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Coal ash analysis and the projected coal consumption of the CLP's power generation

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Abstract

In August 2005, Greenpeace China continued our air pollution monitoring mission in the coal-fired power plants in Hong Kong. We collected coal fly ash samples from the ash lagoons and the cement plant, and obtained an analysis report from a research laboratory in UK. The concentrations of trace elements including some toxic elements we found in the coal fly ash are lower than that reported for coal fly ash from studies in other countries. However, the continuous production and release of these toxic elements from power plants such as arsenic, mercury and lead still poses health hazard to human beings as well as damages to the environment. And the greater proportion of mercury is vented via the flue stack gases rather than being trapped in the fly or bottom ashes. The percentage of gaseous mercury in the waste-streams can be as high as 95% of the total mercury content.

Meanwhile, according to the forecast of the Economic Development and Labour Bureau, there is a 3% of annual increase in power generation in the next five years. With the limited and unstable supply of natural gas, and the maintenance work in the Daya Bay nuclear plant in the second half of 2005, the ratio of coal consumption is expected to further increase. Therefore, the emissions of air pollutants will still keep at a high level, which fails to meet the emission reduction targets for improving the air quality in the Pearl River Delta region by 2010, even when the so-called EnviroCoal is applied. The application of EnviroCoal is simply to meet with the requirements of power plant's license renewal, rather than a long-term solution. Moreover, the emission data of 2004 already revealed that the increased supply of natural gas did not help reduce the emissions of both sulphur

dioxide and particulates. CLP will fail to guarantee a substantial reduction of pollutant emissions in long run, unless they replace its coal-fired power generation with cleaner and safer renewable energy.

Toxic elements in coal fly ash

We collected six coal ash samples respectively from the ash lagoon and cement plants next to the Castle Peak Power Station in Hong Kong. The sample analysis results are as follow:

Sample number	**MI05025**	**MI05029**	**MI05030**	**MI05031**	**MI05032**	**MI05033**
Concentration	mg/kg dry weight					
Arsenic	38	4	5	4	5	7
Cadmium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Calcium	20000	15200	17000	44900	15300	18800
Chromium	35	11	10	10	12	11
Copper	47	11	10	13	13	16
Iron	15700	5860	5590	7590	7930	9580
Lead	15	<10	<10	<10	<10	<10
Magnesium	2780	2100	2070	2810	2620	3290
Manganese	68	59	50	77	74	102
Mercury	0.1	<0.03	<0.03	<0.03	<0.03	<0.03
Molybdenum	8	<1	<1	<1	<1	1
Nickel	58	12	12	15	13	18
Zinc	62	21	17	15	21	20
pH	12.18	9.2	9.26	9.35	9.18	8.87

The levels are generally relatively low compared to standards for hazardous wastes and contaminated land, and are below levels reported for coal fly ash from studies in Spain, Greece, UK and China. The only results we should note are for sample MI05025, in which the levels of arsenic and nickel are notably high compared with other samples. The pH is particularly high, which is at over 12. However, the continuous production and release of these toxic elements still poses health hazard to human beings as well as damages to the environment.

Total amount of selected trace elements in fly ash

In 2004, CLP reported 364 kilo tonnes of ash collected from their power plants in Hong Kong. We derive the following results based on the average concentration of the samples:

Selected trace elements	Average mg/kg dry weight	Total amount produced (kg)
Arsenic	5	1,820
Cadmium	<0.2	<72.7
Chromium	10.8	3,608.3
Lead	<10	<3,640
Manganese	72.4	26,353.9
Mercury	<0.03	<10.9
Molybdenum	<1	<364
Nickel	14	5,096
Zinc	18.8	6,843.3

Toxicity of elements detected in fly ash

Arsenic

Arsenic is toxic to many plants, animals and humans, though lethal doses in animals are somewhat higher than the estimated lethal dose in humans (Kaise *et al.* 1985, USPHS 2000). Most cases of human toxicity from arsenic have been associated with exposure to inorganic arsenic. Long-term low-level human exposures may lead to damage to the vascular system and can cause injury to the nervous system (USPHS 2000). Of greater concern is the increased risk of carcinogenicity through prolonged ingestion of inorganic arsenic.

