materials globally is driven by a number of key benefits. Economically, substituting a portion of Portland cement with SCMs reduces operational manufacturing costs, as current prices are typically less than ordinary Portland. SCMs such as fly ash and GGBS are more capital efficient; as industrial by-products, they do not require significant capital investments in manufacturing capacity. To the degree that SCMs can replace Portland cement, they reduce the need for capital investment in new cement manufacturing assets required to meet market demand.

SCMs add performance improvements to blended cements. When added correctly, fly ash improves the workability of fresh concrete and enhances strength, durability, and resistance to sulfate attack in hardened concrete.

The primary benefits of increased SCM content are performance and cost. However, heightened environmental awareness, accompanied by policies and legislation that support products with lower embodied energy are playing an increasing role in buyer and supplier decisions. The environmental benefits first emerged as drivers in Japanese and European markets, but other markets are now following the lead. The Middle East is a major contributor to this trend, with the government of the UAE implementing regulations in 2015 that require all major infrastructure projects and substructures to use at least 60% slag or ash-containing cements.

In Europe, the new Fehmarn Belt bridge/tunnel has specified only fly ash cement. This project, connecting Denmark and Germany and led by the respective governments, will be a reference case for construction and engineering companies and may lead to greater adoption of fly ash cements in the region and globally.[24]

There is an upward trend in increasing the volumes of fly ash additive permitted in cement and concrete. Australian standards currently permit a 7.5% addition of fly ash in the cement kiln, and the industry is trialling 12.5% additions. The European standard allows for 22.5% fly ash to be milled with clinker. The Chinese standard for ordinary Portland cement (GB 175-2007) allows for up to 40% fly ash additive. Chinese concrete standards allow for between 15% and 70% fly ash, with high w/c prestressed concrete at the lower end of the scale and roller compacted concrete at the upper end.

21.5 Summary

The long-term trend will see continual declines in fly ash supplies in the United States, Western Europe, and Australia with little to no domestic supplies in most of Africa and the Middle East. Short-term shifts in attitudes and policy towards coal power generation, most notably in America, may cause increased supplies, but the low cost of natural gas and declining cost of renewables will likely limit the impact of any coal revival policies.

[24] http://www.globalcement.com/magazine/articles/994-lower-scm-supplies-demand-a-change-in-approach.

Sustained or increasing surpluses of fly ash in China, India, Southeast Asia, and Eastern Europe will create a growing imbalance in geographic supply and demand, stimulating growth in international trade. Delivered prices for cement-grade fly ash will approach and possibly even surpass the delivered price of cement in developed markets, where environmental considerations increase the costs of building cement manufacturing capacity and reward the use of materials with lower embedded energy.

A number of other variables may impact supply and demand. Environmental, health, and safety regulations in exporting and importing countries may impact supply and demand. Supply may be thus impacted through restrictions on use in some applications, restricting or adding cost and complexity to the import/export process or prohibitive regulations regarding local transportation. Demand may be stimulated through carbon credits, tax incentives, or feature projects that validate and give profile to use of high-volume fly ash cements (such as the aforementioned German-Danish Fehmarn Belt bridge/tunnel).

One factor that may have the largest impact on fly ash demand is also the least predictable. Investments in emerging technologies for fly ash utilization have focused on a broad number of product applications and markets. A number of these may achieve technical and commercial breakthroughs that could increase fly ash demand.

Geopolymers, which are alkali-activated cements that use fly ash and GGBS as their main component, have received a substantial amount of investment and interest, particularly in China, India, and Australia. With low-embedded energy and high proportions of recycled content, geopolymer cement systems offer promising benefits. However, technology developers have yet to overcome the disadvantages inherent in the use of alkaline activators, which include higher costs and health and safety issues due to their caustic nature. Workability is another key barrier to widespread adoption, as set times for geopolymers are typically very rapid, and retarders only add additional cost. Nonetheless, with the amount of investment and interest, there is a chance that these barriers will be at least partly overcome. Due to the large addressable market size for geopolymer cement and concrete products, even moderate success would have significant impact on fly ash demand in respective markets; upside demand increase could be in the hundreds of millions of tons globally.

Metal extraction, particularly the extraction of aluminium, has seen investments in the hundreds of millions of dollars in China, where some ashes have more than 50% aluminium oxide content. If the technologies prove to be commercially viable, fly ash could replace bauxite as feedstock for aluminium smelting in some markets. The potential volumes for this application would see demand for higher aluminium ashes increase by tens of millions of tons per year. Thus far, efforts such as the Datang processing facility in Inner Mongolia have demonstrated technical capability, but operating costs, particularly those associated with neutralizing the strong alkali solutions used in the process, have prevented commercial viability.

A number of companies have invested in developing methods for using fly ash as a substitute for clays in the manufacturing of industrial ceramics. Fly ash is essentially the unburned clay and trace minerals and metals present in the coal during combustion. While chemically similar, fly ash has unique physical properties that are derived from having been fired at high temperature and converted into fine particulate.

Technology developers demonstrated the ability to produce a range of industrial ceramics with beneficial properties and a promising cost base. An example is in the manufacture of ceramic tiles, wear-resistant ceramics, and refractories using 40–80% fly ash substitute for industrial clays. Moderate market share for fly ash-derived refractories and ceramic tiles alone would represent tens of millions of tons of ash demand each. Whether such technologies can be deployed at full scale with commercial viability remains to be seen.

On the supply side, advancements in ponded ash beneficiation could unlock billions of tons of fly ash currently stockpiled in landfills. The prospect of diminishing supplies, and the acknowledged costs and risks of maintaining ash ponds in the United States, have propelled research and development in ponded ash beneficiation over the last decade. As quality ash supplies become scarcer and more expensive, the ability to upgrade lower quality stocks will become increasingly valuable.

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