

European Commission

**Economic Evaluation
of Air Quality Targets
for Heavy Metals**

Final Report

January 2001

Entec UK Limited

Report for

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European Commission

Economic Evaluation of Air Quality Targets for Heavy Metals

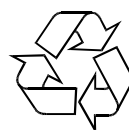
Final Report

January 2001

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Executive Summary

Introduction

Council Directive 96/62/EC on ambient air quality assessment and management provides the framework for the development of subsequent Daughter Directives on specific air pollutants. Directive 96/62/EC is concerned with the setting of “limit values” based on levels of concentrations of a pollutant in ambient air during a defined period of time. The Commission plans to come forward with proposals for limit values for certain heavy metals and the findings of this study are to assist in the development of these proposals.

The principal objective of this study was to identify and estimate the costs and benefits of meeting potential air quality limit values for the following heavy metals:

- arsenic;
- cadmium; and
- nickel.

In addition, mercury is also considered although, as potential limit values or risk factors were not available for mercury during the timescale of this study, only a less extensive analysis has been possible for this metal.

The areas of interest to this study have included the 15 EU Member States and six Accession Countries.

The Working Group on arsenic, cadmium and nickel compounds has proposed a number of potential air quality limit values to be considered in this study as shown in Table 1. It is assumed that the limit values would apply in 2010 and that the values relate to annually averaged concentrations.

Table 1 – Ambient Concentrations to Consider in the Cost Benefit Analysis

Pollutant	Concentration (ng/m ³)
Arsenic	1
	4
	5
	13
	20
Cadmium	0.5
	5
	15
Nickel	3
	10
	30
	50

Emission source groups of interest

The assessment of costs and benefits associated with potential air quality limit values has considered all significant emission source groups for the metals of interest. Establishing exactly which sectors to evaluate has involved investigations of relevant emissions inventories; reviews of ambient air quality information and judgements based on process knowledge. This has identified the sectors as listed below. The analysis of each sector is presented separately in the main report.

Iron and Steel Processes

- Integrated iron and steel works
- Electric arc steelmaking (including stainless steel production)

Non Ferrous Metals Processes

- Copper production
- Nickel and nickel alloy production
- Zinc production
- Lead production

Combustion Processes

- Public power (coal)
- Public power (fuel oil)
- Other combustion plant
- Road transport
- Shipping

Other Processes

- Petroleum refineries
- Cement production
- Waste incineration
- Chlor-alkali production
- Glass production

In addition, whilst concentrations in the vicinity of industrial areas are the primary concern for the metals of interest, certain urban locations also have elevated concentrations. Therefore, we have performed a check to ensure that the above mentioned sectors will ensure adequate coverage of emission source groups relevant to both industrial and urban areas.

Methodology

For each of the sectors of interest we have followed a systematic sequence of discrete steps leading to the estimation of the costs and benefits of meeting the potential ambient air quality standards. In brief, our approach for each sector has been as follows:

1. Investigation of the *profile of the sector* in terms of numbers of processes; types of processes; size / capacity of processes; geographical distribution etc;
2. Investigation into *emission sources* including relevant process details, emission factors etc;
3. Analysis of *current air quality data*. A wide range of information sources have been consulted to endeavour to gather the best available recent ambient air quality data;
4. Review of applicable *emission reduction techniques*. This considers the abatement efficiency of techniques as well as details on capital and operating costs;
5. Assessment of *future air quality under the 2010 business as usual (BAU) scenario* i.e. taking into account agreed policies that will affect emissions in the future;
6. *Comparison of future air quality against the potential limit values* to identify areas of exceedance and sectors responsible;
7. Investigation into *packages of additional emission reduction techniques* that enable compliance with each of the limit values;
8. Identification of the *least cost package* including a detailed *cost assessment*; and
9. *Benefit analysis* considering both human health and environmental benefits.

For each of the sectors of interest this report presents the findings of the above methodology under the following headings:

- Profile of sector;
- Emission sources;
- Current air quality data;
- Emission reduction techniques;
- Future air quality under the business as usual scenario; and
- Costs and benefits of complying with potential limit values.

Business as usual trends in emissions

Overall, emissions of arsenic, cadmium, mercury and nickel across the EU have been declining in recent years with the implementation of improved environmental controls. Furthermore, there are several adopted or proposed policies at an EU and international level that are expected to secure significant further reductions in heavy metals from certain sectors. These are taken into account as far as possible in estimating business as usual (BAU) air concentrations of these metals for 2010.

The IPPC Directive is expected to have an important impact on emissions of heavy metals from iron & steel, non ferrous metals, combustion process, petroleum, cement and glass sectors. The application of Best Available Techniques (BAT) will require the installation of the most effective economically viable techniques to reduce metal emissions, taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. This will lead to greater convergence of emissions performance within each sector across the EU-15 by 2007 and across the Accession Countries by 2010 (on the working assumption of a 3 year transition period).

Under the proposed revisions to the Large Combustion Plant Directive (LCPD), existing large combustion plants will be required to comply with the emission limit values for new plant in the current LCPD (88/609/EEC) by 1/1/2008, or implement a national emission reduction plan to achieve equivalent reductions within the same timescale. Existing waste incineration and co-incineration processes are assumed to comply with the provisions of the proposed Waste Incineration Directive by 2005 for the EU-15 and 2008 for the Accession Countries (again assuming a 3 year transition period).

Other policies of relevance to the BAU scenario include the UNECE Heavy Metals Protocol, the UNECE Multi Pollutant Protocol, the proposed National Emission Ceilings Directive, the Kyoto Protocol and the Air Quality Daughter Directive (in particular limit values for lead and PM₁₀).

Estimated costs of complying with the potential limit values

Based on our extensive investigations, we have developed summary tables (Tables 2, 3 and 4) indicating the estimated incremental annual costs to each sector of complying with the potential limit values. The baseline for the assessment is the predicted BAU performance in 2010, ie taking into account any improvements in emissions under the IPPC Directive, the proposed Waste Incineration Directive etc.

Costs are presented in year 2000 prices, with historic cost data updated using a 3% inflation rate. Capital costs have been annualised assuming Discount Rates (DR) of 2, 4 and 6% and an economic life of the equipment of 15 years has been assumed.

For the cost estimates, operating companies are faced with various options to enable them to go beyond their BAU commitments and predicting the most viable future compliance route has not been straightforward. For the key sectors incurring potential compliance costs the compliance techniques have been assessed following detailed investigation and the following used as the most appropriate:

- Iron & steel (Electric arc furnaces) - additional enclosure, extraction and abatement for control of fugitive emissions and main process emissions or, for a small proportion of plants where abatement improvements are not considered possible, an increase in stack height (subject to acceptability);
- Copper - additional covered storage, extraction and abatement for control of fugitive emissions and main process emissions;
- Nickel - additional techniques for control of fugitive and/or main process emissions to be determined following operating companies' feasibility studies;
- Zinc - additional techniques for control of fugitive and/or main process emissions to be determined following operating companies' feasibility studies; and
- Petroleum refining - desulphurisation of refinery fuel oil followed by on-site combustion (the key alternative technique of switching to natural gas firing was not selected due to potential limitations in gas supply across the area of interest and the potential lack of future market for unused fuel oil).

The uncertainty associated with the choice of compliance technique, combined with the diverse range of elements that constitute total installed capital costs and annual operating costs, and the

scaling up of estimates for representative sites to the sectors as a whole introduces an overall uncertainty of the cost estimates of in the region of $\pm 50\%$.

As can be seen in the Tables, based on current information the lowest limit values are unlikely to be achievable for all sites in many or all of the metals sectors. This is primarily due to historical deposition of particulates; fugitive emissions from extensive material storage and handling activities; emissions from neighbouring mineral workings and industrial sites etc. Furthermore, a small number of sites may not be able to comply with the highest limit values. A key reason for this is due to residential properties located in very close proximity to the site boundary. Ambient metal concentrations can reduce by a significant factor from close to the site boundary, say 100m away, to a point 1km away.

Table 2 Estimated Costs of Compliance with the Proposed Arsenic Limit Values (Note 1)

Sector	Estimated total costs of compliance (€m pa)				
	20ng/m ³	13ng/m ³	5ng/m ³	4ng/m ³	1ng/m ³
Iron and steel – integrated works	0	0	0	0	Unlikely to be achievable for all sites
Iron and steel – electric arc (inc stainless steel)	0	0	0	0	Unlikely to be achievable for all sites
Copper production	Unlikely to be achievable for at least 1 of 9 sites	16 (@2%DR – Discount Rate) 17 (@4%DR) 19(@6%DR) Totals for up to 9 sites	Unlikely to be achievable for all sites	Unlikely to be achievable for all sites	Unlikely to be achievable for all sites
Nickel and nickel alloy production	0	Compliance achieved from investment into Ni reductions	Compliance achieved from investment into Ni reductions	Unlikely to be achievable for all sites	Unlikely to be achievable for all sites
Zinc production	0	0	0	0	Unlikely to be achievable for all sites
Lead production	Unlikely to be achievable for at least 1 site	Insufficient data to quantify costs	Unlikely to be achievable for all sites	Unlikely to be achievable for all sites	Unlikely to be achievable for all sites
Power gen – coal	0	0	0	0	0
Power gen – oil	0	0	0	0	0
Small oil fired combustion plant	0	0	0	0	0
Road transport	0	0	0	0	0
Shipping	0	0	0	0	0
Petroleum refining	0	0	0	0	Compliance achieved from investment in Ni reductions
Cement production	0	0	0	0	0
Incineration	0	0	0	0	Note 2
Glass production	0	0	0	0	0
Total for all sectors	Unlikely to be achievable for at least 2 sites	16 (@2%DR) 17 (@4%DR) 19(@6%DR) Plus costs for lead sector.	Unlikely to be achievable for all copper and lead sites.	Unlikely to be achievable for all copper, nickel and lead sites.	Unlikely to be achievable for all iron and steel, copper, nickel, zinc and lead sites.

Notes

1. Figures are best estimates. Upper estimates are +50%; lower estimates are –50%.
2. Two surveyed sites would require improvements in ambient As to comply. However, the contributors to the elevated As are considered to be nearby metals works and historic deposition.

Table 3 Estimated Costs of Compliance with the Proposed Cadmium Limit Values (Note 1)

Sector	Estimated total costs of compliance (€m pa)		
	15ng/m ³	5ng/m ³	0.5ng/m ³
Iron and steel – integrated works	0	0	Unlikely to be achievable for all sites
Iron and steel – electric arc (inc stainless steel)	0	0 (Note 2)	Unlikely to be achievable for all sites
Copper production	Unlikely to be achievable for at least 1 of 9 sites	Unlikely to be achievable for at least 2 of 9 sites. For others, compliance due to investment into As reductions	Unlikely to be achievable for all sites
Nickel and nickel alloy production	0	0	Compliance achieved from investment into Ni reductions
Zinc production	Some costs expected for up to 5 of 14 sites based on historic data	20 (@2%DR) 22 (@4%DR) 24 (@6%DR) Totals for 5 sites. Historic data suggests this might not be achievable for some of the 14 sites	Unlikely to be achievable for all sites
Lead production	Unlikely to be achievable for at least 1 site	Insufficient data to quantify costs	Unlikely to be achievable for all sites
Power generation – coal	0	0	0
Power generation – oil	0	0	0
Small oil fired combustion plant	0	0	0
Road transport	0	0	0
Shipping	0	0	0
Petroleum refining	0	0	Compliance achieved from investment in Ni reductions
Cement production	0	0	0
Incineration	0	0	Note 3
Glass production	0	0	0
Total for all sectors	Some costs expected for zinc sites and unlikely to be achievable for at least 2 sites	20 (@2%DR) 22 (@4%DR) 24 (@6%DR) Unlikely to be achievable for at least 2 sites plus costs for lead sites.	Unlikely to be achievable for all iron and steel, copper, zinc and lead sites.

Notes

1. Figures are best estimates. Upper estimates are +50%; lower estimates are –50%.
2. Assuming high concentration at one location in Germany is due to nearby zinc plant
3. At surveyed sites concentrations are above limit value but are expected to fall below limit value with future decline in background concentrations, a decline in cadmium content of waste and implementation of the Waste Incineration Directive.

Table 4 Estimated Costs of Compliance with the Proposed Nickel Limit Values (Note 1)

Sector	Estimated total costs of compliance (€m pa)			
	50ng/m ³	30ng/m ³	10ng/m ³	3ng/m ³
Iron and steel – integrated works	0	0	0	Unlikely to be achievable for all sites
Iron and steel – electric arc (inc stainless steel)	0	Compliance costs for a small proportion of sites	48 to 64 (@2%DR) 51 to 67 (@4%DR) 54 to 73 (@6%DR) Totals for 34 sites. May not be achievable for all sites (Note 2)	Unlikely to be achievable for all sites
Copper production	0	0	Unlikely to be achievable for all sites	Unlikely to be achievable for all sites
Nickel and nickel alloy production	0	0	5 (@2%DR) 6 (@4%DR) 6 (@6%DR) Totals for 4 sites	Unlikely to be achievable for all sites
Zinc production	0	Insufficient data	Insufficient data	Insufficient data
Lead production	0	0	Insufficient data	Unlikely to be achievable for all sites
Power gen – coal	0	0	0	0
Power gen – oil	0	0	0	0
Small oil fired combustion plant	0	0	0	0
Road transport	0	0	0	0
Shipping (vicinity of ports)	0	0	Compliance costs will exist but insufficient data to quantify	Unlikely to be achievable for all sites
Petroleum refining	0	116 (@2%DR) 126 (@4%DR) 136 (@6%DR) Totals for 11 sites	345 (@2%DR) 375 (@4%DR) 405 (@6%DR) Totals for 48 sites	530 (@2%DR) 576 (@4%DR) 622 (@6%DR) Totals for 68 sites
Cement production	0	0	0	0
Incineration	0	0	0	0
Glass production	0	0	0	0
Total for all sectors	0	116 (@2%DR) 126 (@4%DR) 136 (@6%DR)	398 to 414 (@2%DR) 432 to 448 (@4%DR) 465 to 484 (@6%DR) Plus costs for shipping, zinc and lead. Unlikely to be achievable for all copper sites	530 (@2%DR) 576 (@4%DR) 622 (@6%DR) Plus unlikely to be achievable for iron and steel, copper, nickel, lead and shipping

Notes

1. Due to assumptions for pet. refining, costs regarded as upper estimates. Lower estimates are –50%.
2. For one site investigated, the compliance technique (significant stack height increase) may not be acceptable to planning authorities.

Estimated benefits of complying with the potential limit values

The reductions in carcinogenic effects associated with arsenic, cadmium and nickel are summarised in Tables 5, 6 and 7. They are based on unit risk factors of $1.5 * 10^{-3} (\mu\text{g.m}^{-3})^{-1}$ for arsenic, $1.8 * 10^{-3} (\mu\text{g.m}^{-3})^{-1}$ for cadmium and $1 * 10^{-4} (\mu\text{g.m}^{-3})^{-1}$ for nickel, with an additional higher risk factor for nickel refineries of $3.8 * 10^{-4} (\mu\text{g.m}^{-3})^{-1}$ to reflect the potential presence of the more carcinogenic species, nickel sub-sulphide, at certain plants. For each of the metals being considered in this study, cancer of the lung, brought about through inhalation, has been identified as the most likely carcinogenic effect.

The valuation of these health benefits is based on the latest available, but currently interim, figures from DG Environment for the value of preventing a statistical fatality (VPF).

Non-carcinogenic effects of these metals due to oral and inhalation uptake have also been considered. However, ambient concentrations in the vicinity of sites of interest are in almost all cases considered to be below the critical thresholds for non-carcinogenic health effects.

Despite adopting a systematic and rigorous approach, it must be stressed that a number of factors contribute to the significant uncertainty attached to the quantified benefits of reduced carcinogenic effects. These include:

- the difficulty in predicting the definitive quantity of metal emissions likely to be reduced by measures targeted at fugitive emissions, and hence the difficulty in accurately estimating the likely improvements in air quality;
- the uncertainty of ambient measurements and modelling predictions;
- the uncertainty associated with unit risk factors, population data and valuation data; and
- the uncertainty associated with scaling up benefits from representative sites to the sectors as a whole.

Based on our understanding of these factors an overall level of uncertainty of +/- one order of magnitude is considered appropriate. Furthermore, the recommended valuation figures have been developed for assessing effects on large population groups - with health benefits of interest to this study primarily associated with areas relatively local to the source the actual willingness to pay to reduce mortality risk may be higher than the valuation figures considered.

In addition to the abovementioned benefits, other potential benefits to be gained by implementing the limit values will include:

- reduced adverse health effects due to reductions in exposure to other metals;
- reduced mortality and morbidity effects due to reductions in exposure to PM_{10} ;
- reduced adverse impacts on ecosystems and crops; and
- reduced occupational exposure to carcinogenic metal pollutants (potentially important where better control is achieved over fugitive emissions).

Therefore, on the basis of the above considerations, the quantified benefits presented in the following tables may be significant underestimates of the total benefits.

Table 5 Estimated Valuation of Reduction in Carcinogenic Effects from Compliance with Arsenic Limit Values (Note 1)

Sector	Estimated Valuation of Carcinogenic Effects (€m pa)				
	20ng/m ³	13ng/m ³	5ng/m ³	4ng/m ³	1ng/m ³
Total for all sectors	No compliance techniques specified	0.19 to 0.90	No compliance techniques specified	No compliance techniques specified	No compliance techniques specified

Note

1. Figures are best estimates. Due to the significant uncertainties as discussed, the lower estimate is minus one order of magnitude and the upper estimate is plus one order of magnitude.

