Mercury Sources, Transportation and Fate in Australia

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Summary

BACKGROUND

Mercury is among the most bio-concentrated trace metals in the food chain. It is a naturally occurring metal found in small quantities throughout the environment in both the atmosphere and in aquatic and terrestrial ecosystems. While it is continuously released, transported, transformed and stored in and between these compartments, the atmosphere is considered to be the dominant transport medium of mercury in the environment.

At the *24th Session of the United Nations Environment Program Governing Council/ Global Ministerial Environment Forum* in 2007 it was concluded that:

- "current efforts to reduce risks from mercury are not sufficient to address the global challenges posed by mercury", and
- "further long-term international action is required to reduce risks to human health and the environment and that, for this reason, the options of enhanced voluntary measures and new or existing international legal instruments will be reviewed and assessed in order to make progress in addressing this issue."

On 20th February 2009 the UN Environment Programme's (UNEP) Governing Council agreed on a plan for a global approach to reduce population and ecosystem exposure to mercury. The landmark decision, taken by over 140 countries, sets the stage for the development of an international mercury treaty to deal with world-wide emissions and discharges of this pollutant. The Council also agreed that the risk to human health and the environment was so significant that accelerated action under a voluntary Global Mercury Partnership is needed whilst the treaty is being finalised.

In conjunction with the 2009 UN process, revised estimates (in 2008) of global emissions of mercury have been made. These estimates reveal that:

- The largest sectoral source is the combustion of fossil fuels, largely coal. This sector accounts for a total of ~46% of emissions of mercury to atmosphere, about 25% from electrical power plants and 20% from industrial and residential heating.

- Emissions from gold production arises from both large scale industrial production (~6% of total global emissions) and from small scale and artisanal gold mining and production (~18%, and largely in developing countries).
- The mining, smelting and production of metals other than gold, and cement production each account for ~10% of global emissions.
- The emission **estimates are subject to large uncertainties,** largely due to lack of data, uncertainty in the data that are available, and a reliance on data from other locations.

To date, there has been little systematic, coordinated effort to understand the nature of mercury emissions in Australia and as such there is significant uncertainty in our current understanding of the sources, fate and impacts of mercury in Australia. These uncertainties include:

- emission source strengths from stationary sources in Australia;
- emissions from natural sources (eg, bushfires, water bodies and vegetation), and re-emission of previously deposited mercury; and
- the relative contributions of the different chemical forms of mercury (ie, elemental, oxidised and particulate) in many sources.

In an effort to address these uncertainties and to improve the understanding of mercury in Australia, the Department of the Environment, Water, Heritage & the Arts (DEWHA) commissioned Macquarie University and CSIRO to carry out a study to determine the sources, transportation and fate of mercury in Australia. The study has six parts:

- Collection of Data on Mercury Emissions, Sources and Trends from Anthropogenic and Non-Anthropogenic Sources (part A)
- Study of the transport and fate of mercury in Australia (part B)
- The identification of gaps in the scientific data related to mercury in Australia. (part C)
- The identification of areas or populations especially at risk from mercury in Australia (part D)
- The collation of information into an inventory of mercury sources and emissions in Australia (part E)
- Study of the availability, efficiency and costs of control technologies (part F)

This Final Report addresses all parts of the study's brief.

