Mercury emissions from India and South East Asia

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Abstract

Mercury is an element of growing global concern. The United Nations Environment Programme plans to finalise a new global legally binding instrument on mercury by 2013, to coordinate actions to reduce emissions of mercury.

It has been well established that Asia represents not only the region contributing to greatest current mercury emissions but also the region with the fastest growth rate. Despite this, emissions from human activities in most countries in this region are not well characterised.

This report summarises the limited data available on mercury emissions from India, Cambodia, Indonesia, Malaysia, the Philippines, Thailand and Vietnam. These countries were specifically selected as they are areas of potentially significant growth in energy use in the near future. Information is given on the major sources of mercury in these countries, concentrating mostly on coal combustion and the non-ferrous metal industry. Although it is beyond the scope of this report to make new estimates for emissions, information is provided on current fossil fuel use and industrial activity as well as projections for these sectors to 2020 to give an indication of the general scale of these sources and the potential for increased emissions in the future.

Some countries have established regulations or action plans on emissions and these are summarised where possible. Recommendations are then made for potential actions which could be taken in each country to encourage action and achieve economic reduction in mercury emissions.

Acronyms and abbreviations

ACI	activated carbon injection
AMAP	Arctic Monitoring and Assessment Programme
BFBC	bubbling fluidised bed combustion
CBFC	circulating fluidised bed combustion
EMB	Environment Management Bureau, Philippines
ESP	electrostatic precipitators
Exec	extended emissions control, AMAP scenario where emissions control technologies currently used in Europe and the USA are used elsewhere
FBC	fluidised bed combustion
FGD	flue gas desulphurisation
GW	gigawatt
IGCC	integrated gasification combined cycle
iPOG	interactive (computer programme) Process Optimisation Guidance, UNEP
ktoe	kilotonnes oil equivalent
LBIM	Legally Binding Instrument on Mercury
LHV	lower heating value
MATS	Mercury and Air Toxics Standard, USA
Mtce	million tonnes of coal equivalent
Mtoe	million tonnes of oil equivalent
MFTR	maximum feasible technology reduction, AMAP scenario where all available solutions/measures are implemented
MW	megawatt
NTPC	National Thermal Power Ltd, India
OECD	Organisation for Economic Co-operation and Development
POG	Process Optimisation Guidance document, UNEP
SQ	status quo, AMAP scenario where current patterns, practices and uses continue. Economic activity increases but emissions control practices remain unchanged
UNEP	United Nations Environment Programme

Contents

Acronyms and abbreviations 2

Contents. 3

1 Introduction 5

2 Mercury emissions in India 9
2.1 Mercury emissions from coal combustion 9
2.1.1 Estimates for mercury emissions from coal combustion 9
2.1.2 The coal sector in India 11
2.2 Mercury emissions from the non-ferrous metal industry 12
2.3 Projected emissions to 2020 13
2.4 Legislation and action plans 15
2.5 Pathways to reduction 16
2.6 Sumary and comments 18

3 Mercury emissions in South East Asia 19
3.1 Cambodia 19
3.2 Indonesia 21
3.3 Malaysia 23
3.4 The Philippines 24
3.5 Thailand 30
3.6 Vietnam 32
3.7 Summary and comments. 35

4 Conclusions and recommendations 38

5 References 41

1 Introduction

Mercury emissions have surged and fluctuated through human history. During the 19th century the activities associated with the American gold and silver rush released up to 1500 t/y of mercury into the global atmosphere. This declined during the wars and depression of the early 20th century to under 1000 t/y. However, the recent decades have seen a resurgence in emissions due to further gold mining along with other sources such as coal combustion, metal processing and cement production. The current rate of emission to the atmosphere is around 1000 t/y (Streets and others, 2012).

In the build-up to the completion of the 2013 United Nations Environment Programme (UNEP) Global Legally Binding Instrument on Mercury (LBIM) there is growing interest in the amount of mercury arising from different sectors and from different global regions. For the UNEP Instrument to be most effective, control strategies should be targeted towards those regions and sectors which could achieve the most significant mercury reduction. To this end, there has been growing interest in establishing emission inventories. Much of this work has been carried out under the auspices of UNEP, using their Mercury Inventory Toolkit (UNEP, 2011a). This is a relatively simple interactive Excel spreadsheet based on default emission factors which allows national activity data to be used to produce a standardised emission inventory for mercury for individual countries. More accurate, country-specific, emission factors can be used if these are available. Information on the UNEP inventory toolkit is available here:
http://www.unep.org/hazardoussubstances/Mercury/MercuryPublications/GuidanceTrainingMaterialToolkits/MercuryToolkit/tabid/4566/language/en-US/Default.aspx

This report includes the most recent inventories produced by UNEP and AMAP (the Arctic Monitoring and Assessment Programme). However, supplementary data have been included where possible. Although these inventories include all uses of mercury, including gold production, batteries and so on, this report concentrates on emissions from coal combustion and from non-ferrous metal industries.

Where information has been made available, this report summarises the assumptions made in the preparation of the inventories reported. But in many instances, the default values provided by UNEP (2011a) are used. This leads to estimates with relatively high levels of uncertainty and, in many cases, the values reported err towards estimating the maximum emissions from source categories such as coal combustion. For example, the default input emission factor range in the UNEP Toolkit is 0.05–0.5 g Hg/t coal for coal combustion, representing the minimum and maximum values respectively. The range used in the AMAP (2008) report for UNEP was 0.1–0.3 g/t for coal combustion in power plants and 0.3 g/t for coal combustion in residential and commercial boilers. By comparison, the data in the recent US EPA information collection project in advance of the new emission standard – MATS (mercury and air toxics standard) suggested values from well below 0.1 g/t up to 0.38 g/t, a wider range than that used by AMAP and UNEP. However, for the basis of making estimates of emissions where data are sparse, the use of average values (excluding outliers and extreme values) makes sense. Of course, countries using the UNEP toolkit are encouraged to prepare their own emission factors based on typical national coal use where possible. This should take into account factors such as the average mercury content of coal combusted, whether the coal is washed and how effective the method is for mercury removal, and the control technologies in place on the fleet of operational coal-fired plants. In some countries, however, this level of information is not available and the UNEP toolkit allows a ‘best guess’ estimate to be made.

As part of the UNEP work towards establishing national emissions inventories, AMAP (2008) has prepared an inventory of emissions for 2005. The emission factors are shown in Table 1. Using these values, estimates were made for global regions for the year 2005. Total emissions from the Asian region (excluding Russia) amounted to 65% of the global total emissions from human activities. The

Table 1 Emission factors used in the AMAP mercury emission inventory (AMAP, 2008)	
Source	Emission factor
Coal combustion	
Power plants	0.1–0.3 g/t
Residential and commercial boilers	0.3 g/t
Oil combustion	0.001 g/t
Non-ferrous metal production	
Copper	5.0 g/t Cu produced
Lead	3.0 g/t Pb produced
Zinc	7.0 g/t Zn produced
Cement production	0.1 g/t cement
Pig iron and steel production	0.04 g/t of steel
Waste incineration	
Municipal waste	1.0 g/t waste
Sewage sludge wastes	5.0 g/t waste
Mercury production (primary)	0.2 g/t ore mined
Gold production (large-scale)	0.025–0.027 g/t gold mined
Caustic soda production	2.5 g/t

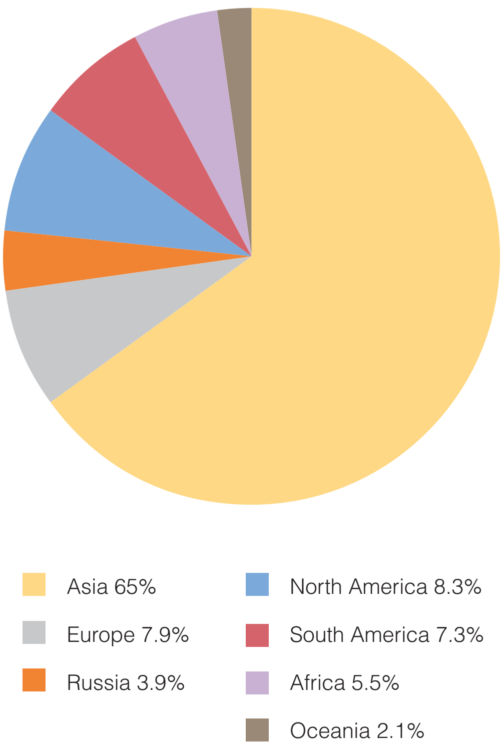

Figure 1 Total global emissions of mercury from human activities for 2005 by region (AMAP, 2011)

country contributions are shown in Figure 1 (AMAP, 2011). Figure 2 then shows the comparatively rapid increase in emissions from Asia from 1990 to 2005. Unfortunately there are no figures demonstrating how the different countries within Asia contribute to this total. However, the majority of emissions are from China, which is not surprising given the size and population of the country and the recent rapid growth in investment in energy production.

For Asia, the largest source of mercury emissions to the atmosphere was stationary combustion at 622 t/y, around 64% of the total emissions from this region. The next largest sources were cement production (138 t/y, 14%) non-ferrous metal production (90 t/y, 9%) and gold production (59 t/y, 6%)(AMAP, 2008).

Uncertainties in the emission calculations were estimated at ±25% for stationary fuel combustion and ±30% for cement, iron and steel, and non-ferrous metal production. The uncertainty was at least five times higher for

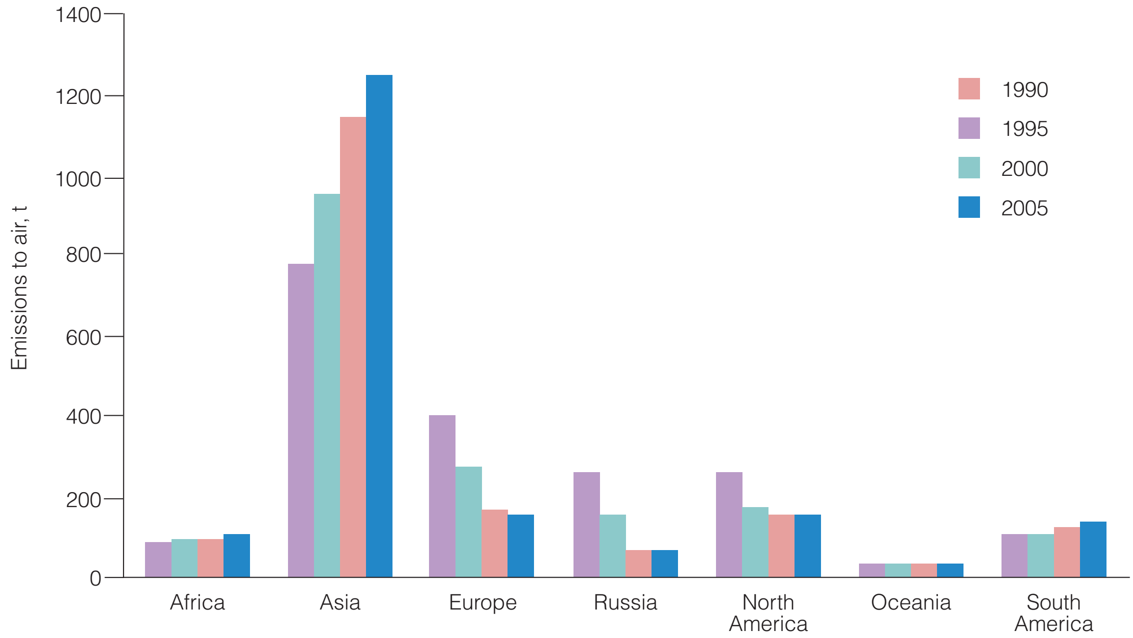

Figure 2 Increase in regional mercury emissions 1990 to 2005 (AMAP, 2011)

emissions from waste incineration and completely unknown for mercury and gold production. The uncertainty for total emission estimates for the Asia region were estimated at ±40%.

In a now somewhat dated report, Pacyna and Pacyna (2001) estimated global emissions of trace metals from human activities and put the total emissions of mercury at 1475 t/y for 1995. Of this, 860 t/y (58%) was estimated to arise from Asia. China was reported to contribute to 495 t/y (34%) of the total, and India to 117 t/y (8%).

In 2003, Pacyna and others (2003) updated their estimate to a global emission from human activities for 1995 to 1912.8 t/y of which 1074.3 (56%) was from Asia. Of this Asian total, 860.4 t/y (80%) was from stationary combustion, 87.4 t/y (8%) was from non-ferrous metal production, 81.8 t/y (7%) was from cement production and the remaining 4% from pig iron and steel production, and waste disposal.