Table 6 Estimated Valuation of Reduction in Carcinogenic Effects from Compliance with Cadmium Limit Values (Note 1)

Sector	Estimated Valuation of Carcinogenic Effects (€m pa)		
	15ng/m ³	5ng/m ³	0.5ng/m ³
Total for all sectors	No compliance techniques specified	0.07 to 0.31	No compliance techniques specified

Note

1. Figures are best estimates. Due to the significant uncertainties as discussed, the lower estimate is minus one order of magnitude and the upper estimate is plus one order of magnitude.

Table 7 Estimated Valuation of Reduction in Carcinogenic Effects from Compliance with Nickel Limit Values (Note 1)

Sector	Estimated Valuation of Carcinogenic Effects (€m pa)			
	50ng/m ³	30ng/m ³	10ng/m ³	3ng/m ³
Total for all sectors	No compliance techniques specified	0.08 to 0.37	0.15 to 1.09	0.23 to 1.10 (benefits due to petroleum refineries only)

Note

1. Figures are best estimates. Due to the significant uncertainties as discussed, the lower estimate is minus one order of magnitude and the upper estimate is plus one order of magnitude.

Discussion

Whilst this assessment has endeavoured to identify and utilise the best available and most recent air quality data for arsenic, cadmium and nickel across the EU and Accession Countries, the quality of the overall pool of relevant data across the area of interest varies considerably, with

some important metal emitting industries (e.g. petroleum refining and stainless steel production) having only relatively sparse data.

The current limited availability of relevant ambient air quality data for arsenic, cadmium and nickel in the vicinity of industrial sites should be borne in mind in the forthcoming stages of developing air quality policy for these pollutants.

However, it is clear that improvements in the body of data are taking place on a continuous basis, for example the recent DETR heavy metals monitoring project for 30 industrial sites in the UK, therefore it is considered important that any new information made available within the policy development timescale is taken into account.

Information on air quality measurements and abatement techniques for mercury has been gathered as far as possible, for example, covering the chlor-alkali sector. Such information can assist, as required, the Working Group on mercury.

The important contextual points described in this summary prevent a simple comparison of costs and environmental benefits. At a glance, the summary tables show that the costs outweigh the specific quantifiable benefits of the reduction in cancers due to arsenic, cadmium and nickel exposure. However it is stated that there will be other important secondary environmental benefits of improving air quality of these metals. These include benefits due to reductions in exposure of other metals and PM₁₀, reductions in adverse impacts on ecosystems and crops and reductions in occupational exposure, particularly where improvements are targeted at fugitive emissions. The benefits due to these other effects will clearly improve the balance towards the benefits, although by how much is not possible to fully quantify with the currently available information.

Whilst the complex petroleum refining sector has been subject to considerable scrutiny in our report, including specific input from CONCAWE, the level of the estimated compliance costs may merit further site specific investigations to develop at a more disaggregated level the assumptions on business as usual performance, compliance techniques and associated costs to develop further the estimates of the implications of potential limit values.

This study has identified that there is a relatively small number of non-ferrous metals processes that, by virtue of residential housing being in very close proximity to the site boundaries (for example, 100m away or less), would not be expected to be able to comply with even the highest potential limit values with available techniques. It is recommended that these sites are consulted as proposals for limit values develop.

Furthermore, with increasingly stringent potential limit values, current information indicates that more sites and sectors may not be able to achieve compliance using available techniques, as indicated in Tables 2 to 4. Consultation with these sites / sectors would therefore also be recommended, dependent on the limit values taken forward in policy development.

Glossary

ADMS	Atmospheric Dispersion Modelling System
As	Arsenic
AQDD	EU Air Quality Daughter Directive (1999/30/EC)
AQS	The Air Quality Strategy for England, Scotland, Wales and Northern Ireland
BAT	Best available techniques
BAU	Business as usual scenario
BREF	BAT Reference Document
Cd	Cadmium
CONCAWE	The oil companies' European organisation for environment, health and safety
DETR	UK Department of the Environment Transport and the Regions
DR	Discount rate
EAF	Electric arc furnace
Est	Estimate
ESP	Electrostatic precipitator
FGD	Flue gas desulphurisation
Hg	Mercury
HFO	Heavy fuel oil
IPPC	Integrated Pollution Prevention and Control
ISF	Imperial Smelting Furnace
LCP	Large combustion plant
LCPD	Large Combustion Plant Directive
LS	Liquid steel
Mtoe	Million tonnes oil equivalent
Mtpa	Millions of tonnes per annum
NAEI	National Atmospheric Emissions Inventory
Ni	Nickel
PM ₁₀	Particulate matter which passes through a size selective inlet with a 50% efficiency cut-off at 10µm aerodynamic diameter
pa	per annum
tpa	tonnes per annum
TSP	Total suspended particulates
TWh	Tera Watt hour

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1 Introduction

1.1 This Report

Council Directive 96/62/EC on ambient air quality assessment and management provides the framework for the development of subsequent daughter directives on specific air pollutants. Directive 96/62/EC is concerned with the setting of “limit values” based on levels of concentrations of a pollutant in ambient air during a defined period of time.

The Commission plans to come forward with proposals for limit values for certain heavy metals. The findings of this study are to assist in the development of the position paper and to assist the Commission in developing subsequent proposals for limit values.

The principal objective of this study was to identify and estimate the costs and benefits of meeting potential air quality limit values for the following heavy metals:

- arsenic;
- cadmium; and
- nickel

The areas of interest to this study have included the 15 EU Member States and six Accession Countries.

In addition to arsenic, cadmium and nickel, mercury is also considered. However, potential air quality limit values or risk factors were not available during the timescale of this study therefore the coverage of mercury has been more limited compared to the other metals

1.2 Methodology

The overall methodology to meeting the project objectives is illustrated in Figure 1.1.

As can be seen from the figure there is a sequence of discrete steps that has been followed in order to estimate the costs and benefits of meeting the alternative ambient air quality standards.

This sequence of steps has been followed for each sector that may potentially contribute to exceedences of any of the potential air quality limit values under the business as usual (BAU) scenario.

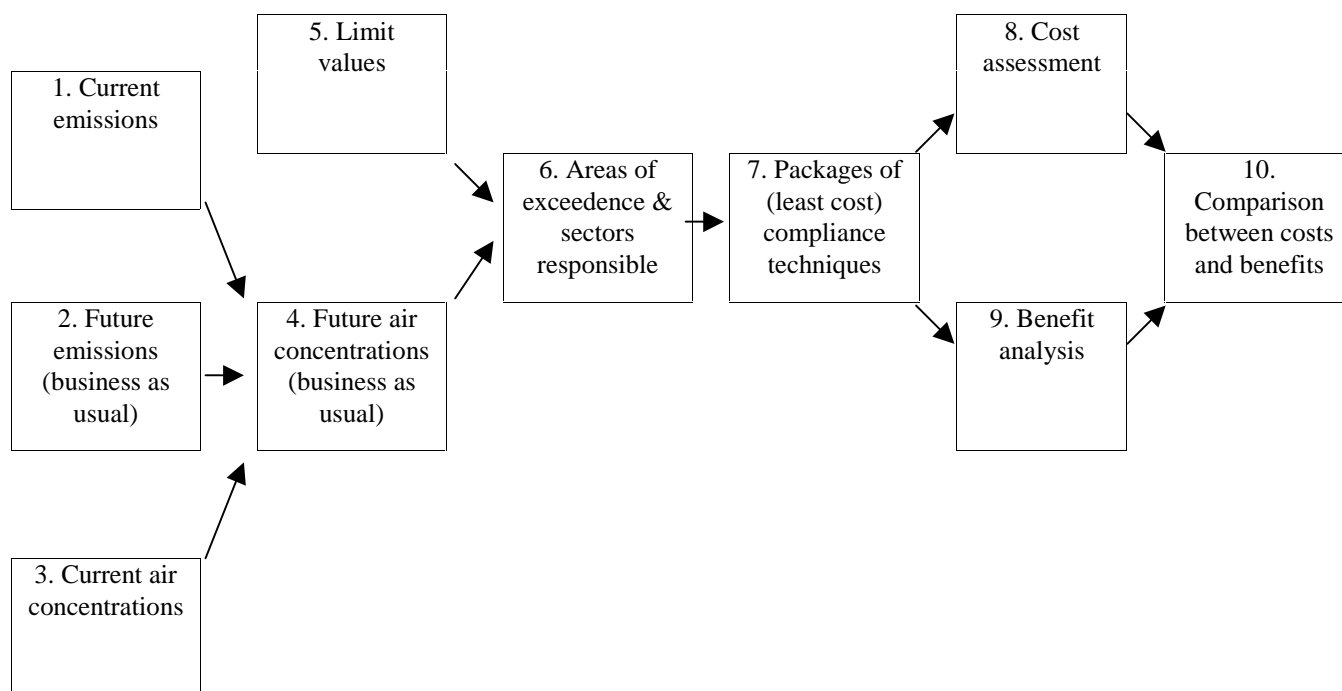


Figure 1.1 – Overall Methodology

In brief, our approach for each sector has been as follows:

1. Investigation of the *profile of the sector* in terms of types of processes causing arsenic, cadmium, mercury and nickel emissions; numbers of processes; size / capacity of processes; geographical distribution; sectoral growth trends etc;
2. Investigation into *emission sources* including relevant process details, emission factors etc;
3. Analysis of *current air quality data* plus emissions data. A wide range of information sources have been consulted to endeavour to gather the best available ambient air quality monitoring results on an annual average basis for arsenic, cadmium, mercury and nickel in the vicinity of plants in the sector. This has included direct consultation with industrial companies as well as consultation with Member State regulatory authorities, research organisations, trade associations etc. In certain instances it has been necessary to supplement ambient measurement data with estimations from air quality modelling using realistic emission scenarios;
4. Review of applicable *emission reduction techniques* including reviews of Best Available Techniques (BAT) as defined by the IPPC Directive. This considers the abatement efficiency of techniques as well as details on capital and operating costs;
5. Assessment of *future air quality under the 2010 business as usual (BAU) scenario* i.e. taking into account agreed policies that will affect emissions in the future such as the IPPC Directive; the proposed Waste Incineration Directive etc. For this task, the diversity of the sectors and sites necessitates assessment on a case-by-case basis. In cases where limit

values are complied with based on current air quality it is reasonably assumed that compliance will also be achieved in the future. In cases where limit values are not complied with based on current air quality the most applicable and practicable approaches have been adopted including:

- For sectors with sites having a readily manageable number of discrete emission points and with quantified emissions such as incinerators and cement kilns, dispersion modelling work (as described in Appendix 2) is used to predict the changes in process contributions to ambient air quality, which are then added to background concentrations. Judgement has been applied taking into account modelling results and ambient air quality measurements.
 - For sectors with significant unquantified fugitive emissions such as non ferrous metals and sites with a complex range of emission sources and structures such as oil refineries we have carefully assessed the measured concentrations in the ambient air, which will provide the best basis for air quality assessments. For some sites sufficient information is available to also undertake dispersion modelling to predict the impact of emission reduction measures. A combination of judgement and consultation at a site level has been used to establish the most appropriate method of analysis.
6. *Comparison of future air quality against the limit values* to be considered in this study to identify areas of exceedance and sectors responsible;
 7. Investigation into *packages of additional emission reduction techniques* that enable compliance with each of the limit values, involving critical reviews of information gathered and selected dispersion modelling;
 8. Identification of the *least cost packages* including a detailed *cost assessment*. Costs are presented in year 2000 prices, with historic cost data updated using a 3% inflation rate. Capital costs have been annualised assuming discount rates of 2, 4 and 6% and an economic life of the equipment of 15 years has been assumed, unless otherwise indicated;
 9. *Benefit analysis* considering both human health and environmental benefits. The benefit analysis methodology is described in Section 10; and
 10. Finally, a comparison of costs and benefits.

1.3 Uncertainty

We have endeavoured to provide information that is as accurate as possible by adopting a thorough approach to this project. However, with projects of this nature there is inherently a degree of uncertainty. This section addresses the uncertainty associated with the cost and environmental benefit estimates.

Cost Estimates

Due to the diverse range of elements that constitute total installed capital costs and annual operating costs, and the need to present costs on an equivalent basis, the cost estimates are subject to a degree of uncertainty. For future investments, estimations may be based on plant and equipment that has yet to be fully specified, thus introducing an additional element of uncertainty. Furthermore, additional uncertainty is introduced when scaling up costs from

representative sites to the sector as a whole. Overall, the estimated range of uncertainty attached to the cost estimates is considered to be in the range $\pm 50\%$.

Benefit Estimates

Ambient heavy metals monitoring projects, with sampling undertaken according to the relevant standards and with analysis performed by accredited laboratories can achieve an overall uncertainty in the region of $\pm 25\%$. However, detailed information to assess the uncertainty is not readily available for many of the measurement results and hence it might be appropriate to assume slightly greater uncertainty overall. Furthermore information on whether the sampling is based on total suspended particulate (TSP) or PM_{10} is not always available, with a TSP sample clearly recording a higher metal concentration than a PM_{10} sample in the vicinity of industrial sites (by in the region of 20% although this is site specific and varies with distance from the site).

For certain sites where suitable ambient measurement data is not available we have undertaken dispersion modelling using the ADMS (Atmospheric Dispersion Modelling System) model, described in Appendix 1. All dispersion modelling programmes have an inherent uncertainty due to the use of particular algorithms to simulate the complex atmospheric behaviour of emissions. The ADMS model has state-of-the-art scientific components and it exhibits similar performance to the US EPA model AERMOD, when evaluated with field data (Hanna et al, *Evaluation of ISC3, AERMOD and ADMS Dispersion Models with Observations from Five Field Sites*, HC Report P020, Washington DC, 2000). A considered view of the approximate uncertainty associated with the use of ADMS and other such models is in the region of ± 30 to 50%.

The uncertainty attached to the air quality assessments is combined with the uncertainty of unit risk factors, population data, benefits valuation data and scale up factors to derive benefits for the sector as a whole. On this basis it is considered that the overall uncertainty is likely to be in the range \pm one order of magnitude.

2 Potential Limit Values

The Working Group on arsenic, cadmium and nickel compounds has proposed ambient concentration ranges as shown in Table 2.1 to be considered in the cost benefit analysis. This table includes the range of concentrations to be considered, the range proposed by the majority of the Working Group for setting limit values and any relevant additional points in the range.

The compliance deadline for the limit values is assumed to be 2010 and the values relate to annually averaged concentrations.

The upper bound of the concentration range is somewhat lower than current pollution levels around the most polluted industrial hotspots, whilst the lower bound of the range corresponds to urban background levels in less polluted regions of Europe.

Table 2.1 - Ambient Concentrations to be Considered in the Cost Benefit Analysis (in ng/m³)

Pollutant	Concentration range to be considered in analysis	Concentration range proposed by the majority of WG for setting limit values	Specific additional concentrations to consider	Overall set of concentrations to consider
Arsenic	1.0 to 20	4 to 13	5	1
				4
				5
				13
				20
Cadmium	0.5 to 15	5		0.5
				5
				15
Nickel	3 to 50	10 to 50		3
				10
				30
				50

3 Prioritisation of Sectors to Investigate

The economic evaluation of heavy metal air quality targets will need to address all significant emission source groups of arsenic, cadmium and nickel. Establishing exactly which source groups require evaluation has involved investigations of relevant emissions inventories; reviews of ambient air quality information and judgements based on process knowledge.

The primary source of information has been emission inventories - with the most detailed inventory for each metal at a sectoral level across the EU being the UBA-TNO report on "The European Atmospheric Emission Inventory of Heavy Metals and Persistent Organic Pollutants for 1990".

Whilst more up-to-date inventories are available for certain metals in certain countries for certain source groups this is the most up-to-date comprehensive inventory available to the study. However, it is considered suitable for the specific purpose of assisting in the decisions of which sectors to investigate. This requires scrutiny of the relative importance of source groups rather than absolute emissions. The inventory has not been used for any other purpose in this study.

A summary of the emissions data for each metal and each sector for the EU-15 is shown in Appendix 1. Figures are presented for emissions in tonnes per year and also as a percentage of total emissions of that metal.

All source groups contributing more than 1% of total emissions of any of the four heavy metals are considered significant in the context of this project. These include:

- Integrated iron and steel works (in particular, Sinter plants, Coke oven plants, Blast furnaces, Basic oxygen steelmaking);
- Electric arc steelmaking;
- Copper production;
- Lead production;
- Zinc production;
- Chlor-alkali production;
- Cement and lime production;
- Glass production;
- Waste incineration;
- Road transport combustion;
- Other transport combustion;
- Public power (coal);
- Public power (fuel oil);
- Commercial, institutional & residential combustion (coal);
- Commercial, institutional & residential combustion (fuel oil);

-
- Industrial combustion (coal); and
 - Industrial combustion (fuel oil).

Furthermore, from a review of ambient concentrations in the Position Paper it is considered that nickel production processes should also be investigated. In addition, the combustion of residual oil by petroleum refineries could be a concern with regard to ambient nickel concentrations, hence this sector also warrants investigation. Therefore the additional sectors to investigate include:

- Nickel production
- Nickel alloy production
- Petroleum refineries

The detailed investigations of these sectors are presented in the following sections:

Section 5 - Iron and Steel Processes

- Integrated iron and steel works (inc sinter plants, coke oven plants, blast furnaces, basic oxygen steelmaking)
- Electric arc steelmaking

Section 6 - Non ferrous Metals Processes

- Copper production
- Nickel and nickel alloy production
- Zinc production
- Lead production

Section 7 - Combustion Processes

- Power generation - Coal-fired plant
- Power generation - Oil-fired plant
- Oil and coal fired small combustion plant
- Road transport
- Shipping

Section 8 - Other Processes

- Petroleum refineries
- Cement production
- Waste incineration
- Chlor-alkali production
- Glass production

4 Key Policies Affecting Future Emissions

Overall emissions of arsenic, cadmium, mercury and nickel across the EU have been declining in recent years with the implementation of improved environmental controls. Furthermore, there are several adopted or proposed policies at an EU and international level that are expected to secure significant further reductions in heavy metals from certain sectors. These are taken into account as far as possible in estimating business as usual (BAU) air concentrations of arsenic, cadmium, mercury and nickel for 2010.