Arsenic and certain arsenic compounds are known to be carcinogenic to humans by both the oral and inhalation routes. The US Department of Health and Human Services in its 9th Report on Carcinogens lists arsenic compounds as “known to be human carcinogens”. Skin cancer is the prevalent form resulting from exposure, though there is also evidence for an increased risk of internal cancers, including liver cancer (USPHS 2001).

Chromium

Both chromium (III) and chromium (VI) can accumulate in many aquatic species (Kimbrough *et al.* 1999). Whilst chromium (III) is an essential trace element in animals, chromium (VI) is non-essential and toxic at low concentrations (USPHS 2000, Goyer 1996). Chromium (VI) compounds are corrosive, and allergic skin reactions readily occur following exposure. Damage to the kidney and liver has also been reported (USPHS 2000).

Hexavalent chromium (VI), has been classified by The International Agency for Research on Cancer as a known carcinogen (IARC 1998). Also, the US Department of Health and Human Services in its 9th Report on Carcinogens, lists classifies chromium (VI) compounds as “known to be human carcinogens” (USPHS 2001). Studies have shown significant amounts of chromium in leachate from fly ash to be present in the hexavalent form (Lecuyer *et al.*1996)

Lead

When released to the environment, lead has a long residence time compared with most pollutants, remaining accessible to the food chain and to human metabolism far into the future (Sauve *et al.* 1997, USPHS 2000, Alloway 1990).

Lead has no known nutritional biochemical or physiological function (Goyer 1996). The toxic effects of lead include damage to the kidneys, cardiovascular and nervous system. Of particular concern is the effect of relatively low exposure on cognitive and behavioural development in children (Pirkle *et al.* 1998, USPHS 2000, Goyer 1993, Nriagu 1988).

Mercury

The concentrations of mercury in the fly ash samples were significantly lower than the other elements analysed for. These data, however, does not fully reflect the quantities of mercury in all waste-streams from coal combustion. The greater proportion is vented via the flue stack gases rather than being trapped in the fly or bottom ashes. The amount released to atmosphere will depend on the end-of-pipe technologies employed. According to the study by Llorens *et al.*, the percentage of gaseous mercury in the waste-streams can be as high as 95% of the total mercury content, i.e. below 218 kg in the fly ash. Therefore, we should not under-estimate the risk that the gaseous mercury is released to the environment from the power plants.

Mercury, a toxic heavy metal, is emitted by power plants in its most lethal form, elemental mercury. Large amounts of elemental mercury are “vaporised” by the power plant, react with ozone, and return to the earth in or around water sources. This mercury combines with bacteria in the water forming methylmercury, a compound poisonous to humans and animals.

Humans are most commonly exposed to mercury by eating contaminated seafood. Mercury can cause brain damage, liver degeneration, abnormal heart rhythms, gastrointestinal problems as well as affect the nervous system. Mercury poisoning poses the greatest health risk to infants and pregnant women.

Nickel

Very small amounts of nickel have been shown to be essential for normal growth and reproduction in many species of animals, plants and micro-organisms (USPHS 2000, Alloway 1990). Human toxicity generally only result through intake of high levels of nickel (USPHS 2000).

There is, however, evidence for the carcinogenicity of nickel and certain nickel compounds. The US Department of Health and Human Services, in its 9th Report on Carcinogens, lists nickel and its compounds as “reasonably anticipated to be human carcinogens” (USPHS 2001).

In many countries, fly ashes produced from coal combustion are utilised rather than disposed of, in part as cement raw material. Although this method can reduce the immediate leaching of heavy metals and other toxic substances, weathering and erosion over time will ultimately cause their release back to the environment.