Jaffe and others (2005) have produced an interesting report based on the measurement of mercury in remote locations and the traceability of these back to source regions. Results suggest that emissions of mercury from the Asia region may be significantly greater (more than double) the values estimated by Pacyna and others (2003). It was suggested that this could be due to a number of reasons including underestimation of emissions from this region, re-emissions of previously deposited Hg, natural emissions or errors in the understanding of the chemistry of atmospheric Hg.

From this brief review of the most quoted estimates of global mercury emissions it is clear that there is a significant amount of uncertainty in actual values for emissions from different regions and sectors. Despite this, there is fairly unanimous agreement that Asia is the largest regional source of emissions and, within this, stationary combustion is the largest single source sector (somewhere between 64% and 80%) with cement production (7–14%) and non-ferrous metal combustion (8–9%) contributing significantly less. Emissions from gold production remains the sector which poses the greatest challenge with respect to the estimation of actual emissions since much of the activity in this sector is small-scale or illegal. Emissions from gold production are beyond the scope of this report.

Chapter 2 of this report looks at published estimates for mercury emissions in India concentrating on emissions from coal combustion and the non-ferrous metal industries. Information on potential growth in these sectors is included along with a short discussion of the potential growth in emissions to 2020. Chapter 3 then presents similar work on mercury emissions from different sectors in Cambodia, Indonesia, Malaysia, the Philippines, Thailand and Vietnam now and to 2020. Countries such as China and Japan were not included as these countries have well established national emission inventories and already have action plans working towards mercury reduction from the energy sector. Where possible, Chapters 2 and 3 discuss any potential regulations, action plans or changes in national priorities which could affect mercury emissions from the selected countries in the future. Potential pathways to reducing emissions are discussed, concentrating as much as possible on the technologies and techniques which would be most appropriate for mercury reduction in each country.

2 Mercury emissions in India

India is one of the fastest growing countries in the world in terms of both population (currently over one billion and growing) and economy. The need for energy is therefore great, and with energy production comes the burden of potential emissions.

The AMAP (2008) global inventory for 2005 estimated total 'by-product' emissions (including emissions to all media) from India at 171.9 t/y. India ranked second in the top countries for mercury emissions but, at 8.93% of the global total, was significantly behind China at 42.85%. Looking only at emissions to the atmosphere, the 2005 inventory for India is included in Table 2. Emissions from stationary combustion dominate the inventory. A separate study by Mukherjee and others (2010) puts total emissions from India for 2004 at 222–310 t/y, slightly higher than the AMAP estimate, but still within the same order of magnitude.

The following sections discuss mercury emissions from coal combustion and the non-ferrous metal industry now and into the future.

2.1 Mercury emissions from coal combustion

Stationary combustion (all fuels) is by far the largest sector for mercury emissions in India amounting to almost 140 t/y (87% of emissions; Table 2). Coal is the main source of energy in India but oil, natural gas and hydro power are also part of the energy mix. India is the third largest producer of hard coal after China and the USA and around 70% of the heat and electricity production in India is from indigenous coals (Mills, 2007).

2.1.1 Estimates for mercury emissions from coal combustion

The estimate of emissions from coal combustion in India is extremely dependent on the mercury content of the coal – that is, the mercury emission factor. For the 2008 AMAP inventory, as shown in

Table 2 Mercury emissions India 2005 and 2020, kg/y (AMAP, 2008)

	2005	2020 projections		
		SQ	Exec	MTFR
Stationary combustion	139,659.5	208,842.3	92,724.9	67,635.7
Non-ferrous metal production	4,330.3	4,330.3	1,568.4	1,144.1
Pig iron and crude steel	1,523.3	1,523.3	551.7	402.5
Cement production	11,416.0	17,124.0	5,024.4	3,664.9
Large-scale gold production	124.8	124.8	124.8	124.8
Mercury production (primary)	0	0	0	0
Incineration municipal waste	0	0	0	0
Caustic soda production	4,002.5	0	0	0
Other	0	0	0	0
Total	161,056.5	231,944.8	99,994.3	72,971.9

Table 2, the highest value in the default emission factor range shown in Table 1 was used along with a coal consumption total of 404.7 Mt hard coal (anthracite and bituminous), 60 Mt soft coal (lignite and brown coal), and 38.1 billion m^3 natural gas. The total emissions of mercury to the atmosphere from stationary combustion were estimated at just under 140 t/y. Little or no reduction was made for mercury capture due to co-benefit effects of pollution control systems as most plants are fitted with only basic ESP systems (electrostatic precipitator) (Sundseth, 2012). Normally ESP systems can achieve some co-benefit mercury reduction, up to around 30% for some coals, but this is highly dependent on coal characteristics such as halogen and unburnt carbon content. However, Indian coals generally have high ash content and ESP systems do not cope well with such coals.

Indian coals are reported to have higher mercury contents than coals from other countries, with values cited in the literature ranging from 0.11–0.80 mg/kg. Kumari (2011a) cites a range of 0.18–0.61 mg/kg with a mean of 0.334 mg/kg, based on the analysis of coals taken from eight coal-fired power plants in India sampled between 2004 and 2006. This range is broader than the emission factors used in the AMAP inventory calculations. Based on the India-specific emission factors, Kumari (2011a) estimated that mercury emissions from coal combustion in power generation in India in 2008 were somewhere in the range of 59–200 t/y. However, Kumari (2011a) then argues that this range is 'extreme' and suggests that the mean value for 2008, 112 t/y, should be more representative of the true value. This was based on a coal consumption value of 321.21 Mt – representing only coals used in thermal power plants – which is lower than the coal consumption values used by AMAP, above, hence the lower emission estimate. Unfortunately, no information was given on the halogen (especially chlorine) content of the coal which has a significant effect on the behaviour of the mercury through the power plant.

Mukherjee and others (2010) used the same emission factors as Kumari (2011a) to estimate emissions from coal combustion in power plants in 2004 (373 Mt of coal combusted) at 120.85 t/y, which is similar to the 140 t/y estimated by AMAP in Table 2. Again, the difference in the estimate reflects the different value used for total annual coal consumption. It is not clear from the paper by Mukherjee and others (2010) whether any reduction factor due to control technologies was applied to the emission estimate.

New data from the Central Institute of Mining and Fuel Research (CIMFR, 2012) suggest that mercury concentrations in 66 coals studied ranged from 0.003 to 0.34 g/t with an average of 0.14 g/t. This value is relatively low compared to previously published values and those used by UNEP (*see above*). Measurements made at three full-scale plants suggest that the mercury emitted from the stack varied from 27% to 81% of that arriving through the coal feed. This large variation in these numbers is significant and makes it difficult to get a true representation of the amount of mercury which may be captured within existing pollution control systems. From the 0.14 g/t emission value above, CIMFR (2012) estimated that the annual mercury emissions from coal-fired power plants in India amounted to 38.5 t/y in 2008. The report also predicted that emissions would reach 106.1 t/y by 2016 and 148.7 t/y by 2021. However, this was based on the assumption from the UNEP tool kit of only 90% mercury capture in particulate control systems. Since this new CIMFR study has shown that the capture efficiency may actually be higher and the actual emission percentage lower, the emission estimates are likely to be on the high side. However, in order to confirm this, more work is needed on more plants to get an idea of the efficiency of existing particulate control systems in the average plant in India

From the numbers cited above it is clear that the estimate for mercury emissions from coal combustion in India would benefit greatly from more accurate data on mercury contents in coals combusted and also from better agreement on the annual tonnage of coal combusted. The emission factors quoted in the literature cited here range from the lower values of 0.15 g/t up to 0.61 g/t. More accurate data on the actual mercury concentrations of coals fired at different plants, used in a bottom-up calculation, would give a more accurate and reliable estimate of total emissions. Further, an up to date calculation based on current coal use would also be beneficial, bearing in mind the rapid increase in coal consumption.

2.1.2 The coal sector in India

According to Kumari (2011a) there were 'over 50' coal-fired power plants in India amounting to 14.6 GW in 2008 of which 6.6 GW were centrally owned (government), 3.8 GW state owned and 4.2 GW privately owned. These plants are quite evenly distributed throughout the country. Data from the IEA for 2010 puts the Indian coal capacity at a much higher value of around 100 GW. The reason for the discrepancy between the values quoted by Kumari and that of the IEA (and Wikipedia) may be due to some difference in definition or categorisation of plants. The IEA value is likely to include all plants in operation during the latest study (2010-11) period. The Indian coal-combustion sector is currently growing at an incredible rate which may also explain the disagreement between even more recently published figures.

The efficiency of coal-fired plants in India has been raised as one of the challenges facing the country with respect to efficient power production and reduced pollution. Of the installed 15 GW capacity, almost all plants are based on subcritical pulverised coal technology. Actual plant efficiencies have been measured at as low as 22.8%, and the 2006 country average of 27.6% (LHV basis) was significantly lower than the OECD average of 36.7%. Mills (2007) reviews power plant efficiency in India and the moves towards improvement under the NTPC's (National Thermal Power Ltd) Renovation and Modernisation Programmes and currently the average plant efficiency is reported to be around 30%.

There were around 60 bubbling fluidised bed combustors (BFBC) in operation in 2007 with 19 firing washery rejects and opportunity fuels (Mills, 2007). The number may have increased since then. In addition there are around 20 CFBC (circulating fluidised bed combustion) units, mainly at industrial facilities (Mills, 2010).

Indigenous Indian coals are very high in ash (around 45%), high in moisture (4–20%) and low in sulphur (0.2–0.7%) (Kumari, 2011a) and many plants were designed specifically to deal with this. Coal cleaning has not been common. Although 70% of thermal coal is transported over 400 km to the end user, only 20% of this was cleaned (Bhattacharyya, 2007). It has been estimated that coal washing to reduce the ash by 10% would incur additional transport and washery costs but that this would be outweighed by savings in total transport costs (Dua, 2003). Since coal washing would reduce transport cost and emissions of almost all pollutants, whilst increasing efficiency and reducing coal use, the increased use of coal washing in India would be an extremely economic and beneficial move forward.

By 2007 there were around 28 washeries in operation in India cleaning coal for power production and the total capacity amounted to around 70.35 Mt/y in 2007, less than 20% of the total coal used (Mills, 2007). However, this may increase in the future due to legislated changes. The Indian government has imposed a limit of 34% ash on coals for electricity production in an attempt to increase the overall efficiency and environmental performance of the coal fleet. Further, from 2002, the transport of coal with an ash level of more than 34% to power plants more than 1000 km from the pithead or located in urban or sensitive areas has been prohibited. Coal India Ltd announced in December 2011 that it planned to set up 20 new washeries with a combined capacity of 111 Mt. At present, Coal India operates 17 washeries with a capacity of 39.4 Mt. Of these 17, 11 were for washing coking coal. It is estimated that these plants will reduce ash levels by 7–8% (Mills, 2012).

As mentioned earlier, around 70% of the energy produced in India is from indigenous coals. However, coal blending with imported coals and other fuels is practised at some plants to improve process economics, for environmental reasons or in order to obtain optimal combustion performance (Buhari, 2003). Coal blending is therefore a simple option to improve combustion performance whilst complying with the requirement for <34% ash. For example, an Indian (Korba) coal of 40%, can be combined with 10% low ash Chinese coal, 20% washed Grade F Korba coal and 30% raw local coal. However, current coal blending methods have been described as 'rudimentary' with only one advanced blending facility (Reliance Energy's Dahanu power plant) in place by 2007 (Mills, 2007).

2.2 Mercury emissions from the non-ferrous metal industry

Mercury is released from the non-ferrous metal industry as a result of the coal used but mainly due to the mercury present in the sulphide ores of the metals (Cu, Pb and Zn).

The non-ferrous metal industry in India is significant, with some of the world's largest producers located in the country. Kumari (2011a) lists the major producers of non-ferrous metal in India as well as details of location, ownership and production rates. Kumari also provides details of the production processes used in each. The production rate of Cu has increased from 394 kt/y in 2003 to 734 kt/y in 2007 and that of Zn has increased from 278 kt/y to 440 kt/y in the same period. The production of Pb has been more stable, only increasing from 118.5 kt/y to 123.8 kt/y between 2003 and 2007.

As with coal, the mercury concentration of ores varies from location to location and from mine to mine. Selecting emission factors for the non-ferrous metal industry therefore has the same problems as that for emission factors for coal combustion. Emission factors can be found in the literature in the range 5.81–15 mg/kg for Cu, 15.71–43.6 mg/kg for Pb and 7.5–156 mg/kg for Zn. The higher emission factors are commonly associated with developing regions, especially China.