The key policies impacting on future emissions of arsenic, cadmium, mercury and nickel are discussed in this section.

IPPC Directive (Council Directive 96/61/EC)

The Directive concerning integrated pollution prevention and control (the IPPC Directive) is expected to have a major impact on emissions of heavy metals from existing processes. With regard to this study, significant implications are expected for the iron & steel, non ferrous metals, combustion process, petroleum, cement and glass sectors.

Existing processes covered by the IPPC Directive will be required to have applied Best Available Techniques (BAT) by 2007.

BAT means the most effective techniques to prevent, and where that is not practicable, to reduce emissions and the impact on the environment as a whole. 'Available' techniques are those that can be implemented in the relevant sector under economically and technically viable conditions.

Permit conditions under IPPC will take into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. Therefore within each sector there are likely to be variations in what BAT is likely to mean for individual sites and hence careful interpretation of the BAT Reference Documents is required. However, it is important to appreciate that compared with the current situation, the IPPC Directive will lead to greater convergence of emissions performance within each sector across the Member States and, at a later date, the Accession Countries (see discussion later in this section).

The following BAT Reference Documents are relevant to this study:

- BAT Reference Document on the Production of Iron and Steel;
- BAT Reference Document on Cement and Lime Manufacturing Industries;
- BAT Reference Document on Non Ferrous Metals Industries;
- Draft BAT Reference Document on Glass Manufacturing Industry; and
- Draft BAT Reference Document on Chlor-Alkali Manufacturing Industries.

Proposed Revisions to the Large Combustion Plant Directive

The proposed revisions to the Large Combustion Plant Directive (LCPD) are likely to have significant implications on heavy metal emissions from existing coal and oil fired large combustion plant (LCPs, i.e. having a thermal input of 50MW or greater). The majority of LCPs in this category are likely have been licensed before 1 July 1987, and for these LCPs the proposed revisions would offer Member States two alternatives. By 1/1/08 at the latest they shall either:

- ensure that existing plants comply with the emission limit values contained in Directive 88/609/EEC as amended by Directive 94/66/EC. This would mean the following emission limit values that are relevant to heavy metal emissions:
 - particulates - 50mg/Nm³ for solid fuel LCPs >500MWth; 100mg/Nm³ for solid fuel LCPs <500MWth; 50mg/Nm³ for all liquid fuel LCPs;
 - SO₂ - 400mg/Nm³ for solid and liquid fuel LCPs >500MWth; less stringent limits for smaller plant. For solid fuel LCPs >400MWth operating at <25% load factor a less stringent limit of 800mg/Nm³ would apply. Particulate emissions will be significantly reduced for those existing coal and oil fired plant that are required to fit flue gas desulphurisation (FGD) to meet the SO₂ emission limit values.
- define and implement an emission reduction plan on a national level to reduce total annual emissions of SO₂, NO_x and dust from existing plants to levels that would have been achieved by applying the emission limit values in Directive 88/609/EEC to the existing plants in operation in the year 2000.

Furthermore, existing (pre-1987) plants may be exempted from compliance with the emission limit values and from their inclusion in the national emission reduction plan provided that the operator undertakes not to operate the plant for more than 20,000 hours starting from 1/1/08.

Proposed Waste Incineration Directive

The Proposed Waste Incineration Directive will replace the existing Directives on Municipal Waste Incineration (89/369/EEC and 89/429/EEC) and its scope will extend to cover a wide range of incineration and co-incineration processes. It will also include and up-date the provisions of the Hazardous Waste Incineration Directive (94/67/EC), which applied to existing plant in June 2000.

The Proposed Directive would potentially have significant implications on heavy metal emissions from existing incineration (municipal waste, clinical waste, sewage sludge, hazardous waste and other thermal treatment processes for wastes) and co-incineration (cement, power, steel etc) processes. There will be directly applicable ELVs for specific metals and also ELVs for particulates.

The requirements for existing incineration plant, taken from the Common Position text adopted by the Council on 25 November 1999 are shown in the following table. For comparison the corresponding requirements in the original Directive for Municipal Waste Incineration are also shown.

Table 4.1 - Selected ELVs for Incinerators in the Proposed Waste Incineration Directive compared to ELVs in the Existing Municipal Waste Incineration Directive

Pollutant	Proposed Waste Incineration Directive (Note 2)		Existing Municipal Waste Incineration Directive (88/369) (Note 1)	
	ELV (mg/Nm ³)	Averaging period	ELV (mg/Nm ³)	Averaging period
Particulates	10	Daily	30	7 day average
	30	Half hourly		
Cd and Tl	Total 0.05	30 mins to 8 hours	0.2 (Cd and Hg)	7 day average
Hg (mercury)	0.05	30 mins to 8 hours	see above	
Sb, As, Pb, Cr, Co, Cu, Mn, Ni and V	Total 0.5	30 mins to 8 hours	1 (Ni and As only)	7 day average

Notes

1. Applies to municipal waste incinerators authorised to operate from 1/12/90.
2. Specific emission limit values for co-incineration in cement kilns are shown in Section 8.2.

The compliance deadline for existing plant is expected to be 2005.

UNECE Protocol to the 1979 Convention on Long Range Transboundary Air Pollution on Heavy Metals

The UNECE Heavy Metals Protocol has been signed by all 15 Member States and 5 of the 6 Accession Countries of interest to this study (Estonia has not signed it). However, so far the Protocol has been ratified only by Canada.

The basic obligations of the Protocol include:

- Reduction of total annual emissions of lead, cadmium and mercury from the level in the specified reference year.
- No later than 8 years after entry into force (entry into force will be 90 days after “the date on which the sixteenth instrument of ratification, acceptance, approval or accession has been deposited with the Depository.”) apply best available techniques (BAT) in accordance with Annex III of the Protocol. Under the Heavy Metals Protocol, the definition of BAT is identical to the definition in the IPPC Directive (96/61/EC). For existing plant, alternative emission reduction strategies are allowable provided that equivalent overall reductions are achieved. The source categories to which best available techniques are specified include:
 - combustion of fossil fuels in utility and industrial boilers;
 - primary iron and steel industry;
 - secondary iron and steel industry;
 - iron foundries;
 - primary and secondary non ferrous metals industry;

-
- cement industry;
 - glass industry;
 - chlor-alkali industry; and
 - municipal, medical and hazardous waste incineration.
- No later than 8 years after entry into force apply limit values in accordance with Annex V of the Protocol. For existing plant, limit values will only apply insofar as they are technically and economically feasible. The processes to which limit values apply include:
 - combustion of fossil fuels;
 - sinter plants;
 - pellet plants;
 - blast furnaces;
 - electric arc furnaces;
 - production of copper and zinc;
 - production of lead;
 - cement industry;
 - glass industry;
 - chlor-alkali industry; and
 - municipal, medical and hazardous waste incineration.

Air Quality Daughter Directive (Council Directive 1999/30/EC) relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air)

The limit values for lead and particulate matter are particularly relevant to this study and they represent business as usual commitments. The limit values are summarised in the following table.

Table 4.2 Air Quality Limit Values for Lead and Particulate Matter

Pollutant	Limit	Averaging period	Date to be achieved by
Lead	0.5µg/m ³	calendar year	1/1/05 (or 1/1/10 in the immediate vicinity (<1000m) of specific industrial sources on sites contaminated by decades of industrial activity. In such cases the limit value as from 1/1/05 will be 1.0µg/m ³)
PM ₁₀	50µg/m ³ , not to be exceeded more than 35 times a calendar year	24 hours	1/1/05
	40µg/m ³	calendar year	1/1/05
	indicative limit of 50µg/m ³ , not to be exceeded more than 7 times a calendar year	24 hours	1/1/10
	indicative limit of 20µg/m ³	calendar year	1/1/10

However, due to the complications regarding PM₁₀ in that a large proportion of PM₁₀ in the vicinity of a specific emission source will have originated from a multitude of other sources of primary and secondary particulates it is difficult to forecast which techniques at a site specific level would be necessary to comply with the PM₁₀ limit values in the vicinity of that site. Therefore, it has not been possible to build the PM₁₀ limit values into the business as usual scenario in a comprehensive way within the scope of this study.

UNECE Protocol to the 1979 Convention on Long Range Transboundary Air Pollution on Sulphur Dioxide, Nitrogen Oxides, Volatile Organic Compounds and Ammonia (Multi Pollutant Protocol)

This Protocol was adopted formally in December 1999 in Gothenburg, Sweden and allows over 30 countries in Western, Central and Eastern Europe as well as North America to reduce emissions of sulphur dioxide, nitrogen oxides, volatile organic compounds (VOCs) and ammonia in a co-ordinated way. It aims to deliver benefits to health and ecosystems by reducing levels of ground level ozone, acidification and eutrophication. Emissions targets have been set for each country for each of the four pollutants.

Proposed National Emission Ceilings Directive

EU governments reached a first common position in June 2000 on a Directive fixing caps on emissions of four key air pollutants from 2010. Under the National Emission Ceilings Directive (NECs) Directive, EU countries will significantly reduce output of sulphur dioxide, nitrogen oxides, volatile organic compounds (VOCs) and ammonia within a decade over 1990 levels. All countries have pledged to go somewhat further than they volunteered under the 1999 UNECE Multipollutant Protocol.

Kyoto Protocol

Under the Kyoto Protocol on Climate Change developed nations in total agreed to cut their emissions of greenhouse gases (CO₂, nitrous oxide, methane, HFCs, PFCs and SF₆) by 5% below 1990 levels - and by 30% below projected levels - by the commitment period of 2008-12.

The overall greenhouse gas reduction target agreed for EU Member States by the commitment period is 8%, from 1990 levels.

Specific targets have been agreed at an individual country level and the commitments of member states under the Kyoto Protocol have been taken into account, in particular with regard to projected coal and oil consumption in public power generation.

Other Policies

In addition, implications of Auto-Oil and the SCLF Directive are discussed in the petroleum refining section and the Euro-Chlor program is discussed in the chlor-alkali section.

Compliance Deadlines for Accession Countries of EU policies

It has been advised that this study should assume that a 3 year transition period is likely for the Accession Countries implementing the Waste Incineration Directive and the IPPC Directive. This would imply compliance by Accession Countries by 2008 and 2010 respectively. Therefore it is assumed that the key industrial and combustion processes covered by this study will be compliant with the above mentioned Directives by the potential compliance date for air quality limit values for heavy metals. The overall Community policies on air quality are assumed to be implemented linearly between now and 2015.

5 Iron & Steel Sector

5.1 Introduction

The metals being considered for the iron and steel sector include arsenic, cadmium, nickel and mercury. The bulk of the analysis will be based on the first three metals because potential limit values have been proposed for those metals and because relevant data is more available for those metals.

Integrated iron and steel works are considered in Section 5.2, whilst electric arc steelmaking is considered in Section 5.3. The latter section includes stainless steel production (significant with regard to nickel emissions) which, according to Eurofer data, is predominantly undertaken in electric arc furnaces.

Current Legislative Controls

Heavy metal emissions from the iron and steel sector can be controlled directly or, through controls on emissions of particulates or other pollutants, they can be controlled indirectly. Current control legislation includes:

- Regulations of emissions to atmosphere at a Member State level e.g. Integrated Pollution Control under the Environmental Protection Act, 1990 in the UK, Federal Law on Immission Control (*BImSchG*) in Germany, Air Pollution Act in The Netherlands.
- Air Quality Standards regulations for particulate matter and lead.

Future Legislative Controls

Regulatory factors which will have an impact on heavy metal emissions in the iron and steel sector in the future include:

- IPPC Directive – the need to meet BAT requirements (see Section 4).
- UNECE Heavy Metals Protocol – the need to meet BAT requirements plus emission limit values (see Section 4).
- Air Quality Daughter Directive limit values for PM₁₀ and lead (see Section 4).

5.2 Integrated Iron and Steel Works

5.2.1 Profile of Sector

Integrated iron and steel works comprise a complex range of processes including sinter plants, pelletisation plants, coke oven plants, blast furnaces and basic oxygen furnaces. About two thirds of the EU's crude steel production is from the 40 integrated works (the blast furnace – basic oxygen furnace route), with one third from electric arc furnaces (see Section 5.2).

In an integrated iron and steel works the blast furnace is the main operational unit where the primary reduction of oxide ores takes place leading to liquid iron (pig iron). The two types of iron ore preparation plants are the sinter plants and the pellet plants (which are much less common than sinter plants). Sinter is generally produced at the iron works from pre-designed mixtures of fine ores, residues and additives. The liquid iron from the blast furnace is transported to a basic oxygen furnace where the carbon content is lowered to less than 1%, thus resulting in steel.

Production of oxygen steel has remained fairly steady since 1985 whereas electric arc furnace steel production has gradually increased. However, the blast furnace – basic oxygen route is predicted to remain the dominant means of steel production at least up to 2015 (European Commission, 2000).

The industry is currently undergoing considerable structural change which is likely to be accelerated due to the highly competitive market conditions worldwide. Further consolidation is expected to take place, as evidenced by the growing number of alliances, co-operative ventures and take-overs.

The locations of integrated steelworks in the EU-15 are shown in Figure 5.1 (European Commission, 2000).

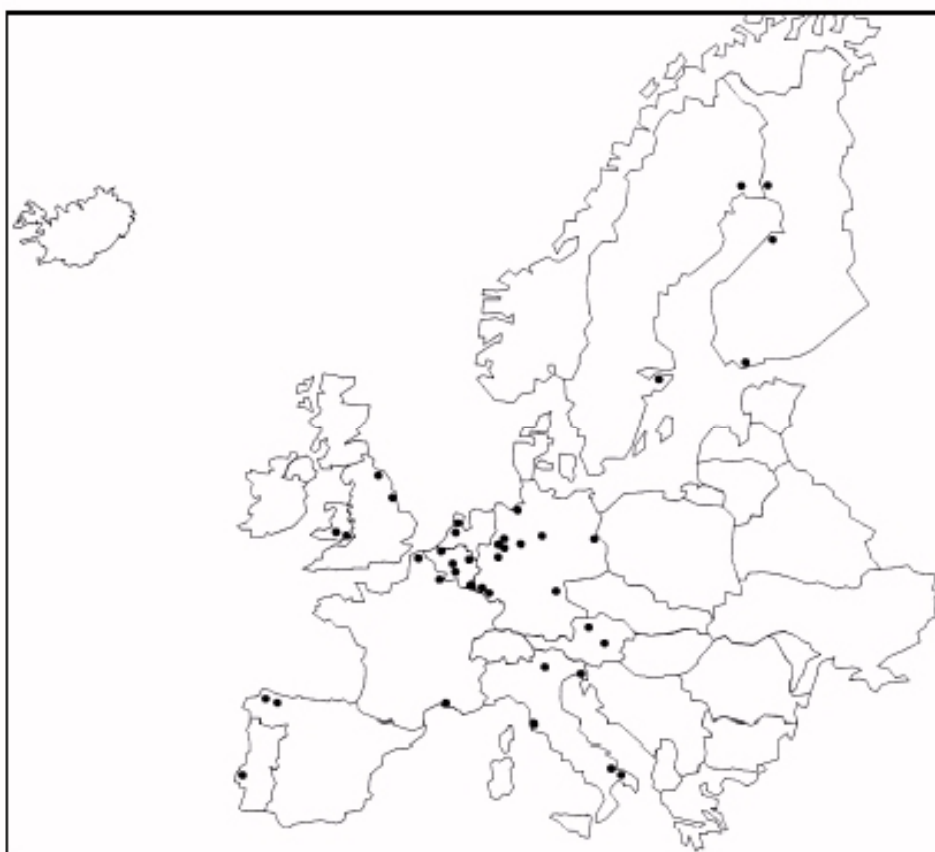


Figure 5.1 – Geographical Distribution of Integrated Steelworks in the EU

Germany has the largest steel industry in Europe, producing 40 m tonnes of crude steel in 1996, ie 27% of EU-15 production. The six largest producers (Germany, Italy, France, UK, Spain and Belgium) accounted for 83% of EU production in 1996.

The estimated number of sinter plants and basic oxygen furnaces in the EU-15 and Accession Countries are given in Table 5.1 (European Commission, 2000 and Eurofer, 2000).

Table 5.1 – Estimated Number of Sinter Plants and Basic Oxygen Furnaces in the EU-15 and Accession Countries

Country	Estimated number of sinter plants	Estimated number of basic oxygen furnaces
UK	5	11
Spain	2	8
Sweden	0	3
Portugal	1	2
Netherlands	3	6
Luxembourg	0	3
Italy	7	12
Ireland	0	0
Greece	0	0
Germany	12	26
France	6	7
Finland	3	5
Denmark	0	0
Belgium	5	13
Austria	2	6
Czech Republic	1	4
Poland	4	6
Hungary	2	2
Slovenia	0	0
Estonia	0	0
Cyprus	0	0
Total	58	114

5.2.2 Emission Sources

In integrated steelworks, sinter plants dominate the overall atmospheric emissions for most pollutants including heavy metals. For example nickel emissions from sinter plants are estimated to be 0.020g/t liquid steel compared with 0.007g/t liquid steel from blast furnaces and negligible emission factors for other processes within a steelworks. Lead emissions (an approximate indicator for heavy metal emissions) from sinter plants are estimated to be 3.7g/t liquid steel compared with 0.9g/t liquid steel from basic oxygen steelmaking and 0.1g/t liquid steel from blast furnaces.

