Study Supporting the Development of a Cross-Media

MERCURY REDUCTION STRATEGY FOR NORTH RHINE-WESTPHALIA

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The State of North Rhine-Westphalia, represented by
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ABSTRACT

Methylmercury poses a severe threat to human health and the environment. It originates mainly from gold mining and coal combustion. Similar to carbon dioxide, mercury emissions do not pose an acute health risk in the direct vicinity of power plants. Mercury spreads around the globe, is washed out into rivers through rainfall and ends-up in oceans. There it is transformed by microorganisms into the highly poisonous substance methylmercury. Methylmercury levels in edible fish from oceans, rivers and lakes are continually rising. In human beings, methylmercury causes severe damage to the brain, especially in early childhood development, leading to a loss of intelligence.

On this background the state government of North Rhine-Westphalia considers it necessary to significantly reduce the input of mercury into the environment.

This report aims to indicate reduction measures for those industrial facilities with highest mercury emissions, to identify pilot implementation projects and to demonstrate legal opportunities for action. To this purpose the project team conducted extensive research into the emissions situation with support from the Ministry for Environment Protection (MKULNV), the State Agency for Nature, Environment and Consumer Protection (LANUV) and in particular the five district governments.

The project team also examined the latest best available techniques for reducing mercury releases to air and water. Emissions from coal-fired power plants and incineration facilities are at the focus of this research. Additionally, emissions from waste co-incineration facilities (e.g. cement and lime plants) and emissions from landfills as well as from chemical and physical waste treatment plants were considered.

Mercury emissions from industrial facilities in North Rhine-Westphalia account for a large proportion of total mercury emissions in Germany (3 t/a, 30%).

In North-Rhine Westphalia, lignite-fired power plants emit over 50% of the total mercury from industrial facilities. 23% of emissions originate from hard coal-fired power plants, 7% from cement and lime plants, 6% from chemical facilities, 5% from a secondary copper smelter and 4% from waste incineration plants.

Requirements to significantly reduce mercury levels are currently only in place for the chlor-alkali industry (to be largely reduced by the end of 2017).

There is high potential for reductions, particularly regarding mercury emissions to air from coal-fired power plants. Mercury emissions are already reduced by coal power plants with abatement techniques for dust, nitrogen oxides and sulphur dioxide (co-benefit effect), resulting in emissions far below the current legal limits. However, they generally do not apply mercury-specific reduction techniques. Current waste gas emission levels, in most cases around 3-6 µg/m³, can be reduced below 1 µg/m³ using specific techniques. As a result, electricity production costs would increase by less than 1%. The resulting mercury emission reduction would equal 80-85%, corresponding to 1.8 t per year. This would avoid more than half of all mercury emissions from North Rhine-Westphalia and almost 20% of emissions Germany-wide.

The legal section demonstrates that industrial plant operators can be required to achieve the emission reductions described in the technical section.
SUMMARY

*Mercury makes children dumb – Danish scientist rings the alarm bells.* This headline from 1997 refers to a study of Faroe Island inhabitants published by Philippe Grandjean of the University of Southern Denmark. He found mercury in the hair and in the umbilical cords of 900 pregnant women. Eight years later, after examining the children, he was able to establish a clear correlation: the higher the mercury concentrations in the mothers, the poorer the linguistic capabilities, attention span, memory, spatial perception and motoric skills of the children. The mercury levels resulted from regularly consuming whale meat. [Press Release 1997] [MacKenzie 1997] This was nothing new: the World Health Organization (WHO) had already published a detailed study of the dangers of mercury-contaminated fish in 1990. [WHO 1990]

Living organisms in oceans, lakes and rivers transform mercury into its most poisonous form methylmercury which organisms are unable to break down. This means that mercury accumulates along the food chain particularly in larger and older fish. In human beings methylmercury accumulates in the central nervous system (i.e. in the brain and spinal cord) causing nerve damage. The damage is particularly severe in embryos and infants as methylmercury inhibits the development of the brain. [Kalberlah et al. 2015]

“It is only the dose which makes a thing poison.” This proverb from Paracelsus is also true of mercury. The mercury concentrations in the air and water today are far below levels that would lead to acute health risks. The legal limits for predatory fish (1000 µg/kg) and other fish species (500 µg/kg) imposed by food standard regulations are generally met. [BTag 2015a] Whether or not consumption of fish meeting such standards presents a health risk, depends entirely on the amount of fish consumed and whether the person in question is pregnant, breastfeeding, or a small child.

Toxicologists have evidence to suggest that mercury can also cause dementia and ADHD. [Hassauer et al. 2012] [Kalberlah et al. 2015]

The “tolerable daily intake” (TDI), currently applied as the basis of acceptable limits according to food regulations, is therefore viewed critically. In 1972 the WHO specified a daily tolerable mercury intake of 0.48 µg/kg body weight (bw), but reduced this to 0.23 µg/kg bw in 2003 following the Faroe study. Most recently in 2012 a working group of the EU health authority EFSA determined a daily limit of 0.19 µg/kg bw. In the USA a maximum daily intake of 0.1 µg/kg bw has been recommended since 2000 following the Faroe study. [Kalberlah et al. 2015]

For a body weight of 70 kg the EU maximum intake corresponds to 93 µg of methylmercury per week. In the US the maximum value is 49 µg methylmercury per week. However, today’s food regulation allows up to 200 µg methylmercury in a 200-gram fillet of predatory fish and up to 100 µg in other fish species. On the other hand, fish is a particularly healthy food, and many fish species are only mildly contaminated. [Widhalm et al. 2007] Pregnant and breast-feeding women should however avoid eating contaminated fish species as recommend by the Federal Institute for Risk Assessment in 1999 and reconfirmed in

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1 Higher concentrations of mercury are particularly found in eel, pike, halibut, swordfish, monkfish, sturgeon and catfish.