Kumari (2011a) selected a range of emission factors based on those published in the literature to estimate emissions from non-ferrous metal production in India:

Cu	5.81–15 mg/kg
Pb	15.71–43.6 mg/kg
Zn	8–25 mg/kg

Based on metal production rates for 2003 and 2007, the mercury emission values were estimated:

	2003	**2007**
Cu	2.1–5.8 t	3.0–7.2 t
Pb	1.2–3.3 t	1.4–3.8 t
Zn	2–6.3 t	3.3–10 t

Kumari's calculation resulted in a estimate of a total of 5.5–15.5 t/y mercury from the non-ferrous metal industry in 2007, with 80% of this coming from Zn and Cu production. Kumari (2011a) stressed that the 'scarcity' of Indian emission factor data means that the ranges for estimated emissions are large and subject to error. He also noted that the emission factor may be skewed upwards (towards a potential over-estimate) by including the higher emission factors obtained from developing regions.

In the AMAP (2008) inventory, emissions from the non-ferrous metal industry were estimated to be 4.3 t/y, only around 2.7% of the total emissions of mercury to the atmosphere in India (Table 2) and significantly lower than the estimate of Kumari (2011a).

Mukherjee and others (2010) used 2004 non-ferrous metal production totals, as shown in Table 3 to produce mercury emission estimates. Emissions from the iron and steel industry were estimated at 2.88 t/y for 2004-06, as shown in Table 2. Emissions from the non-ferrous metal industry were estimated as follows:

	2000	**2004**
Cu	3.84 t/y	6.0 t/y
Pb	0.17 t/y	0.125 t/y
Zn	4.4 t/y	5.96 t/y

The total for the non-ferrous metal industry for 2004 was therefore 12.09 t/y which is a factor of three higher than that estimated by AMAP for 2005 in Table 2 and more in agreement with the data from Kumari (2011a).

It is clear that the emission estimates for the non-ferrous metal industry would benefit greatly from

Table 3 Metal and cement production industry totals for India in 2004 (Mukherjee and others, 2010)

	Mt/y
Copper	0.401
Secondary copper	0.007
Lead	0.042
Secondary lead	0.04–0.05
Zinc	0.238
Secondary zinc	0.065
Pig iron	0.025
Raw steel	0.032
Cement	0.11

more accurate emission factors obtained specifically for the Indian situation – taking into account the local coals and ores and the specific technologies used.

2.3 Projected emissions to 2020

By 2015, India could become the fourth largest market for coal with demand expected to reach 790 Mt/y. The projected rate of coal consumption up to 2020 is the highest in the world (Mills, 2010). The GAINS model assumptions for India assume that coal consumption for power generation amounted to 5062 PJ in 2000 and had reached 7733 PJ by 2010. The projections for 2020 and 2030 are 13,698 and 28,028 PJ respectively. This represents a two- to threefold increase in coal energy use between 2000 and 2020 and an almost sixfold increase between 2000 and 2030. From the current total generating capacity (all fuels) of over 185 GW the IEA estimates that this will increase by between 600 and 1200 GW before 2050. For comparison, the total generating capacity of the EU was 740 MW in 2005. The growth is therefore immense, even on a global scale.

The Government of India has established five- year plans for the development of new power facilities in the future. The 11th plan (2007-12) aimed for 44 GW of new coal, 2 GW of new gas, 17 GW of new hydro plants, and 3.2 GW of new nuclear. The 12th plan (2013-17) includes 44.5 GW of new coal, 30 GW of new hydro and 12 GW of new nuclear (Kumari, 2011a). Although, as is increasingly common in the current global economic climate, not all of these plants may be commissioned or built within the planned time period, it is clear that the growth in the use of coal in India is increasing at an incredible rate. However, recent news articles suggest that coal supply stocks are running low in India with some plants holding only four days supply instead of the usual 20–30 days. The shortage is due to a combination of factors such as heavy rain, industrial action by workers and a supply-demand mismatch. New plant build will be dependent on this problem being solved (Mills, 2012).

The new coal plants planned for construction in India in the coming decade are mainly larger units – 25 x 500 MW and 6 x 660 MW under construction. Most of these plants will be subcritical but there is a move towards supercritical units, with the aim of having at least 24 GW of supercritical capacity by 2020. There are also plans for a series of 'Ultra Mega Power Projects' each of around 4 GW, several of which are already under development (Mills, 2010). Plans for new supercritical plants in India are being announced with increasing frequency but it is unclear whether all the plants will reach fruition. However, supercritical plants should be an important feature in the Indian power sector in the coming years (Mills, 2012). Legislation affecting the requirement for the installation of emission control technologies on existing and new plants is discussed in Section 2.4 below.

Kumari (2011a) calculated potential emissions from coal combustion in India for 2020 based on projected coal use and using the same emission factor (0.334 g/t) as was used to estimate current emissions (*see* Section 2.1). Coal consumption for power generation was projected to increase from 333,539 kt/y in 2009 to 410,264 kt/y in 2020, based on a incremental annual increase of 1.9%, year on year. Assuming no change in legislation or pollution control technologies (no co-benefit effects from any flue gas cleaning equipment) the projected emissions for 2020 for coal combustion amounted to 68–250 t/y.

Table 4 Scenarios considered in the AMAP report to estimate emissions for 2020 (AMAP, 2008)	
Title	Assumptions
SQ	Status Quo, where current patterns, practices and uses continue. Economic activity increases but emissions control practices remain unchanged.
Exec	Extended Emissions Control, where emissions control technologies currently used in Europe and the USA are used elsewhere (such as those required under LRTAP conventions, EU directives and so on). This would include control technologies such as ESP or baghouses and FGD systems on coal combustion systems.
MFTR	Maximum Feasible Technology Reduction, where all available solutions/measures are implemented leading to maximum mercury reduction with cost being a secondary consideration. This would mean the use of activated carbon injection (ACI) and other similar sorbent-based systems.

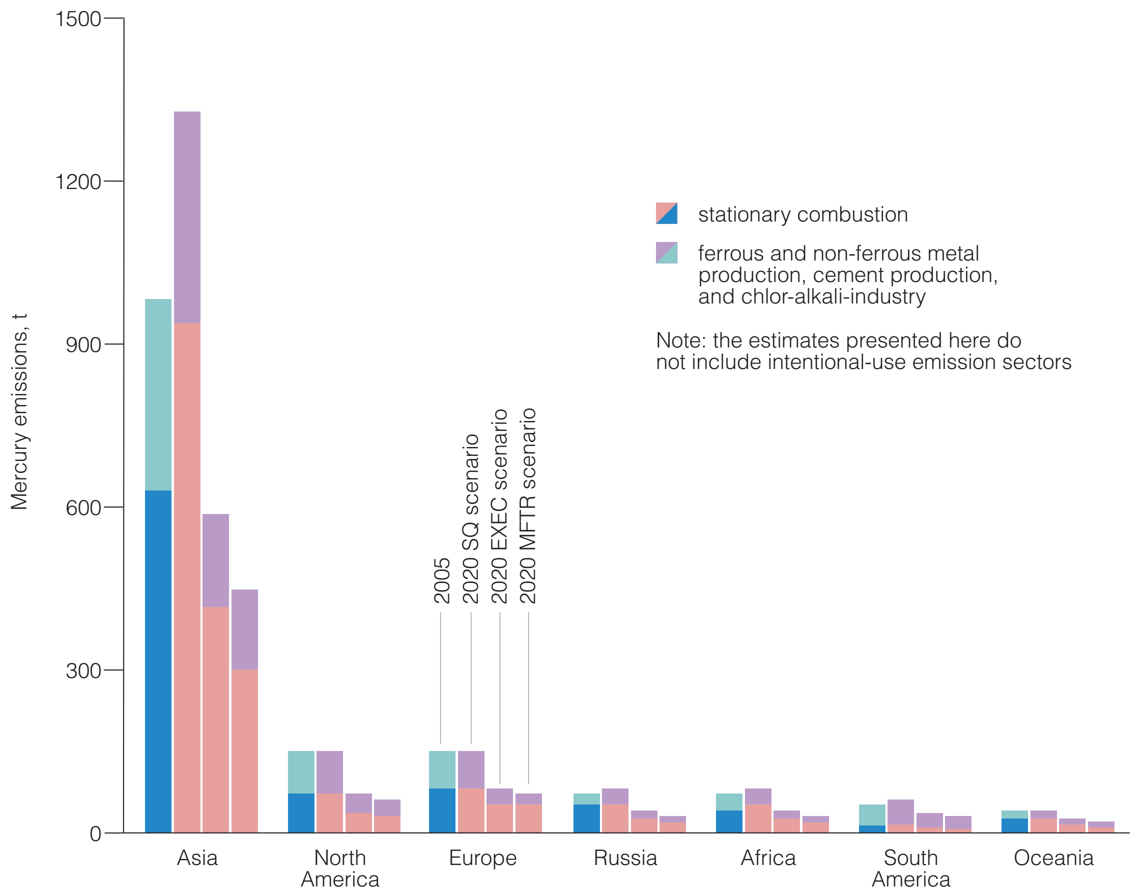

Figure 3 Estimated mercury emissions to 2020 from different continents under various energy scenarios (AMAP, 2008)

Corbitt and others (2011) have considered mercury deposition maps for the present and for 2050 under four different IPCC scenarios. The results aim to show the possible future deposition patterns for mercury globally in order to emphasise where the greatest problems may arise and where action may be most appropriate. Although the study does not look at individual country information it does summarise potential emissions from the different global regions. The study was prepared using the

GEOS-Chem model. The four scenarios used were based on variations in industrial growth. The worst-case scenario, A1B, assumed heavy used of coal with limited control technologies and the best-case scenario, B1, assumed aggressive transition away from fossil fuels and implementation of control technologies with up to 70% efficiency for mercury capture in developed countries. The intermediate scenarios, A2 and B2, assumed intermediate levels of action. The results of the study concentrated on the effects on mercury deposition rather than emissions to the air. Under scenario A1B, emissions from East Asia were predicted to increase by 47% by 2050 (based on 2005-07 data).

The AMAP report from 2008 estimated mercury emissions to 2020 from individual countries under various energy scenarios, as summarised in Table 4. Results for the Asia region are shown compared to other regions in Figure 3.

The results for India were included in Table 2 *(see page 9)*. Coal combustion and cement production were predicted to increase whereas the activity in other industries, such as non-ferrous metal production, were expected to remain constant. The more recent report by CIMFR, 2012) also suggests a significant increase in mercury emissions from coal combustion from almost 40 t/y currently to over 106 t/y by 2016 and over 148 t/y by 2021.

It is clear that, should no action be taken to reduce emissions, the total emissions from India could increase by 44% within the next decade, the largest increase being in the coal combustion sector. However, the application of 'standard' emission control technologies for particulates and SO_2 (ESP or baghouses and FGD systems; flue gas desulphurisation) could not only halt this increase in emissions but lead to an overall reduction in emissions of 38%. The use of ACI (activated carbon injection) or similar mercury-specific technologies could reduce emissions by almost 55%.

In reality, however, the likelihood of India deciding to implement any control technologies across the large coal-combustion fleet within the next decade is small and so the SQ projection is most likely to be the true path of mercury emissions for the near future.

Although emissions from the non-ferrous metal production sector were not predicted to increase under the SQ scenario, they were not predicted to fall either, without the application of control technology requirements.

2.4 Legislation and action plans

Indian coal is low in sulphur and therefore SO_2 emission limits have not been a priority and minimum stack height is currently the only provision to reduce SO_2 pollution locally. However, new plants over 500 MW must include space provision on site to facilitate the installation of flue gas desulphurisation technology in the future, in case legislation is established (Kumari, 2011a). The IEA CCC CoalPower database notes that there are currently several FGD units in operation in India: Dahanu units 1 and 2, Mundra units 1, 5 and 6, Ratnagiri units 1 and 2 and Trombay unit 5. Together this amounts to a total of 3250 MW of capacity with FGD in place.

There are no NOx emission limits. Emission limits for particulates were introduced in 1981 and since then, plants have been retrofitted with particulate control systems, mostly ESP.

As mentioned earlier, Indian coal is challenging with respect to low energy content and high ash. Most Indian power plants are running at efficiencies significantly below the global average. Efforts are being made to tackle these issues through Government programmes on plant efficiency improvements and new limits for coal ash (<34%). This latter approach may lead to more coal washing and blending in future. A meeting on 'Clean Coal for Green Power' in New Delhi in 2008 proposed that coal washing should become an integral part of all major coal projects. As a result, Coal India Ltd has proposed to set up 20 coal washeries in different coalfields to wash 110 Mt/y coal (Mills, 2012).

Indian coals have proved difficult to wash and therefore washeries built in India may prove more expensive than similar facilities built elsewhere. USAID (US Agency for International Development) is currently working with NTPC to improve several washeries (Mills, 2007).