In addition to the production of ashes containing toxic elements as a result of coal burning, some toxic elements are also emitted to the atmosphere in gaseous form. The fraction of certain elements that are emitted in flue gases compared to the amounts in all waste-streams have been estimated; these include mercury (up to 95%), lead (up to 40%) and arsenic (up to 30%) (Llorens *et al.* 2001). The use of flue gas scrubbing with lime (calcium oxide) can significantly reduce the fraction of gaseous arsenic released to the atmosphere through sorption to lime particles (Senior *et al.* 2000).

Apart from trace elements in the fly ashes, other pollutants released from coal-fired power generation still create enormous environmental and health

impacts.

Projection of sulphur dioxide and ash emissions in the next five years

In the lately published CLP's Social and Environmental Report, we found that even though the coal consumption was decreased by 13% and the gas consumption was increased by 44% between 2003 and 2004, the emissions of sulphur dioxide and particulates still increased by 1.3% and 29% respectively. This clearly shows that the sulphur content in coal was increased. With the supply of high-sulphur content, low-quality coal and the 6% increase of power generation in 2004, the increase in the natural gas supply obviously failed to reduce the air pollutants.

In August 2005, CLP announced that they secured a 5-year, 10-million tonne contract with Adaro's EnviroCoal. CLP claimed that it is the most environmentally friendly coal available, which will help cut sulphur dioxide emissions by one-third by 2007. However, the Economic Development and Labour Bureau forecasted a 3% of annual increase of power generation in the next five years, mainly due to huge demand from the neighbouring Guangdong Province. With regard to the power shortage in mainland China, CLP's power sale to Guangdong Province will continue to rely on coal-fired power generation. This will not only worsen the air quality of the Pearl River Delta region, but also discourage the renewable energy expansion initiated by the National Development and Reform Commission.

In the next five years, with the limited and unstable supply of natural gas and the maintenance work in the Daya Bay nuclear plant, the ratio of coal consumption is expected to further increase. Therefore, even with the application of EnviroCoal, the emissions of air pollutants will still keep at a certain level, which fails to meet the targets for improving the air quality of Pearl River Delta region. Environmental Protection Department released a commissioned study in April 2002, requiring reduction targets for several air pollutants, namely sulphur dioxide, nitrogen oxides, respirable suspended particulates (RSP) and volatile organic compounds (VOC). Using the level of pollutant emission in 1997 as a baseline, the target should be reached by 2010. In 2003, a consensus was reached between the Hong Kong SAR and Guangdong Provincial government on the emission targets. The emission reduction targets for electricity generation were set as follows:

Air pollutants	**Sulphur dioxide**	**Nitrogen oxides**	**Respirable suspended**

			particulates
Emission reduction target (%)	40%	20%	55%
1997 level by all power plants (kilotonne)	54.4	56.1	3.75
2004 levels by CLP plants (kilotonne)	51.8	28.6	2.2
2010 target level (kilotonne)	32.6	44.9	1.69
Estimated target* for CLP in 2010 (kilotonne)	25.4	30.4	1.14

* In 2004, the CLP generated 25,109 GWh of electricity, while Hong Kong Electric generated 12,108 GWh. Therefore, CLP should be responsible for approximately 67.6% of reduction target for power generation.

According to the brochure of Castle Peak Power Station, approximately 9 million tonnes of coal was consumed between October 1992 and September 1993 period. In 1992, it was reported coal consumption was recorded 224,941 TJ, while 133,403 TJ was recorded in 2004. Therefore, we estimated that over 5.33 million tonnes of coal was used in 2004.

