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UNEP

# REDUCING MERCURY EMISSIONS FROM COAL COMBUSTION IN THE ENERGY SECTOR IN SOUTH AFRICA

## FINAL PROJECT REPORT

**Report prepared by: Dr Gregory Scott - Special Advisor: Industrial Process Engineering, Department of Environmental Affairs, Republic of South Africa, October 2011**

environmental affairs

Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

## Disclaimer

Based on the agreement between the United Nations Environment Programme (UNEP) and the South African Department of Environmental Affairs (DEA), the UNEP agreed to co-operate with the DEA with respect to the project entitled: "Reducing mercury emissions from coal combustion in the energy sector in South Africa". The information provided in this report is based primarily on published data derived from the participating companies and institutions.

This report has been prepared as part of the above mentioned project for the UNEP Chemicals Branch, Division of Technology, Industry and Economics. Material in this report can be freely quoted or reprinted. However, acknowledgement is requested together with a reference to the report.

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The electronic version of the report can be found on UNEP website: www.unep.org/

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## Summary

This report provides a summary of the mercury emissions from coal-fired power generation facilities in South Africa. The work represents a collaboration between the Department of Environmental Affairs and the United Nations Environment Programme Global Mercury Partnership, who provided technical and financial support to the project.

The emission inventory results presented in this report are a combination of emission factor calculations and actual emission measurements at two of the 18 coal fired power generation facilities in South Africa. This work builds on the initial emission inventory work undertaken by the South African Mercury Assessment (SAMA). Key findings of this report indicate that the mercury emissions from coal-fired power generation are estimated at 39.4 tons/annum for 2009. There is a high degree of uncertainty in this estimate since the bulk of the emissions are estimated using emission factors. Mercury emissions from this sector appear to be increasing due to increased electricity demand and South Africa's dependence on coal-fired power generation. It is estimated that emissions have increased by 45% since 2000 (27.1 tons/annum). Further work is required to fine tune the national mercury emissions inventory to remove the current uncertainty.

The report also highlights the relative lack of trace element analysis of the different coals utilised by the power generation sector in South Africa. Many of the emission factor calculations were based on historical mercury concentrations and where no information was available the national average was applied. This added to the uncertainty of the final emission estimation. The report makes recommendations for further work regarding trace element analysis in South African coals.

Mercury emissions from the coal-fired power generation sector are expected to decrease in South Africa over the next 20 years, based on the Department of Energy's Integrated Resource Plan 2010 (IRP 2010). This reduction will be achieved through a combination of decommissioning of older coal-fired facilities and the construction of new coal-fired facilities with advanced air pollution control units which will reduce mercury emissions. South Africa will also increase the base load provided by renewable energy sources, which will see our dependence of coal-fired generation decrease from 90% to 65%. A number of other smaller projects will also contribute to reduction in mercury emissions (i.e. biomass combustion, retrofitting of fabric filters).

The report acknowledges that further research and investigation is required to understand the extent of mercury emissions from the coal-fired power generation sector.

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## List of Figures and Tables

## List of Abbreviations and Symbols

| | |
|---|---|
| As | Arsenic |
| Ba | Barium |
| Ca | Calcium |
| Cl | Chlorine |
| Co | Cobalt |
| Cr | Chromium |
| Cu | Copper |
| DEA | Department of Environmental Affairs |
| ESP | Electrostatic Precipitator |
| Ga | Gallium |
| Ge | Germanium |
| Hg | Mercury |
| IPP | Independent Power Producer |
| IRP | Integrated Resource Plan |
| kg | Kilogram |
| Mn | Manganese |
| MW | Megawatt |
| Na | Sodium |
| Ni | Nickel |
| NOx | Oxides of Nitrogen |
| $O_2$ | Oxygen |
| Pb | Lead |
| PM | Particulate Matter |
| POG | Process Optimisation Guidance |
| ppm | Parts per Million |
| Rb | Rubidium |
| SARM | South African Reference Material |
| Se | Selenium |
| $SO_2$ | Sulphur Dioxide |
| Sr | Strontium |
| SSFA | Small Scale Funding Agreement |
| U | Uranium |
| UNEP | United Nations Environment Programme |
| US-EPA | United States Environmental Protection Agency |
| V | Vanadium |
| Y | Yttrium |
| yr | Year |
| Zn | Zinc |
| Zr | Zirconium |

# 1. Introduction

## 1.1 Project Objectives

The Department of Environmental Affairs (DEA) and the United Nations Environment Programme (UNEP) entered into a Small Scale Funding Agreement (SSFA) to co-operate with respect to a project entitled: "Reducing mercury emissions from coal combustion in the energy sector – Part 1" in South Africa. The project objectives to which the SSFA relates is a reduction of mercury emissions, consistent with UNEP Governing Council priorities identified in Decisions 24/3 and 25/5 and is also consistent with the goal of the reduction of mercury emissions from coal under the UNEP Global Mercury Partnership.

The project encompasses the following objectives:

1. Promote approaches to mercury release control and abatement in the coal-fired energy generation sector through optimization and enhancement of pollution abatement techniques and processes in conjunction with energy and resource efficiency improvements;
2. Update and further develop existing inventories of mercury releases in the topical sector through comprehensive analysis of statistical and experimental data;
3. Inform industry, decision-makers and expert community on the problems of mercury releases in the sector and promote emission reductions.

In order to achieve the project objectives the following tasks were undertaken as part of the study:

1. Collection and analysis of available information on coal: amount of coal used by coal type, results of coal analysis (including Hg, As, Se, Cl, Ca, Na content) and information on extent of coal preparation by coal type;
    - Collection of available information (or estimation) of coal consumption (projected coal use) for energy generation for the target years 2020 and 2050, if possible;
    - Chemical analysis of selected samples of coal on Hg, As, Se, Cl, Ca, Na to present a general representative picture of South African coals fired for energy generation;
2. Collection of available information on coal-fired power plants: installed power plant capacity by combustion process, approximate locations of power plants, air pollution control configuration and efficiency by pollutant (PM, $SO_2$, $NO_X$, and Hg) and by plant, plant capacity factor, plant heat rate, boiler operating conditions, and ash split; information on any available results of measurements of PM, $SO_2$, $NO_X$ or Hg emissions in power plants;
3. Development of example Hg emission factors based on data sets from selected power plants which have as complete datasets as possible;
4. Comparison of example emission factors to emissions based on actual measurements, as available;
5. Revision of existing emission factors, as necessary, based on the above collected information;
6. Development of improved emission inventories based on the results from the above tasks (coal use, power plant information, and revised emission factors), and analysis of uncertainties of the data calculated;

7. Distribution of improved emission inventories to the network of experts and stakeholders for comments;
8. Prediction of future mercury emission trends for the status quo and for the Process Optimisation Guidance (POG) mercury control implementation scenario;
9. Hosting of information seminars to gather and disseminate information during the project.