Coal is seen as an intrinsic part of India's future industrial growth and India has a roadmap for clean coal technologies. This starts with the aforementioned coal beneficiation and power plant efficiency improvements in the short term, but aims towards demonstration of advanced coal combustion systems and potentially a carbon sequestration demonstration project before 2020. Ray and others (2009) proposed that India should establish a National Clean Coal Technology Centre. However, nothing seems to have been established as yet. BHEL is working towards demonstrated clean coal technologies in India starting with a pressurised moving bed gasification system, (6.2 MW, combined cycle) the first in a move towards establishing integrated gasification combined cycle (IGCC) technology in India. There have been various proposals for the development of larger (100–125 MW) IGCC demonstration projects but none seems to have reached construction phase. There is a small (52.5 MW) IGCC plant in operation at the Sanghi cement plant in Gujarat (Mills, 2012).

A Centre for Power Efficiency and Environmental Protection is reported to have been established under the NTPC to work on reducing CO_2 emissions and improving performance of coal-fired power plants. India was also the first Asian country to join the US Government's FutureGen Initiative – it is unclear whether India is still involved now that FutureGen 2.0 has switched to the oxyfuel process. Ray and others (2009) suggested that more pilot studies should be taken up by private companies and governmental organisations to promote cleaner use of coal in India.

2.5 Pathways to reduction

This brief literature review has highlighted several issues which are fundamental to the understanding of the challenge of mercury emissions in India and therefore to the goal of reducing these emissions. Although it is agreed that India is a significant contributor to the global mercury burden, the actual values are still somewhat ill-defined. More accurate emission factors, specific for Indian coals and non-ferrous metal ores, combined with up-to-date activity data and potential reductions due to co-benefit technologies would provide insight into the true scale of the challenge and would also potentially highlight areas, sectors and even specific plants and units which would be most appropriate for remedial action.

India is making commendable moves towards efficiency in its new plants, with the first three new supercritical plants (Sipat, Barh and Mundra) having come on line within the last year. The country hopes to have its first 800 MW ultra-supercritical power plant operating by 2017 (Mills, 2012). If this momentum continues, then there will be a beneficial reduction in all emissions compared to what might have been had the country continued to install subcritical combustion systems with lower efficiencies.

While India has already embarked on several admirable schemes to improve energy efficiency and reduce emissions, these would benefit from further evaluation to promote synergistic possibilities for enhanced multi-pollutant reduction. For example, coal washing and blending is being promoted to reduce the ash content of Indian coals. This practice could be extended or controlled in such a way as to maximise blends to promote reduction of all pollutants, including mercury. Further, coal washing would be an economic means of increasing energy efficiency whilst decreasing emissions and total fuel use.

UNEP (2012) have produced the POG (Process Optimisation Guidanc Document) which provides a summary of the options available for mercury control from coal combustion, covering everything from coal cleaning and blending, through co-benefit controls to more mercury-specific bolt-on approaches such as activated carbon and sorbent injection. UNEP have also made available the iPOG – an interactive computer model which allows coal and plant-specific data to be used to determine potential mercury reduction options most suited for each plant on a case-by-case basis. It is beyond the scope of this report to list mercury control options in detail and the interested reader is referred to the UNEP documents for more information. Perhaps the most important thing to note, however, is that although mercury reductions can be achieved with techniques and technologies such as coal washing, coal blending, co-benefit effects (from FGD and DeNOx technologies) and oxidation, the success of each of these approaches varies significantly from coal to coal and from power plant to power plant. Therefore, in order to determine which approaches would be most suitable for mercury reduction in India, significantly more data are required specifically on the content and mode of occurrence of mercury in Indian coals, on the chlorine content, and on the performance characteristics of Indian coal-fired plants. Based on general assumptions of the behaviour of low sulphur coals in plants with only particulate control systems in place, multipollutant options would be most suitable for Indian coal-fired plants – these could include the use of oxidant and sorbent additives to maximise the capture of sulphates, particulates and mercury in the solid ash from the plant. Since there are many different oxidants and sorbents available, preliminary testing would be required at several full-scale plants to determine which would be most appropriate to cope with the specific characteristics of Indian coals.

And so, in order to determine the most appropriate means to reduce mercury emissions from coal combustion and non-ferrous metal production in India, there will be a significant amount of work required. Proposed actions include:

- Measurement and characterisation of mercury in Indian coals. Current data on mercury in Indian coals are sparse. New data on mercury contents of coal fired at plants (after coal washing, if washing is performed) would improve emission inventories significantly. Characterisation of the mode of occurrence of mercury in Indian coals would provide information which would help to predict the washability of these coals and the behaviour of mercury during combustion. This information is crucial to the development of the most cost-effective means of reducing mercury emissions from coal combustion.
- Measurement and characterisation of mercury in Indian non-ferrous metal ores. More accurate data on mercury input into the non-ferrous metal industry in India will mean more accurate emission estimates and greater potential for targeting reduction strategies appropriately.
- Stack-gas monitoring at coal-fired plants and non-ferrous metal plants. Emission data, along with speciation, will allow the calculation of more accurate emission factors and a greater understanding of the behaviour of mercury in these systems. At the moment there are little or no data on the behaviour of mercury in Indian coal-fired plants firing Indian coals, or for Indian non-ferrous metal plants using Indian ores. These data are intrinsic to the understanding of the mercury problem in these sectors in India and crucial to the development of appropriate reduction strategies.
- A database of existing plants and plants under construction along with details of coals fired, control technologies in place and so on will provide the information needed to keep up to date with mercury emissions as India moves forward with its rapid energy expansion into the future.
- Application of the POG and iPOG, as produced by the UNEP Coal Partnership (UNEP, 2012), could help increase the understanding of potential cost-effective mercury reduction. Data obtained from coal characterisation, emission monitoring, and a power plant database can be input into the iPOG to demonstrate the most appropriate methods of mercury reduction for each plant.
- Projects and workshops on enhancing potential co-benefit effects of existing and potential flue gas technologies would benefit plant operators and provide them with the knowledge needed to make expert judgements on potential plant retrofits in the future.
- The current national requirement for coal washing and blending should be encouraged and expanded. Additional expert advice (through demonstration projects and workshops) could provide the understanding needed to maximise the mercury (and other pollutant) reduction potential of these approaches. It is also important that the coal washing approaches be studied in order to ensure that washery wastes do not end up causing further pollution elsewhere.

- The current national move towards improving plant efficiencies should be encouraged and could perhaps benefit from expert input as to how minor changes in plant operation can be used to reduce pollutant emissions whilst increasing plant productivity.
- Pilot and full-scale demonstrations of cost-effective, multi-pollutant control technologies specifically suited to the Indian situation could alleviate potential concerns that mercury emission reduction is likely to be prohibitively expensive. Low cost, relatively non-invasive approaches such as the use of oxidants and sorbents would be ideal for those plants concerned that FGD is not an option due to financial, practical and other concerns (such as limited water availability). Projects based on these strategies have already been demonstrated in Russia by UNEP and similar approaches should be tested in India.

2.6 Sumary and comments

With a rapidly growing population, India will host the greatest increase in energy use in the world over the next decade and much of this will be coal-based. India faces a significant challenge with respect to mercury emissions for several reasons:

- Indian coals are reported to contain higher than average mercury – this needs to be confirmed.
- Indian coals are particularly low grade (35–45% ash) and therefore more coal needs to be fired to produce power.
- The majority of Indian coal-fired plants are running below their designed efficiency and most are not fitted with any flue gas cleaning systems that could achieve mercury co-benefit reduction;
- The Indian non-ferrous metal industry is one of the largest in the world and growing.
- Current and impending environmental legislation in India will not have a significant effect on future mercury emissions.

For India to take control of current and future mercury emissions there needs to be a significant investment of expertise, time and money in improving the existing emission inventories. The emission factors currently used for estimating mercury emissions from coal and the non-ferrous metal industry are not specific to the Indian situation and therefore the published estimates can only be seen as best guesses. An emission inventory based on a bottom-up approach – using Indian-specific coal emission factors and plant-by-plant activity data – would not only give more accurate data but would also provide better guidance on potential hot-spot areas and help to pin-point the most cost-effective options for reduction.

Better emission factor and activity data, along with more detailed coal characterisation, would also provide the information needed to make a more expert decision on which control strategies could be best for India. For example, it is known that there is a move towards increased coal cleaning in the country, to reduce the high ash contents of the indigenous coals, and therefore a greater understanding of the mode of occurrence of mercury in Indian coals would allow coal companies to determine the most appropriate methods of coal cleaning to reduce mercury along with the ash. The increase in coal blending operations at some plants could also be manipulated to include consideration of coal mercury and chlorine contents to enhance co-benefit mercury control in existing pollution control systems.

Reducing mercury in India will be a significant challenge, especially since some of the most common means of mercury control (FGD and SCR systems) are not present on existing plants and are not likely to be required within the next decade. It is therefore imperative that mercury reduction strategies concentrate on a better understanding of mercury in Indian coals and non-ferrous metal ores to ensure that immediate action can be taken based on current practices. This would include coal cleaning and blending options and plant efficiency upgrading. It is also possible that economic, front-end multi-pollutant control strategies such as oxidation or sorbent use could increase the capture of mercury and other pollutants in existing particulate control systems.

3 Mercury emissions in South East Asia

Although China and India dominate when considering mercury emissions from Asia, there are several other countries that have growing economies and emerging energy markets. The following sections review published inventories from these countries and include a summary of their energy sectors. Projections to 2020 are included along with a discussion of any relevant legislation or actions plans. The majority of these projections are based on the AMAP (2008) scenarios which were summarised in Table 4 *(see page 14)*.

In each country section, below, suggestion are given for potential targets for action for mercury reduction.

3.1 Cambodia

According to the IEA CCC Coal Power Database, there are currently no coal-fired plants in operation in Cambodia. The electricity in the country is provided by 500 MW of oil-fired and hydro-electric capacity. There is, however, 1800 MW of new build coal-fired power to be constructed in Koh Kong province. This will be the first-phase of a 3660 MW project at Laem Yai Saen. The investors in the project include several power producers in Thailand. The finished project will produce power for Cambodia with the remaining power being exported to Thailand. The new plant, which will fire coal from Indonesia, is scheduled for construction in 2012 and to enter operation in 2016. However, ongoing tensions between the Cambodian and Thai governments has lead to delays and these delays may continue. This introduction of new power is seen as the beginning of growth in this sector with demand predicted to increase to >3000 MW by 2025 (Platts, 2012).

Mercury emissions from Cambodia for 2005 were estimated in the AMAP (2008) study, as shown in Table 5. The only source of mercury identified at that time was cement production.

Sambo (2010) and UNEP (2011b) worked together to produce an estimate of emissions from Cambodia using the UNEP inventory toolkit and the results are shown in Table 6. These results represent maximum total releases from each sector to all media and not just emissions to the

Table 5 Mercury emissions in Camboda 2005 and 2020, kg/y (AMAP, 2008)

	2005	2020 projections		
		SQ	Exec	MTFR
Stationary combustion	0	0	0	0
Non-ferrous metal production	0	0	0	0
Pig iron and crude steel	0	0	0	0
Cement production	8.0	12.0	3.5	2.6
Large-scale gold production	0	0	0	0
Mercury production (primary)	0	0	0	0
Incineration municipal waste	0	0	0	0
Caustic soda production	0	0	0	0
Other	0	0	0	0
Total	8.0	12.0	3.5	2.6

Table 6 Mercury releases from Cambodia, 2007-08 (Sambo, 2010)

Category of release	Maximum release, kg/y
Extraction and use of fuels/energy sources	119.511
Primary metal production (small-scale gold mining)	1182.0
Production of other minerals and materials	0.0013
Intentional use of mercury for industrial processes	–
Consumer products	8,485.362
Other intentional uses	163.019
Production of recycled metals	–
Waste incineration	67.329
Waste deposition/land-filling	4,665.56
Crematoria and cemeteries	162.384
Total	14,845.178

atmosphere. This suggests that a maximum of around 0.8% of the total 14.9 t/y of mercury released in the country was from extraction and use of fossil fuel and energy sources. Of this, the major sources were the use and extraction of crude oil (72.2 kg/y); use of gasolene, diesel and other distillates in power plants (28.5 kg/y); use of gasolene, diesel and other distillates in the transport sector (28.5 kg/y); and biomass for power and heat production (0.17 kg/y) (MOE, 2008).

It was estimated that around 20% of the total releases (around 3 t/y) were to the atmosphere. Of this, the major sources were consumer products (57%, largely as batteries), waste disposition/land-filling and waste water treatment (31%) and primary metal production (8%).

With respect to emission projections for the future, the AMAP (2008) study (*see* Table 4) suggests that cement production could increase within the next decade but that emissions could be controlled to some extent with basic or state-of-the-art control technologies. At the time of the AMAP study there was no information available on potential new coal build. As mentioned earlier, if construction proceeds as planned, there could be a new 1800 MW coal plant on-line by 2016 and even more by 2025. Although this is not a huge amount of coal capacity, this is a new fuel sector for Cambodia. It is likely that the Indonesian coal to be fired at the plant will have average or below average mercury concentrations. However, it is not clear at this stage whether the new planned plant will be installed with flue gas control technologies that will reduce mercury emissions by co-benefit effects. Many Indonesian coals are low in sulphur which may mean that plants are less likely to install FGD systems.