Studies of the popular yellowfin tuna from the Pacific Ocean showed no change in mercury concentrations between 1971 and 1998, however, since 1998 the concentration has continued to increase by 3.8% each year. [Drevnick et al. 2015]

Recent studies of fish consumption and mercury exposure in mother-child pairs in 17 EU states showed high exposure in countries with higher fish consumption for example Belgium, Denmark, Portugal, Spain and Sweden, and in general in “frequent fish-eaters”; 11% of frequent fish-eaters exceed the tolerable daily intake. [Bellanger et al. 2013]

In 2000 the EU Water Framework Directive laid down strict target values to address water contamination (Environmental Quality Standards). Measures must be implemented for “priority hazardous substances” leading to a “cessation or phasing-out of discharges, emissions and losses” of such substances. [EU WRRL 2013] As a benchmark for low mercury exposure to humans and the environment, the EU ruled that mercury concentrations in fish shall not exceed 20 µg/kg (wet weight) (Environmental Quality Standard EQS for biota) and in waters the maximum admissible concentration (MAC) of 0.07 µg/l must not be exceeded. [EU UQN-RL 2013]. The Water Framework Directive is thereby working towards the goal of phasing out and eventual cessation of mercury input into waters. The Federal Government stated that whilst improvements have been observed in individual rivers, Germany is far from reaching the target: "In fish from environmental testing sites on the Rhine, the Saar, the Elbe, the Mulde, the Saale and the Danube rivers the Environmental Quality Standard for mercury is continually and extensively exceeded with concentrations 5-25 times higher than the limit." [BTag 2015b]

Due to the global spread of mercury emissions, the United Nations Environmental Programme conducted extensive research into mercury exposure and, as with climate protection, pushed towards a global agreement. In 2013, 128 states including Germany signed the “Minamata Convention”. ² The treaty includes global measures to reduce mercury emissions, in particular at the two main sources: gold mining and coal combustion. [UNEP 2013] [UN Minamata 2013]

In 2016, a guidance document elaborated by sector experts will be finalized on best available techniques and best environmental practices (BAT/BEP) for coal-fired power plants, waste incineration facilities, cement plants and non-ferrous metal smelters. ³ [UNEP 2015] [UNEP 2016]

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² The treaty will come into force as soon as it has been ratified by 50 states, usually through a parliamentary decision.

³ Website on the Minamata treaty and BAT/BEP guidance: [http://www.mercuryconvention.org](http://www.mercuryconvention.org)
Due to the high risk mercury poses to human health and the environment, the state government of North Rhine-Westphalia deems it necessary to significantly reduce mercury input to the environment. In 2014, the state commissioned Ökopol and their partners to draft this report which is to indicate effective measures to significantly reduce mercury input to the environment. [MKULNV 2014]

One focus of this study are reduction methods for mercury releases to air and water from coal-fired power plants. Mercury reduction measures in the waste sector are also examined.

The German energy industry, comprising mainly coal-fired power plants, has released 7 tons of mercury into the atmosphere every year for the past two decades. As other sectors reduced mercury emissions, the percentage of coal-fired power plants increased from 41% (1995) to 68% (2013) of the total emissions in the last 20 years. [UBA NaSE 2015]

With around 10 tons of mercury emissions each year, Germany is one of the largest emitters in Europe along with Poland and Greece (each approx. 10 t). The total emissions from all 28 EU states amounted to approximately 70 tons in 2013. [EEA 2008] [EEA 2015]

According to the European Pollutant Release and Transfer Register (E-PRTR) mercury emissions from large industrial facilities in Germany are by far the highest in Europe (6.94 t). In 2013 these emissions were two times higher than the emissions of Poland, the second highest industrial facilities emitter (3.32 t). [E-PRTR 2015]

**Mercury emissions to air in North Rhine-Westphalia**

Industrial facilities in North Rhine-Westphalia release around 3 tons of mercury each year, causing almost a third of the total annual mercury emissions in Germany (around 10 tons). [UBA NaSE 2015] [LANUV 2015]

Three quarters of mercury emissions of North Rhine-Westphalia originate from coal-fired power plants (2.2 t). Lignite power plants alone emit half of the mercury emissions of North Rhine-Westphalia (1.5 t), and hard coal plants around one quarter (0.7 t). [LANUV 2015] Coal power plants in North Rhine-Westphalia are thus responsible for approximately one third of the annual mercury emissions from the entire German energy sector (2.2 of 7 tons). [LANUV 2015] [UBA NaSE 2015]

Other larger mercury sources in North Rhine-Westphalia are, provided here with their respective emissions in the study’s reference year (2012): a secondary copper smelter (146 kg), three chlor-alkali chemical plants (174 kg), 11 cement plants, (214 kg), two lime plants (45 kg), one gypsum plant (19 kg) and one iron ore sinter plant (15 kg). Over 70 waste incineration facilities released a total of 104 kg in 2012. [LANUV 2015]

Figure 1 shows the proportions of various emission sources for the year 2012. It includes all plants and factories listing mercury in their emission reports according to the German Federal Emission Protection Directive. [11. BImSchV 2013]

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4 The European Environment Agency calculates mercury emissions based on fossil fuels. The total was 60 tons in 2013 for 28 EU countries, not including Greece (Greece constantly released 13 tons from 1990-2008; no data for 2009-2013; estimated here at approximately 10 tons and added to the EU value).
In the 2012, 385 operators of installations in North Rhine-Westphalia with reporting duties listed mercury emissions from 653 sources (chimneys, cooling towers, vents).