## 1.2 Background

The African continent contains approximately 5% of the world's proven recoverable reserves of coal (World Energy Council, 2007). Energy consumption in Africa is projected to grow at an annual rate of 2.3% from 2004 until 2030, while the average consumption in the first-world nations is expected to rise at 1.4% annually (US Energy Information Administration, 2007).

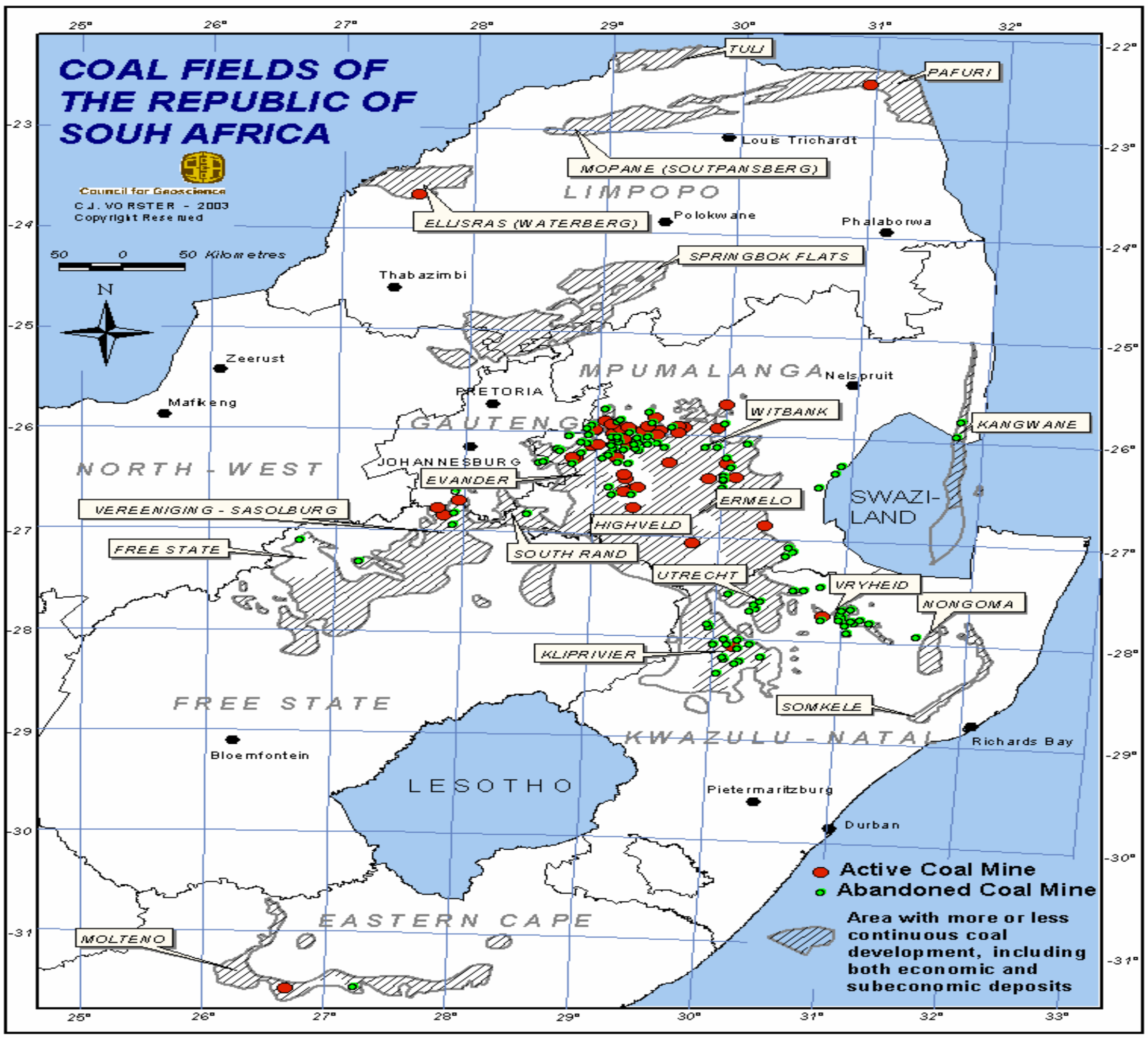


Figure 1: Coalfields of South Africa (Vorster, 2003)

Coal reserves will undoubtedly continue to be a part of Africa's energy mix as it grows into the future. South Africa accounts for 96% of Africa's proven recoverable coal reserves, ranking it sixth in the world (Merrill and Tewalt, 2008). In 2007, South African mines produced 247.7 million tons of coal, with 182.8 million tons sold locally and 67.7 million tons exported, making it the fourth largest exporter of coal in the world. The coal mines in South Africa are located in five provinces i.e. Limpopo, Mpumalanga, Free State, Kwazulu-Natal and the Eastern Cape Province (Figure 1). Most coal mines are concentrated around the towns of Witbank, Ermelo and Secunda (Schmidt, 2008). There are 19 official coal fields but 70% of recoverable reserves lie in just three of them: Highveld, Waterberg and Witbank (Vorster, 2003).The coal mining industry in South Africa is highly concentrated with five companies accounting for 90% of the saleable coal production. The eight largest mines account for 61% of the total output. The number of operational collieries has been decreasing over the past ten years, with a relatively small number of large-scale producers supplying coal primarily to electricity and synthetic fuel producers. Figure 2 provides a summary of the coal use profile in South Africa.