Overall, based on information in the Iron and Steel BAT Reference Document it is considered that the key processes to be investigated within integrated steelworks include sinter plants and basic oxygen furnaces, a view that has been confirmed by discussion with Corus.

The *sinter plant* essentially consists of a large travelling grate of cast iron. The material to be sintered (a mixture of fine ores, additives, iron-bearing recycled material etc) is placed on top of a layer of recycled sinter and as the mixture proceeds along the grate, the combustion front creates sufficient heat to convert the fine particles together into a porous clinker referred to as sinter. The sinter is then charged to the blast furnace.

The objective of *basic oxygen steelmaking* is to oxidise the undesirable impurities still contained in the hot metal from the blast furnaces. The processing stages include pre-treatment of hot metal, the oxidation process in the basic oxygen furnace (BOF), secondary metallurgical treatment and casting. Particulate matter is emitted both during the charging of scrap and hot metal and during tapping from the BOF. A secondary ventilation system is often installed to abate the particulate emissions that occur. This usually comprises of a canopy hood, a dog house and a fabric filter or ESP for particulate abatement. During charging and tapping some fugitive emissions are released through the roof of the converter building (25 to 100g/t liquid steel).

Emission factors for sinter plants and basic oxygen furnaces are shown in Table 5.2, based on information from the BAT Reference Document.

Table 5.2 – Emission Factors for Sinter Plants and Basic Oxygen Furnaces (Note 1)

	Arsenic (g/t LS)	Cadmium (g/t LS)	Mercury (g/t LS)	Nickel (g/t LS)
Sinter plants	No data	0.002 to 0.04 (Note 2)	0.016 to 0.149	0.002 to 0.04 (Note 2)
Basic oxygen furnace	0.0 to 0.02	0.07 to 0.20	0.0 to 0.02	No data

Notes

1. LS – liquid steel
2. Lower value with quench and fine scrubber after ESP or ESP with fabric filter

5.2.3 Current Air Quality Data

Air quality data in the vicinity of integrated steelworks is presented in Table 5.3 for arsenic, Table 5.4 for cadmium, Table 5.5 for mercury and Table 5.6 for nickel.

Table 5.3 Arsenic

Country	Ambient concentration (ng/m ³)	Date	Site	Location of concentration	Emission rate (kgpa)	Ref
Finland	1.2	1998	Raahe	Near iron & steel plant		Position Paper
Germany	1	1999	Rhein-Ruhr area	Not specified		German steel industry association (VDEh)
NL	1.0	1998/9	Hoogovens, Ijmuiden	Nearest housing to the site at Wijk aan Zee. (1.5km in NW direction). Modelled figure checked against monitored data from nearby Beverwijk		RIVM, 1999 RIVM, 2000
UK	1.64	1999	Corus, Scunthorpe	-	30 (Sinter plant)	DETR, 2000
UK	1.86	1999	Corus, Llanwern	-	20 (Sinter plant)	DETR, 2000
UK	No data	1999	Corus, Teesside	-	20 (Sinter plant)	UK Steel
UK	No data	1999	Corus, Port Talbot	-	20 (Sinter plant)	UK Steel

Notes

1. Preliminary results for the first 8 months of a 12 month project - running mean

Table 5.4 Cadmium

Country	Ambient concentration (ng/m ³)	Date	Site	Location of concentration	Emission rate (kgpa)	Ref
Germany	1.4	1999	Rhein – Ruhr area	Not specified		German steel industry association (VDEh)
NL	0.50	1998/9	Hoogovens, Ijmuiden	Nearest housing to the site at Wijk aan Zee. (1.5km in NW direction). Modelled figure checked against monitored data from nearby Beverwijk		RIVM, 1999 RIVM, 2000
Poland	4	Assumed 1999	Huta Katowice	Border of the steelworks		Biprohut, 2000

Country	Ambient concentration (ng/m ³)	Date	Site	Location of concentration	Emission rate (kgpa)	Ref
	3	Assumed 1999	Huta im. T. Sendzimira	Not specified		Biprohut, 2000
UK	0.79	1999/2000	Corus, Scunthorpe	Nearest sensitive receptor where max concs occur - 2.25km east of the site boundary	140 (Sinter plant)	DETR, 2000 (1) and UK Steel
UK	1.59	1999/2000	Corus, Llanwern	Nearest sensitive receptor where max concs occur - 600m north east of site boundary	70 (Sinter plant)	DETR, 2000 (1) and UK Steel
UK	No data	1999	Corus, Teesside	-	120 (Sinter plant)	UK Steel
UK	No data	1999	Corus, Port Talbot	-	120 (Sinter plant)	UK Steel

Notes

1. Preliminary results for the first 8 months of a 12 month project - running mean

Table 5.5 Mercury

Country	Ambient concentration (ng/m ³)	Date	Site	Location of concentration	Emission rate (kgpa)	Ref
EU	0.18 to 0.19	N/A	Sinter plants	Vicinity of sinter plants		European Commission, 2000
UK	0.21	1999	Corus, Scunthorpe	-	80 (Sinter plant)	UK Steel
UK	0.44	1999	Corus, Llanwern	-	40 (Sinter plant)	UK Steel
UK	No data	1999	Corus, Teesside	-	90 (Sinter plant)	UK Steel
UK	No data	1999	Corus, Port Talbot	-	90 (Sinter plant)	UK Steel

Table 5.6 Nickel (Note 1)

Country	Ambient concentration (ng/m ³)	Date	Site	Location of concentration	Emission rate (kgpa)	Ref
Germany	5.1	1999	Rhein – Ruhr area	Not specified		German steel industry association (VDEh)
NL	2.2	1998/9	Hoogovens, Ijmuiden	Nearest housing to the site at Wijk aan Zee. (1.5km in NW direction). Modelled figure checked against monitored data from nearby Beverwijk		RIVM, 1999 RIVM, 2000
Poland	5.4	Assumed 1999	Huta im. T. Sendzimira	Not specified		Biprohut, 2000
UK	2.44	1999/2000	Corus, Scunthorpe	Nearest sensitive receptor where max concs occur - 2.25km east of the site boundary	40 (Sinter plant)	DETR, 2000 (2) and UK Steel
UK	3.93	1999/2000	Corus, Llanwern	Nearest sensitive receptor where max concs occur - 600m north east of site boundary	20 (Sinter plant)	DETR, 2000 (2) and UK Steel
UK	No data	1999	Corus, Teesside	-	30 (Sinter plant)	UK Steel
UK	No data	1999	Corus, Port Talbot	-	30 (Sinter plant)	UK Steel

Notes

1. Verein Deutscher Eisenhüttenleute (VDEh, 2000) report that ambient air measurements undertaken to investigate nickel concentrations in the vicinity of steelworks have revealed strong indications of extraneous, but as yet undetermined sources.
2. Preliminary results for the first 8 months of a 12 month project - running mean

A number of organisations contacted (in Spain, Austria, Italy, Belgium and France) did not have ambient heavy metal concentration data in the vicinity of their sites or had such limited data that it would not be useful to the study.

5.2.4 Emission Reduction Techniques

For sinter plants, the techniques or combinations of techniques that are considered as BAT for reducing heavy metal emissions are summarised in Table 5.7 (European Commission, 2000. European Commission, 2000. Best Available Techniques Reference Document on the Production of Iron and Steel, March 2000).

Table 5.7 Emission Reduction Techniques for Sinter Plants

Type of technique	Details of technique	Reduction efficiency	Capital cost	Operating cost
Waste gas de-dusting	Advanced electrostatic precipitators (ESPs): These include Moving Electrode Electrostatic Precipitators (MEEP) as installed at Krupp Hoesch Stahl, Dortmund and EKO Stahl, Eisenhüttenstadt; the use of energy pulse superimposition as installed at Thyssen Krupp Stahl, D-Duisberg or the Electrostatic Space Cleaner Super (ESCS).	With MEEP and ESCS particulate emissions of <math><40 \text{ mg/m}^3</math> are achievable and with energy pulse superimposition emissions of 20 to 30 $\text{mg/m}^3</math> are achievable. These figures compare with operational data for current sinter plants of 20 to 160 \text{mg/m}^3</math>.$	1.1 M Euro per filter for 500,000 m^3/h waste gas flow for MEEP	
	It is considered that MEEP presents significant maintenance problems and is not considered to be a viable technique if further reductions are required.			
	ESP plus fabric filter. Experience at the only EU plant to use fabric filters is positive, with the continuous dosage of lime and lignite coke. This is the Stahlwerke Bremen plant in Bremen, Germany. The use of fabric filters poses problems in terms of the fabric handling the high temperatures and the abrasiveness of the sinter. Filter blinding is also reported as a problem. However, one considered view from an industry source is that the use of fabric filters might be the best long term solution for achieving significant reductions in particulate emissions.	Particulate emissions of less than 20 $\text{mg/m}^3</math> are achievableHeavy metal emissions after the ESP and after the fabric filter are as follows: As – 0.009 \text{mg/m}^3</math> and 0.0003 \text{mg/m}^3</math>; Cd – 0.076 \text{mg/m}^3</math> to 0.001 \text{mg/m}^3</math>; Hg – 0.013 \text{mg/m}^3</math> to 0.0013 \text{mg/m}^3</math> and Ni – 0.01 \text{mg/m}^3</math> to 0.006 \text{mg/m}^3</math>.$	5M to 15M Euro (1996) for 1,000,000 $\text{m}^3/3\text{h}$ waste gas Allowing 30% to represent a total installed cost (Corus, 2000) and updating to 2000 prices the cost range is 7M to 22M Euro (2000 prices)	0.5 to 3.2 Euro (1996) /t sinter 2 to 14M Euro pa (2000 prices) assuming 4Mtpa sinter.
Pre-dedusting (eg ESP or cyclones) plus high pressure wet scrubbing system.	Particulate emissions of <math><50 \text{ mg/m}^3</math> are achievable			
Waste gas recirculation (to reduce quantity of waste gases for end-of-pipe treatment), if sinter quality and productivity are not significantly affected	Recirculation of part of the waste gas from the entire surface of the sinter strand.	At Hoogovens Ijmuiden waste gas recirculation has enabled a reduction in particulate emissions from 500g/t sinter to 170g/t sinter (figures apply to when particulate emissions were abated only by cyclones). Overall a particulate emission reduction of between 50 to 60% can be expected with this technique.	17M Euro (1996)	operational savings due to reduced coke breeze input were 2.5M Euro pa (1996) although other sinters are considered unlikely to gain such good savings due to lower baseline fuel consumption
	Sectional waste gas recirculation based on local suction of the sintering waste gases under the strand and its local recycling above the sinter bed.	A particulate emission reduction of 56% has been achieved with this technique, although this reduction also includes the effect of upgrading the ESP.	8M to 10M Euro (1997)	Some operating savings due to 6% reduction in coke

Type of technique	Details of technique	Reduction efficiency	Capital cost	Operating cost
Additional measures specifically addressed at minimising heavy metal emissions	<p>Use of fine wet scrubbing systems (ag AIRFINE) in addition to an ESP in order to remove water soluble heavy metal chlorides, especially lead chloride. In the EU two commercial plants are in operation. It has been commented that no more similar plants are currently planned to be built.</p> <p>For most sinter plants the requirement to recirculate the waste gas adversely affects the sinter; there are significant operational costs associated with electricity consumption (e.g. 4MW may be required) and liquid effluents are generated. Therefore this technique is not considered to be attractive in comparison to the alternatives.</p> <p>Bag filter with lime addition, as discussed above,</p> <p>Exclusion of dust from the last ESP field from recycling to the sinter strand, dumping it on a secure landfill (Many of the sinter plants in Europe are operated with closed filter dust cycles – this means all precipitated dust is recycled to the sinter plant and closed cycle plants have higher alkali and metal chloride emissions).</p>	Heavy metal concentrations are reported to be removed by >90% due to their water solubility. Heavy metal concentrations after the fine wet scrubber are reported to be: As <0.001 mg/m ³ (<0.002g/t sinter); Cd 0.003 mg/m ³ (0.0067g/t sinter); Hg 0.01 mg/m ³ (0.02g/t sinter) and Ni <0.001 mg/m ³ (<0.002g/t sinter).	Voest-Alpine Stahl, Linz - capital cost 39M Euro (1996); Hoogovens Ijmuiden, NL - capital cost 40M Euro (1997)	Voest-Alpine Stahl, Linz - operating cost 0.3M Euro pa; Hoogovens Ijmuiden, NL - operating cost N/A.

For basic oxygen steelmaking, the techniques or combinations of techniques that are considered as BAT for reducing heavy metal emissions are summarised in Table 5.8 (European Commission, 2000. European Commission, 2000. Best Available Techniques Reference Document on the Production of Iron and Steel, March 2000)

Table 5.8 Emission Reduction Techniques for Basic Oxygen Steelmaking

Type of technique	Details of technique	Reduction efficiency	Capital cost	Operating cost
Hot metal pre-treatment	Particulate abatement by means of efficient evacuation and subsequent purification by means of fabric filtration or ESP	Particulate emissions of 5 to 15 mg/m ³ achievable (Fabric filtration) or 20 to 30 mg/m ³ achievable (ESP)		
Basic oxygen furnace and primary de-dusting	Suppressed combustion to reduce the quantity of flue gas <i>and</i>		5 to 25 Euro (1996)/GJ	operating savings can give a one year payback
	Dry ESPs (this is increasingly common eg at Voest-Alpine Stahl, Linz and Thyssen Stahl, Duisburg) <i>or</i>	Achieving particulate emissions between 10 and 50 mg/m ³	24 to 40M Euro(1996) for a 1Mtpa steelmaking plant	2 to 4Euro(1996) /t LS

Type of technique	Details of technique	Reduction efficiency	Capital cost	Operating cost
	Scrubbing (eg at Hoogovens Ijmuiden, NL)	Achieving particulate emissions between 10 and 50 mg/m ³	24 to 40M Euro(1996) for a 1Mtpa steelmaking plant	2 to 4Euro(1996) /t LS
Secondary de-dusting	Efficient evacuation during charging and tapping with subsequent purification by means of fabric filtration or ESP Efficient evacuation during hot metal handling, deslagging of hot metal and secondary metallurgy with subsequent purification by means of fabric filtration or equivalent. Fume suppression with inert gas (solid CO ₂) during reladling of hot metal from torpedo ladle to charging ladle	Fabric filtration - 5 to 15 mg/m ³ achievable; ESP - 20 to 30 mg/m ³ achievable.	Capital cost of ESPs and fabric filters 12 to 20M Euro(1996)	operating cost 0.8 to 4Euro(1996) /t LS.

5.2.5 Future Air Quality Under the Business as Usual Scenario

The German steel industry association, Verein Deutscher Eisenhüttenleute (VDEh, 2000), have reviewed ambient heavy metal concentrations measured by their members (with data claimed to be viewed as representative by the regulatory authorities) and consider that whilst significant reductions in heavy metal concentrations in the vicinity of steelworks in Germany have been achieved over the past 20 years (eg Cd concentrations in Northrhine-Westfalia have fallen from 11ng/m³ in 1974 to approximately 1ng/m³ in 1998) hardly any further changes have been recorded for heavy metals over the past few years. Furthermore they consider that corresponding developments of the ambient air concentrations over time are asymptotic. They have noticed this even in the vicinity of decommissioned production sites. Therefore, on this basis, ambient metal concentrations in the vicinity of steelworks in Germany are not expected to decline much below current levels in the future.

The opinion of VDEh, given their knowledge of the conditions in their member companies' integrated steelworks and electric arc furnaces, is that there is only a marginal possibility to reduce emissions further and, in particular, ambient concentrations. They consider that there is no identifiable potential offered by currently available air pollution control equipment when considering the principle of BAT in cost-benefit terms.

Corus in the UK consider that their sinter plants comply with BAT. Particulate emissions are in the range of 50 to 60mg/m³ which are at the high end of emissions performance of techniques that are considered to be BAT. More advanced techniques to reduce particulates are included in the BAT Reference Document and are presented in Section 5.2.4.

For the Polish site at Huta Katowice there are plans to modernise the de-dusting equipment, change the charge materials, and eventually replace the most 'burdensome' technologies. The estimated reduction in cadmium is expected to be 25%, resulting in a reduced ambient concentration of approximately 3ng/m³. For the other Polish site details of modernisation plans have not been provided.

5.2.6 Costs and Benefits of Complying with Potential Limit Values

With future air quality in the vicinity of integrated steelworks expected to be only marginally lower than the figures quoted in Section 5.2.3 all three metals (As, Cd and Ni) are of concern with regard to at least some of the potential limit values for most sites. Notably however, the ambient concentrations in the vicinity of the Hoogovens site in the Netherlands are within the lowest limit values for all metals.

Following discussions with VDEh the locations of the monitoring points near the German steelworks are not necessarily positioned solely with steelworks in mind and other industries may be making the dominant contribution to ground level metals concentrations. Hence our assessment has taken this into account.

Of the sites not expected to comply with the lowest proposed limit values under the business as usual scenario, it is considered that one of the UK integrated steel works is reasonably representative. This is because the particulate emissions from the sinter plant (50 to 60mg/m³) represent better than average current performance across the EU, i.e. with some convergence to higher standards under IPPC the performance at the plant might be predicted to be roughly mid-range.