The largest proportion of emissions (72%) originated from only 32 large individual sources (mainly large coal-fired power plants as well as three chemical companies, three cement plants and one copper smelter) each releasing more than 30 kg mercury each year (2.1 t). Eight of these sources had annual emissions above 100 kg, a further eight sources emitted 50 to 100 kg and 16 sources recorded mercury emissions of 30 to 50 kg. In the midrange there were 24 sources with 10-30 kg and 86 sources with 1-10 kg. 492 sources of mercury (78%) – the largest number by far – emitted less than 1 kg in 2012. [LANUV 2015]

**Mercury emissions to water in North Rhine-Westphalia**

Besides air emissions, mercury releases to water were also studied, originating from power plants, waste incineration facilities, chemical-physical treatment facilities or landfills in 2012, all regulated in the appendices 27, 33, 47 and 51 of the German Waste Water Ordinance (AbwV).

Mercury load data were mainly available from operators with direct discharge into receiving waters. With two exceptions (Marl, Scholven), all hard coal-fired plants (Appendix 47) discharge directly into water. Six waste water treatment facilities reported waste water from waste incineration facilities (Appendix 33).

In 2012 mercury emissions to water from all direct discharging facilities according to Appendices 27, 33, 47, 51 totaled 6.7 kg. [LANUV 2015] Information was also available for two hazardous waste incineration facilities, which indirectly discharge via waste water and which amounted to 4.2 kg of mercury. [BezRegK 2015]
In total, a mercury discharge of 10.9 kg was determined. The mercury load from other indirectly discharging facilities was not available (i. a. two hard coal plants).

Hard coal-fired power plants (Appendix 47 AbwV) discharged approximately 30% (3.3 kg) of the mercury load recorded in 2012. Due to different control techniques, vast differences were evident in the average mercury concentrations (< 0.05 µg/l to 11.5 µg/l). As a result, and also due to varying facility sizes, there were significant differences in the discharges with mercury loads ranging from 0.007 kg to 0.85 kg.

Regarding mercury discharge from hazardous waste incineration lines (Appendix 33 AbwV), one treatment facility discharged approximately 34% (3.7 kg) of the load recorded in 2012 (in 2014, the load was reduced to 0.3 kg through improvement measures). The discharge of another treatment facility was 0.5 kg (4%). The discharge from two other waste incineration facilities (Appendix 33 AbwV) occurred via an industrial treatment facility also treating effluent water from several chemical production processes. The discharge amounted to 29% of the mercury load calculated for 2012 (3.1 kg).

Regarding mercury from chemical-physical waste treatment facilities (Appendix 27 AbwV), only one reported direct discharge to water (4 g). Waste water of all other facilities was treated indirectly in external treatment facilities. They were not quantifiable as discharge volumes are not measured.

In 2012, 23 landfill sites (Appendix 51 AbwV) reported direct discharges into receiving water. However, nearly all measurement values were below the detection limit (50 or 100 ng/l), meaning that the mercury load was only 0.3 kg.

Individual facilities

Besides describing current emissions, this report also aims to recommend pilot facilities suitable for emission reduction measures.

Facilities emitting mercury are often made up of several operating units. Measures to reduce mercury have to be adapted to each individual unit, referred to as boilers, units or lines. For this reason, individual operation units are addressed.

Large individual sources particularly suitable for pilot projects in reduction measures are highlighted.

Lignite combustion plants

Lignite power plants are responsible for the largest proportion (52%) of mercury emissions in North Rhine-Westphalia with 1,525 kg from 48 individual furnaces. Three further smaller plants did not report a mercury load.

Table 1 shows the locations of five large-scale lignite power plants in the Rhenish lignite mining region. Together they release 50% of mercury emissions in North Rhine-Westphalia (1,461.3 kg).
In 2012, these large lignite power plants consisted of 32 individual operating units. Since 2013, 24 units have been in operation. Further smaller lignite plant locations include a briquette factory with four units (36.1 kg), a lignite refining plant with four units (18.7 kg) and 11 smaller lignite combustion plants for industrial or urban heat and steam generation (9.0 kg).

In Germany lignite power plants with a total rated thermal input of 50 MW or more are subject to daily average value limits of 30 µg/m³ and half-hour averages of 50 µg/m³. From 2019 an annual average value of 10 µg/m³ will apply to existing plants. Annex 2, Table 46 on page 179 provides an overview of current limits. [13. BImSchV 2013]

At the beginning of June 2015 a European Union working group concluded that applying best available techniques (BAT) in existing lignite power plants with a thermal output of 50-300 MWth is associated with emission levels of < 1 to 10 µg/Nm³; and in larger facilities with an output above 300 MW emission levels of < 1 to 7 µg/Nm³. In new facilities values of < 1 to 5 µg/Nm³ (50-300 MW) or < 1 to 4 µg/Nm³ (from 300 MW) were determined. The EU BAT conclusions state that by implementing mercury-specific reduction techniques, emission values below 1 µg/m³ can be achieved in all facilities. These BAT associated emission levels are expected to take effect from 2021 when they will apply as annual averages. [LCPDC 2015]

In the USA, since April 2015, an emission limit value of 4.0 lb/TBtu (depending on efficiency approx. 4.4-5.0 µg/m³, see conversion in Annex 1 on page 246) has applied to existing lignite power plants in all federal states as a 30-day “rolling” average value (hourly average value over 30 days). [US MATS 2012] In some states strict limits have already been in force for several years.