RESULTS

Anthropogenic emissions

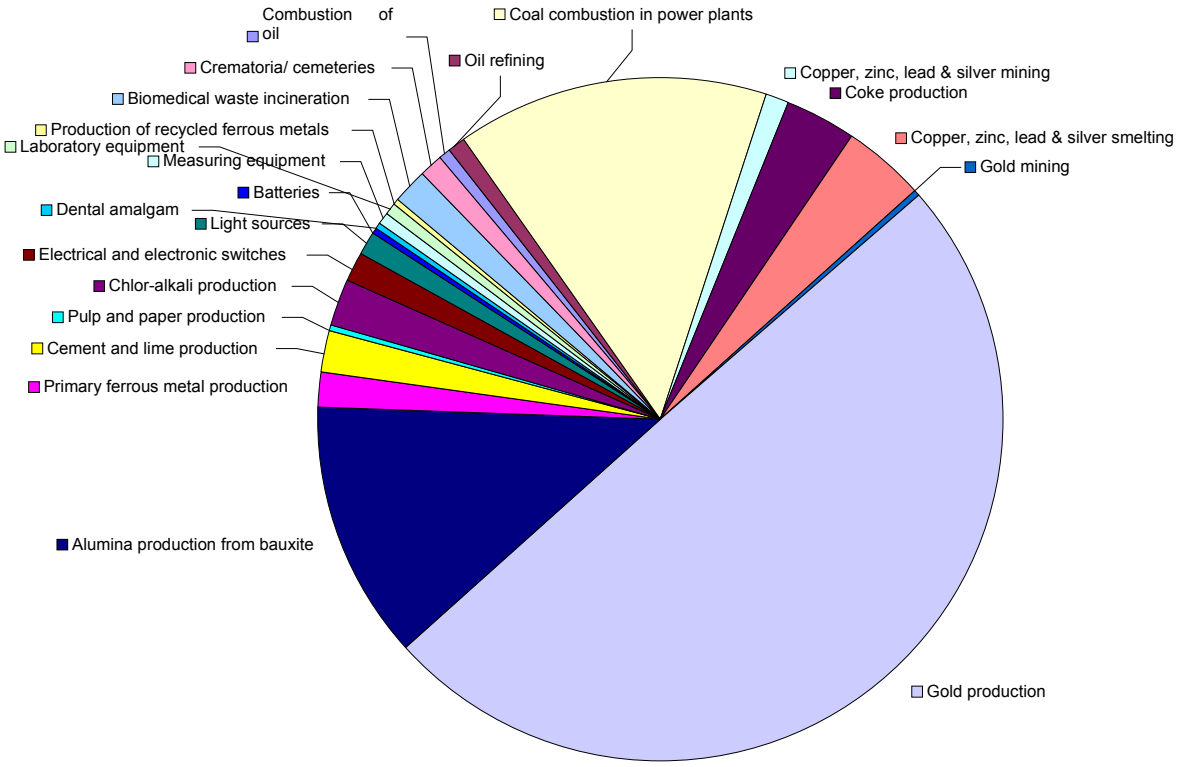
Derivation of an inventory of Australian emissions of mercury from anthropogenic sources in 2006 was undertaken using a range of data sources. These included the National Pollutant Inventory (NPI), and overseas protocols and emission factors (eg, those included in the *UNEP Toolkit for identification and quantification of mercury releases*). There is considerable uncertainty in the emission estimates so obtained, not least because of the very high reliance on overseas sources of information, assumptions and emission factors. Hence the mercury emission inventory should be used with caution, and the impacts predicted using it should recognise the limitations which these uncertainties impose on any conclusions or decisions which may be based on data from the emission inventory. Notwithstanding the preceding note of caution, it is considered that the new inventory represents a significant advance upon previous data, will enable qualified assessments to be undertaken (as is done in parts of this study) and provides a platform for further improvement with advances in knowledge and as resources permit.

The following conclusions may be made about the estimated emissions of mercury to the atmosphere from Australian anthropogenic sources:

- The best estimate of total emissions of mercury to the atmosphere in 2006 was around 15 tonnes. Using a very different methodology the most recent global emission estimate (in 2008) reports total anthropogenic emissions from Australia at ~34 tonnes/year. The difference between the two methods is largely due to a much higher estimate for emissions from stationary combustion in the global estimate. It can be convincingly argued that the estimate presented in the current report for stationary combustion (largely coal-fired power stations) is more accurate as it uses NPI reported emissions which incorporate estimates of mercury capture in air pollution control devices (the global estimate does not include any mercury capture), and is supported by a comparison of top-down and bottom-up estimates of mercury from Australian stationary sources.
- Three sectors contribute substantially to Australian anthropogenic emissions; these are gold production (49.7%), coal combustion in power plants (14.8%), and alumina production from bauxite (12.2%).
- A range of other diverse sectors contribute smaller proportions of the emitted mercury. These include industrial sources (mining, smelting, and cement production), and intentional use of mercury in products.
- It is difficult to determine historical trends in mercury emissions given the large uncertainties in the data. Past historical data is likely to be even more uncertain. However it is clear that the intentional

use of mercury in products is in decline. In addition all mercury cell-based chlor-alkali plants in Australia have now ceased operation, and emissions from this source have decreased significantly since this time.