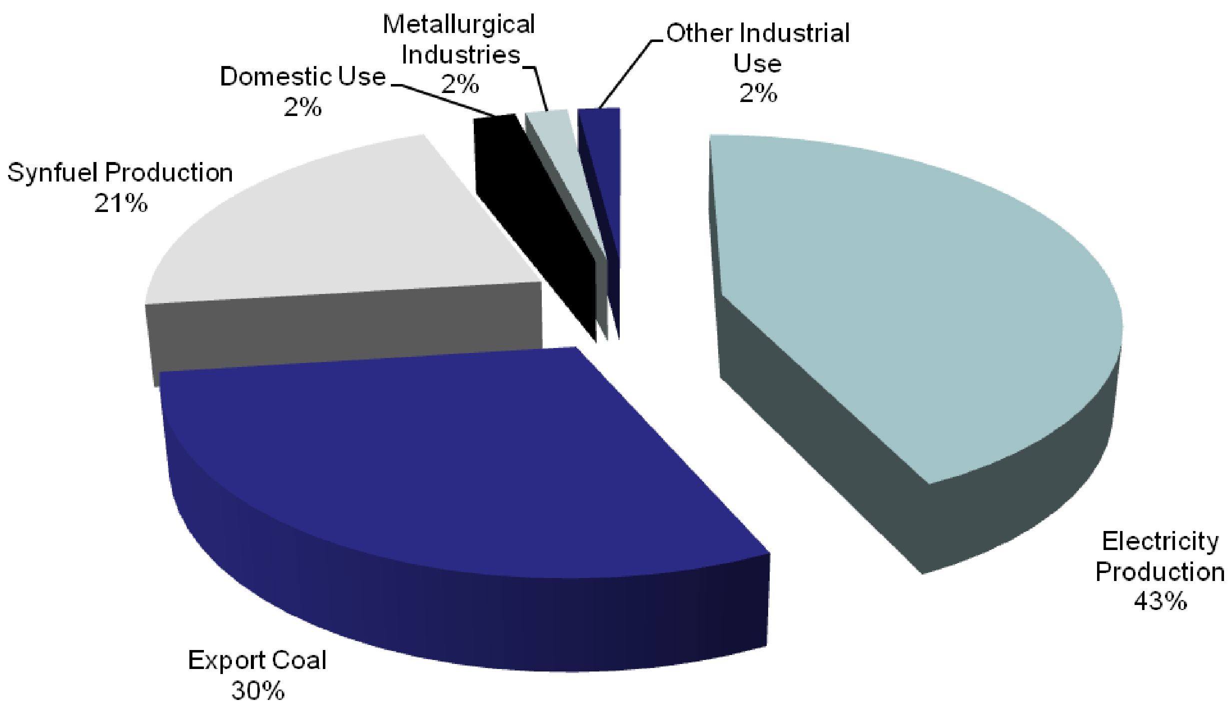


Figure 2: Coal Use Profile of South Africa (Grobbelaar, 2001)

## 1.3 Sources of Information

There is relatively little published information regarding trace elements in South African coals (Bergh *et al.*, 2009; Leaner *et al.*, 2009). The few academic studies and journal articles are the primary source of information presented in this report, together with primary information gathered from main participants in the project (Eskom and Sasol). The mercury emissions data presented in this report is the first measured mercury emissions to be reported in South Africa.

The lack of readily available information highlights the need for further research and measurement in South Africa.

## 2. The South African Power Generation Sector

### 2.1 Overview

Coal meets ~90% of South Africa's primary energy needs (Spalding-Fetcher and Matibe, 2003). Eskom is South Africa's only electricity utility and is the largest producer of electricity in Africa and one of the top seven utilities in the world (Schmidt, 2008). Figure 3 shows the sources of power generation in South Africa.

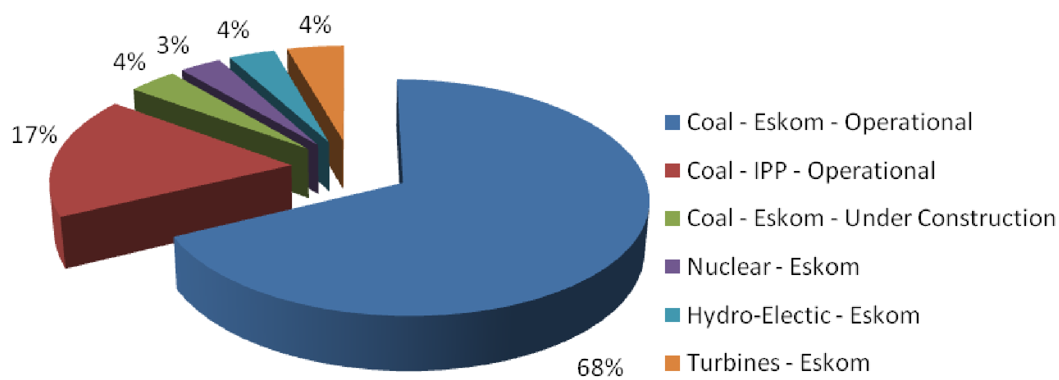


Figure 3: Breakdown of the South African power generation sector

It appears that coal-fired power generation will remain the dominant power generation source for South Africa for the foreseeable future. This is confirmed by the current construction of two new coal-fired power stations (Mudupi and Kusile). The Department of Energy's Integrated Resource Plan for Electricity – 2010 (IRP 2010) details a potential move away from coal-fired generation into renewable generation (wind, solar and imported hydro). There are also plans to expand the nuclear fleet with the addition of three new stations. More details on the future generation scenarios and how this may influence the country's mercury emissions are presented later in this report.

### 2.2 Coal-fired Power Generation

Coal-fired power generation is the dominant source in South Africa. Table 1 provides a summary of the coal-fired power stations in South Africa. Eskom currently operates 13 coal-fired power stations with another two stations currently under construction. In addition to the Eskom generation capacity, electricity is also generated by a number of industrial operators for internal use. The largest of these producers is Sasol and is included in this assessment. Electricity is also generated at three small independent power producers (IPP), which are old municipal power stations. A small number of old municipal power stations (Queenstown, Bloemfontein) are currently mothballed but there are no plans to return these facilities to service in the foreseeable future.