Figure 2 shows mercury emissions in 2012 (bars) from the largest lignite power plants listed in Table 1. The dots represent Hg concentrations in flue gases as registered in emission reports.

Table 1: Lignite power plant locations with the highest mercury emissions in 2012

<table>
<thead>
<tr>
<th>Number of Units</th>
<th>Power Output [MWth]</th>
<th>Power Output [MWnet]</th>
<th>Operator</th>
<th>Location (Name)</th>
<th>Hg Emission 2012 [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>10,613</td>
<td>3,430</td>
<td>RWE</td>
<td>Bergheim (Niederaußem)</td>
<td>497.1</td>
</tr>
<tr>
<td>7**</td>
<td>n/s</td>
<td>3,780*</td>
<td>RWE</td>
<td>Grevenbroich (Neruth)</td>
<td>497</td>
</tr>
<tr>
<td>6</td>
<td>6,168</td>
<td>1,946</td>
<td>RWE</td>
<td>Eschweiler (Weisweiler)</td>
<td>298.7</td>
</tr>
<tr>
<td>10** (2)</td>
<td>n/s</td>
<td>1,800** (600)</td>
<td>RWE</td>
<td>Grevenbroich (Frimmersdorf)</td>
<td>119</td>
</tr>
<tr>
<td>2</td>
<td>640</td>
<td>171</td>
<td>RWE</td>
<td>Hürth (Goldenberg)</td>
<td>49.5</td>
</tr>
<tr>
<td>32** (24)</td>
<td>11,127** (9,927)</td>
<td></td>
<td></td>
<td></td>
<td>1,461.3</td>
</tr>
</tbody>
</table>

* incl. 2 new units each providing 1,050 MW since end of 2012 (‘BoA 2’, ‘BoA 3’)
** incl. 9 units which were decommissioned in 2012 with an output of 150 MW. (in brackets: values for 2013)
Emission quantities can vary even when the flue gas concentrations are the same because furnaces have different outputs or operating times and therefore release different quantities of waste gases.

Figure 3 shows emission concentrations and mercury loads of 48 lignite power plants in North Rhine-Westphalia (the graph is available in a larger scale in Annex 3 on page 258). The concentration values and loads were unavailable for three smaller facilities. Only six of the 48 lignite power plants conduct continuous measurements (marked as black squares in the graph), four of these are smaller fluidized bed furnaces.

With the exception of one small fluidized-bed combustion, all lignite power plants in North Rhine-Westphalia already comply with the annual mercury emission limit value of 10 µg/m³ required in Germany from 2019. The weighted average was 4.9 µg/m³.
In order to meet the aforementioned upper limit value of 10 µg/m³ (for outputs < 300 MWth) or 7 µg/m³ (≥ 300 MWth), based on best available techniques which will apply in the EU 2021, further action is only required for a few individual combustion plants. The lower emission limit value of < 1 µg/m³ based on mercury-specific BAT as concluded by the EU working group is currently generally exceeded by 3 - 8 times.

However, it should be noted that the emission concentrations reported are generally based on periodic, individual annual measurements in which an average value is determined from three individual half-hourly measurements. Measurement values vary greatly from year to year. Values can sometimes deviate by more than 300 % at the same plant location.

To prove that the emission limit values for power plants will be maintained without continuous measurement, mercury analyses of the lignite are required. Exemplary data submitted for expert analysis indicated average mercury concentrations in Rhenish lignite from one power plant unit ranging from 0.05 to 0.09 mg/kg DS (dry substance) with a variation of approximately ± 50%. The data for lignite from another power plant, which came from a neighboring open-pit mine, showed an average of 0.15 mg/kg DS and also had a variation of ± 50%. [BezRegD 2015] [BezRegK 2015]

Chapter 3 (page 109 onwards) describes mercury reduction techniques for lignite power plants. These technologies are well-proven and do not require high investment costs. Mercury is mostly transferred into the scrubber waste water, leading to low mercury contamination in gypsum from the flue gas treatment.

The application of latest best available techniques in lignite power plants reduces emissions to annual averages below 1 µg/m³. With this target value, future operating values would be approximately 0.8 µg/m³. In comparison with 2012, 82% of mercury emissions from lignite power plants can thereby be avoided (1.2 tons per year). This corresponds to a reduction of the total mercury emissions from North Rhine-Westphalia by 41%. The investment and operational costs of mercury reduction techniques in the individual plants generally amount to less than 1% of the costs of electricity generation.

Facilities that are particularly suitable for mercury reduction pilot projects are the lignite power plant units “Niederaußem K”, “Neurath F” and “Neurath G”. They were built a few years ago and create a combined output of 3,200 MWth. This corresponds to approximately a third of the output from the five largest lignite power plant locations. The total mercury emissions of the three units were 364 kg in 2012.

By reducing the average concentration values of approximately 5 µg/m³ in 2012 to 0.8 µg/m³, mercury emissions from lignite plants can be reduced by 84% at these three facilities, i.e. a mercury load of 306 kg. This is equal to approximately 10% of the total mercury emissions from North Rhine-Westphalia in 2012.

Emission reduction at direct discharges to water from lignite power plants have not been considered as direct discharge to water does not occur. It is common practice to redirect a mixture of contaminated scrubber waste water and fly ash into the mine.
In order to transfer the concentrated mercury from the scrubbing waste water to a sink (underground storage), it would be necessary to change the practice of directing waste water and fly ash to the mine.