Sambo (2010) at the Department of Environmental Pollution Control at the Ministry of the Environment for Cambodia, has worked with UNEP to produce an action plan for mercury reduction which concentrates on the following priorities:

- develop guidelines/regulations for major emission sources;
- create a comprehensive emission inventory;
- reduce mercury emissions;
- produce mercury waste management approaches;
- establish mercury monitoring;
- establish mercury research programmes;
- education, awareness and communication.

For the moment, UNEP and other project work on mercury reduction in Cambodia is being concentrated on artisanal small-scale gold mining and on waste management issues.

The current action plan for Cambodia (MOE, 2008; Sambo, 2010) mentions the consideration for monitoring and regulating emissions from electricity generation but since there were no coal-fired plants in operation during the preparation of this action plan, it does not consider control options for this sector. However, with the imminent construction of at least 1800 MW of coal capacity, this will become an issue in future.

Since coal combustion will be a new venture for Cambodia, this is the ideal time for information and technology transfer to be applied to ensure that those involved with these projects will have the information and skill available to them to make the projects as efficient and clean as possible. Modelling systems such as the UNEP Coal Partnership's iPOG, a free program to estimate emissions of mercury based on plant and coal characteristics, would be a useful tool to predict emissions from planned plant configurations and proposed coal types in order to determine economic options for mercury control such as coal blending or the use of chemical oxidants.

3.2 Indonesia

Table 7 shows the AMAP (2008) estimate for Indonesian mercury emissions in 2005 to be 13,373.5 kg/y. The major source was large-scale gold production (5648.8 kg/y; 42%) followed by stationary combustion (3338.2 kg/y; 25%), cement production (1960.0 kg/y; 22%) and non-ferrous metal production (1314.5 kg/y; 10%).

Indonesia relies on coal for only 14% of its current (2006) total primary energy supply. The majority of power comes from oil (37%), biomass and waste combustion (28%), and gas (17%). Biomass is the primary fuel used for residential heating and cooking. Although Indonesia does not use much coal, it is a major exporter of coal into the international market (166.5 Mt/y from the largest Indonesian coal companies in 2007), and represents some of the cheapest coal production in the world (Baruya, 2009).

Despite vast resources of indigenous coal, Indonesia has suffered from power shortages for many years, with end users such as hospitals and shopping malls using their own generators regularly to maintain power. The situation has improved somewhat since the 1990s. Before 1990 the total

Table 7 Mercury emissions in Indonesia 2005 and 2020, kg/y (AMAP, 2008)

	2005	2020 projections		
		SQ	Exec	MTFR
Stationary combustion	3,338.2	4,754.9	2,111.2	1,539.9
Non-ferrous metal production	1,314.5	1,314.5	476.1	347.3
Pig iron and crude steel	112.0	112.0	40.6	29.6
Cement production	2,960.0	4,440.0	1302.8	950.3
Large-scale gold production	5,648.8	5,648.8	5,648.8	5,648.8
Mercury production (primary)	0	0	0	0
Incineration municipal waste	0	0	0	0
Caustic soda production	0	0	0	0
Other	0	0	0	0
Total	13,373.5	16,270.2	9,578.4	8,515.8

generating capacity in the country was 10 GWe but this had increased to somewhere between 25 GWe and 31 GWe (depending on source cited) by 2006. Of this, 34% is from coal, 26% from combined cycle gas turbines, 11% from hydro and 10% from diesel (the remainder being gas, oil and geothermal). Coal-fired generation has increased from 0.2 GWe in 1996 to 10 GWe in 2005, increasing coal consumption from 6 Mt/y to 27 Mt/y. This growth is expected to continue (*see below*) (Baruya, 2009).

Around 80% of the installed coal-fired capacity in Indonesia is fitted with some form of sulphur control – either scrubbing or sorbent based systems. A similar number of plants are fitted with low NOx burners (Baruya, 2009). It can therefore be assumed that there is significant co-benefit mercury control at these plants.

Industrial demand for coal in Indonesia amounted to around 18.6 Mtce in 2006 and is increasing. This is largely for non-metallic minerals production, mostly cement, using around 5 Mtce in 2006. Around 1–2 Mtce/y coal is used in the pulp and paper industry. The remaining coal is used in 'other' industry which may include brick and ceramic works (Baruya, 2009).

As part of the national policy to promote greater energy security, 8 GWe of current diesel-fired capacity is being converted to coal and an additional 10 GWe of coal capacity was due for completion by 2010, in addition to the 25–31 GWe of total generating capacity present in 2006. However, lack of reliable repair and maintenance has meant that some stations are not fully used, with the current rate of utilisation estimated at only 60%. The average efficiency of the currently operational plants is estimated at 30%, which is low considering that 80% of the capacity was built after 2000.

The Indonesian Government's 'crash-programme' was established to tackle the shortage and intermittency of the power supply. Under Phase I, 10 GWe of new capacity (all coal) was due online by the end of 2010 with a further 10 MWe to come online as soon afterwards as was possible, financially. Not all of the initial 10 GWe of capacity was completed within the 2010 timescale and further delays are expected.

A new supercritical coal-fired plant (815 MWe, 40–44% net efficiency), Paiton III, (east of Java) was due for completion in 2012 but has run into financing issues. Tanjung Jati, West Java, is also proposed as a site for a new 1320 MWe supercritical station for 2015 but there is no sign of activity on this (Baruya, 2009).

The challenges Indonesia faces with respect to rapid investment in, and construction of, new coal-fired plants to supply increasing energy demand have not all been met and it is not easy to distinguish which plans are on hold and which may be abandoned entirely. However, it would appear that, between 2006 and 2012, Indonesia doubled its coal-fired power generation capacity (from around 10 GWe to over 20 GWe).

The Ministry of Energy and Mineral Sources in Indonesia estimates that overall domestic consumption of coal will rise from around 50 Mt/y in 2006 to 220 Mt/y in 2025 at which point coal will make up around 35% of the primary energy mix in the country (Baruya, 2009).

Under the AMAP (2008) 2020 business-as-usual scenario (SQ; *see* Section 2.3), total emissions of mercury are predicted to increase, as shown in Table 7. All of this increase is predicted to arise from stationary combustion and cement production. However, emission reduction could be achievable in all sectors, except for large-scale gold production, based on the application of standard or advanced control technologies.

Although the raw data were not available, the data given by AMAP for mercury emissions from coal combustion for 2005 and 2020 (Table 6) would suggest that there will be only a small increase in emissions from this sector. This suggests that the AMAP study did not expect there to be a significant increase in coal use in Indonesia between 2005 and 2020. This does not agree with the Ministry of

Energy and Mineral Sources estimate, mentioned above, that overall domestic consumption of coal will rise from around 50 Mt/y to 220 Mt/y between 2006 and 2025. It can therefore be assumed that the AMAP estimates in Table 7 may underestimate future mercury emissions from coal combustion in Indonesia. However, at this stage it is not simple to determine whether this will be the case in practice. Indonesia certainly plans to install significantly more coal capacity in the coming decades – more than a four-fold increase. However, continued economic and political constraints may mean that the actual increase in coal capacity is significantly lower.

It is likely that any new coal-build in Indonesia would install SO_2 and NOx control, as this is common on most existing plants in the country (>80%). Therefore it can be assumed that co-benefit mercury control would be achieved. The future of mercury emissions in Indonesia will therefore be a balance between increased coal use, and effective mercury control through co-benefit measures. In order to achieve significant mercury control from the coal combustion sector, Indonesian coal-fired plants would benefit from mercury monitoring to ensure that co-benefit effects are indeed maximised. If additional mercury reduction is required, options such as coal blending and coal additives (oxidants or sorbents) would be most appropriate.

Although no further information could be found, data from the AMAP (2008) study (Table 7) suggest that mercury production from the non-ferrous metal industry in Indonesia is not expected to increase in the future, and may well decrease should control technologies be applied.

3.3 Malaysia

Malaysia currently has a relatively low coal demand at around 30 Mt/y, contributing only 12% of the country's primary energy supply in 2007. Natural gas supplies 48% of the primary energy supply with oil at 35% and the remainder coming from combustibles, renewables (biomass) and hydroelectric. Energy demand has grown at more than 9%/y between 1997 and 2007.

There have been issues with power blackouts in the country due often to severe weather issues such as lightning strikes to power lines (Baruya, 2010b).

Of the 28–29 GWe of capacity in place in 2009, more than 50% was from combined cycle gas turbines. Coal contributed 25% to the installed capacity (around 8 GWe). The majority of coal plants are around 440 MWe in size. According to Baruya (2010b) the utilisation of the coal fleet is around 50% over the year suggesting that there is spare capacity. Since 2000 there have been three major coal-fired developments of over 1 GWe each and three smaller projects of around 100 MWe. The 1100 MWe Manjung Plant in Perak, which fires bituminous and subbituminous coal, is fitted with low NOx burners, particulate controls and seawater FGD. The Tanjung Bin 1240 MWe plant fires subbituminous coals and is also fitted with NOx and SO_2 controls. In fact 'most' of the country's power stations are fitted with controls for particulates, SO_2 and NOx (Baruya, 2010b).

Emissions of mercury from Malaysia amounted to 4766.8 kg/y in 2005, as shown in Table 8. Stationary combustion is by far the greatest source of emissions to the air (1917.7 kg/y; 61%) followed by cement production (1432.0 kg/y; 30%), pig iron and crude steel production (248 kg/y; 5%) and large-scale gold production (169.1 kg/y; 4%).

Further data are available from the Malaysian Ministry of Natural Resources and Environment (MMNRE, 2006) who produced a report on the substance flow of mercury in Malaysia under UNEP guidance. Emissions of mercury from coal combustion were estimated at 210–1120 kg/y, amounting to 32% of total emissions to all media (not just air). Coal combustion in other sectors contributed a further 90–930 kg/y (14%). Cement production accounted for 340–1710 kg/y, amounting to 28% of releases. The remaining sources each contributed 3% or less to emissions apart from gold and silver extraction which was responsible for 30–360 kg/y (5.4%).

Table 8 Mercury emissions in Malaysia 2005 and 2020, kg/y (AMAP, 2008)

	2005	2020 Projections		
		SQ	Exec	MTFR
Stationary combustion	2,917.7	4,245.2	1,884.9	1,374.9
Non-ferrous metal production	0	0	0	0
Pig iron and crude steel	248.0	248.0	89.8	65.5
Cement production	1,432.0	2,148.0	630.3	459.7
Large-scale gold production	169.1	169.1	169.1	169.1
Mercury production (primary)	0	0	0	0
Incineration municipal waste	0	0	0	0
Caustic soda production	0	0	0	0
Other	0	0	0	0
Total	4,766.8	6,810.3	2,774.0	2,069.2

The large ranges quoted reflect the wide range of the UNEP emission factors used. Total coal sales in Malaysia amounted to 10.53 Mt. For the MMNRE (2006) estimation it was assumed that 8.47 Mt of this coal was used in power generating plants whilst the cement and iron and steel industries consumed 2.06 Mt. There are currently no data on the mercury content of the coal fired in Malaysia. However, since it is known that all plants are installed with FGD, it was assumed that mercury emissions would be reduced by 50%, based on mercury input via the coal.

As mentioned previously, a few new plants have come online in Malaysia in the last decade, all fitted with control technologies for particulates, SO_2 and NOx. Although a further new coal-fired unit of 300 MWe was proposed for an area on the eastern coast of Sabah, a region which has suffered outages due to transmission problems, the project has been delayed due to public protest. There has been no opposition to the proposal for a gas-fired plant in the region. The renewable energy movement carries momentum in Malaysia (Baruya, 2010b).

Although an increase in coal demand is likely in the future, this increase is likely to be 'modest' compared with other countries in the region. New capacity under construction is hydro-electric and gas-fired with a few gas and biomass plants. Coal for power generation could increase from the current 8 GWe to 14–15 GWe by 2030. The most likely area of growth in coal use is the cement sector (Baruya, 2010b).

As shown in Table 8, emissions from Malaysia could increase within the next decade and this will probably be due to increased activity in stationary combustion and cement production. These emissions could be reduce under the various reduction scenarios and, since FGD and De-NOx technologies are common in Malaysia, the Exec scenario is likely to be the most representative.

3.4 The Philippines

Based on the AMAP (2008) study, total mercury emissions from the Philippines amounted to 5417 kg/y in 2005, with the greatest sources being stationary combustion (1995.3 kg/y; 37%), large-scale gold production (1509.8 kg/y; 28%) and cement production (1040 kg/y; 19%). These values are shown in Table 9.