Table 1: Summary of the installed capacity and location of all coal-fired power stations in South Africa

| Power Station | Latitude | Longitude | Installed Capacity |
|---|---|---|---|
| Eskom – Arnot | 25°56'38"S | 29°47'29"E | 2 352 MW |
| Eskom – Camden | 25°56'38"S | 30°47'29"E | 1 520 MW |
| Eskom – Duvha | 25°57'40"S | 29°20'19"E | 3 600 MW |
| Eskom – Grootvlei | 26°46'10"S | 28°29'50"E | 1 200 MW |
| Eskom – Hendrina | 26°01'54"S | 29°36'04"E | 1 965 MW |
| Eskom – Kendal | 26°05'21"S | 28°58'10"E | 4 116 MW |
| Eskom – Komati | 26°05'26"S | 29°28'20"E | 940 MW |
| Eskom – Kriel | 26°15'16"S | 29°10'41"E | 3 000 MW |
| Eskom – Lethabo | 26°44'26"S | 27°58'34"E | 3 708 MW |
| Eskom – Majuba | 27°06'00"S | 29°46'11"E | 4 110 MW |
| Eskom – Matimba | 23°40'06"S | 27°36'44"E | 3 990 MW |
| Eskom – Matla | 26°08'28"S | 29°16'55"E | 3 600 MW |
| Eskom – Tutuka | 26°46'33"S | 29°21'10"E | 3 654 MW |
| City of Tshwane – Rooiwal | 25°33'19"S | 28°14'17"E | 300 MW |
| City of Tshwane – Pretoria West | 25°45'28"S | 28°08'48"E | 180 MW |
| Kelvin Power | 26°06'57"S | 28°11'39"E | 600 MW |
| Sasol 1 | 26°49'20"S | 27°50'53"E | Steam only |
| Sasol 2 & 3 | 26°33'18"S | 29°09'57"E | 1 020 MW |

Figure 4 shows the location of the power stations indicated in Table 1 above. The majority of the coal-fired power stations are located on the Mpumalanga Highveld, directly on the Witbank and Highveld coal fields. The Matimba power station in the north is located on the Waterberg coal field. The close proximity of the power stations is a concern, with 17 power stations located within a 250km radius. The opportunity for cumulative impacts of emissions from these stations is greatly enhanced.

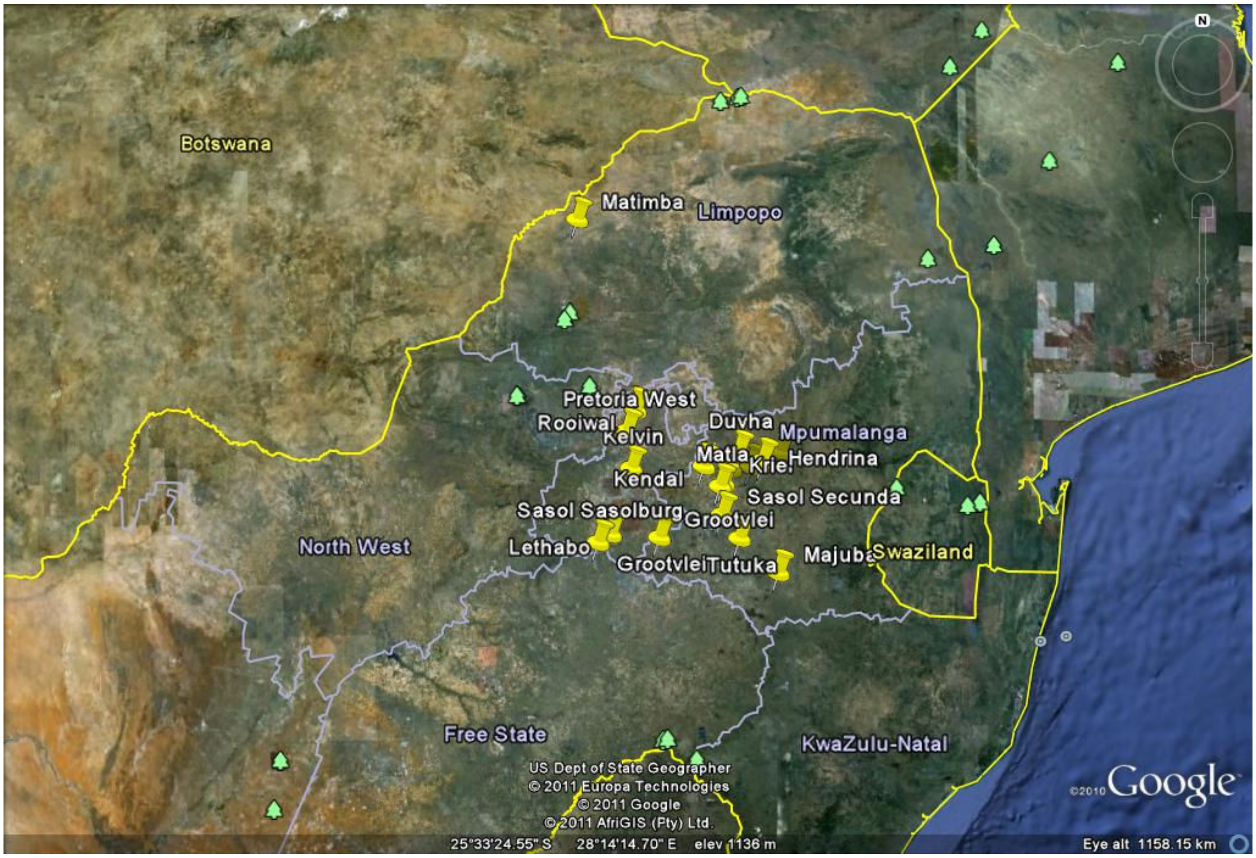


Figure 4: Location of the coal-fired power stations in South Africa

Table 2 summarizes the coal information by power station. The coal consumption data provided is for the 2009 / 2010 financial year, while the mercury data is an average concentration over years of analysis at each station. In situations where the mercury concentration for a coal at a power station is not known, the average mercury concentration in South African coal reported by Gericke et al. (2007) is assumed (0.31 mg/kg). The coal consumptions presented have been confirmed by both Eskom and Sasol, while the consumptions presented for the IPPs is the maximum design capacity for these plants. Historical trace element analysis of the coal used at the Eskom power stations was provided, but this was only presented as an average for each station (Table 3). The raw coal, coarse ash and fly ash was analysed, but only the results for the raw coal are presented here. In addition, the trace element compositions of three South African reference coals (Ring and Hansen, 1984) are also presented in Table 3.