We assumed that the EnviroCoal would be applied from 2006, and each year 2 million tonnes will be used between 2006 and 2010 period. According to the government estimate, 3% increase in power generation is forecasted in the next five year. Therefore, we made the following projections of sulphur dioxide and particulate emissions, and the ash production as follows:

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Overall coal consumed (TJ) (3% increment assumed)	137,405	141,527	145,773	150,146	154,650	159,290
EnviroCoal consumed (TJ) (2,000 kT per year)	--	49,404	49,404	49,404	49,404	49,404
Percentage EnviroCoal mix (%)	N/A	34.9	33.9	32.9	31.9	31.0
Sulphur dioxide emission (kilotonne)	53.3	39.3	41.7	43.0	45.5	46.9
Ash production (kilotonne)	375	278	289	302	314	327

Particulates emission (kilotonne)	2.3	1.7	1.8	1.9	1.9	2.0

(Source: EnviroCoal's specification and the blending calculator can be found at www.ptadaro.com)

Once the EnviroCoal is applied, we can see the sharp decrease in the emission of air pollutants, especially sulphur dioxide and particulates. And the levels of sulphur dioxide and particulates emissions in 2006 and 2007 may not exceed the emission caps, which were set for the Castle Peak Power Station's license renewal (EPD 2005). However, the annual increase of conventional coal applied counteracts the reductions, and hence the air pollutant emissions gradually increase again. Even so, in the first year of EnviroCoal application, the emissions of sulphur dioxide and particulates will not reach the target, i.e. 25.4 kilotonnes and 1.14 kilotonnes respectively. The application of EnviroCoal is obviously the CLP's trick to blind the people's attention over the environmental hazards of coal. This move is simply to meet with the requirements of license renewal, rather than a long-term solution. After the renewing license in 2008, it is predicted that CLP will fail to take other measures to curb the continuous increasing trend of pollutant emissions.

Health impacts of air pollutants

Coal-fired power plants release substantial quantities of nitrogen oxide and sulphur dioxide and particulates into the air. Long-term exposure to fine particulate matter increases the risk of cardiopulmonary disease, asthma, bronchitis, as well as upper and lower respiratory problems.

Sulphur dioxide

Sulphur dioxide is a colourless, irritating gas, is a product of burning coal, which combines with ammonia to create fine particulate matter. Fine particulate matter can travel long distances and can be inhaled deeper into the lungs than other larger particles. The inhalation of high levels of sulphate aerosols is associated with premature death and increased sickness and mortality from lung disorders, such as asthma and bronchitis.

Particulate matter

Particulate matter, or soot, is the general term defining small pollution particles in the atmosphere. Particulate matter is so deadly because its small size allows it to

be inhaled deeper into the lungs than larger particles. Breathing high concentrations of particulate matter can damage lung tissue and contribute to cancer and respiratory disease. Living in places with increased levels of particulate matter will increase mortality from respiratory and cardiovascular disease.

Toxic heavy metals
The continuous production and release of these toxic elements such as arsenic, mercury and lead, to whatever low level, pose health hazard to human beings as well as damage the environment.

Conclusions and demands

The coal ash samples we collected from the ash lagoons and the cement plant contains toxic trace elements of below levels reported from similar studies in Spain, Greece, UK and China. However, the existence of these toxic elements such as arsenic, mercury and lead, to whatever low level, still poses health hazard to human beings as well as damages to the environment. And the greater proportion of mercury is vented via the flue stack gases rather than being trapped in the fly or bottom ashes. The percentage of gaseous mercury in the waste-streams can be as high as 95% of the total mercury content. We should keep an eye on the levels of these trace elements in the coal fly ash, either stored in the ash lagoons, sold to the cement plants, or emitted to the surrounding environment.

The application of the so-called EnviroCoal in the coal-fired power generation will somehow reduce the emissions of sulphur dioxide and particulates. However, this move is simply to catch up with the requirements of power plant's license renewal, rather than a long-term solution. The emission levels fail to reach the reduction targets for improving the air quality in the Pearl River Delta region by 2010, and will rise again due to the increasing electricity demand, especially from the neighbouring Guangdong Province. Moreover, the emission data of 2004 already revealed that the increased supply of natural gas did not help reduce the emissions of both sulphur dioxide and particulates. By the same token, EnviroCoal will fail to help CLP meet the reduction targets in long run. EnviroCoal itself is not clean compared with other renewable energy such as wind, whereas the clean wind energy resource is abundant all over the Guangdong Province. For the sake of our climate and air quality, wind is undoubtedly the most feasible option for CLP.