**Hard coal furnaces**

Hard coal power plants are the second largest source of mercury emissions in North Rhine-Westphalia (22%) with 659 kg, originating from 38 individual sources. Mercury load reports were unavailable for two smaller facilities.

Table 2 lists the 10 largest hard coal power plant locations, which together release 20% of mercury emissions in North Rhine-Westphalia. In 2012 the locations included 26 individual power plant units (in total 20 units from 2014 due to the decommissioning of 7 units and commissioning of one new unit).

Table 2: Hard coal furnace locations with the highest Hg emissions to air from NRW in 2012

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Power Output [MWth]</th>
<th>Power Output [MWel]</th>
<th>Operator</th>
<th>Location (Name)</th>
<th>Hg Emissions 2012 [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3,739</td>
<td>1,390</td>
<td>STEAG/RWE</td>
<td>Voerde</td>
<td>186</td>
</tr>
<tr>
<td>4</td>
<td>6,203</td>
<td>2,123</td>
<td>E.ON</td>
<td>Gelsenkirchen (Scholven/Buer)</td>
<td>144</td>
</tr>
<tr>
<td>4</td>
<td>1,432</td>
<td>487</td>
<td>Mark-E</td>
<td>Werden-Elverlingsen</td>
<td>51.5</td>
</tr>
<tr>
<td>3* (0)</td>
<td>2,083* (0)</td>
<td>800* (0)</td>
<td>STEAG</td>
<td>Herne (Shamrock)</td>
<td>50.5</td>
</tr>
<tr>
<td>3</td>
<td>3,129</td>
<td>1,350</td>
<td>STEAG</td>
<td>Duisburg (Walsum)</td>
<td>44.2</td>
</tr>
<tr>
<td>2</td>
<td>1,800</td>
<td>640</td>
<td>STEAG</td>
<td>Voerde (Voerde-West)</td>
<td>39.5</td>
</tr>
<tr>
<td>3* (0)</td>
<td>793* (0)</td>
<td>319</td>
<td>E.ON</td>
<td>Datteln</td>
<td>26</td>
</tr>
<tr>
<td>1</td>
<td>1,528</td>
<td>720</td>
<td>RWE</td>
<td>Werne (Gersteinwerk)</td>
<td>15.6</td>
</tr>
<tr>
<td>1* (0)</td>
<td>880* (0)</td>
<td>350* (0)</td>
<td>E.ON</td>
<td>Dortmund (Knepper)</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>1,313</td>
<td>507</td>
<td>STEAG</td>
<td>Lünen</td>
<td>12</td>
</tr>
<tr>
<td>1 (2)*</td>
<td>732 (2,847)</td>
<td>305 (1105)</td>
<td>RWE</td>
<td>Hamm</td>
<td>4.46</td>
</tr>
<tr>
<td>26* (20)</td>
<td>23,632* (21,991)</td>
<td>8,941* (8,322)</td>
<td></td>
<td>Total in 2012 [kg]: 587.76</td>
<td></td>
</tr>
</tbody>
</table>

* Power plants in Datteln, Knepper and Schamrock decommissioned in 2013, Hamm Unit E newly operating since 2014 (in brackets: values since 2014)

For hard coal power plants with a total rated thermal input of 50 MW or more, a daily average emission limit of 30 μg/m³ and a half-hourly average limit of 50 μg/m³ applies in Germany. An annual average emission limit value of 10 μg/m³ for existing plants will come into effect from 2019. For hard coal power plants with outputs of 50-300 MWth, is associated with emission levels of < 1 to 9 μg/Nm³ and in larger facilities with an output of 300 MW or more, levels of < 1

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5 See also Fehler! Verweisquelle konnte nicht gefunden werden., Fehler! Verweisquelle konnte nicht gefunden werden. on page 176 for applicable limit values in Germany
to 4 µg/Nm³. For new facilities BAT associated levels of < 1 to 3 µg/Nm³ (50-300 MW) or < 1 to 2 µg/Nm³ (above 300 MW) were defined. The EU BAT conclusions state that by implementing mercury-specific reduction techniques, emission values below 1 µg/m³ can be achieved in all facilities. These emission levels are expected to take effect from 2021 on when they will apply as annual averages. [LCPDC 2015]

In the USA existing hard coal power plants in all federal states have been subject to emission limits of 1.2 lb/TBtu since April 2015 (depending on efficiency approx. 1.5 µg/m³; see conversion in Annex 1, page 246). This is a “rolling” 30-day average value (average of 30 daily average values). Some states have already been enforcing strict requirements for many years. [US MATS 2012]

Figure 4 shows emission concentrations of 38 hard coal power plants in North Rhine-Westphalia (the graph is available in a larger scale in Annex 4 on page 259). The concentration values and mercury loads of two further facilities are unavailable. Only 19 of the 38 hard coal furnaces conduct continuous measurements (marked as black squares in the graph).

The mercury concentration values from 2012 indicate that around 30% of hard coal power plant units in North Rhine-Westphalia already achieve mercury emission values below 1.0 µg/m³ (11 units) through the co-benefits of efficient waste gas treatment for nitrogen oxides, dust and sulphur dioxide. The weighted average value for all units was 6.4 µg/m³.

Almost all hard coal power plant units are already below the annual average value of 10 µg/m³ which is to come into effect in 2019 (three of five units with higher emissions have since been decommissioned). Therefore, the implementation of this emission limit value will result in practically no further mercury reductions.