Table 2: Summary of the coal information at power station level

| Power Station | Coal Consumption Tons / annum | Average Hg Concentration mg/kg (Gericke, 2007) | Coal Preparation |
|---|---|---|---|
| Eskom - Arnot | 6.8 million | 0.17 | Partly washed |
| Eskom – Camden | 4.7 million | 0.31 | No washing |
| Eskom – Duvha | 11.7 million | 0.23 | Partly washed |
| Eskom – Grootvlei | 1.6 million | 0.31 | No washing |
| Eskom – Hendrina | 6.9 million | 0.21 | Partly washed |
| Eskom – Kendal | 13.9 million | 0.44 | No washing |
| Eskom – Komati | 0.7 million | 0.31 | No washing |
| Eskom – Kriel | 8.5 million | 0.29 | No washing |
| Eskom – Lethabo | 18.2 million | 0.36 | Partly washed |
| Eskom – Majuba | 12.3 million | 0.29 | No washing |
| Eskom – Matimba | 14.6 million | 0.45 | Fully washed |
| Eskom – Matla | 12.4 million | 0.29 | No washing |
| Eskom – Tutuka | 10.6 million | 0.29 | No washing |
| City of Tshwane - Rooiwal | 1.4 million | 0.31 | No washing |
| City of Tshwane – Pretoria West | 0.85 million | 0.31 | No washing |
| Kelvin Power | 2.8 million | 0.31 | No washing |
| Sasol 1 | 1.8 million | 0.31 | No washing |
| Sasol 2 & 3 | 14.8 million | 0.15 | No washing |

Table 3: Average trace element concentrations (ppm) for coal used at Eskom power stations

| Power Station / Ref Coal | Hg | V | Cr | Mn | Co | Ni | Cu | Zn | Ga | Ge | As | Rb | Sr | Y | Zr | Ba | Pb | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Eskom – Arnot | 0.17 | 44.4 | 114.9 | 131.1 | 3.7 | 62.4 | 10.7 | 40.2 | 11.3 | 2.3 | 4.8 | 6.1 | 284 | 17.3 | 90 | 276 | 15.7 | 2.4 |
| Eskom – Duvha | 0.23 | 39.2 | 49.4 | 106.3 | 5.8 | 20.2 | 24.6 | 38.6 | 13.9 | 2.1 | 3.4 | 11.8 | 415 | 22.4 | 118 | 378 | 20.2 | 3.5 |
| Eskom – Hendrina | 0.21 | 36.4 | 84.4 | 57.0 | 7.4 | 40.2 | 12.2 | 68.8 | 12.0 | 3.4 | 12.9 | 9.6 | 251 | 21.3 | 112 | 362 | 19.2 | 3.6 |
| Eskom – Kendal | 0.44 | 41.6 | 58.3 | 78.2 | 4.8 | 25.6 | 15.7 | 18.6 | 16.9 | 2.0 | 3.0 | 14.8 | 498 | 24.4 | 140 | 500 | 20.5 | 3.0 |
| Eskom – Kriel O/C | 0.29 | 32.7 | 51.8 | 87.8 | 2.5 | 23.9 | 13.4 | 30.3 | 11.8 | 1.6 | 3.7 | 4.9 | 682 | 17.9 | 94 | 524 | 17.4 | 1.3 |
| Eskom – Kriel U/G | 0.38 | 37.4 | 49.7 | 77.5 | 4.8 | 19.9 | 15.1 | 18.9 | 14.1 | 1.5 | 3.0 | 10.9 | 562 | 20.6 | 116 | 346 | 20.8 | 2.0 |
| Eskom – Lethabo | 0.36 | 57.5 | 81.7 | 115.0 | 6.9 | 36.9 | 22.8 | 30.4 | 17.9 | 1.2 | 2.4 | 17.1 | 361 | 27.2 | 171 | 428 | 23.8 | 5.3 |
| Eskom – Majuba | 0.29 | 35.6 | 55.2 | 88.4 | 6.9 | 27.6 | 16.4 | 30.1 | 13.6 | 1.0 | 5.1 | 10.7 | 320 | 23.7 | 145 | 357 | 24.9 | 3.3 |
| Eskom – Matimba | 0.45 | 57.6 | 48.9 | 156.4 | 8.1 | 26.1 | 18.0 | 45.3 | 16.9 | 1.8 | 3.8 | 21.1 | 186 | 26.0 | 164 | 347 | 23.3 | 4.5 |
| Eskom – Matla | 0.29 | 34.7 | 53.1 | 77.4 | 3.9 | 23.3 | 14.9 | 15.9 | 12.6 | 1.8 | 4.2 | 7.9 | 749 | 19.2 | 71 | 637 | 17.5 | 1.2 |
| Eskom – Tutuka | 0.29 | 41.2 | 69.9 | 97.7 | 11.1 | 38.9 | 12.2 | 34.1 | 13.3 | 2.6 | 4.9 | 7.9 | 430 | 29.7 | 90 | 285 | 22.4 | 2.0 |
| SARM 18 (Witbank) | - | 23.0 | 16.0 | 22.0 | 6.7 | 10.8 | 5.9 | 5.5 | - | - | - | 8.1 | 44 | - | 67 | 78 | - | 1.5 |
| SARM 19 (Free State) | - | 35.0 | 50.0 | 157.0 | 5.6 | 16.0 | 13.0 | 12.0 | 14.0 | 13.0 | - | 9.0 | 126 | - | 351 | 304 | 20 | 5.0 |
| SARM 20 (Sasolburg) | 0.25 | 47.0 | - | 80.0 | 8.3 | 25.0 | 18.0 | 17.0 | 16.0 | - | - | 10.0 | 330 | 29.0 | - | 372 | 26 | 4.0 |