Table 9 Mercury emissions in the Philippines 2005 and 2020, kg/y (AMAP, 2008)

	2005	2020 Projections		
		SQ	Exec	MTFR
Stationary combustion	1,995.3	2,941.2	1,305.9	952.5
Non-ferrous metal production	857.5	857.5	310.6	226.6
Pig iron and crude steel	14.4	14.4	5.2	3.8
Cement production	1,040.0	1,560.0	457.7	333.9
Large-scale gold production	1,509.8	1,509.8	1509.8	1,509.8
Mercury production (primary)	0	0	0	0
Incineration municipal waste	0	0	0	0
Caustic soda production	0	0	0	0
Other	0	0	0	0
Total	5,417.0	6,882.9	3,589.2	3,026.6

UNEP (2011b) collated data suggest that the total emissions to all media, not just atmospheric emissions, may amount to 1670 kg/y, although the lower estimate (based on lower emission factors) could be 133.9 kg/y. Around 25% of this total mercury release was estimated to be emissions to the atmosphere – up to 420 kg/y, assuming the higher rate of emission. This is significantly lower than the AMAP (2008) estimate of 5417 kg/y, shown in Table 9.

For the purpose of completeness and including all published inventories for the Philippines, it should be noted that a further inventory by De Gala and Ocfemia (undated) has been produced based on the maximum UNEP emission factors. This report produced an estimate of 106,423 kg/y of total emissions of mercury to the air in the Philippines (unspecified year) with 20% of emissions arising from the extraction and use of fuel and energy resources. This estimate is significantly higher than the UNEP and AMAP estimates. It is unclear what assumptions were made with respect to fuel use in the De Gala and Ocfemia estimate.

In the UNEP (2011b) study, the total mercury release to all media, only 3% was estimated to arise from the extraction and use of fuel and energy sources. The largest sectors for mercury use were primary metal production (80–70% from copper and 10% from gold and silver) and 'other intentional product/process uses' (6%). Of the emissions from the extraction and use of fossil fuels, the emissions from coal combustion in power generation were estimated at only 0.3% of the total mercury releases in the country. Geothermal power production gave rise to 3% of the total. This would suggest that there is a significant disagreement in the data on the amount of coal consumed in the Philippines between the UNEP (2011) and the AMAP (2008) study.

The Philippines Environment Management Bureau (EMB, 2011) created their own emission inventory for the country using the UNEP mercury inventory toolkit and based on 2005 data.

According to the inventory, total emissions to air amounted to 78,628 kg/y, of which the top three principal subcategories releasing mercury into the air in the Philippines were:

- Primary Virgin Metal Production – 39,507 kg Hg/year (50%);
- Extraction and Use of Fuel and Energy Resources – 31,886 kg Hg/year (40%);
- other intentional use (thermometer, etc) – 7064 kg Hg/year (<9%).

The estimate for coal combustion in large power plants was based on 2005 Philippines Energy Data.

The total coal consumption amounted to 10 Mt per year, where 28% was indigenous coal and 72% imported from other countries. In the calculation, it was assumed that all the coal consumption in the Philippines is used by coal-fired power plants. Emissions to air are summarised in Table 10. In addition to the 485 kg/y that was estimated to be emitted to the air from coal combustion, a further 54 kg/y was estimated to end up in waste materials from the plant – the capture efficiency being estimated at 10% of mercury input to each plant. This estimate was based on using the lower value for the mercury emission factor listed in the UNEP toolkit – that is, the 0.05 g/t value. Using the emission factor at the higher end of the range (0.5 g/t) gives an emission estimate of 4850 kg/y to the air. The full-range for potential mercury emissions from coal combustion is therefore 485–4850 kg/y, which covers the 1995.3 t/y estimated by AMAP for emissions from stationary fuel combustion, discussed above.

Around 39,507 kg/y of mercury is estimated to arise from primary metal extraction and initial processing (aluminium, gold, copper, zinc and lead). Industrial activity is also significant with fifteen cement plants along with sinter, nickel, chemical paper, phosphor and other plants in operation.

The EMB (2011) and AMAP (2008) studies produce vastly different estimates for total mercury emissions to the atmosphere for the Philippines – 80,755 t/y and 5417 t/y respectively. However, some of this is due to the different categorisation of sectors. The greatest difference is due to the significant amount of emissions from gold and silver extraction and geothermal power production estimated in the EMB study. The AMAP study estimates emissions from all stationary combustion at 1995.3 t/y and EMB puts emissions from coal combustion alone at 485–4850 t/y. The AMAP estimate includes the use of other fuels (but did not give data for the individual categories) and therefore the numbers for coal are within the same range in each study. Similarly the AMAP and EMB values for emissions from cement production, 1040 t/y and 1203 t/y respectively, are also largely in agreement. The AMAP estimate for non-ferrous metal production, 857.5 t/y, would appear to be much higher than the estimate from EMB which puts lead production at 9 t/y and copper extraction at 3 t/y.

Table 10 Mercury air emissions in the Philippines, kg/y (EMB, 2011a)

Source	Emissions, kg/y
Gold and silver extraction	39,495
Geothermal power production	31,395
Miscellaneous product use	6,840
Cement production	1,203
Electrical switches	532
Coal combustion in power generation	485
Light sources with mercury	397
Laboratory equipment	218
Chlor-alkali production	105
Disposal of industrial waste	46
Crematoria	38
Thermometers	13
Lead extraction and initial processing	9
Natural gas -extraction, refining and use	6
Pulp and paper	6
Manometers and guages	5
Copper extraction and initial processing	3
Lime and lightweight aggregate production	3
Controlled landfill/deposits	2
Total	80,755

Assuming that the EMB has more recent and more country-specific activity data, their estimates can be considered to be likely to be more accurate than those from AMAP. However, the continued use of the UNEP inventory tool kit, and the default emission factors suggest that accuracy could be improved further with country-specific data.

The data used in the EMB study concentrated on all the power plants shown in Figure 4 except for Mindanao (232 MW) which came on-line after the study year, 2005.

Figure 4 Coal-fired power plants in the Philippines

The Presidential Decree No. 972 Coal Development Act of 1976 promotes the accelerated exploration, development, exploitation, production and utilisation of coal. Coal resources in the Philippines are significant, estimated at around 23 Mt of hard coal, 182 Mt of subbituminous coal and 119 Mt of lignite. Coal consumption has increased rapidly in recent years with over 7.3 Mt being produced in 2010, a further almost 11 Mt being imported amounting to a coal consumption rate of (run-of-mine) of over 18.3 Mt/y. Of this 72.44% was used in power generation, 23.42% in the cement industry and the remaining 4.14% in other industry (Kessels, 2012).

The growth in coal use recently is significant. Between 2009 and 2010, coal use for power generation increased from 16,476 GWh to 23,039 GWh – an increase of 39.83%. Coal combustion for power generation made up 26.6% of the power production output (GWh) with the remainder coming from natural gas (32.1%), geothermal (16.7%), hydropower (15.8%), oil (8.7%) and renewables (0.1%).

There are currently eight coal-fired power plants in the Philippines amounting to over 4100 MW capacity, as shown in Figure 4. At least three of these plants (Cebu, Toledo and Mindanao are fluidised bed combustion (FBC) systems. The rest appear to be pulverised coal fired units. Only Quezon and Sual appear to be fitted with low NOx burners and FGD at this stage, the remainder of the pulverised coal fired units are fitted with ESP systems. The growth in coal use is predicted to continue with ten new coal-fired plants, amounting to a further 1930 MW in capacity either planned or under construction, as shown in Figure 5. At least three of these new units will be circulating FBC (CFBC) units.

There has recently been an announcement for a further new 600 MWe coal-fired project in Mindanao as a joint project between Japan's Toyota Tsusho and Thailand's Electricity Generating companies. A further project will replace the 100 MW diesel-fired plant in Zamboanga with a 100 MW coal-fired unit (Power Technology, 2012).

There are at least 35 oil-fired power plants in the country amounting to 1978.60 MW of capacity. Using the UNEP default emission factors for oil of 1–100 mg Hg/t of oil gives an emission estimate of 0.37–37.23 kg Hg/y for this sector of which 90% is emitted to the air and the remainder is considered as general waste. There are also three natural gas plants totalling 1763 MW in capacity which, based on the UNEP default emission factor of 2–200 µg/m^3, lead to emissions of 5.78–578 kg Hg/y, all of which is presumed to be atmospheric.

A total of over 12,000 kt of cement was produced in 2006. The UNEP emission factors are 0.02–0.1 g/t, giving a total emission of between 241 and 1203 kg Hg/y.

As shown in Table 9, emissions from stationary combustion and cement production may increase under the AMAP SQ business-as-usual scenario. With the rapid installation of new coal-fired capacity, as discussed above, it is unclear whether the AMAP estimate is up to date with the potential growth in emissions from this sector. Coal use will increase, and possibly double, within the next decade. But many of these plants appear to be installed with FGD and DeNOx systems which could provide co-benefit mercury reduction. Further, some of the new plants will be CFBC systems which tend to emit significantly lower concentrations of mercury than pulverised coal fired units (Sloss, 2008).

The Philippines is currently reviewing the 1997 Chemical Control Order for Mercury and Mercury Compounds. This order applies largely to the importation, use and distribution of mercury and mercury compounds and, for the moment, sources such as chlor-alkali and electrical apparatus remain as permitted users of mercury. There are also pollution control and clean air laws but, for the moment, none of these lists specifically mercury. However, the Environment Management Bureau (EMB, 2011b) of the Philippines Department of Environment and Natural Resources, is establishing a national mercury task force to deal with the mercury issue. Within this plan there are remits for the following:

- encouragement of emissions monitoring and stack testing (target years 2009-15);
- encourage emission reduction in individual facilities (2009-15);
- improvement and refinement of emission inventories (current).

Although the task force acknowledges the effectiveness of emission controls and regulatory measures, it would appear that no limits or actions have been established as yet.

Figure 5 Proposed new coal-fired power plants in the Philippines

The recent mercury inventory produced by the EMB shows that the Philippines is already working to improve the accuracy of their national mercury emission inventory. The activity data used in their 2011 study are far more appropriate to a national inventory calculation than the generic data used in the 2008 AMAP study. However, the inventory could be improved significantly by replacing the use of default UNEP inventory toolkit emission factors (which range by a order of magnitude in some sectors) with country-specific emission factors. This could be achieved by a series of emission monitoring studies at representative emission sources.

As for the potential for mercury reduction from coal-fired units, more information is needed on the actual application rate of FGD and SCR systems in the country and how well these work for mercury reduction. Oxidants and/or sorbents could be used to enhance co-benefit capture. Those plants without FGD or SCR systems could consider multi-pollutant options such as oxidants and sorbents, possibly in conjunction with advanced particulate control systems. A study on the mercury capture efficiency in the country's FBC and CFBC systems would be of great interest and there is potential for testing for the applicability of oxidants and sorbents in these combustion systems.

3.5 Thailand

The AMAP (2008) emission inventory for Thailand for 2005 is shown in Table 11. By far the largest source of emissions in stationary combustion (6083.5 kg/y; 60% of the total). Cement production is also a significant source (3032.0 kg/y; 30%).

Thailand produces around 18–19 Mt of coal/y and had a total national coal demand of 32–36 Mt in 2008. Around 70% of the current electricity demand is supplied by natural gas with only 12.6% coming from low quality lignite and 8.2% from imported coal (Kessels, 2010).

There is a significant cement industry in Thailand, although 'many' of the cement factories use fuel oil rather than coal. Cement production in 2006 amounted to 39.4 Mt and clinker production amounted to 40.8 Mt. There is little or no domestic or residential use of coal in Thailand (Kessels, 2010).

Thailand has air emission regulations. The emission limit for mercury from 'Infected Waste Incinerators' is 50 µg/m^3 and for any industrial emission source the standard is 3 mg/m^3 for non-combustion systems and 2.4 mg/m^3 for combustion systems (PCD, 2012). This is higher than would be expected for mercury concentrations in the flue gas of the average coal-fired power plant and is therefore unlikely to require any control action to be taken.