The figure and table below summarise the relative contribution of sources and sectors to Australian anthropogenic emissions to the atmosphere in 2006.



Natural emissions

Mercury is a naturally occurring substance in a variety of environmental media and hence it is also emitted from vegetation, soil, water bodies and during fires. It is believed that a large part (up to 50 percent) of the mercury that is emitted from natural sources is actually of anthropogenic origin (Mason *et al.* 1994a) that is "re-emitted" from natural sources after having previously been emitted from an anthropogenic source to the atmosphere or to a water body. Evaporation of mercury from the oceans' surface, emission of mercury from soil, vegetation and the release of mercury in forest fires, are consequently a mix of natural and re-emitted mercury. It is clear that care needs to be taken when referring to natural emissions since the term "natural" in this context may be somewhat misleading. In the context of this report "natural emissions" will, by definition, also include re-emissions.

Estimates of mercury emissions from the natural sources in Australia are highly uncertain, due to both the large uncertainties inherent in estimating these emissions, and also to the lack of relevant Australian data. The magnitude of the mercury emissions released depends on a number of biological, chemical, physical and meteorological factors, of which few are fully understood, and many are subject to very large uncertainties.

Relative Contributions of anthropogenic sources of mercury emissions to the atmosphere in Australia in 2006

Sector	Emissions, kg/year	Proportion of Total Emissions (%)
Gold smelting	7642	49.7
Coal combustion in power plants	2271	14.8
Alumina production from bauxite	1872	12.2
Copper, zinc, lead & silver smelting	629	4.1
Coke production	500	3.2
Chlor-alkali production	340	2.2
Cement and lime production	313	2.0
Primary ferrous metal production	247	1.6
Biomedical waste incineration	236	1.5
Electrical and electronic switches	207	1.3
Light sources	177	1.2
Crematoria/ cemeteries	172	1.1
Copper, zinc, lead & silver mining	169	1.1
Oil refining	101	0.7
Combustion of oil	101	0.7
Measuring equipment	92	0.6
Laboratory equipment	80	0.5
Production of recycled ferrous metals	63	0.4
Dental amalgam	59	0.4
Batteries	36	0.2
Gold mining	29	0.2
Pulp and paper production	14	0.1
Total	15346	

Previous works estimated emissions of 117 -567 tonnes of mercury per year from land and water surfaces in Australia (Nelson *et al.* 2004). In this study a more detailed approach based on land and vegetation classifications resulted in an estimate of about 148 tonnes emitted annually from vegetation and soil but

not including emissions from the ocean. The mercury released from these various natural sources is mainly in the form of elemental mercury, although small quantities of dimethyl mercury are also released (Lindquist *et al.* 1991; Schroeder and Munthe 1998b).

Fires are also an important but highly uncertain source of mercury, and emit elemental, divalent and particulate forms of mercury (Porcella *et al.* 1996). Two recent estimates of Australian emissions from this source of 129 and 19 ± 9 tonnes/year have been made, and in this study a detailed modelling approach results in an estimate of 41.8 tonnes annually.

The natural sources are estimated to contribute 93% of the mercury emitted annually in continental Australia, demonstrating that natural emissions in Australia are significant in comparison to anthropogenic emissions but also highly uncertain. Future research should address this uncertainty.

Transport and fate of mercury

This component of the study entailed the use of numerical meteorological and transport models and the air emissions inventory for mercury (as discussed above) to generate best estimates of annual average ambient mercury concentrations and wet and dry deposition mass. *Wet deposition* is the transfer of a substance, in this case mercury, from the atmosphere to the surface via precipitation. In this regard it should be noted that although elemental gaseous mercury is relatively insoluble, reactive gaseous mercury is very soluble and particulate mercury is readily scavenged by cloud water droplets (Seigneur et al. 2001). Thus it may be expected that the majority of the mercury mass deposited by precipitation will be in the form of reactive gaseous mercury and particulate mercury. *Dry deposition* refers to the transfer of gas and aerosol phase mercury to “sinks” on vegetation (such as leaf stomata), soil and water surfaces by atmospheric turbulence and molecular diffusion. For particulate mercury, deposition rates may also be enhanced by gravitational settling of the particles.