Further action is only required for a few individual combustion plants to meet the aforementioned upper limit values of 9 µg/m³ (for capacities < 300 MWth) or 4 µg/m³ (≥ 300 MWth), based on best available techniques and applied in the EU from 2021. The lower mercury emission limit value of < 1 µg/m³ based on mercury-specific BAT as concluded by the EU working group is currently generally exceeded by 2-4 times.
However, it should be noted that at least half of the emission concentrations reported are based on periodic annual measurements in which an average value is calculated on the basis of three individual half-hour measurements. The mercury concentrations in hard coal vary greatly from year to year meaning that individual measurements involve a high level of uncertainty.

Mercury reduction techniques for hard coal power plants are described in chapter 3 from page 109). These techniques are tested and imply low cost. Mercury can be largely discharged in the sludge from the wet flue gas scrubbing of waste water treatment so that neither gypsum (utilized in cement industry) nor fly ash or scrubber waste water will be more heavily contaminated with mercury.

The application of latest best available techniques in hard coal power plants reduces emissions to annual average values below 1 µg/m³. With this target value, future operating values would be approximately 0.8 µg/m³. In comparison with 2012, 80% of mercury emissions from hard coal power plants can thereby be avoided (527 kilograms per year). This corresponds to a reduction of the total mercury emissions from North Rhine-Westphalia by 18%. The investment and operational costs of mercury reduction techniques in the individual plants generally amount to less than 1% of the costs of electricity generation.

Hard coal power plants that are particularly suitable for pilot projects in mercury reduction are “Hamm Unit E” (new), “Duisburg-Walsum 10” (new), “Duisburg-Walsum 9”, “Voerde A” and “Voerde B”. Two units have only recently started operation. The combined output of the suggested units amounts to 3,390 MWel and accounts for a large portion of the total output from the largest hard coal power plant locations. In 2012 the total mercury released from the three older units was 230.2 kg not including emissions from the new units Walsum 10 in Duisburg and Unit E in Hamm.

By reducing the concentration value from an average of around 8.0 µg/m³ (in 2012) to values of around 0.8 µg/m³, mercury emissions from these three existing facilities can be reduced by around 90% i.e. a mercury load of 206.8 kg (plus emission reductions achievable at Walsum 10 and Hamm Unit E). This corresponds to around 7% of the total mercury emissions in North Rhine-Westphalia in 2012.

Waste water discharge from combustion plants

Data were available for a total of 15 direct discharges from power plants where the waste water came from the flue gas scrubber of a combustion facility (3.3 kg). In Germany, a general limit of 0.03 mg/l applies for mercury discharges from waste water treatment facilities of power plant flue gas scrubbers (see also Annex 2, Table 46 on page 179 on limits applicable in Germany).

Mercury discharges from the power plant sector resulted from one oil refinery power plant (0.0028 kg) and 14 hard coal power plants (3.3 kg).

Seven hard coal-fired power plants discharged mercury loads of between 7 and 93 grams in 2012. Seven further hard coal-fired power plants discharged between 149 and 855 grams. As a general rule low discharge concentrations correspond to low annual mercury loads.
Figure 5 shows average values of mercury discharge concentrations measured in 2012 (diamonds) and the respective annual mercury loads (number above the diamond, in grams). The average annual concentration value is often based on only a few official measurements. For example, the highest concentration and load values in 2012 (724 g) were based on just two measurements with extremely different values. The second highest concentration and load values in 2012 were based on four measurements (855 g); the facility’s self-monitoring measurements suggest a load that is only half this value (490 g). [LANUV 2015]

Note: Load values are indicated in gram per year above each concentration value. Information about the facility operators can be found in Table 15 on page 77.

Figure 5: Mercury emissions (value above the diamonds) and emission concentrations (diamonds) of the waste water treatment facilities of 15 power plants with direct water discharge in North Rhine-Westphalia in 2012

By applying latest best available techniques, annual average values of 0.06 µg/l can be achieved in facilities permitted under Appendix 47 AbwV (flue gas scrubbers of combustion plants). Maximum values of up to 0.1 µg/l may occur when applying these techniques.

With the application of latest best available techniques, facilities in North Rhine-Westphalia have the potential to reduce mercury emissions by around 3 kg/a. This is equal to 96% of the mercury discharge in 2012.

Waste incineration facilities

Mercury emissions from waste incineration facilities were taken from 71 locations and amounted to 104 kg in 2012 i.e. 3.5% of the total emissions from North Rhine-Westphalia.

In Germany the daily average limit value for mercury emissions from waste incineration facilities is 30 µg/m³ with a half-hourly average limit values of 50 µg/m³. From 2019 an annual average limit value of 10 µg/m³ will come into effect; for new facilities this applies from 2016. [17. BImSchV 2013]

See also Fehler! Verweisquelle konnte nicht gefunden werden., Fehler! Verweisquelle konnte nicht gefunden werden. on page 176 on applicable limits in Germany.
In 2006 the EU published a reference document on best available techniques (BAT) in the waste incineration sector. In this document it was concluded that best available techniques at that time were associated with half-hourly average values of 1-30 µg/Nm³ and daily average values of 1-20 µg/Nm³ in new and existing facilities. Annual average values based on BAT were not determined. Since 2007 these value ranges have provided a reference for regulatory authorities EU-wide. Levels associated with BAT will come into legal effect once the BAT reference document has been revised within the new framework of the Industrial Emissions Directive. The revision began in 2015. The revised document is to take account of technological progress and is expected to be finalized in 2017. \[BREF WI 2006\] \[EU IED 2010\]

Techniques for reducing mercury releases in waste incineration have been established in such facilities for many years. They are described in chapter 3 (from page 109). Using latest best available techniques, annual average levels below 1 µg/m³ can be achieved. The investment and operational costs of mercury reduction techniques are reasonably low; the techniques are proven. Mercury is mainly released via the utilized activated carbon which is expelled together with filter dust and landfill.