The emission limits for new coal-fired plants range from 640 ppm SO_2 (around 1800 mg/m^3) for

Table 11 Mercury emissions in Thailand 2005 and 2020, kg/y (AMAP, 2008)

	2005	2020 Projections		
		SQ	Exec	MTFR
Stationary combustion	6,083.5	8,891.8	3,947.9	2,879.7
Non-ferrous metal production	576.0	576.0	208.6	152.2
Pig iron and crude steel	212.0	212.0	76.8	56.0
Cement production	3,032.0	4,548.0	1,334.4	973.4
Large-scale gold production	177.2	177.2	177.2	177.2
Mercury production (primary)	0	0	0	0
Incineration municipal waste	0	0	0	0
Caustic soda production	0	0	0	0
Other	0	0	0	0
Total	10,080.6	14,404.9	5,744.9	4,238.4

Table 12 Emission standards for existing power plants in Thailand (PCD, 2012)

Existing power plants	Emission standard value*					
	SO_2, ppm		NOx as NO_2, ppm		Particulate, mg/m^3	
Bangpakong (thermal plant, unit 1-4)	800	320	250	200	320	120
Bangpakong combined cycle plants unit 1 and 2 unit 3 and 4	60		450 230		60	
Pranakomtai (thermal plants) unit1 unit 2	800	320	180		240	120
Pranakomtai (combined cycle plants) unit1 unit 2	60		250 175		60	
Pranuakomnua power plant	500		180		150	
Surattani power plant	1000		200		320	
Langrabua power plant	60		250		60	
Nongjok power plant	60		230		60	
Sainoi power plant	60		230		60	
Wangnoi power plant	60		175		60	
Nampong power plant	60		250		60	
Other power plants which use: coal oil lignite	700 1000 60		400 200 200		320 240 60	

plants under 300 MW down to 320 ppm (around 900 mg/m^3) for plants over 500 MW (PCD, 2012). These limits are not challenging compared with limits set in the EU or USA.

Thailand has six coal-fired power plants in operation (according to the IEA CCC CoalPower database) as well as with some CFBC boilers and biomass units and some gas plants. Emission limits for the existing plants, on a plant-specific basis, are summarised in Table 12 – the lower emission limits are set for gas-fired plants and the higher limits for coal-fired units. Most coal-fired plants in Thailand appear to have FGD and NOx combustion control systems.

The largest of the coal-fired plants, the 1625 MW Mae Moh plant, has had serious SO_2 emission problems in the past with significant damage to the local environment and significant negative public reaction. Since then, FGD has been installed on all ten of the operating units and three further units have been taken off-line (CCC, 2012).

Thailand produced a revised power development plan in 2007 which stated that the total national grid capacity would increase from 29,140 MW in 2008 to 52,000 MW by 2021. To enable this there will be 7500 MW capacity of old plant to be retired and a total of 30,390 MW of new build. The limited supply of local natural gas resources are likely to mean an increase in the use of coal. The Thai Power Plan of 2009-12 outlines projections for increased energy to 2021 which suggests that, although the use of lignite will probably remain unchanged, power from imported coal will increase by around a factor of four, as shown in Figure 6. Table 13 shows the proposed timetable for new build plants over the next decade. It should be noted that it is expected that these with be private sector investments and

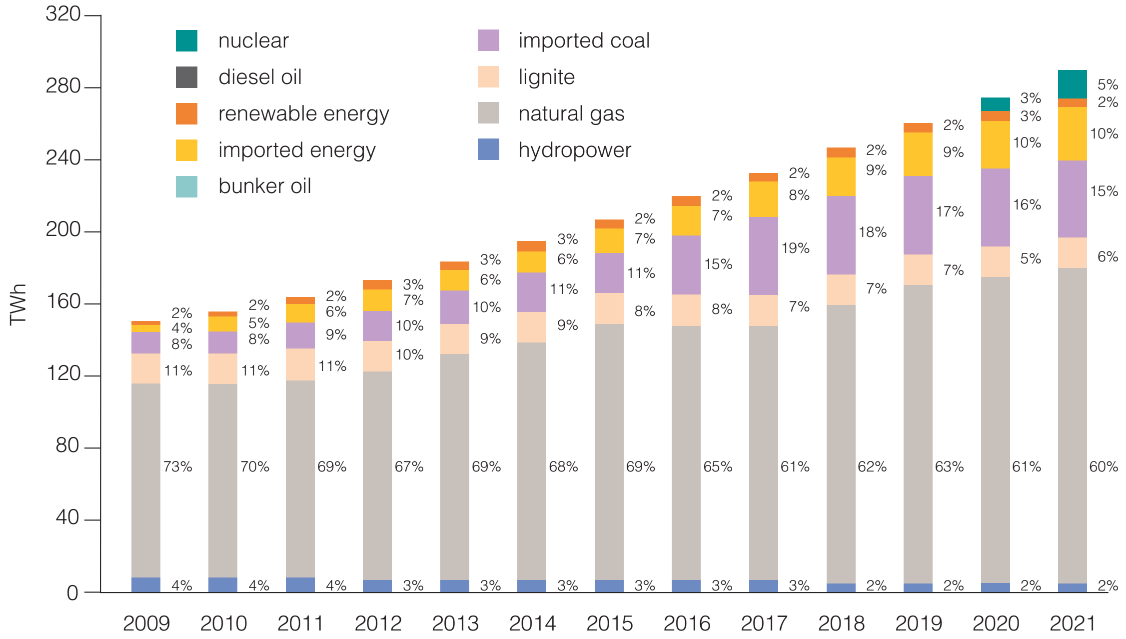

Figure 6 Thailand power plant 2009-12 (Kessels, 2010)

that some new capacity will arise from import of electricity from neighbouring countries. An additional 1100 MW of coal is expected between 2011 and 2015 with a further 700 MW between 2016 and 2021, giving a total new coal build of 1800 MW. This is significantly smaller than the 12,600 MW of new gas build and 4000 of new nuclear build expected between 2011 and 2012 (Kessels, 2010).

The coal being used in Thailand is of relatively low quality and this seems to result in new build plants being basic pulverised coal fired units, despite the fact that supercritical and ultra-supercritical systems could be more appropriate, economic and environmentally beneficial. Further, many of the existing plants are over 20 years old and would be suitable for upgrading to advanced combustion systems (Kessels, 2010).

According to the AMAP (2008) projections, emissions from stationary combustion and cement production could lead to an increase of 43% in total emissions of mercury by 2020, under the SQ scenario. Significant reductions could be achieved with both standard and advanced control technologies. Although the growth in the use of coal will be significant, the continued application of SO_2 and NOx control technologies will help reduce mercury emissions. However, more country-specific mercury emission factors and more detail of the mode of occurrence of mercury in the coals used in Thailand could go a long way to helping maximise mercury reducing by co-benefit effects and highlight further potential cost-effective options such as coal washing or blending.

3.6 Vietnam

Table 14 shows the AMAP estimates for mercury emissions from Vietnam in 2005. Stationary combustion (1980 kg/y; 55%) and cement production (1320 kg/y; 43%) are the two largest sources of emissions. From a literature review, it does not appear that anyone has applied more country-specific data or used the UNEP toolkit to produce an independent estimate for mercury emissions in Vietnam.

Vietnam produced around 43 Mt coal in 2009 but used only 20–25 Mt. Biomass and waste combustion comprised 46% of the country's primary energy demand in 2006 with coal and coal

Table 13 Power construction plan, 2009-21 (Kessels, 2010)

Year	Project to construct by EGAT		Project to construct by private sector			Purchasing neighbouring countries	
	Name of project	MW	Name of project	Large, MW	Small, MW	Name of project	MW
Total installed capacity at end of 2008				10,018	2079		
Producing increase							
2009	Pranakorn (South) No 3	710	SPP – Renewable energy		27	Num Thern 2	920
	Bangpakong No 5	710					
	Hydropower (small)	6					
2010	Pranakorn (North) No1	670	SPP – Cogeneration		90		
	Hydropower (small)	35					
2011	Hydropower (small)	38	Gec-Co 1	660		Num Nguem 2	597
			SPP – Renewable Energy		250		
2012			SPP – Renewable Energy		65	Thern Hin Boon (to enlarge)	220
			SPP – Cogeneration		924		
2013			SEC – No 1-2	1600			
			National Power Supply No 1-2 SPP – Cogeneration	270	540		
2014	Jana No 2	800	National Power Supply No 3-4				
	Wang Noi No 4	800	Power Generation Supply No 1-2	270			
			SPP – Cogeneration	1600	90		
2015							450
2016	Coal EGAT No 1-2	1400	New Power Plan (Khanom district)	800			450
2017	Coal EGAT No 3-4	1400					450
	Power Plan in South EGAT	800					
2018	Pranakorn (South) No 4-5	1600					450
	Pranakorn (North) No 2	800					
	Bangpakong No 6	800					
2019	Bangpakong No 7	800					500
	New Power Plan EGAT No 1	800					
2020	Nuclear Power EGAT No 1	1000	New Power Plan IPP (2 x 800)	1600			500
	Nuclear Power EGAT	800					
2021	Nuclear Power EGAT No 2	1000					500
	New Power Plant (South) EGAT	800					
New Power Plan 2009-21		15769		7600	1986		5037
Total System Producing to end 2021 (to offset old Power Plan)		26027		17059	3266		5677

products provided only 17%. With respect to power generation, hydro power has been the dominant energy source in the past providing 42% of the total. Gas provides 37% of the generation (in 2006), coal 17% and oil 4%. (Baruya, 2010a).

By 2007, there were nine coal-fired power plants in Vietnam (1024 MW), all of which fire anthracite except for the 100 MW Na Duong lignite plant. Many of these plants (1200 MW) were built between 2001 and 2006 and are therefore regarded as modern and relatively efficient (around 36%). Sorbent injection is used for SO_2 control at the 800 MW of capacity that is based on circulating fluidised bed combustion (CFBC). A further 900 MW of the pulverised coal fired capacity has FGD installed and two of the 600 MW units at the Pha Lai power station are fitted with wet limestone FGD and low NOx burners. It can therefore be assumed that some co-benefit mercury reduction is being achieved at most new plants. However, there is a 'significant amount' of capacity in older plants or even under construction which do not have any form of acid gas emission control (Baruya, 2010a).

Vietnam is currently constructing new electricity generating capacity at an impressive rate. Two plants, 220 MWe Son Dong and the 1200 MWe Quang Ninh-1 came online between 2008 and 2009. Construction has also begun on another seven plants amounting to 9006, MWe including the 4400 MWe Long Phu (Soc Trang; 3 units) plant and the 1800 MWe Thai Binh (2 units) and these units should be online by 2015. All of these plants are standard subcritical stations. The coal in Vietnam (local anthracite) are high rank with low volatility and therefore the plants must be designed specifically to cope with these characteristics. New coal projects have been proposed for after 2015 and the latest data suggest that this would mean eleven new coal-fired plants amounting to a further 17,705 MWe of coal capacity. However, as emphasised by Baruya (2010a), it is almost impossible to obtain an accurate forecast for such a dynamic economy as Vietnam.

Do and Sharma (2011) also predicted an increase in fossil fuel use from 2007 to 2025. The estimate for the increase in coal consumption between 2007 and 2025 suggested that coal-use would increase six-fold, from 9.9 Mtoe to 64.2 Mtoe. Other authors suggest a significantly lower growth rate. For example, Toan and others (2011) have summarised the projected energy demand in Vietnam for 2010, 2015, 2020 and 2030 based on the Vietnam Institute for Energy's Master Plan VI. The current coal demand in 2010 was 59,440 ktoe whereas the energy production amounted to 77,063 ktoe, meaning a surplus of 17,313 ktoe/y which can be sold abroad. Coal is responsible for about 36% of the total energy production. By 2020 coal use will have increased by 50% to 75 Mt/y and will contribute around 39% of the total energy production in ktoe. However, by 2020 the total energy production of the country will have fallen behind the actual demand by 28,217 ktoe and this is expected to worsen significantly by 2030 when the deficit will reach 104,820 ktoe, even with an increase in energy production from all sectors. In response to this potential problem, the country has produced a National Energy Development Strategy for 2020 with outlook to 2050 which concentrates on security of supply, development of new energy sources and power networks, and creating a competitive market, in addition to building Vietnam's first nuclear power plant by 2020.

In terms of energy output, the current generating capacity in Vietnam is around 17 GWe (2009). This is expected to increase to 40 GWe by 2015, although this estimate may be somewhat optimistic due to the global drop in economic growth and there is 'great uncertainty' in the future demand needs of the country (Baruya, 2010a).

As shown in Table 14, increased in activity in the stationary combustion and cement production sectors are likely to be responsible for a 49% increase in mercury emissions by 2020, under the AMAP SQ scenario.

Data on mercury emissions from Vietnam are extremely limited and even a more up-to-date estimate based on standard emission factors and current coal use would provide a more accurate emission estimate for the country than anything which has been published so far. A more in-depth analysis, based on country-specific coal analysis and plant data would give a superior estimate whilst providing

Table 14 Mercury emissions in Vietnam 2005 and 2020, kg/y

	2005	2020 Projections		
		SQ	Exec	MTFR
Stationary combustion	2,980.0	4,470.0	1,984.7	1,447.7
Non-ferrous metal production	0	0	0	0
Pig iron and crude steel	31.2	31.2	11.3	8.2
Cement production	2,320.0	3,480.0	1,021.1	744.8
Large-scale gold production	120.8	120.8	120.8	120.8
Mercury production (primary)	0	0	0	0
Incineration municipal waste	0	0	0	0
Caustic soda production	0	0	0	0
Other	0	0	0	0
Total	5,452.0	8,102.0	3,137.8	2,321.5

information which would be more appropriate for producing estimates on future emissions whilst pinpointing potential target areas and actions for reduction. Compared to the other countries discussed in this report, Vietnam has by far the greatest need for more accurate mercury estimation to establish a base level analysis of current emissions. That is not to suggest that Vietnam has a particular problem with mercury, rather that the lack of data means that it is not possible to determine whether emissions are of particular concern.