Therefore, we strongly demand

- Environmental Protection Department to enforce the implementation of the emission reduction targets, and ensure the power plants to take the appropriate steps to curb the emissions of pollutants. The SAR government should reserve the rights to penalise the power companies that fail to meet the targets, and impose targets for emission reduction and wind energy development during the review of the criteria for issuing and renewing the power plants' licenses.
- Environmental Protection Department to revise the Air Quality Objectives (AQO) so as to ensure the general public is fully informed about all the pollutants, including the atmospheric toxic heavy metals and their compounds.
- Power companies to make sure the emission levels of air pollutants reach the targets set by the Environmental Protection Department for improving the air quality in Pearl River Delta Region by 2010.
- Power companies to announce a concrete timetable to phase out coal-fired power generation and heavily invest in wind energy as a long-term solution to the air pollution, with regard to the increasing electricity demands of both Hong Kong and Guangdong Province.

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Appendix
Method of sample collection and analysis

Sample 1: MI05025

Location: Gammon Construction, Tsing Yi
Date of collection: July 12, 2005
Time: 12:00 Noon

Description of site and sample
The site is a cement manufacturing plant. Our members got verbal confirmation from an engineer in the plant that all the fly ash used in their plant is bought from CLP. The fly ash sample is provided by the same engineer.

According to our observation, fly ash from CLP is transported from the Castle Peak Power Plant in an enclosed truck to the cement plant. Upon arrival the plant unloaded the fly ash directly from the vehicle to the manufacturing unit of the cement plant. The general environment of the plant is dusty. Breathing is particularly difficult, yet the whole process of fly ash transportation is seemingly enclosed.

Sample 2: MI05029
Location: CLP lagoon in Lung Kwu Tan, Tuen Mun
Date of collection: Aug 10, 2005
Time: 12:00 Noon

Description of site and sample
The site is previously a lake area, but now has become a hardened surface covered by soft material. The cover layered is soaked with water as it rained last night. On the entire hardened surface, the white covering layer is found by the margin, next to rock and dead plant.

The sample is supposed to be fine sediment, but due to rain last night, it is a bit wet, constituting a thin layer of a few centimetres. The ash is greyish white in colour.

Sample 3: MI05030
Location: CLP lagoon in Lung Kwu Tan, Tuen Mun
Date: Aug 10, 2005
Time: 12:30 PM

Description of site and sample
The site is about 100m away from the first site. It is also previously a lake area, but now has become a hardened surface covered by soft material. The layer is soaked with water as it rained last night. On the entire hardened surface, the white covering layer is found by the margin, next to rock and dead plant.

The sample is supposed to be fine sediment, but due to rain last night, it is a bit wet, constituting a thin layer of a few centimetres. The ash is greyish white in

colour.

Sample 4. MI05031
Location: CLP lagoon in Lung Kwu Tan, Tuen Mun
Date: Aug 10, 2005
Time: 12:45 PM

Description of site and sample
The site is by the fresh water lake, where a greyish white layer is floating and pushed by the wave to the shore. Maybe due to the different in density, the border separating the water and layer is quite clear.

The sample is as soft as defrosting butter, the thickness of the layer is about a few centimetres. When a certain amount of it is lifted up by the spatulas, it will not collapse right away; therefore the layer should already be quite solid.