The application of latest best available techniques in waste incineration plants is associated with yearly average levels below 1 µg/m³. This target value implies future annual average values of about 0.8 µg/m³. Thereby, compared to 2012, around 50% of mercury emissions from waste incineration facilities are avoided (approx. 50 kg per year). This corresponds to a 1-2% reduction of the total mercury emissions in North Rhine-Westphalia.

Facilities for pilot projects in this sector are not a priority. The techniques are already established and widely used in the industry, and the possible reductions in the individual facilities would be low during standard operations. However, in cases of illegal mercury input, the new techniques would lead to significant emission reductions.

Power plants with waste co-incineration

Mercury emissions from 24 power plant units authorized for waste co-incineration have been included in the power plant emissions, apart from one fluidized bed facility in the city of Werdohl (North Rhine-Westphalia), which incinerates sludge and hard coal and is included with the sludge incineration plants.

Cement and lime plants with waste co-incineration

In 2012 the 12 kilns at the 11 cement plants in North Rhine-Westphalia presented relatively high mercury emissions (214 kg). This is equivalent to 7% of the total emissions. Lime plants were responsible for 1% of emissions (35 kg).

11 out of the 12 cement work kilns (182.5 kg mercury emissions) were authorized to co-incinerate waste; one kiln (30.3 kg Hg) was not authorized to incinerate waste. Mercury originating from the dedusting of a clinker cooler and from a coal pulverizer was only reported by one cement plant (1.2 kg).

Mercury emissions partly result from the limestone used.
This is also valid for the three lime plants which reported mercury emissions of 35.1 kg in 2012. Three out of four lime kilns possessed a license to co-incinerate waste (34.9 kg emissions); the fourth kiln reported 0.2 kg.

Of the kilns with a permit to co-incinerate waste, five lime kilns had emissions between 4 and 9 kg, two cement kilns and three lime kilns emitted 10 to 17 kg of mercury; four cement kilns reported mercury emissions between 21 and 34 kg, which is equivalent to the emissions of a large hard coal power plant.

Figure 6 shows emission concentrations and annual loads of 11 cement kilns and 3 lime kilns with a license to co-incinerate waste.

In Germany a daily average limit value of 30 µg/m³ and a half hour average limit value of 50 µg/m³ applies to mercury emissions from cement plants with co-incineration. If mercury is proven to originate from the lime stone and waste co-incineration does not result in increased emissions, limit values of 50 µg/m³ as a daily average and 100 µg/m³ as a half hourly average are permissible upon application. The annual average limit value of 10 µg/m³ to apply to waste incineration facilities from 2019 does not apply to cement and lime plants with co-incineration, meaning that the application of the new limit value will not result in any reductions. [17. BImSchV 2013]

In October 2008 a European Union working group determined best available techniques (BAT) for cement, limestone and magnesium oxide production. After the approval of the Industrial Emissions Directive [EU IED 2010], the information available at that time was carried over to the binding BAT conclusions without updates.

The BAT reference document for the production of cement, limestone and magnesium oxides determined for the EU that best available techniques as of 2008 are associated with average levels of < 50 µg/Nm³ over the sampling time (min 0.5 hours). The BAT reference document concludes that values above
30 µg/Nm$^3$ are to undergo further observation and with values of 50 µg/Nm$^3$ additional measures are to be considered (“e.g. reducing waste gas temperature, activated carbon”). The same values apply to co-incineration in cement plants. With regard to the use of waste, the reference document remarks that: “Lower values were reported when using BAT”. Since the publication of the BAT conclusions in April 2013 the BAT associated levels apply to new facilities, and will apply to existing facilities from 2017. \([BREF CLM 2010] [BATC CLM 2013] [EU IED 2010]\)

With common techniques for reducing mercury emissions, mercury is “shuttled” out of the combustion process to be mixed into the cement. Sorbents can be added to increase the efficiency of this technique. This is practiced in several cement plants in North Rhine-Westphalia. The mercury-laden sorbent and shut-tled dust are mixed into the cement in the clinker mill of the cement plant. Measurement values for the resulting emissions are not available. After cement use mercury is fixed with relative stability in the hardened cement or concrete. Reduction techniques for cement plants are described in chapter 3.1.4 (from page 142).

Reduction techniques for mercury removal from the environment are not yet applied in cement plants in Germany. In the framework of this project it was not possible to determine achievable emission levels with reasonable costs by adding sorbents. **This requires further investigation. Due to the relatively high emission levels of individual facilities, the following cement plants would be particularly well suited for pilot projects to test the techniques for removal and disposal of mercury: Locations Ennigerloh, Beckum-Kollenbach and Geseke Milke, which each release over 30 kg mercury each year.**

**Possible legal action**

The legal section (chapter 5) demonstrates that it is possible to demand that facility operators achieve the emission reductions described in the technical section. This can be achieved by changing the limit values in the relevant regulations (13th and 17th Ordinance for the Implementation of the Federal Immission Control Act, Appendices to the Waste Water Ordinances). Additionally, authorities can impose tighter limit values on existing facilities without changes in law, through the fixation of subsequent orders.

**Further investigation required into other large sources of mercury**

In 2012 further facilities with particularly high mercury releases to air were four chloralkali electrolytic processes (181 kg) in the chemical industry and one secondary copper smelter using scrap metal as a raw material (146 kg).