## 2.3 Mercury Emissions – UNEP Toolkit

All historical estimates of mercury emissions from coal-fired power stations in South Africa were based on emission factors. Pacyna *et al.* (2003, 2006) estimated South Africa's anthropogenic mercury emissions were 256.7 tons in 2000. The bulk of the emissions originated from industrial sources, followed by stationary combustion. The report considered coal combustion and gold mining as the most significant sources. Based on this estimate, South Africa was ranked as the second highest emitter in the world, accounting for 16% of global anthropogenic emissions. The publication of this assessment triggered the need for a comprehensive assessment of mercury pollution in South Africa. The South African Mercury Assessment (SAMA) (Leaner *et al.*, 2007) was established in response to the Pacyna *et al.* (2006) publication. Subsequently Dabrowksi *et al.* (2008) (9.75 tons), Leaner *et al.* (2009) (30.96 tons) and Masekoameng *et al.* (2010) (27.1 – 38.9 tons) have all published mercury emission estimates for coal combustion from South African power stations that are considerably lower than the Pacyna *et al.* (2006) estimate. Leaner et al. (2009) highlights the need for more analysis of South African coal samples and/or mercury emission measurements to improve the national mercury emission estimates. The most recent mercury emission estimates for South Africa are based on mercury concentrations measured in coal used at Eskom power stations in 2001 (Gericke et al., 2007). Based on these coal mercury concentrations, the emissions estimate was updated for 2009 / 2010 coal consumption data at the coal-fired power stations. Table 4 provides a summary of the emission estimate using UNEP Toolkit for the identification and quantification of mercury releases (UNEP, 2005).

The total emission estimate of 39.4 tons is in line with the figures reported by Masekoameng *et al.* (2010), but caution is raised as this emission estimate is based on limited knowledge of the mercury concentration in the coal and the assumptions associated with the use of the UNEP Toolkit emission factors. The confidence in the emissions estimate could be improved by the regular analysis of the mercury content of coal burned in South African power stations and mercury emission testing. The first mercury emission testing was undertaken in April 2010 at two of the Eskom station (Duvha and Kendal). The results from this emission testing are presented in Section 2.4.

Table 4: Mercury Emission Estimates for 2009/10 Financial Year (March 2009 – February 2010)

| Power Station | Estimated Mercury Emission (kg) |
|---|---|
| Eskom – Arnot | 578.0 |
| Eskom – Camden | 728.5 |
| Eskom – Duvha | 1883.7 |
| Eskom – Grootvlei | 347.2 |
| Eskom – Hendrina | 724.5 |
| Eskom – Kendal | 5504.4 |
| Eskom – Komati | 214.2 |
| Eskom – Kriel | 2218.5 |
| Eskom – Lethabo | 5896.8 |
| Eskom – Majuba | 1599.0 |
| Eskom – Matimba | 5913.0 |
| Eskom – Matla | 2901.6 |
| Eskom – Tutuka | 2766.6 |
| City of Tshwane - Rooiwal | 217.0 |
| City of Tshwane – Pretoria West | 263.5 |
| Kelvin Power | 434.0 |
| Sasol 1 | 502.2 |
| Sasol 2 & 3 | 2220.0 |
| **Total** | **39438.7** |

Figure 4 shows the historical trend of mercury emissions from coal-fired power stations in South Africa from 2000 – 2006 and the results from this research for 2009. The linear regression shown on Figure 5 indicates an increasing trend. The increasing trend can be attributed to an increase in electricity generation over the period, with three old stations being returned to service. In addition, Eskom have been reporting a decrease in the quality of the coal being combusted in the power stations, with rising sulphur levels.

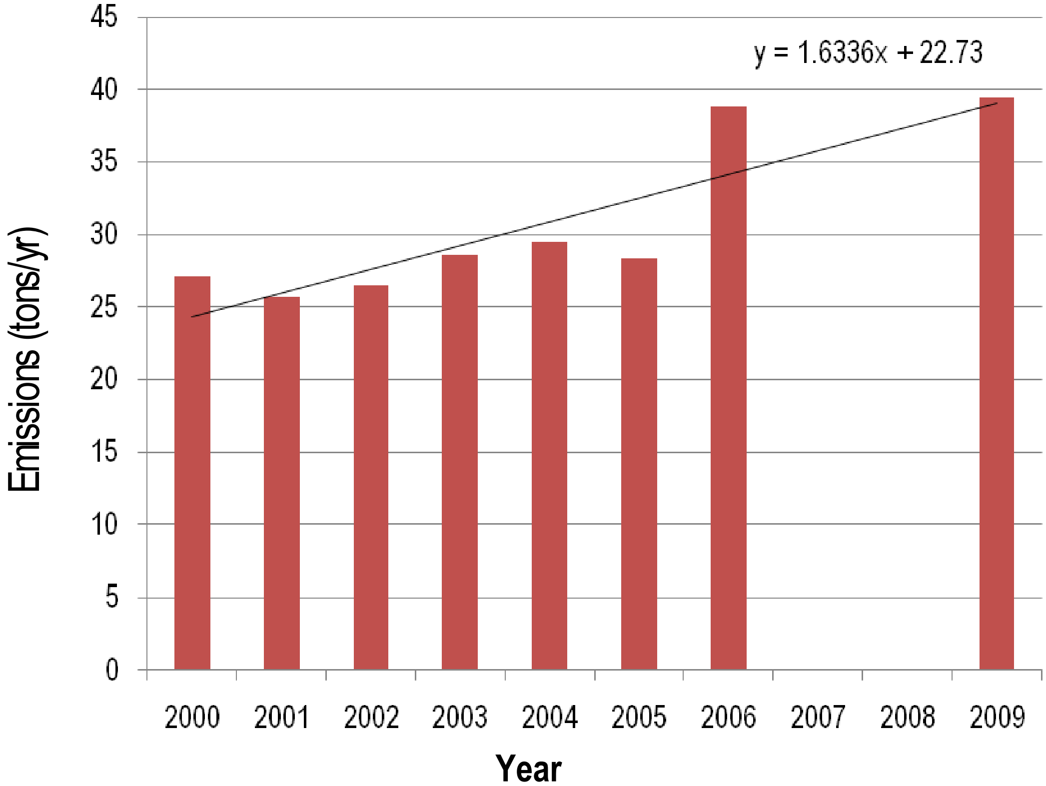


Figure 5: Historical estimated mercury emissions from coal-fired power stations in South Africa (after Masekoameng et al., 2010)

## 2.4 Mercury Emissions – Emission Testing

The US-EPA provided in-kind support to the project by undertaking mercury emission testing at two of the Eskom power stations as part of their contribution to the UNEP Global Mercury Partnership initiative. The US-EPA has developed a method for the determination of Total Vapour Phase Mercury Emissions from coal-fired combustion sources using Carbon Sorbent Traps (EPA Method 30B). This method is routinely used to characterize the emissions from coal-fired power stations for regulatory applications. The uniqueness and appeal of this method originates from its portability, ease of use and high data quality.