Sample 5. MI05032
Location: CLP lagoon in Lung Kwu Tan, Tuen Mun
Date: Aug 10, 2005
Time: 1:00 PM

Description of site and sample
In terms of the characteristics of the site, this one is more or less similar to MI05029 and MI05030. However, one major difference is that, there are small and shallow holes spread very regularly on the surface of the layer. This might be due to the heavy rain last night. Moreover, this sample can be tab more easily than 029 and 030. Therefore, it is possible that the sample in this site is fresher than 029 and 030, in other words, less solidified than the two.

Sample 6. MI05033
Location: CLP lagoon in Lung Kwu Tan, Hong Kong
Date: Aug 10, 2005
Time: 1:15 PM

Description of site and sample
The site is about 100m away from the site of MI05031, by the fresh water lake, where a greyish white layer is floating and pushed by the wave to the rock shore. Maybe due to the different in density, the border separating the water and layer is quite clear.

The sample is soft like defrosting butter, the thickness of the layer is about a few centimetres. When a certain amount of it is lifted up by the spatulas, it will not collapse right away; therefore the layer should already be quite solid. in other word, the textures of both MI05031 and MI05033 look similar.

Summary of methods with MCERTS accreditation

SAMPLE PREPARATION

Drying of a sub-sample was carried out after homogenisation in an oven at <30°C until sample appears dry. Sample size fractionation was carried out by sieving the sample through a 10mm mesh sieve. The homogeneity of the air-dried (<10mm) fraction was then improved by grinding up using a ball mill, jaw crusher. A portion of the ground sample was then taken for % dry weight 30 and at 105° C.

SAMPLE DIGESTION FOR ANALYSIS OF As, Se, Hg, Ba, Co, Mn, V, Cd, Cr, Cu, Ni, Pb and Zn (accredited dets)

The method employs aqua regia reflux extraction of metals from soils. The resulting digests are suitable for metals analysis by inductively coupled plasma optical emission spectroscopy (ICPOES), mercury analysis by cold vapour atomic absorption spectroscopy (CVAAS) and Se by Hydride generation atomic fluorescence (HGAFS).

Digestion equipment: Gerhardt Kjeldatherm trace metal digestion system with water cooled condensers and 250 ml digestion tubes.

Procedure: Open Tube Digestion of Solid Samples

1.0000 ± 0.1000g of well mixed, dry sample was weighed into an anti-static weighing boat then transferred sample into an acid washed digestion tube. Two reference materials of an appropriate matrix and two blanks were digested with each batch of samples. 2.5±0.05ml of nitric acid (4.2), followed by 7.5±0.2ml of hydrochloric acid (4.4) were added to make aqua regia. The contents of the tubes were allowed to stand at room temperature in a fume extracted area for a minimum period of eight hours.

The samples were then digested using the following sequence: 60ºC for 10 minutes, 80ºC for 10 minutes, 100ºC for 10 minutes, 160ºC for 2 hours, 30 minutes cooling time.

When the program was finished, the inside of each condenser was rinse down with small portions of laboratory water and the contents of each tube quantitatively transferred into a labelled 50ml plastic centrifuge tube and make to 50±2ml with laboratory water. The acid digest is suitable for analysis by ICPOES, CVAAS and HGAFS.

SAMPLE ANALYSIS and PERFORMANCE

Determinand	Analytical technique	MRV (1g taken) mg/kg	Linear range (mg/kg)
Se	HGAFS	0.1	10
Hg	CVAFS	0.03	0.25
As	ICP-OES (189.0nm-MSF model for Cd interference)	2	100
Ba	ICP-OES (233.5nm)	5	2000
Cd	ICP-OES (228.8nm)	0.2	500
Co	ICP-OES (228.6nm)	1	500
Cr	ICP-OES (267.7nm)	1	500
Cu	ICP-OES (324.8nm)	1	500
Mn	ICP-OES (257.6nm)	1	2500
Ni	ICP-OES (232.0nm)	1	500
Pb	ICP-OES (220.4nm)	1	500
V	ICP-OES (292.4nm)	1	500
Zn	ICP-OES (213.9nm)	2	1000