Chlor-alkali electrolysis must be ceased by December 2017 at the latest due to obligatory BAT conclusions. \([BREF CAK 2013] [BATC CAK 2013]\) The releases to air (182 kg) from the chemical industry in North Rhine-Westphalia will thus be reduced to a large extent. One exception is a facility that uses an amalgam process for the production of alcoholates. Aside from this operation no further action is required for air emissions from the chemical industry.
The cessation of chlor-alkali electrolysis at the end of 2017 will also lead to a significant reduction in mercury releases to water. However, some larger sources of mercury emissions require further investigation into reduction options.

The secondary copper smelter belongs to the non-ferrous metals industry. In this sector a daily average mercury limit value of 0.25 g/h or 50 µg/m³ currently applies according to the German Technical Instructions on Air Quality Control (2002).

An EU working group established the following regulations for best available techniques in the non-ferrous metals industry in March 2014: With the application of BATs “raw material selection” and “use of sorbents”, emission levels between 10 µg/m³ to a maximum of 50 µg/m³ can be achieved. A footnote in the BAT reference documents indicates that the lower end of this range can be achieved using sorbents combined with a dust filter (apart from in rotary kilns). The BAT conclusions are to be published by the EU in 2016 meaning that the limit value range will apply EU-wide by 2021. These values represent daily average values or mean values over the sampling period. [BREF NFM Draft 2014]

Besides the selection of low-mercury raw materials, common techniques for reducing mercury emissions include the addition of sorbents. Mercury is bound to flue gas particles and thereby expelled and removed. To increase efficiency special sorbents can be used which have been pretreated with sulphur or bromine. These reduction techniques are similar to those used in dry flue gas scrubbing in waste incineration facilities as described in chapter 3 (from page 109).

According to the facility operator, the doubling of mercury emissions, which were 70 kg/a in 2007 and 2008 and 146 kg in 2012, is not due to increased production but rather due to the increased mercury concentrations in secondary raw materials and the expansion of measurement techniques to include additional sources. By using other sorbents containing active carbon, mercury emissions were reduced to 122 kg in 2013 and 87 kg in 2014. [Aurubis 2015] [E-PRTR 2015]

Within the scope of this project it was not possible to determine if further reductions would be achievable by changing the sorbent, and with reasonable costs. This requires further investigation. As the secondary copper smelter continues to be a relatively large source of emissions (87 kg in 2014), it is particularly well suited for a pilot project into further mercury reduction.

Relevance estimation of further mercury sources

Preliminary research into further sources of mercury emissions indicate that there are probably no relevant emission amounts from these activities. However further investigation is required to improve the data quality and to quantify the following sectors:

- Mercury emissions from steel production and foundries (air)
  (Emission reports from 2012 specify 24.2 kg, thereof 95% from one sintering plant and a steel mill, the rest from 7 small sources)
- Mercury emissions from mineral oil refineries (air, water)
  (a small number of measurements suggest low emissions)
• Mercury emissions from gas combustion (air)  
  (measurements show low emission concentrations)
• Mercury emissions from municipal waste water treatment (water)  
  (reports of relatively high PRTR values can be explained with high volume flows and measurements that were largely below the detection limit. The load calculations were based on half of the detection limits; investigations with lower detection limits showed a low relevance)
• Mercury emissions from gas compressor stations (air)  
  (detailed investigations were not possible in the context of this project)
• Mercury emissions from crematories (air)  
  (estimated emission volume < 10 kg in 2012)
• Mercury emissions ending-up on soils from sewage sludge application on fields (water)  
  (Estimates possible for input quantities but difficult to determine the percentage leaching into surface waters)

Further action
The investigation into the data on mercury relevant facilities reveals that many relevant sources of mercury are not obliged to continuously measure emissions due to the use of exemption clauses.

This means that data provided on mercury emissions from nearly all lignite power plants, as well as data of half of the hard coal power plants, are estimates based on annual individual measurements (realized during 0.02% of total hours of a year).

If in future the implementation of BAT associated levels leads to annual limit values far below 10 µg/m³ the current monitoring practice will no longer be suitable.

One option is to conduct continuous emission monitoring. As a result of US requirements measuring instruments have become more accurate and require less maintenance.

Another option is long-term sampling in adsorption tubes which is legally recognized in the US as an alternative to continuous measurement. [US EPA 2012] [US EPA PS 12B o. J.]

Compared with continuous measurement and the standard reference method, measurements taken from adsorption tubes are highly accurate. [Mayer et al. 2014] Long-term sampling in adsorption tubes is a particularly interesting alternative to continuous measurement in the case of coal-fired power plants, if no particular mercury reduction technique needs to be monitored to maintain the yearly average value – for example because the mercury content of the coal is low or low emissions are monitored by other parameters (e.g. measuring mercury concentration in scrubbers). The EU working group CEN TC 264 WG 8 are currently working on transferring the US EPA methods for long-term sampling with the goal of establishing a European standard. [Reinmann 2014]

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7 Assuming that mercury-specific reduction techniques are installed at all 18 crematories (Hg specific sorbents or GORE®-Filter), approx. 100,000 cremations in 2012, emission factor 54.6 mg/cremation = 5.5 kg
Pilot projects at coal-fired power plants to measure mercury in adsorption tubes are recommended (Sorbent Trap Monitoring System). This will help to validate the CEN measurement method and work towards its legal recognition as an alternative to continuous measurements.

Possible facilities for pilot measurements are power plants that are testing mercury specific reduction techniques and have either installed latest-generation, reliable, continuous emission monitoring systems or conduct comparative measurements with the standard reference method.

Complementing continuous mercury emission measurement data with long-term sampling could help to remove some of the widespread uncertainty regarding the total mercury emissions in North Rhine-Westphalia.