The overall objective of the field testing effort was to collect representative and high quality mercury emissions and ancillary process data from two power stations in South Africa, so that representative mercury emission characterizations (i.e., emission factors, mass balances, and activity factors) could be derived from these sources. The emission testing took place from 12 – 16 April 2010 at the Duvha and Kendal Power Stations, near Emalahleni (Witbank). The Duvha Power Station was selected for testing due to the fact that the power station runs the flue gas from three units through fabric filters and from three units through electrostatic precipitators (ESP). The results of the emission testing could be used to assess the effectiveness of these air pollution control devices in removing mercury from flue gas. The Kendal Power Station was selected due to the fact that it is one of the largest power stations operated in South Africa (4116 MW installed capacity) and that it historically had the highest concentration of mercury in the coal (0.44 ppm) that it fired. This power station also has six units serviced by ESPs. It must be noted that there is only particulate control equipment installed at both of these power stations. Table 5 provides a summary of the results of the mercury concentrations measured in the flue gas at the Duvha Power Station.

Table 5: Results of the mercury concentrations in the flue gas at Duvha Power Station

| Unit Number | Average Concentration $\mu g/m^3$ @ 3% $O_2$ | Fraction of Oxidised Hg (% $Hg^{+2}$) | Calculated Annual Emission kg Hg /yr |
|---|---|---|---|
| 1 | 13.81 | 89 | 231.7 |
| 2 | 4.65 | 73 | 64.0 |
| 3 | 4.09 | 88 | 52.8 |
| 4 | 35.49 | 56 | 511.9 |
| 5 | 29.01 | 54 | 386.2 |
| 6 | 40.37 | 55 | 510.2 |

It is clear from the results presented in Table 5 that Units 1 – 3 are units that are serviced by fabric filters as the mercury emissions as significantly lower than Units 4 – 6. This is also borne out by the oxidised fraction of the mercury is higher in Units 1 – 3. Based on the results of the emission tests, each of which were carried out over a minimum of 30 minutes, the extrapolated annual mercury emission for the Duvha Power Station was calculated to be 1756.8 kg/yr. This compares well to the emission estimate of 1883.7 kg/yr calculated using the UNEP Toolkit. The average mercury concentration in the coal sampled during the emissions testing was 0.15 ppm (range 0.11 – 0.21 ppm), whereas the average historical mercury concentration in the coal was 0.23 ppm. Applying the UNEP Toolkit methodology to the new coal mercury concentration provides an annual emission estimate of 1228.5 kg/yr. This is considerably lower (~30%) than the measured emission, which would indicate that the UNEP Toolkit underestimated the mercury emissions. Caution is however raised due to the fact that the measured emission was only taken for a short period of time and then the emissions extrapolated for an entire year. The $SO_2$ and $NO_x$ emissions were also measured during the testing and Table 6 provides a summary of the results.

Table 6: Results of the $SO_2$ and $NO_x$ concentrations in the flue gas at Duvha Power Station

| Unit Number | $SO_2$ Concentration ppm @ 10% $O_2$ | $NO_x$ Concentration ppm @ 10% $O_2$ |
|---|---|---|
| 1 | 428 | 374 |
| 2 | 538 | 314 |
| 3 | 696 | 293 |
| 4 | 678 | 363 |
| 5 | 687 | 326 |
| 6 | 776 | 324 |

Table 7 provides a summary of the results of the mercury concentrations measured in the flue gas at the Kendal Power Station.

Table 7: Results of the mercury concentrations in the flue gas at Kendal Power Station

| Unit Number | Average Concentration µg/m$^3$ @ 3% $O_2$ | Fraction of Oxidised Hg (% $Hg^{+2}$) | Calculated Annual Emission kg Hg /yr |
|---|---|---|---|
| 1 | 39.20 | 70 | 495.0 |
| 2 | 43.45 | 54 | 553.1 |
| 3 | 49.13 | 52 | 485.3 |
| 4 | 46.03 | 52 | 536.1 |
| 5 | 39.47 | 48 | 518.3 |
| 6 | 46.34 | 54 | 442.6 |

The mercury concentration in the flue gas for all units appears consistent. The results for the ESP units are comparable with the results from the Duvha Power Station. Based on the results of the emission tests, each of which were carried out over a minimum of 30 minutes, the extrapolated annual mercury emission for the Kendal Power Station was calculated to be 3030.4 kg/yr. This is considerably less than the emission estimate of 5504.4 kg/yr calculated using the UNEP Toolkit. Applying the UNEP Toolkit methodology to the new coal mercury concentration provides an annual emission estimate of 2877.3 kg/yr. This compares well to the emission estimate calculated using the measured concentrations. This is also an underestimation when compared to the UNEP Toolkit methodology, but again caution is raised due to the limited of the emission measurement. Further emissions testing and coal testing is recommended. The $SO_2$ and $NO_x$ emissions were also measured during the testing and Table 7 provides a summary of the results.

Table 7: Results of the $SO_2$ and $NO_x$ concentrations in the flue gas at Kendal Power Station

| Unit Number | $SO_2$ Concentration ppm @ 10% $O_2$ | $NO_x$ Concentration ppm @ 10% $O_2$ |
|---|---|---|
| 1 | 949 | 410 |
| 2 | 996 | 482 |
| 3 | 938 | 348 |
| 4 | 925 | 446 |
| 5 | 965 | 433 |
| 6 | 1038 | 403 |

## 2.5 Mercury Emissions – Emission Factors

Based on the limited information available from the measured data presented in Section 2.4 above, it is not possible to derive local mercury emission factors at this time. Additional mercury emission testing and simultaneous coal sampling will be required. In the interim, South Africa will proceed with the refinement and expansion of the national mercury emissions inventory (Leaner *et al.*, 2009) using the UNEP Toolkit. Sectors identified for more detailed analysis include the pulp and paper, cement and ferroalloy (ferrochrome, ferrosilicon, ferromanganese and ferrovanadium).

## 2.6 Mercury Emissions – Fugitive Sources

A small but significant source of mercury emissions, related to coal-fired power generation, is the spontaneous combustion of coal in the mines surrounding the power stations. The spontaneous combustion of coal seams in the Witbank and Sasolburg coalfields was studied by Pone *et al.* (2007). The study describes and documents the chemical compounds associated with burning coal fires, including trace elements.