To achieve significant reductions in heavy metal emissions it is considered that fabric filtration techniques would be implemented for the sinter plant as presented in Table 5.7 (according to Corus, heavy metal emissions from the basic oxygen steelmaking process are not significant). The costs of implementing fabric filtration for one representative sinter plant are as follows:

Capital costs:

- 7 to 22M Euro (2000 prices)
- 0.6 to 1.8M Euro pa @ 2% discount rate
- 0.6 to 2.0 M Euro pa @ 4% discount rate
- 0.7 to 2.2 M Euro pa @ 6% discount rate

Operating costs:

- 2 to 14M Euro pa (2000 prices)

Total costs:

- 3 to 16M Euro pa (to 0 decimal places, all discount rates)

Modelling work based on applying fabric filters to both of the sinter plant stacks reveals that such techniques would have little impact on ambient concentrations of arsenic, cadmium and nickel. At the nearest sensitive receptor the reduction in ambient concentrations is less than 0.1ng/m³ for each of the pollutants. This would not, in itself, enable compliance with the lowest limit values. Therefore it is clear that not all sites in this sector would be able to comply with the lowest limit values.

On the basis of the available information, air quality limit values that could be complied with by 2010 are as follows:

- Arsenic 4ng/m³
- Cadmium 5ng/m³

-
- Nickel 10ng/m³

Compliance with these limit values is not expected to result in significant costs or benefits for the sector as a whole.

5.3 Electric Arc Steelmaking

5.3.1 Profile of Sector

About one thirds of the EU's crude steel production is from the estimated 245 electric arc furnaces (EAFs).

The major feedstock for the EAF is ferrous scrap, which mainly comprises of scrap from inside the steelworks, cut-offs from steel product manufacturers, and post-consumer scrap. Direct reduced iron is also increasingly being used as a feedstock.

The production of stainless steel is covered in this sector as data from Eurofer indicates that the majority of steelworks that produce stainless steel operate electric arc furnaces. This is a significant process with regard to nickel emissions.

The production of carbon steel and low alloyed steels represents about 85% of steel production, with the following operations:

- raw material handling and storage
- furnace charging
- EAF scrap melting
- steel and slag tapping
- ladle furnace treatments
- slag handling
- continuous casting

For high alloyed and special steels the production sequence is more complex and tailor made for the end products.

The estimated number of electric arc furnaces in the EU-15 and Accession Countries is given in Table 5.9 (European Commission, 2000 and Eurofer, 2000).

Table 5.9 - Estimated Number of Electric arc Furnaces in the EU-15 and Accession Countries

Country	Estimated number of electric arc furnaces
UK	16
Spain	29
Sweden	13
Portugal	1
Netherlands	2
Luxembourg	2
Italy	74
Ireland	1
Greece	9
Germany	53
France	32
Finland	2
Denmark	2
Belgium	6
Austria	3
Czech Republic	23
Poland	14
Hungary	2
Slovenia	4
Estonia	0
Cyprus	0
Total	288

5.3.2 Emission Sources

Emission factors for EAFs based on information in the BAT Reference Document include:

As – no data

Cd - <1 to 72 mg/t LS (liquid steel)

Hg – 6 to 4470 mg/t LS

Ni – 1 to 1400 mg/t LS

5.3.3 Current Air Quality Data

Table 5.10 Arsenic

Country	Conc (ng/m ³)	Date	Location	Descr of loc	Emission rate (kgpa)	Ref
Austria	below detection limit	not specified	Bohler- Edelstahl			Bohler- Edelstahl, 2000
Finland	4 (average)	1998	Outokumpu, Tornio	Measurements at nearest housing, 1.5km from site. (TSP sample)		Outokumpu, 2000
Germany	4	1999 (1/99 to 10/99)	Duisburg- Bruckhausen	700m windward of steel mill		Position Paper
Poland	1.0	Assumed 1999	Huta Ostrowiec	Ostrowiec town		Biprohut, 2000
UK	2.64	1999	Corus, Rotherham	-	117	DETR, 2000 (1)
UK	No data	1999	Corus, Stockbridge	-	17	UK Steel
UK	No data	1999	ASW Tremorfa, Cardiff	-	No data	UK Steel
UK	No data	1999	Avesta Sheffield	-	9	UK Steel

Note

1. Preliminary results for the first 8 months of a 12 month project - running mean

Table 5.11 Cadmium

Country	Conc (ng/m ³)	Date	Location	Descr of loc	Emission rate (kgpa)	Ref
Austria	below detection limit		Bohler- Edelstahl			Bohler- Edelstahl, 2000
Finland	below 1	1998	Outokumpu, Tornio	Measurements at nearest housing, 1.5km from site. (TSP sample)		Outokumpu, 2000
Germany	16.8	1998	Duisburg – Meiderich	Vicinity of steel industry. It is understood that the high concentrations could be due to a nearby zinc plant.		Position Paper

Country	Conc (ng/m ³)	Date	Location	Descr of loc	Emission rate (kgpa)	Ref
Germany	1.6	1999 (1/99 to 10/99)	Duisburg-Bruckhausen	700m windward of steel mill		Position Paper
Poland	0.50 (2)	Assumed 1999	Huta Lucchini Warszawa, Warszawa	Peak concentration		Biprohut, 2000
	2.2	Assumed 1999	Huta Ostrowiec	Ostrowiec town		Biprohut, 2000
UK	0.77	1999/2000	Corus, Rotherham	Nearest sensitive receptor where max concs occur - 600m north east of site boundary	54	DETR, 2000 (1) and UK Steel
UK	No data	1999	Corus, Stockbridge	-	12	UK Steel
UK	No data	1999	ASW Tremorfa, Cardiff	-	22	UK Steel
UK	No data	1999	Avesta Sheffield	-	60	UK Steel

Notes

1. Preliminary results for the first 8 months of a 12 month project - running mean
2. Company estimate of annual average concentration based on 30 minute average figure of 2ng/m³.

Table 5.12 Mercury

Country	Conc (ng/m ³)	Date	Location	Descr of loc	Emission rate (kgpa)	Ref
UK	0.33	1999	Corus, Rotherham	-	55	DETR, 2000(1) & UK Steel
UK	No data	1999	Corus, Stockbridge	-	16	UK Steel
UK	No data	1999	ASW Tremorfa, Cardiff	-	6	UK Steel
UK	No data	1999	Avesta Sheffield	-	59	UK Steel

Note

1. Preliminary results for the first 8 months of a 12 month project - running mean

Table 5.13 Nickel

Country	Conc (ng/m ³)	Date	Location	Descr of loc	Emission rate (kgpa)	Ref
Austria	<10, but >3		Bohler- Edelstahl	(Nearest housing is about 150m from site)		Bohler-Edelstahl, 2000
Belgium	50 (Note 2)	Assumed 1999	Genk	Measurement point is 100m from the site boundary	600 to 700	ALZ, 2000
Finland	10 (average)	1998	Outokumpu, Tornio	Measurements at nearest housing, 1.5km from site. (TSP sample)		Outokumpu, 2000
Germany	19.4	1998	Duisburg – Meiderich	Vicinity of steel plant		Position Paper
Germany	18	1999 (1/99 to 10/99)	Duisburg-Bruckhausen	700m windward of steel mill		Position Paper
Germany	23.4	1998	Siegen	Vicinity of steel plant. Site reported to be upwind of measurement & other sources thought to be key contributors		LUA, 1998, VDEH
Poland	1 (Note 3)	Assumed 1999	Huta Lucchini Warszawa, Warszawa	Peak concentration		Biprohut, 2000
	2.7	Assumed 1999	Huta Ostrowiec	Ostrowiec town		Biprohut, 2000
UK	8.29	1999/2000	Corus, Rotherham	Nearest sensitive receptor where max concs occur - 600m north east of site boundary	220	DETR, 2000 (Note 1) and UK Steel
UK	No data	1999	Corus, Stockbridge	-	270	UK Steel
UK	No data	1999	ASW Tremorfa, Cardiff	-	19	UK Steel
UK	63 to 98, mid-range figure 80	1999	Avesta Sheffield	At works boundary, 350m from melting shop. Nearest housing is 1km from melting shop.	3000	Avesta Sheffield

Notes

- 1) Preliminary results for the first 8 months of a 12 month project - running mean
- 2) Contributors to the background concentration will include a coal and oil fired power station, domestic coal burning etc. However, the Government, who operate the measurement station, believe that the majority of the ambient concentrations are due to ALZ emissions.
- 3) Maximum concentration based on 30 minute average. Annual average figure would be lower.

Certain organisations contacted did not have ambient heavy metal concentration data in the vicinity of their sites or had such limited data that it would not be useful to the study. These included Krupp Thyssen Nirosta (stainless steel plants in Krefeld and Bochum in Germany);

5.3.4 Emission Reduction Techniques

For electric arc steelmaking, the techniques or combinations of techniques that are considered as BAT for reducing heavy metal emissions are summarised in Table 5.14 (European Commission, 2000. European Commission, 2000. Best Available Techniques Reference Document on the Production of Iron and Steel, March 2000).

Table 5.14 Emission Reduction Techniques for Electric Arc Steelmaking

Type of technique	Details of technique	Reduction efficiency
Dust collection	A combination of direct off gas extraction and hood systems <i>or</i> dog-house and hood systems <i>or</i> total building evacuation.	98% and greater collection efficiency of primary and secondary emissions from EAFs are achievable
Waste gas dedusting	A well designed fabric filter.	Achieving particulate emissions of less than 15 mg/m ³ . The minimisation of the dust content correlates with the minimisation of heavy metal emissions except for heavy metals present in the gas phase like mercury

5.3.5 Future Air Quality Under the Business as Usual Scenario

The ALZ plant in Genk, Belgium is already complying with BAT. Emissions of particulates from the stacks are between 1 and 2mg/m³ whereas the BREF Document states that <5mg/m³ is BAT. Fugitive emissions from this site are not significant.

The Outokumpu plant in Tornio, Finland report that following the planned renovation of the steel making shop in 2004 (involving closing the roof lanterns and venting to bag filters) the ambient concentrations are expected to be approximately 2ng/m³ for As, 0.5ng/m³ for Cd and 5ng/m³ for Ni.

For the Huta Lucchini Warszawa site it is understood that BAT is already complied with and that no major changes can be expected in the foreseeable future. Details of the other Polish site are not available.

Avesta Sheffield have no current plans to make any improvements to reduce their emissions and the techniques that the company has adopted are considered by the Environment Agency (2000) to represent BAT.

The Corus Rotherham site is operating in accordance with BAT currently. The bag house is achieving between 2 and 5mg/m³ particulates (performance achievable by BAT) the capture facilities represent BAT. Therefore ambient metals concentrations are not expected to change noticeably under the business as usual scenario.

5.3.6 Costs and Benefits of Complying with Potential Limit Values

Site A

At this site it is not considered possible to improve on the abatement measures and hence the only option available is to increase the height of the stacks to aid dispersion. Based on dispersion modelling, increasing the current stack heights from approximately 30m (10m effective stack height due to terrain) to 90m (70m effective stack height) is estimated to enable compliance with the nickel limit value of 10ng/m³ at nearest housing (compared with current concentrations of approximately 50ng/m³). The capital (assumed total) cost of installing these taller stacks (7 stacks) to reduce ground level concentrations of nickel is estimated to be:

8.4M Euro

0.70M Euro pa @ 2% discount rate

0.77M Euro pa @ 4% discount rate

0.84M Euro pa @ 6% discount rate

Whilst the change in the dispersion profile achieved by taller stacks could ensure compliance with a nickel limit value of 10ng/m³, overall net health benefits would not be expected to be noticeable because the greater dispersion would simply disperse the emissions further afield. Therefore benefits to residents living close to the site would be counter acted by effects on residents living further afield.

This is based on the simplifying assumption that the nickel unit risk factor varies linearly with ambient concentration and that there is no threshold of carcinogenic effects for nickel.

Site B

At this site if further improvements to emissions were required the company would close the melt shop roof, increase the extraction rate and install additional fabric filters. Importantly, however, the company does not know yet whether this would be a practical proposition as closing melt shop roofs does lead to occupational exposure risks unless air flows are safely managed. Detailed feasibility studies would be required to confirm whether this would be a practical proposition. Such work is expected to cost:

Capital cost

10 to 17M Euro

0.8 to 1.4M Euro pa @ 2% discount rate

0.9 to 1.5M Euro pa @ 4% discount rate

1.0 to 1.7M Euro pa @ 6% discount rate

Operating cost

0.8M Euro pa

Total cost

1.6 to 2.2M Euro pa @ 2% discount rate

1.7 to 2.3M Euro pa @ 4% discount rate

1.8 to 2.5M Euro pa @ 6% discount rate

The summarised benefits for implementing the compliance strategy at this site to comply with a nickel limit value of $10\text{ng}/\text{m}^3$ at nearest housing are detailed in the following table.

Table 5.15 - Health Benefits from Implementing Compliance Strategy at Site B (Note 1)

Pollutant	Current Emission Rates (kg pa)	Average reduction in conc ⁿ within area of interest due to compliance techniques (ng/m^3) (Note 4)	Radius of area of interest (m) (Note 2)	Distance of nearest housing (m)	Population within area of interest (Note 5)	Reduction in cancers per annum (Note 6)	Valuation of reduction in cancers (€m per annum) (Note 7)
As	9	0.12 (Note 3)	10,000	1,000	100,000 to 600,000	2.6×10^{-4} to 1.5×10^{-3}	see total
Cd	60	0.02 (Note 3)	10,000	1,000	100,000 to 600,000	5.1×10^{-5} to 3.1×10^{-4}	see total
Ni	3,000	0.96 (Note 3)	10,000	1,000	100,000 to 600,000	1.4×10^{-4} to 8.2×10^{-4}	see total
As, Cd and Ni			10,000	1,000	100,000 to 600,000	4.5×10^{-4} to 2.6×10^{-3} (Note 5)	4.1×10^{-4} to 2.3×10^{-3} (low est) 8.1×10^{-4} to 4.7×10^{-3} (best est) 2.0×10^{-3} to 0.011 (high est)

Notes

1. Quantified health effect benefits for the metals of interest relate to carcinogenic effects only as information on ambient concentrations in the vicinity of sites in this sector suggests that the non carcinogenic effect critical concentrations are not exceeded (See Section 10.1.2).
2. In general, elevated ambient concentrations due to industrial sources reduce to near background levels a few kilometers from the site. 10km has been selected to define the area of interest to ensure that good coverage is achieved of the most significant areas likely to experience benefits. Choosing a larger area is not expected to significantly impact on the results because the larger population would be counter-acted by a smaller average reduction in concentration across that population.
3. Ambient concentrations for arsenic and cadmium are based on a pro-rata to nickel (the most significant metal emitted). The ratio is assumed to be Ni / Cd / As - 1.0 / 0.02 / 0.12.
4. Based on urban conditions, which are applicable to the site of interest.
5. This is intended to be a generic population density suitable for scaling across the sector. Based on a high range population density equally split between urban (for the site of interest, 38.8 people per hectare) and rural (generic for England and Wales, 0.37 people per hectare) and a low range population density taken as the average population density for England and Wales (3.30 people per hectare).
6. These figures are based on unit risks of 1.5×10^{-3} for arsenic, 1.8×10^{-3} for cadmium and $1 \times 10^{-4} (\mu\text{g} \cdot \text{m}^{-3})^{-1}$ for nickel (which is applicable to general exposure to nickel, not including exposure to nickel sulphide which is only relevant to certain nickel processes).
7. See Section 10.2 for details of the valuation methodology.

Site C

At this site, to achieve further reductions in emissions would require better containment of charging and tapping emissions and improved extraction. The ballpark cost of this would be in the region of:

Capital cost

8 to 17M Euro

0.6 to 1.4M Euro pa @ 2% discount rate

0.7 to 1.5M Euro pa @ 4% discount rate

0.8 to 1.7M Euro pa @ 6% discount rate

Operating cost

0.8M Euro pa

Total cost

1.4 to 2.5M Euro pa, covering all discount rates

This technique would effectively eliminate fugitive emissions. Alternative techniques such as investment in a 'dog house' to enclose the fumes would be excessively costly as it would involve fundamental changes to the structure of the melt shop and would essentially require investment in a new plant (at roughly 170M Euro capital cost). Furthermore steelmakers find that dog houses restrict the movement of steel within the meltshop and can be very noisy.

In the vicinity of this site, current ambient nickel concentrations would be compliant with a limit value of 10ng/m^3 but not a limit value of 3ng/m^3 . The modelling results indicate that the

incremental improvement due to better containment of emissions and improved abatement will not in themselves be sufficient to make the step change to compliance with $3\text{ng}/\text{m}^3$.

Overall

Arsenic

For arsenic, of the sites for which data is available, compliance would be expected to be demonstrated with a limit value of $4\text{ng}/\text{m}^3$ for the BAU2010 case.

However, even with techniques to achieve better performance than BAU2010 in order to comply with $10\text{ng}/\text{m}^3$ for nickel (see below), it is considered that the lowest limit value for arsenic ($1\text{ng}/\text{m}^3$) is not realistic for this sector.

Cadmium

For cadmium, of the sites for which data is available, compliance would be expected to be demonstrated with a limit value of $5\text{ng}/\text{m}^3$ for the BAU2010 case.

However, even with techniques to achieve better performance than BAU2010 in order to comply with $10\text{ng}/\text{m}^3$ for nickel (see below), it is considered that the lowest limit value for cadmium ($0.5\text{ng}/\text{m}^3$) is not realistic for this sector.

This analysis assumes that the exceptionally high figure for cadmium reported in the Duisburg area of Germany is primarily due to a nearby zinc plant. Such plants can contribute to relatively high cadmium concentrations.