3.7 Summary and comments

The countries summarised above are varied in their mercury emissions and their potential energy futures. Although mercury from sources such as cement use and the non-ferrous metal industry may increase in some of these countries, it is the mercury emissions from coal combustion in the energy sector which may be of most concern. Table 15 summarises the state of understanding of the coal combustion sector in each country and the Table 16 summarises potential options for mercury reduction. These should be regarded as very generalised conclusions but indicate those areas of most concern and those options which may achieve the most economic results.

Table 15 Coal combustion for power generation in South East Asia – current knowledge

Country	Coal characteristics	Plant characteristics	Control technologies	Legislation/ Emissions monitoring
India	Poor	Poor	Basic particulate controls	limited
Cambodia	Fair (Indonesian coal)	Fair (delays on build)	Unknown (not decided yet)	none found
Indonesia	Fair	Fair (some efficiency issues at some plants)	Good (80% capacity has FGD)	some sulphur and NOx control but not Hg
Malaysia	Fair	Good	Good (FGD and SCR on all new plants)	? But public pressure is promoting less carbon-intensive energy options
Philippines	Fair	Fair FBC and CFBC systems would be candidates for Hg testing	Sketchy (“Many” plants have FGD)	some monitoring planned for coal-fired plants
Thailand	Good (Coal is of poor quality)	Fair FBC and CFBC systems would be candidates for Hg testing Plants are modified to fire low-quality coals	Good (“Most” plants have FGD)	some sulphur and NOx control but not Hg
Vietnam	Poor	Poor	Sketchy (FGD on newer units)	none found

Table 16 Coal combustion for power generation in South East Asia – potential options for Hg reduction

Country	Coal washing	Coal blending	Co-benefit potential (FGD and SCR)	Most promising Hg-specific options
India	high	high	none/very limited	coal washing, blending, plant efficiency improvements, multi-pollutant options such as oxidants and sorbents, possibly in conjunction with advanced particulate control systems
Cambodia	minimal	unknown	? (unknown as yet)	? (unknown as yet)
Indonesia	minimal	unknown	High – 80% capacity has FGD	co-benefit effects, additional oxidants, improvement in efficiency of older plants
Malaysia	unknown	unknown	High – "most" plants have FGD	co-benefit effects, additional oxidants
Philippines	unknown	unknown	Moderate – "many" plants have FGD	co-benefit effects, additional oxidants, potential for FBC and CFBC specific studies for Hg control
Thailand	? high (low grade coal)	? high (low grade coal)	High – 'most' plants have FGD	co-benefit effects, additional oxidants, improvement in efficiency of older plants Low-grade coal is used – more study needed on the mercury characteristics of these coals
Vietnam	unknown (challenging coal)	unknown (challenging coal)	High on new plants with FGD Low on older units with no FGD	co-benefit effects, additional oxidants on units with FGD, multi-pollutant options on other units

4 Conclusions and recommendations

As stated by UNEP (2011b) national inventories only give a rough estimate of mercury releases. However, ‘having an inventory with uncertain release estimates and a description of the uncertainty is generally better than having no inventory at all’. The emission inventories from organisations such as UNEP and AMAP provide a basis for the understanding of relative mercury emissions from sectors and regions globally. However, to obtain a true representation of emissions from individual countries, country-specific emission factors and activity data are essential. For the countries covered in this report, the emission factors used have generally been default emission factors and the activity data used in different studies have been inconsistent. In order to establish a true baseline of current emissions and to establish the sectors and sources most suitable for targeting mercury reduction, these emission inventories must be improved significantly and must be maintained into the future. Country and coal/ore-specific emission factors should be produced by extensive analysis of the coals used at coal-fired plants (taking into account any cleaning or blending). Stack monitoring would confirm emission values and provide information on any co-benefit mercury reduction occurring inside the plant. Activity data can be maintained with a national database of facilities including production/consumption totals of raw materials. Once these activities have established more accurate baseline data for mercury emissions it will become far easier to determine the most appropriate means of mercury reduction and will also provide the means of determining the success of these activities moving forward.

India presents the biggest challenge based simply on the current size and growth rate. It is reported that mercury concentrations in Indian coals are above average. Indian coals are also low grade and high in ash and so more coal is required to produce power. The potential for reducing emission factors for mercury in Indian coals by coal beneficiation is therefore significantly higher than elsewhere in the world. Currently Indian legislation does not include any requirement for FGD and DeNOx technologies which could offer co-benefit mercury reduction. And so, since co-benefit mercury reduction from pollution control technologies is unlikely to be realised within the next decade, coal cleaning and blending options are likely to be the most cost-effective means for mercury reduction in the immediate future. Currently there are moves towards coal washing and blending in India and these current projects should be encouraged and expanded as much as possible.

Many Indian power plants operate well below design efficiency, thus producing more pollution per MW of generated power. Current activities to improve plant efficiency should be encouraged and the POG and iPOG should be promoted to enhance the mercury control in existing combustion systems.

The Indian non-ferrous metal industry is large but, as with the coal combustion sector, the emission factors currently being used to estimate total emissions are default emission factors. Work needs to be invested in improving the quality of data on emissions from these sources. Although it does not appear that this sector is likely to grow significantly in the future, this may well change as global markets change. Further, the emissions from this sector are significant and are not expected to decline without some form of intervention. This sector would benefit from improved emission data along with an evaluation of the state of the technologies currently being used. Only then will it be possible to determined how to reduce mercury emissions from the sector through process controls or technology changes.

Although India and China dominate emission inventories for mercury in Asia, there are other South East Asian countries that contribute to total mercury emissions. These countries are generally regarded as developing or emerging economies, some of whom are somewhat behind the rest of the world with respect to pollution control. However, many have installed or are installing some of the most advanced combustion and pollution control systems available.

In Cambodia, mercury emissions arise mostly from consumer products, waste deposition and small-scale gold mining. However, the country is currently constructing its first coal-fired facility in conjunction with Thailand and could have 3600 MW in place by 2025. It is not known whether the new facility will be installed with technologies likely to result in co-benefit effects, so now is the time to promote knowledge and technology transfer to Cambodia to ensure that mercury emissions from coal combustion do not become an issue in the future.

Indonesia has around 10 GW of coal-fired capacity in place of which 80% has sulphur control systems in place. It would therefore be interesting to determine what amount of co-benefit mercury reduction is being achieved in these plants and whether this can be improved (through oxidation or other coal or flue gas manipulation). Coal use is increasing as diesel plants (8 GW) are being converted to coal and 10 GW of new coal capacity is coming online. There are issues with the efficiency of the current coal fleet and also with shortages of electricity supply. Further, plans for new supercritical plants appear to have been subject to delays. However, coal-used is still expected to have increased by over a factor of four between 2006 and 2025, data which does not appear to have been available when the AMAP mercury emission inventory for the country was produced. The mercury inventory for Indonesia would therefore benefit from updating, especially with country-specific coal and activity data. Indonesia is pro-active with respect to SO_2 and NOx reduction and therefore, although coal use is increasing, significant co-benefit mercury reduction can be expected. Stack monitoring for mercury would be beneficial in Indonesia to ensure that mercury control is optimised and that emissions remain under control in the future.

Malaysia appears to have spare capacity of coal-fired plants with the current utilisation rate of the 8 GW running at only 50%. However, new plants (>3 GW) continue to be built. Most of the country's plants are installed with SO_2 and NOx control systems and should therefore be achieving significant mercury co-benefit reduction. This should be verified with stack emission monitoring. In the future, there appears to be a move towards hydro-electric and gas-fired plants with the Malaysian population favouring renewable options. However, emissions from the cement sector may remain an issue in the future.

The Philippines would benefit greatly from work towards improving emission factors and activity data to produce a definitive emission inventory as the current literature implies significant disagreement. Emissions from cement production appear to be higher than those from coal combustion. Coal use for power generation is increasing rapidly in the Philippines, although many of these plants are FBC and CFBC systems, which typically release lower concentrations of mercury than conventional pulverised coal fired systems. Current coal capacity is around 4100 MW and this is expected to increase by at least 1930 MW within the coming decade. 'Many' of the current plants and those under construction have SO_2 and NOx control systems, which means that significant mercury reduction (>50%) can be assumed. This would benefit from flue-gas monitoring as confirmation. Some of the new plants will be CBFC systems and it would also be beneficial to carry out mercury monitoring on these plants to ensure that mercury emissions are under control. The Philippines Department of the Environment and Natural Resources is establishing a mercury task force which intends to establish emission monitoring and stack testing between 2009 and 2015. This task force could benefit from knowledge and technology transfer from agencies such as UNEP and the US EPA.

Coal combustion dominates the mercury emission inventory for Thailand, with cement production contributing around half the emissions arising from coal combustion. This may be because, although Thailand has a significant cement industry, many of the plants use oil rather than coal. Coal use in Thailand is expected to increase by a factor of around four by 2021, although the use of gas and nuclear power will increase at a greater rate. Most coal-fired plants in Thailand are installed with FGD and DeNOx systems and will therefore be achieving mercury emission reductions, although this should be verified by monitoring and could be improved with additional options such as flue gas oxidation.

Vietnam will potentially see at least a doubling in coal use within the next decade, although the predictions for the energy future of Vietnam are subject to significant uncertainty due to the current economic and political climate. However, of all the countries reviewed in this report, Vietnam is the country with the least country-specific data on mercury emissions. No national inventory has been prepared by anyone other than AMAP/UNEP. Priority should therefore be given to analysis of mercury in coals fired in Vietnam and to stack monitoring in order to establish country-specific data as soon as possible.

The production of energy from coal is projected to increase throughout India and Southeast Asia in the coming years. Each of these countries would benefit from enhanced investigation into the concentration and mode of occurrence of mercury in the coals used in order to help establish a more appropriate emission factor for mercury and also to provide information which could identify which regions would benefit most from cost-effective options such as coal washing and blending. These countries would also benefit from stack emission monitoring studies to establish a baseline of understanding of mercury behaviour in the coal-fired fleet of plants. In some countries, such as Indonesia, Malaysia, the Philippines, Thailand and possibly Vietnam, SO_2 and NOx control technologies are installed on some plants which will mean concomitant co-benefit mercury reduction. In other countries such as India and Cambodia, this appears not to be the case. The effectiveness of the co-benefit reduction of mercury needs to be measured where these systems are installed and, if necessary, recommendations made (such as oxidation or sorbent addition) to promote enhanced mercury control. Where SO_2 and NOx installations are not in place and are unlikely to be installed in the foreseeable future, alternative options such as sorbents or oxidants could be tested. In many countries, mercury control is assumed to be expensive – this misconception needs to be corrected with demonstrations of cost-effective mercury control options at real plants in Southeast Asia.

UNEP have produced useful tools such as the POG and iPOG to help plant operators understand and maximise mercury reduction on a plant-by-plant basis. These tools should be promoted throughout Southeast Asia, along with workshops on how to improve mercury inventories using both the UNEP inventory toolkit (using country-specific emission factors and activity data) and the US EPA emission monitoring toolkit. Emission estimation and measurement is the key to understanding current emission levels accurately and to monitoring increases or decreases in emissions in the future. Finally, circulation of the POG/iPOG along with expert workshops in target countries could go a long way to helping plant operators appreciate that there are numerous and varied options for mercury control and not all of these are expensive or require significant plant retrofit. Demonstration projects on full-scale plants in Southeast Asia should focus on those options which could be most cost-effective for mercury control in this region.

Perhaps the main conclusion with respect to mercury control for South East Asia is that the options will vary from country to country and from plant to plant. They will include coal washing, beneficiation and blending; improving plant efficiencies; enhancing mercury capture in existing pollution control systems such as FGD (with the use of sorbents or oxidants); and the option of multi-pollutant control technologies such as advanced particulate control systems. These, in conjunction with oxidants and/or sorbents) have the potential to capture particulates, SO_2 and mercury along with other trace species simultaneously. These systems may be cost effective in countries where emission reduction for all these species is required simultaneously.

The understanding of mercury combustion chemistry is now reaching a point where data on coal and plant characteristics can narrow the choice of control options down to a few which are likely to be most appropriate in each case. However, for this to be an effective method of selecting mercury control strategies, as much information as possible is needed on coal characteristics, plant configurations and operating parameters. The more data we collate from individual countries and regions, the more effective our mercury control strategies will be.

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