Collieries in the Witbank and Sasolburg coalfields have historically used bord and pillar mining, with typically low recovery ratios, leaving significant coal resources in the pillars, roof and floor. When the old workings are reopened, the ingress of air into the mine resulted in chemisorption and oxidation of the coal leading to spontaneous combustion in some collieries. The work by Pone *et al.* (2007) showed that mercury was released during this spontaneous combustion process. This low level, fugitive emission is near impossible to quantify and is significant as the emissions occur at ground level.

Control of these fires on active mines has proved difficult, with various techniques employed. Cladding, dozing and direct sand dumping have been employed more recently at South African mines. While the problem of spontaneous combustion is far better controlled today when compared to the 1980's, the problem persists and many fires are never completely extinguished (Moolman, 2004).

# 3. Future Trends in Mercury Emissions in South Africa

South Africa will continue to rely on coal-fired power stations for electricity generation into the foreseeable future. The Department of Energy's Integrated Resource Plan 2010 (IRP 2010) maps the power generation options for South Africa up to 2030. The Plan details "committed build" projects which are projects which are currently under construction or are confirmed projects with a high degree of certainty of completion. This includes 10 133 MW of coal-fired generation, 1 020 MW of liquid fuel generation, 2 847 MW of renewable generation and 10 902 MW of decommissioned coal-fired generation capacity. The Plan also details "new build options" which relates to projects that are still in the planning phase or are projects that may change depending on demand. This includes 5 000 MW of coal-fired generation options, 7 650 MW of liquid and gas fired generation options, 11 000 MW of renewable options and 9 600 MW of nuclear options.

The total system capacity will increase from 44 535 MW in 2010 to an estimated 85 241 MW in 2030, with roughly 2 000 MW of new capacity added to the system every year. By 2030 it is estimated that South Africa's reliance on coal-fired power generation will reduce from 90% to 65% of the generation capacity (IRP 2010). South Africa will see a net reduction in mercury emissions from coal-fired power generation. This will be due to the following factors:

1) Eskom will be decommissioning six of the older coal-fired facilities between 2022 and 2029. In addition one of the small IPP facilities will be decommissioned. This will result

in a net mercury reduction of ~5.0 tons/yr.

2) Eskom will be constructing two new coal-fired facilities with the new capacity starting to come on line from late 2012. These facilities will be equipped with advanced pollution control technology and will remove a greater fraction of the mercury emissions than compared to the older facilities. This will result in a net mercury addition of ~4.5 tons/yr.
3) Eskom will be retrofitting fabric filter units to replace ESPs at some of its mid-aged facilities. The fabric filters are more efficient at removing mercury from the flue gas. This process is on-going but is constrained by available financial resources. The replacement of ESPs with fabric filters at three facilities would result in a net mercury reduction of ~2.9 tons/yr.

Based on the above, it is estimated that South Africa's mercury emissions from coal-fired power generation will reduce from ~39.4 tons/yr in 2009 to 36.0 tons/yr by 2030. These reductions exclude the benefit that could be derived from the additional projects that Eskom are investigating and are detailed below.

Eskom are investigating a number of options for reducing $SO_2$ emissions from its facilities. Coal washing is one option that is being investigated by Eskom. The removal of the pyrite fraction in the coal reduces the sulphur content. This may also have an unintended benefit in terms of mercury emissions, as mercury is known to associate with the pyrite fraction. This varies from coal to coal and further investigation and research is required to understand the relationship in the coal used by Eskom. Considering that mercury emissions from coal-fired power generation account for ~75% of the anthropogenic sources in South Africa (Masekoameng *et al.*, 2010), any reduction in emissions from this sector will result in a reduction in the national emission rate. At present there are no plans for a mercury specific intervention for the coal-fired power generation sector in South Africa.

Eskom has also recently embarked on two biomass co-firing projects. The first project is currently under investigation at the Arnot Power Station, where the environmental impact assessment process is currently underway. This project will see the replacement of a portion of the coal with biomass. The final configuration of the ratios and boilers involved is still under consideration. The primary objective of the project is a net reduction in the carbon footprint of the power station, however a co-benefit of this project will be a net reduction in the mercury emissions, since the biomass contains a far lower concentration of mercury than the coal. The second project is still at the trial phase, where torrified wood pellets will be co-fired with coal at the Kriel Power Station. A small short term trial is proposed for late 2011, with the results informing future projects of this nature. Again the primary objective of the project relates to carbon emissions but it will enjoy a co-benefit of reducing net mercury emissions.

## 4. Way Forward

There are two key areas where additional research and investigation is required in South Africa to improve the accuracy of the national mercury inventory from coal-fired power stations.

The first area involves more extensive trace element analysis of the coals used at South African power stations. A programme of regular trace element analysis, together with the traditional proximate and ultimate analyses is required. The lack of readily available data on the mercury content of South African coals has already been highlighted in this report. A demonstration project has been proposed at a pilot scale, where Eskom together with UNEP and its technical experts, seek to demonstrate whether the preparation of South African coals to reduce the mineral matter content is beneficial in reducing mercury emissions from its power stations and whether this treatment is cost-effective. Eskom are already busy with a coal-washing project aimed at reducing sulphur emissions from its power stations. It is proposed to supplement this study with a mercury assessment, which is envisaged to be a potential unintended co-benefit of the project. The details of this project are still being discussed and negotiated between Eskom and the Department of Environmental Affairs, representing UNEP and its technical specialists.

The second area involves the development of an emissions testing programme, specifically targeting mercury emissions from coal-fired power stations. This information is needed to assess the accuracy of the emissions estimates prepared using the UNEP Toolkit. Regular mercury emissions tests would allow for the development of local mercury emission factors. Due to the demonstrated portability, ease of use and high data quality, it is recommended that the South African Government investigate the feasibility of procuring a US-EPA Mercury Emissions Measurements Toolkit. The feasibility assessment would need to include the financial and technical aspects of acquiring the Toolkit.

The current mercury emissions estimate for the coal-fired power sector in South Africa can be considered to have a relatively low degree of confidence. Addressing the issues highlighted in the two areas mentioned above will improve the accuracy and degree of confidence of the national inventory.

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