Nickel

Nickel is the metal of most interest for this sector. On the basis of the available information, a limit value of $10\text{ng}/\text{m}^3$ is thought to be realistic by 2010, although the lowest limit value is not thought realistic.

Some sites will be compliant with $10\text{ng}/\text{m}^3$ under the 2010BAU scenario. It is expected that of the 10 sites where reasonable ambient data is available (although for certain sites the nature of the process is not clear), 5 sites (50%) will be compliant with the limit value under the 2010BAU scenario.

Of the remaining sites a range of techniques may be adopted including the enclosure of melt shops combined with improvements in extraction and abatement, and, where permissible, increasing stack heights. It is thought that increasing stack heights is unlikely to be a widely adopted measure due to the limited or negligible environmental benefits. Dependent on the specific viewpoint of the regulatory authority it might be acceptable as a 'last resort' once the company had adopted the best technology options (BAT) for minimising their process emissions. For the purposes of this study only 20% of companies are assumed to adopt this approach. The remaining 80% are assumed to adopt the engineering modifications similar to Site B - i.e. enclosure, extraction and abatement.

Eurofer data suggests in the region of 56 stainless steel plants across the EU, and according the proportions earlier in this section, an assumed increase of 20% is considered reasonable to cover the Accession Countries - this gives a total number of stainless steel works of 67. With an estimated 50% of sites not expected to comply with $10\text{ng}/\text{m}^3$ under the 2010BAU scenario, costs and benefits for meeting $10\text{ng}/\text{m}^3$ will apply to 50% (or 34) of stainless steelworks across

the EU. Of these 34, 80% (or 27) of plants will improve their abatement techniques and 20% (or 7) are assumed to already be compliant with BAT and hence will seek to improve dispersion.

On the basis of the above assumptions the costs and quantifiable benefits for the sector are as follows.

Table 5.16 - Costs and Health Benefits for Electric Arc Steel Making

Compliance technique to meet 10ng/m ³ Ni	Number of sites expected to adopt this compliance technique	Costs per site (€m per annum)	Total costs (€m per annum)	Reduction in cancers per site due to As, Cd and Ni (per annum)	Total reduction in cancers due to As, Cd and Ni (per annum)	Valuation of reduction in cancers due to As, Cd and Ni (€m per annum)
Enclosure, extraction and abatement	27	1.6 - 2.2 (@2%DR) 1.7 - 2.3 (@4%DR) 1.8 - 2.5 (@6%DR)	43 - 59 (@2%DR) 46 - 62 (@4%DR) 49 - 68 (@6%DR)	4.5x10 ⁻⁴ to 2.6x10 ⁻³	0.01 to 0.07	9x10 ⁻³ to 0.06 (low est) 0.018 to 0.13 (best est) 0.044 to 0.31 (high est)
Increase in stack heights (after already complying with BAT)	7	0.70 (@2%DR) 0.77 (@4%DR) 0.84% (@6%DR)	5 (@2%DR) 5 (@4%DR) 6 (@6%DR)	0	0	0
Total	34	-	48 - 64 (@2%DR) 51 - 67 (@4%DR) 54 - 73 (@6%DR)	-	0.01 to 0.07	9x10 ⁻³ to 0.06 (low est) 0.018 to 0.13 (best est) 0.044 to 0.31 (high est)

Whilst the above table shows that the costs outweigh the specific quantifiable benefits of the reduction in cancers due to As, Cd and Ni exposure there will be other important secondary benefits of the heavy metal air quality limit values. The benefits due to these other effects will clearly improve the balance towards the benefits, although by how much is not possible to fully quantify with the currently available information. These additional benefits include:

- Reduced adverse health effects due to reductions in exposure to other metals;
- Reduced mortality and morbidity effects due to reductions in exposure to PM₁₀;
- Reduced adverse impacts on ecosystems and crops; and
- Reduced occupational exposure to carcinogenic metal pollutants.

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6 Non ferrous Metals Sector

The sub-sectors incorporated within this industry sector and relevant to this study are:

- Primary and secondary copper production;
- Primary nickel production;
- Primary zinc production; and
- Primary and secondary lead production.

The range of raw materials available to the various installations is wide and results in a variety of metallurgical production processes being used.

6.1 Introduction

The metals being considered for the non-ferrous metals sector include arsenic, cadmium, nickel and mercury. The bulk of the analysis will be based on the first three metals because potential limit values have been proposed for those metals and because relevant data is more available for those metals.

Current Legislative Controls

Heavy metal emissions from non-ferrous metals processes can be controlled directly, or indirectly through controls on emissions of particulate or other pollutants. Current control legislation includes:

- Regulations of emissions to atmosphere at a Member State level e.g. Integrated Pollution Control under the Environmental Protection Act 1990 in the UK, Federal Law on Immission Control (*BImSchG*) in Germany, Air Pollution Act in The Netherlands.
- Air Quality Standards regulations for particulate matter and lead.

Emission limit values for non ferrous metals processes under Member State legislative controls are summarised in Table 6.1.

Table 6.1 - Non-Ferrous Metals Sector Emission Limits for Various Member States

Contaminant	Country	Industry	Unit	Limit value (1)
Dust	Austria (2)	All	mg/Nm ³	20
	Belgium	Pb	mg/Nm ³	10
		Other non-ferrous	mg/Nm ³	20
	France	Zn/Pb pyro	mg/Nm ³	10
		Zn/Pb pyro	kg/h	2.5
	Germany	Non-ferrous	mg/Nm ³	20
		Pb	mg/Nm ³	10
	Netherlands	Zn	mg/Nm ³	30
		Sn	mg/Nm ³	5
		General industry	mg/Nm ³	25
	Norway	Zn	kg/h	50
		Cu, Ni	kg/h	2
	Spain	Zn	mg/Nm ³	50
		Pb (general)	mg/Nm ³	50
Pb (refining)		mg/Nm ³	10	
General industry		mg/Nm ³	150	
Cu smelting		mg/Nm ³	150	
Cu refining		mg/Nm ³	300	
Sweden	Cu hydrometallurgy	mg/Nm ³	300	
	Cu, Pb, Zn	mg/Nm ³	20	
	Cu, Pb, Zn	t/y	250	
	Cr-Ni-Pb-Zn	kg/t feed	0.1	
UK (3)	Cr-Ni, Pb-Zn	t/y	7	
Total particulate matter	UK (3)	Zn, Pb	mg/Nm ³	10
Arsenic		Ni (carbonyl process)	mg/Nm ³	30
		Ni (other processes)	mg/Nm ³	10
	Austria (2)	All	mg/Nm ³	1 (As, Co, Ni, CrVI, Se, Te total)
	Belgium (Flanders)	All	mg/Nm ³	1 (As+Se+Ni), if mass flow <5g/hour
	France	Zn/Pb	kg/h	0.01
	Germany	All	mg/Nm ³	1 (4)
Cadmium	Sweden	Cu, Pb, Zn	t/y	8
	UK (3)	Zn, Pb	mg/Nm ³	1 (As+Se+Te)
	Austria (2)	All	mg/Nm ³	0.05
	Belgium (Flanders)	All	mg/Nm ³	0.2 (Cd+Hg+Tl), if mass flow <1g/hour
Nickel	France	Zn/Pb pyro	kg/h	0.2
	Germany	All	mg/Nm ³	0.1 (5)
	Netherlands	Non-ferrous	Mg/Nm ³	0.2
	Norway	Cu	kg/h	2
	Spain	Non-ferrous	mg/Nm ³	17
	Sweden	Zn, Cu, Pb	t/y	0.8
	UK (3)	Zn, Pb	mg/Nm ³	0.5 (Cd+Hg+Tl)
	Austria (2)	All	mg/Nm ³	1(As, Co, Ni, CrVI, Se, Te total)
	Belgium (Flanders)	All	mg/Nm ³	1 (Ni+As+Se), if mass flow <5g/hour
	Germany	All	mg/Nm ³	1 (4)
Mercury	Austria (2)	All	mg/Nm ³	0.1 (Be + Hg)
	Belgium (Flanders)	All	mg/Nm ³	0.2 (Hg+Cd+Tl), if mass flow <1g/hour
	France	Zn/Pb pyro	kg/h	0.01
	Germany	All	mg/Nm ³	0.2 (6)
	Sweden	Zn, Cu, Pb	t/y	0.35
	UK (3)	Cr, Ni, Pb, Zn	kg/h feed	0.4
			mg/Nm ³	0.5 (Cd+Hg+Tl)

Notes

1. For compliance with the limit values the following rules apply:
 - No daily average shall exceed the limit value
 - 97% of the half-hour averages shall not exceed 120% of the limit value
 - No half-hourly average shall exceed 200% of the limit value
 - In Belgium, these rules apply for SO₂ and Nox. For metals the limits must not be exceeded, except for a certain percentage which is allowed for "measurement uncertainties".
2. Austria's limit values are from NE-Metallverordnung BGBl.II 1/1998. The remaining countries' limit values are from OSPARCOM 1998
3. UK figures are achievable releases for new plant using BAT
4. The sum of arsenic, cobalt, nickel, selenium, chromium(VI) and tellurium (if the mass flow is 5g/h or more) shall not exceed 1mg/Nm³
5. The emission limit for cadmium and its compounds was tightened to 0.1mg/Nm³ (if the mass flow is 0.5g/h or more) on 37th conference of the federal ministers of the environment 21/22 November 1991
6. The sum of cadmium, mercury and thallium (if the mass flow is 1g/h or more) shall not exceed 0.2mg/Nm³

Future Legislative Controls

Regulatory factors which will have an impact on heavy metal emissions in the non-ferrous metals sector in the future include:

- IPPC Directive – the need to meet BAT requirements (see Section 4).
- UNECE Heavy Metals Protocol – the need to meet BAT requirements plus emission limit values (see Section 4).
- Air Quality Daughter Directive limit values for PM₁₀ and lead (see Section 4).

6.2 Primary and Secondary Copper Production

6.2.1 Profile of Sub-sector

Refined copper is produced from primary and secondary raw materials by a relatively small number of copper refineries; their product is copper cathode. This is melted, alloyed and further processed to produce rods, profiles, wires, sheets, strips, tubes, etc. This step may be integrated with the refinery but is frequently carried out at another site. About 55% of the feed supplies to the copper refineries are purchased on the international market in the form of copper concentrates, blister, anodes or scrap. The remaining 45% come from domestic copper concentrates as well as domestic copper bearing residue or scrap.

The EU accounts for around 2% of the total world-wide copper mine output. Annual production of copper cathode is approximately 1m tonnes from primary sources and 0.9m tonnes from secondary sources. Three of the secondary smelters and nearly all of the primary smelters have increased their production output. Computer scrap and printed circuit boards are becoming more common secondary sources even though the copper content is low.

Recycling is at a high level as copper can be reprocessed without loss of its intrinsic properties and many secondary materials are available. EU copper refining activity has been able to grow primarily by securing raw materials on the international market and making use of copper or brass scrap and residues generated by consumers and processors.

Table 6.2 summarises copper production across Member States and Accession countries.

Table 6.2 - Production of Copper in 000's Tonnes in 1997

Country	Primary cathode (anode)	Secondary cathode (anode)
Austria		77
Belgium	203 (35)	183 (126)
Finland	116 (171)	
France	6	29
Germany	296	378
Italy	6	80
Poland	847	33
Spain	229 (+61)	63 (+28)
Sweden	95	34
UK	9	58

There are currently nine major refineries in the EU, following the closure of the UK plant at Walsall. Five use primary and secondary materials and the others use secondary materials only. Three companies have capacities of over 2.35 mtpa refined copper cathode capacity; Atlantic Copper (Spain), Union Minière (Belgium) and Norddeutsche Affinerie (Germany). Four others, MKM Hettstedt (Germany), Hüttenwerke Kayser (Germany), Boliden (Sweden) and Outokumpu (Finland) each produce more than 100,000 tonnes per year. Production capacities at other facilities in Italy, Spain, Austria, the United Kingdom and Belgium range between 35,000 and 100,000 tonnes of copper cathode per year.

6.2.2 Emission Sources

Metal compounds can be emitted from most stages of the process, particularly as fugitive releases. Emissions of metals are strongly dependent on the composition of the dust produced by the processes. The composition varies widely and is influenced by the process that is the source of dust and by the raw materials that are being processed. The dust produced from a scrap converter is totally different to that of a matte converter.

Direct and fugitive dust emissions from the smelting, converting and refining stages are potentially high. The significance of the emissions is also high as these process stages are used to remove volatile metals such as Zn, Pb, Cd and As from the copper and these metals are present in the gas and the dust.

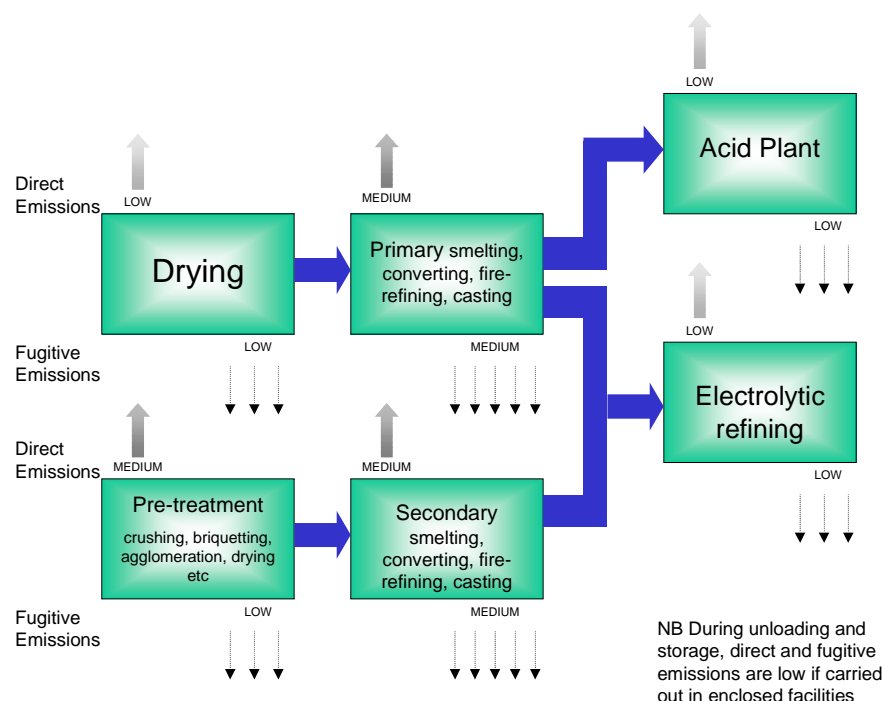
Primary smelters usually contain dust very well and are effectively sealed to minimise fugitive emissions. Concentrate burners or lances are used which are easier to seal. Good maintenance of the furnaces and ducts is practised to minimise fugitive releases and the collected gases are treated in dust removal systems prior to the sulphur recovery processes.

Secondary smelters can be more prone to fugitive releases during charging and tapping cycles. These furnaces have large charging doors and the warping and mis-sealing of these doors is a significant factor. The gases that are collected are usually cooled and dust is removed from the gas streams by electrostatic precipitators (ESPs) or bag filters. High filtration efficiency is usually achieved.

Another key source of fugitive emissions is from stock-piles, loading and unloading of materials from stockpiles and transport operations around the plant.

Because of the batch type of operation the conversion and refining stages can usually not be as well sealed as the smelting stage. The feeding and transfer of matte, slag and metal is a significant potential source of fugitive fume. The use of a ladle or boat transfer system can inhibit the effectiveness of fume collection hoods. Various secondary fume collection systems are used to minimise these fugitive emissions and operate very successfully. Through hood additions of flux and other material can minimise the rollout time. The production of higher-grade matte reduces the number of ladle transfers and therefore reduces the potential for fume. Fugitive or non-collected emissions are therefore very important. These issues are dependent on efficient and effective primary and in some cases secondary fume collection.

The main process steps are summarised below and the relative importance of emissions from each step indicated as low, medium and high. The relative significance of the emissions relates to the process described and serves to indicate which process stages have the highest comparative metal emissions.



6.2.3 Current Air Quality Data

Tables 6.3 to 6.6 summarise the latest available ambient air quality data for arsenic, cadmium, nickel and mercury for the copper production sector.

Table 6.3 Current Air Quality Data for Arsenic

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
Nordic	16	1997	B	1000m from main copper – nickel smelter	-	Position paper
Nordic	11	1999	B	1100m from main copper – nickel smelter ventilation gases stack	1,751	Consultation with site
Germany	16	1999	D	1600m from roof 1 of secondary copper smelter	306	Consultation with site
Germany	5	1999	D	1200m from roof 2 of secondary copper smelter	103	Consultation with site
Germany	5	1999	D	1600m from a stack of secondary copper smelter	25	Consultation with site
Belgium	30	1999	E	75m NE of the plant.	56	Consultation with site
Belgium	<10	1999	A	1150m NNE from the plant	296	Consultation with site
Germany	No data available	1999	F		291 (2)	Consultation with site
Spain	No data available	1998	C		91	Consultation with site
UK	10	1999/00	Walsall - Main process now closed	Nearest sensitive receptor where max concs occur - 150m NE of the copper and copper alloy main site stack and 350m from the M6		Preliminary air quality results for the first 9 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory

Notes

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality, especially at short distances from the plant.
2. Includes fugitive emissions.

Table 6.4 Current Air Quality Data for Cadmium

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
Nordic	0.7	1997	B	1000 m from main copper-nickel smelter	-	Position paper
Nordic	0.7	1999	B	1100 m from main copper-nickel smelter ventilation gases stack	359	Consultation with site
Germany	14.2	1999	D	1600m from roof 1 of copper smelter	13.5	Consultation with site
Germany	2.1	1999	D	1200m from roof 2 of copper smelter	11	Consultation with site
Germany	1.3	1999	D	1600m from stack of copper smelter	No data available	Consultation with site
UK	6	1999/00	Walsall - Main process now closed	Nearest sensitive receptor where max concs occur - 150m NE of the copper and copper alloy main site stack and 350m from the M6	76	Preliminary air quality results for the first 9 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory
Belgium	27	1999	E	75m NE of the plant. 1000m W is another non-ferrous plant	143	Consultation with site
Belgium	No data available	1999	A		54	Consultation with site
Germany	No data available	1999	F		143 (2)	Consultation with site
Spain	No data available	1998	C		28.8	Consultation with site

Notes

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality, especially at short distances from the plant;
2. Includes fugitive emissions.

Table 6.5 Current Air Quality Data for Nickel

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
Nordic	21	1997	B	1000 m from main copper-nickel smelter ventilation gases stack	-	Position paper
Nordic	10	1999	B	1100 m from main copper-nickel smelter ventilation gases stack	792	Consultation with site
Belgium	< 30	1999	A	1150m NNE from the plant	121.3	Consultation with site
UK	8	1999/ 00	Walsall - Main process now closed	Nearest sensitive receptor where max concs occur - 150m NE of the copper and copper alloy main site stack and 350m from the M6	345	Preliminary air quality results for the first 9 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory
Belgium	20	1999	E	75m NE of the plant. 1000m W is another non-ferrous plant.	13	Consultation with site
Spain	No data available	1998	C		31.7	Consultation with site

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality, especially at short distances from the plant.

Table 6.6 Current Air Quality Data for Mercury

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
UK	1	1999/ 00	Walsall - Main process now closed	Nearest sensitive receptor where max concs occur - 150m NE of the copper and copper alloy main site stack and 350m from the M6		Preliminary air quality results for the first 9 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality, especially at short distances from the plant

6.2.4 Emission reduction Techniques

Techniques for dealing with emissions from the handling, storage, drying and treatment stages are summarised in Table 6.7.

Table 6.7 Summary of Abatement Methods for Heavy Metals in Off-gases

Process stage	Component in off-gas	Abatement option
Raw materials handling	Dust and metals	Correct storage, handling and transfer. Dust collection and fabric filter.
Raw materials thermal pre-treatment	Dust and metals	Correct pre-treatment. Gas collection and fabric filter.
Primary smelting	Dust and metals Hg	Process operation and gas collection, gas cleaning followed by gas cooling/final cleaning. If high in feed, removal after SO ₂ gas cleaning.
Secondary smelting	Dust and metals	Process operation and gas collection, cooling and cleaning by fabric filter.
Primary converting	Dust and metals	Process operation and gas collection, gas cleaning.
Secondary converting	Dust and metals	Process operation and gas collection, cooling and cleaning by fabric filter
Fire refining	Dust and metals	Process operation and gas collection, cooling and cleaning by fabric filter or scrubber.
Melting and casting	Dust and metals	Process operation and gas collection, cooling and cleaning by fabric filter.
Pyro-metallurgical slag treatment processes	Dust and metals	Process operation and gas collection, cooling and cleaning by fabric filter.

Best Available Techniques for gas and fume treatment systems are those that use cooling and heat recovery if practical before cleaning. Fabric filters that use modern high performance materials in a well-constructed and maintained structure are applicable. They feature bag burst detection systems and on-line cleaning methods.

Fume production from secondary raw materials can be minimised by the choice of the furnace and abatement systems.

The fume collection systems used can exploit furnace-sealing systems and can be designed to maintain a suitable furnace depression that avoids leaks and fugitive emissions. Systems that maintain furnace sealing or hood deployment should be used. Examples are through hood additions of material, additions via tuyeres or lances and the use of robust rotary valves on feed systems.

Secondary fume collection is expensive and consumes a lot of energy but is needed in the case of some batch converters and for the ventilation of tap-holes, launders etc. The use of an intelligent system capable of targeting the fume extraction to the source and duration of any fume is more energy efficient.

Emerging developments applicable to copper production include the use of modern fabrics for bag filters. More effective and robust fabrics (and housing design) can allow bag life to be extended significantly, improving performance and reducing costs at the same time.

The capture of fugitive emissions can be achieved in a number of ways. The use of intelligent damper controls can improve fume capture and reduce fan sizes and hence costs. Sealed charging cars or skips are used with a reverberatory furnace at a secondary aluminium smelter and reduces fugitive emissions to air significantly by containing emissions during charging.

The abatement efficiency and approximate costs for various BAT are summarised in Table 6.8. Efficiencies quoted are those quoted by the source.

Table 6.8 Summary of BAT Abatement Efficiency and Costs

Technique	Description	Dust efficiency or dust emission concentration	Capital Cost (€m)	Capital Cost (€/Nm ³)	Notes on Operating Costs
Dry ESP gas cleaning ⁽¹⁾ Flash furnace ESP	Gas flow 43,000Nm ³ /h Operating temp. 300-400°C 4 fields, 3,000m ² collection area, single unit	99.9% Outlet: 150-200mg/Nm ³	Equipment supply costs: 1.0 Civil work, etc. excluded; for installed costs approx. 80-100% will have to be added	23	250 kW installed
Dry ESP gas cleaning ⁽¹⁾ Flash furnace ESP	Gas flow 61,000Nm ³ /h Operating temp. 300-400°C 3 fields, 4,800m ² collection area, single unit	99.8% Outlet: 200-300mg/Nm ³	Equipment supply costs: 2.0 Civil work, etc. excluded; for installed costs approx. 80 - 100% will have to be added	32	400kW installed
Bag house, fabric filter ⁽²⁾ Shaft furnace, converter & anode furnace	Gas flow 750,000Nm ³ /h Operating temp. 100°C	<10mg/Nm ³ dust outlet	Total installed cost, including ductwork and stack: 20	27	2.5 - 3 kWh/1000Nm ³ 1g/Nm ³ lime (for anode furnace gas stream)
Bag house, fabric filter ⁽²⁾ TBRC ⁽³⁾	Gas flow 730,000Nm ³ /h Operating temp. 100°C	<10mg/Nm ³ dust outlet	Total installed cost, excluding ductwork and stack: 14	19	2 - 3 kWh/1000Nm ³
Bag house, fabric filter ⁽²⁾ Cooler & fabric filter	Gas flow 70,000Nm ³ /h Operating temp. 100°C	<10mg/Nm ³ dust outlet	Total installed cost, including gas cooler and stack: 2 - 2.5	29-36	1.5 - 4 kWh/1000Nm ³
Wet ESP gas cleaning ⁽¹⁾ Wet gas cleaning for furnace SO ₂ gas	Gas flow 96,000Nm ³ /h Operating temp. 390°C inlet, 35°C outlet 1 radial flow scrubber, 1 ID fan, 2 in-line wet ESP's with a 2,000m ³ total collection area, acid cooler and acid circulation pumps, 1 cooling tower, 900m ³ /h cooling media circulation.	96-97%	Total equipment supply costs: 7.5 - 8 Civil work, etc. excluded; for installed costs approx. 60 - 80% will have to be added	78-83	828kW
Wet ESP gas cleaning ⁽¹⁾ Wet gas cooling and cleaning	Gas flow 250,000Nm ³ /h Operating temp. 370°C inlet, 27°C outlet	96-97%	Total equipment supply costs: 16 - 17 Civil work, etc. excluded; for installed costs	64-68	1250kW

Technique	Description	Dust efficiency or dust emission concentration	Capital Cost (€m)	Capital Cost (€/Nm ³)	Notes on Operating Costs
section for combined SO ₂ in furnace and converter gas	2 radial flow scrubbers, 3 lines with 2 in-line wet ESP's with a 7,000m ³ total collection area, acid cooler and acid circulation pumps, 2 cooling towers, 2,200m ³ /h cooling media circulation.				approx. 70 - 100% will have to be added

Notes

1. Lurgi Umwelt GmbH
2. Copper Expert Group 1998
3. Top Blown Rotary Converter

6.2.5 Future Air Quality Under the Business as Usual Scenario

Table 6.9 summarises the investment plans sites have for complying with existing legislation and investment for complying with the proposed limit values. The sites forecast of 2010 business as usual (BAU) ambient air quality values and predicted air quality after additional investment beyond BAU investment for 2010 are also included. These values are estimates of what the ambient air quality will be at the location of the current ambient monitoring station based on 1999 ambient monitoring data and are a guide. More detailed modelling results have been used for the cost benefit analysis and these are presented in section 6.2.6.

Table 6.9 Predicted Future Ambient Air Quality Values by Sites for Business as Usual Scenario and After Implementing a Limit Value Compliance Strategy

Site	Process description	Existing air abatement techniques	Investment plans to comply with existing legislation	Capital cost (€m)	Strategy for compliance with proposed limit values	Capital cost (€m)	Business as usual air quality values for 2010 (ng/m ³)	Predicted air quality after additional investment for 2010 (ng/m ³)
A, Belgium	<p>The site has two copper refineries (CTM and Hydro mill) and a nickel sulphate facility.</p> <p>The CTM refinery uses blister copper and copper scraps as raw material which is loaded in bulk in the shaft of the furnace using a conveyor. The Hydro mill uses a by-product with 75% copper and arsenic which is handled using a crane and a closed conveyor. The nickel sulphate production facility purifies raw nickel sulphate</p>	<p>PROCESS: There are bag filters on the CTM and Hydro mill and there is a cyclone and a scrubber on the nickel sulphate production facility</p> <p>FUGITIVE: None</p>	No information provided	No data	Optimisation of gas cleaning equipment to reduce emission levels. A 20% reduction has been assumed.	10	<p>As <10</p> <p>Cd No data available</p> <p>Ni <30</p> <p>Hg</p>	(Assume a 20% reduction of BAU2010 values)
B, Nordic	<p>The site consists of a copper and nickel smelter.</p> <p>Concentrates, residues and scrap are used as raw materials in the smelters and nickel mattes and salts are used in the refinery.</p>	<p>PROCESS: Fumes from the slag and matte launders are collected in hoods and and filtered in a bag house.</p> <p>FUGITIVE: Bagfilters</p>	None	None	Bagfilters for smelter fugitive gases.	18	<p>As 11 - 20</p> <p>Cd 0.7 - 1</p> <p>Ni 10 - 21</p> <p>Hg</p>	<p>As 5</p> <p>Cd 0.5</p> <p>Ni 10</p> <p>Hg</p>

Site	Process description	Existing air abatement techniques	Investment plans to comply with existing legislation	Capital cost (€m)	Strategy for compliance with proposed limit values	Capital cost (€m)	Business as usual air quality values for 2010 (ng/m ³)	Predicted air quality after additional investment for 2010 (ng/m ³)
C, Spain	<p>The process uses copper concentrates as a raw material which are handled using silos and close conveyor belts with bag houses in the transfers.</p> <p>A flash furnace is used for smelting and Pierce Smith Converters are used for converting. Anode furnaces and a copper electrolytic refinery are also in use.</p>	<p>PROCESS: Baghouse, electrostatic precipitators and scrubbers</p> <p>FUGITIVE: Bag house</p>	Study currently being undertaken	No data	Study currently being undertaken	No data	<p>As No data available</p> <p>Cd No data available</p> <p>Ni No data available</p> <p>Hg</p>	<p>As 50</p> <p>Cd 25</p> <p>Ni 50-100</p> <p>Hg</p> <p>(Predicted values based on a study)</p>
D, Germany	The plant was founded in 1866 and has been operating from its current location since 1910. The flash smelter, electric furnace for secondary material and the Contimelt began operation in 1972, 1991 and 1980 respectively.	<p>PROCESS: Baghouse, electrostatic precipitators, scrubbers and coolers, double absorption acid plant.</p> <p>FUGITIVE: Secondary hood systems, baghouses, scrubber, acid plant (partly)</p>	<p>Continuous improvement projects annually. Over the past ten years the average operating costs for environmental protection were approximately 50 m Euros per annum</p> <p>The plant complies with BAT and lead imission limits are met</p>	2-3 per annum	<p>Improvement of secondary hoods on the second smelter would be required, together with further covered storage facilities.</p> <p>It is not thought feasible to reduce As and Cd to below 10ng/m³ and the only possibility at present would be to shut down the smelter.</p>	10-15 (for secondary hoods, additional for covered storage facilities - can be extremely high)	<p>As 5 - 16</p> <p>Cd 1.3 - 14.2</p> <p>Ni No data available</p> <p>Hg</p>	<p>As ~10</p> <p>Cd ~10</p> <p>Ni No data available</p> <p>Hg</p>

Site	Process description	Existing air abatement techniques	Investment plans to comply with existing legislation	Capital cost (€m)	Strategy for compliance with proposed limit values	Capital cost (€m)	Business as usual air quality values for 2010 (ng/m ³)	Predicted air quality after additional investment for 2010 (ng/m ³)
F, Germany	<p>There are various furnaces on site, all with different years of start-up. The latest technical improvements were made during 1992-1995.</p> <p>Raw materials include copper, copper alloy scrap, slags, drosses and other secondary raw materials. They are handled using trucks, excavators, front-end loaders and ladles. Storage is partially open (for coarse materials and scrap) and partially in halls and silos.</p> <p>The main process involves three blast furnaces, two converter furnaces, one holding furnace and downstream from the main process there are two reverberatory anode furnaces for tin lead alloy.</p>	<p>PROCESS: Bag filter units for each furnace.</p> <p>FUGITIVE: Hoods and ventilation systems at different points e.g. charging, tapping etc. Special enclosures for converter furnaces.</p>	<p>The following improvements are planned for 2002. Replacement of all blast furnaces and converter furnaces by Isamelt furnaces; replacement of tin lead alloy reverb by drum tyoe furnace.</p> <p>It is anticipated that these improvements will save operating costs and will result in a significant reduction in emissions.</p>	36	The improvements already planned will need to be considered before additional measures are taken.		No data available	No data available

6.2.6 Costs and Benefits of Complying with Potential Limit Values

Site B, Nordic

Site B has had the current 1999 emission data modelled to produce a dispersion model that has been checked against the measured ambient air quality values. Any planned plant modifications to comply with existing legislation have been fed into the model to produce the 2010 business as usual (BAU) scenario. Potential modifications beyond the 2010 BAU scenario to comply with the proposed limit values have been fed in to produce the 2010 compliance scenario.

Business as usual 2010

Based on business (BAU) as usual performance, the following table summarises the limit values which would be expected to be complied with in the vicinity of the site (beyond 1100m from the site).

Pollutant	Limit values to consider (ng/m ³)	Expected compliance? (Y/N)
Arsenic	20	Y
	13	N
	5	N
	4	N
	1	N
Cadmium	15	Y
	5	Y
	0.5	N
Nickel	50	Y
	30	Y
	10	N
	3	N

Limit value compliance 2010

The site's strategy for compliance with the proposed limit values would be to install bagfilters for smelter fugitive gases at a cost of €m 18. This is expected to have the following impact:

- As 20 → 5;
- Ni 21 → 10;
- Cd 1 → 0.5.

This is the only compliance technique suggested and therefore there is one set of associated benefits for trying to comply with proposed limit values.

The following table summarises the limit values which would be expected to be complied with in the vicinity of the site (beyond 1100m from the site) taking into consideration the site's strategy for compliance.

Pollutant	Limit values to consider (ng/m ³)	Expected compliance? (Y/N)
Arsenic	20	Y
	13	Y
	5	Y
	4	N
	1	N
Cadmium	15	Y
	5	Y
	0.5	Y
Nickel	50	Y
	30	Y
	10	Y
	3	N

The summarised benefits for implementing the compliance strategy at this site are detailed in the following table:

Table 6.10 Health Benefits from Implementing Compliance Strategy at Site B

Pollutant	Current Emission Rates (kg pa)	Av reduction in conc ⁿ in area of interest due to compliance techniques (ng/m ³) (Note 2)	Radius of area of interest (m) (Note 3)	Distance of nearest housing (m)	Population within area of interest (Note 4)	Reduction in cancers per annum (Note 5)	Valuation of reduction in cancers (€m per annum) (Note 7)
As	1751 (Process)	5.8	10,000	1,000	150,000	0.019	See total
	1800 (Fugitive)						
Cd	359 (Process)	1.1	10,000	1,000	150,000	4.2x10 ⁻³	See total
	270 (Fugitive)						
Ni	792 (Process)	Negligible due to reductions at copper smelter	10,000	1,000	150,000	Negligible for reductions at copper smelter	See total
	800 (Fugitive) (Note 6)						
As, Cd and Ni			10,000	1,000	150,000	0.023	0.021 (low est) 0.041 (best est) 0.10 (high est)

Notes

1. Quantified health effect benefits for the metals of interest predominantly relate to carcinogenic effects only as information on ambient concentrations in the vicinity of sites in this sector suggests that the non carcinogenic effect critical concentrations are likely to be exceeded in only isolated cases (See Section 10.1.2).
2. Assuming an overall 50% reduction in ambient concentrations of arsenic, nickel and cadmium from 2010BAU levels to 2010 compliance levels.
3. In general, elevated ambient concentrations due to industrial sources reduce to near background levels a few kilometers from the site. 10km has been selected to define the area of interest to ensure that good coverage is achieved of the most significant areas likely to experience benefits. Choosing a larger area is not expected to significantly impact on the results because the larger population would be counter-acted by a smaller average reduction in concentration across that population.
4. This is intended to be a generic population density suitable for scaling across the sector. Based on the average population of 150,000 within a radius of 10km for 7 non-ferrous metals sites.
5. These figures are based on unit risks of 1.5×10^{-3} for arsenic and 1.8×10^{-3} for cadmium.
6. The majority of nickel emissions are due to the adjacent nickel smelter.
7. See Section 10.2 for details of the valuation methodology

Overall

Analysis of the available data for sites within the copper sub-sector indicates considerable variability in the average area concentrations for the BAU2010 case. In some cases site data is limited or no data is available. However, an interpretation of the results is provided below:

Arsenic

For arsenic, two of the four sites for which data is available (sites B and D) are expected to demonstrate compliance with the limit value of 20 ng/m^3 for the BAU2010 case. Of the remaining two sites, site A is expected to demonstrate compliance with the limit value of 13 ng/m^3 for the BAU2010 case. Site E is not expected to demonstrate compliance even with the upper limit value of 20 ng/m^3 for the BAU2010 case.

The potential reduction in concentrations due to compliance strategies indicates that of the four sites for which data is available, three are expected to demonstrate compliance with the limit value of 13 ng/m^3 . The step change to 5 ng/m^3 is not likely to be achievable for all sites, even when the compliance case is considered. Limit values of 5 ng/m^3 or below are therefore not realistic.

One of the sites (site C) is currently undertaking a study to determine the feasibility of achieving a limit value in its strategy for compliance of 50 ng/m^3 for arsenic. No ambient data is currently available for this site, hence an assessment of compliance with the potential limit values is not possible.

Cadmium

For cadmium, of the three sites for which data is available (sites B, D and E), site B is expected to demonstrate compliance with the limit value of 5 ng/m^3 for the BAU2010 case, and site D is expected to demonstrate compliance with the limit value of 15 ng/m^3 for the BAU2010 case.

Site E is not expected to demonstrate compliance even with the upper limit value of 15 ng/m³ for the BAU2010 case.

The potential reduction in concentrations due to compliance strategies indicates that of the sites for which data is available (sites B and D), site B is expected to demonstrate compliance with the limit value of 0.5 ng/m³, and site D is expected to demonstrate compliance with the limit value of 15 ng/m³. The step change to 5 ng/m³ is not likely to be achievable for all sites, even when the compliance case is considered. Limit values of 5 ng/m³ or below are therefore not realistic.

One of the sites (site C) is currently undertaking a study to determine the feasibility of achieving a limit value in its strategy for compliance of 25 ng/m³ for cadmium. No ambient data is currently available for this site, hence an assessment of compliance with the potential limit values is not possible.

Nickel

For nickel, of the sites for which data is available (sites A and B), sites A is expected to demonstrate compliance with the limit value of 30 ng/m³ for the BAU2010 case, and site B is also expected to demonstrate compliance with the limit value of 30 ng/m³ for the BAU2010 case.

The potential reduction in concentrations due to compliance strategies indicates that of the two sites for which data is available, site A is expected to demonstrate compliance with the limit value of 30 ng/m³, and site B is expected to demonstrate compliance with the limit value of 10 ng/m³. The compliance strategy would, however, result in a marked improvement compared to the average area concentrations for the BAU2010 case, although the step change to 10 ng/m³ is not likely to be achievable for all sites, even when the compliance case is considered. Limit values of 10 ng/m³ or below are therefore not realistic.

One of the sites (site C) is currently undertaking a study to determine the feasibility of achieving a limit value in its strategy for compliance of 50 - 100 ng/m³ for nickel. No ambient data is currently available for this site, hence an assessment of compliance with the potential limit values is not possible.

In the context of the potential limit values, further consultation and investigation should take place with site E and site C.

The variation in air quality between the sites within the sub-sector is a function of the following:

- The relative age of the site installation;
- The relative contribution of fugitive emissions compared to direct emissions;
- The background concentrations of the three pollutants.

Determination of the cost of compliance is feasible, based on implementation of various strategies. However, the actual emissions performance of a site can only be predicted. On this basis an initial scale up of costs across the copper production sector to comply with limits of 13 ng/m³ for As, an improvement towards 5 ng/m³ for Cd where possible, and an improvement towards 10 ng/m³ for Ni where possible based on averaged cost data for Sites A, B and D across a total of 9 sites in the sector is:

Capital costs for sector:

€m 122 (€m 9.5 pa @2% DR, €m 10.9 pa @4% DR, €m 12.5 pa @ 6% DR)

Operating costs for sector:

€m 6.1 pa (assumed as 5% of capital costs)

Total costs for sector:

€m 15.5 pa (2%DR), €m 17.0 pa (4% DR), €m 18.6 pa (6% DR)

Taking into account the benefits that could be quantified for site B, an indication of the overall costs and benefits is given in Table 6.11.

Table 6.11 Costs and Health Benefits for Copper Production

Compliance technique to meet 13ng/m ³ As, 5ng/m ³ Cd (where possible) and 10 ng/m ³ Ni (where possible)	Number of sites expected to adopt additional measures	Total costs (€m per annum) (Note 1)	Reduction in cancers per site due to As, Cd and Ni (per annum)	Total reduction in cancers due to As, Cd and Ni (per annum)	Valuation of reduction in cancers due to As, Cd and Ni (€m per annum)
Covered storage, extraction and abatement	9	16 (@2%DR)	0.023	0.21	0.19 (low est)
		17 (@ 4%DR)			0.37 (best est)
		19 (@ 6%DR)			0.90 (high est)

Note

- Capital costs are based on the average costs for Sites A, B and D and multiplied across the sector; Operating costs assumed to be 5% of capital costs;

Whilst the above table shows that the costs outweigh the specific quantifiable benefits of the reduction in cancers due to As, Cd and Ni exposure there will be other important secondary benefits of the heavy metal air quality limit values. The benefits due to these other effects will clearly improve the balance towards the benefits, although by how much is not possible to fully quantify with the currently available information. These additional benefits include:

- Reduced adverse health effects due to reductions in exposure to other metals;
- Reduced mortality and morbidity effects due to reductions in exposure to PM₁₀;
- Reduced adverse impacts on ecosystems and crops; and
- Reduced occupational exposure to carcinogenic metal pollutants.

Note that for some sites (site C, for example) compliance with the proposed limit values is not expected to be achieved.

6.3 Primary Nickel and Nickel Alloy Production

6.3.1 Profile of Sub-sector

The world's primary nickel production in 1996 was approximately 950,000 tonnes and the production capacity is approximately 1,200,000 tonnes. In Europe the production capacity is approximately 200,000 tonnes and the consumption is approximately 330,000 tonnes, therefore Ni is imported. World-wide demand for nickel is expected to remain strong. Table 6.12 summarises European nickel production.

Table 6.12 Summary of European production sites

Producer	Source of raw material	Production capacity tpa Ni	By products
Outokumpu, Finland	Finland, Norway and Australia	36,000	Cu, Co, sulphuric acid
Eramet, France	New Caledonia	16,000	Cobalt chloride, ferric chloride
Falconbridge, Norway	Canada and Botswana	85,000	Cu, Co, sulphuric acid
INCO, UK	Canada	41,000 (Ni powder and pellets)	Nickel sulphate
Treibacher, Austria	Secondary	4,000	FeNi is produced
Larco, Greece	Greece	20,000	FeNi is produced
Total		202,000	

The actual production in total from the above sites was 167,900 tonnes for 1996 compared to 144,800 tonnes for 1994.

Nickel alloy production from secondary materials includes raw materials preparation, melting (including tapping and casting), ingot stripping and dressing, scrap recycling and "electroslag refining" with a throughput of about 7,000 tpa.

Raw materials for the process consist of recycled scrap, purchased scrap and virgin material. Air melting is carried out in an induction furnace, with fume captured by one of two extraction systems fitted with bag filters. Some of the air-melted metal is further refined in vacuum refining furnaces. This is followed by casting.

6.3.2 Emission Sources

Primary nickel is produced from oxidic (limonite and saprolite) or sulphidic ore, about 60% of the nickel comes from sulphide deposits and 40% from oxide deposits. There are several variations in the processes used to produce nickel from these ores and these variations are dependent on the grade of the concentrate and also on the other metals that are present in the material.

Primary nickel metal can be produced from both oxidic ores and sulphidic ores. Typically the primary nickel produced from oxidic ore is in the form of ferronickel.

The major use for nickel in both forms is the production of stainless steel, which accounts for more than 60% of the total use (see Chapter 5). Other uses comprise a wide range of several types of steel alloys including castings and non-ferrous alloys such as monel and inconel. The nickel alloy sector has very low emissions and uses very clean technology so has not been included within this study.

In Europe, there are essentially six different nickel producers each using different techniques, different raw materials or producing different products. There are two nickel producers in the EU that use nickel ore as the raw material, one using oxidic ore to produce ferronickel and the other using sulphidic ore after concentration producing metallic nickel.

There is one smelter in the EU which uses sulphidic nickel concentrate and roasting, smelting and converting are done in the same unit to minimise sources of emissions. In this system, no ladles are used in the smelting of nickel concentrates to the matte, because the matte granulation feed to refinery is just outside the furnace. All tapping points are ventilated and the gases are cleaned in bag filters. The furnace itself is closed. There is one ferrochrome producer in the EU using oxidic ore as feed, this process consists of an electric furnace and a converter as separate units. This may create some fugitive emissions, mainly dust from the ore, but its nickel content is very low because the ore nickel content is around 1%.

Emissions do occur during smelting processes. However, to minimise both direct and fugitive emissions, one smelter in the EU employs a one unit smelting technique, collecting and cleaning ventilation gases, collecting process gases with dust and removing dust from sulphur dioxide gas. The dust is recycled back into the smelting unit by a closed pneumatic system. If ventilation gases are not collected and treated, fugitive emissions occur and can be significant in primary smelting.

Leaching and purification includes grinding which can be wet or dry. In the case of wet grinding there are very low emissions and hardly any fugitives because the matte is granulated into water and remains in the wet form when it is fed to wet grinding. Refining processes are reported to have lower fugitive emissions.

One unique nickel refining process is the carbonyl process, which produces primary electrolytic nickel in the form of pellets or powder from sulphidic ores and primary nickel as ferro-nickel from oxidic ores. Nickel oxide is first reduced with hydrogen in kilns and then refined by the carbonyl process. This process has to be particularly well sealed and therefore the process has hardly any direct or fugitive emissions, however powder production can produce fugitive emissions.

Nickel in the form of ferro-nickel is produced at one company in the EU from secondary nickel consumed directly as remelted scrap and other recycled products but this not a typical plant.

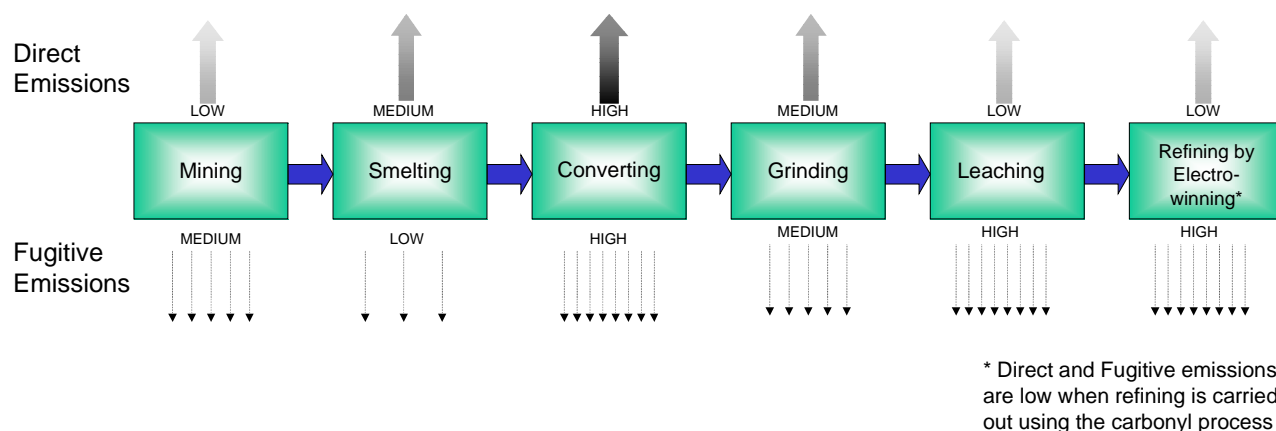
The major fugitive emission sources are:

- dust from storage and handling of concentrates;
- leakage from smelters and converters;
- dust from the exhaust gases of leaching and purification vessels;
- dust from the exhaust gases of casting furnaces; and
- miscellaneous sources including building ventilation air.

Unloading and storage of raw materials can generate dust when the material falls from one conveyor to another, depending on its moisture content. If a front-end loader is used dusting is seen during the transport distance.

The dust that is produced by the smelting process is collected by hoods or in case of a closed furnace by precipitators (e.g. by a fabric filter or a wet scrubber) after the hot dust collector. Tapping off-gas consists of fumes from all exposed metal and slag surfaces. These fumes that arise from tapping will mainly be oxides of the metals involved in the smelting process. Bag filters and wet scrubbers are normally used for cleaning these ventilation gases.

The main process steps are summarised below and the relative importance of emissions from each step indicated as low, medium and high. The relative significance of the emissions relates to the process described and serves to indicate which process stages have the highest comparative emissions.



6.3.3 Current Air Quality Data

Tables 6.13 to 6.16 summarise the available ambient air quality data for arsenic, cadmium, nickel and mercury for the nickel production sector.

Table 6.13 Current Air Quality Data for Arsenic

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
Nordic	11	1999	B	1100 m from main copper-nickel smelter ventilation gases stack	1751	Consultation with site
UK	1.5	1999/00	G	Nearest sensitive receptor where max concs occur -1100m from the main stack of the nickel refinery	No data available	Preliminary results for 9 months of a 12 month project.

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality

Table 6.14 Current Air Quality Data for Cadmium

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
Nordic	0.7	1999	B	1100 m from main copper-nickel smelter ventilation gases stack	359	Consultation with site
UK	0.3	1999/00	G	Nearest sensitive receptor where max concs occur -1100m from the main stack of the nickel refinery	No data available	Preliminary results for the first 9 months of a 12 month project.

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality

Table 6.15 Current Air Quality Data for Nickel

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
Nordic	10	1999	B	1100 m from main copper-nickel smelter ventilation gases stack	792	Consultation with site
UK	16	1999/00	G	Nearest sensitive receptor where max concs occur - 1100m from the main stack of the nickel refinery	1374	Preliminary air quality results for the first 9 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality

Table 6.16 Current Air Quality Data for Mercury

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
UK	0.4	1999/00	G	Nearest sensitive receptor where max concs occur - 1100m from the main stack of the nickel refinery		Preliminary air quality results for the first 9 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality

6.3.4 Emission Reduction Techniques

Table 6.17 summarises techniques for dealing with emissions from various process stages of nickel production operating to the standard of BAT.

Table 6.17 Summary of the Reduction Techniques for Nickel Production

Process stage	Technique	Details of technique	Reduction efficiency
Material handling and storage	Correct storage, handling and transfer. Dust collection and fabric filter if necessary.		
Grinding, drying	Process operation. Gas collection and fabric filter.		
Smelting and converting. (Sulphidic ore)	Gas collection, gas cleaning.	Hot electrostatic precipitators would be used in a gas cleaning system prior to a sulphuric acid plant.	

Process stage	Technique	Details of technique	Reduction efficiency
Slag treatment, Thermal refining and Melting and casting	Gas collection, cooling and fabric filter	<p>Dust arrestment using a fabric filter may require the removal of hot particles to prevent fires.</p> <p>Membrane fabric filter provided the operating temperature is correct and the characteristics of the gas and dust are taken into account in the design.</p> <p>The design of the hooding system needs to take account of access for charging and other furnace operations and the way the source of process gases change during the process cycle.</p>	<p>High performance fabric filters can achieve low levels of heavy metals.</p> <p>The concentration of heavy metals is linked to the concentration of dust and content of the metals in the dust. The BREF note does not detail specific achievable concentrations for all metals emitted to air as it states that the issue is site specific</p>

Emissions to air comprise the captured/abated emissions from the various sources, plus the fugitive or uncaptured emissions from these sources. Modern, well operated abatement systems result in efficient removal of pollutants and current information indicates that the fugitive emissions can be the largest contributor to the total emissions to air.

The abatement efficiency and approximate costs for various BAT are summarised in Table 6.8 in Section 6.2.4. They are based on data for copper industry but provide an indicative guide for nickel production processes.

6.3.5 Future Air Quality Under the Business as Usual Scenario

Table 6.18 summarises the investment plans sites have for complying with existing legislation and investment for complying with the proposed limit values. The sites forecast of 2010 business as usual (BAU) ambient air quality values and predicted air quality after additional investment beyond BAU investment for 2010 are also included. These values are estimates of what the ambient air quality will be at the location of the current ambient monitoring station based on 1999 ambient monitoring data and are a guide. More detailed modelling results have been used for the cost benefit analysis and these are presented in section 6.3.6.

Table 6.18 Predicted Future Ambient Air Quality Values by Sites for Business as Usual Scenario and After Implementing a Limit Value Compliance Strategy

Site	Process description	Existing air abatement techniques	Investment plans to comply with existing legislation	Capital cost (€m)	Strategy for compliance with proposed limit values	Capital cost (€m)	Business as usual air quality values for 2010 (ng/m ³)	Predicted air quality after additional investment for 2010 (ng/m ³)
G, UK	<p>Raw materials used are nickel oxide, nickel sulphate and natural gas. They are handled using containerised storage, bulk off-loading, total process enclosure, through gas lock valves and nickel powder packing with LEV.</p> <p>Nickel carbonyl refining is carried out. Kilns are totally enclosed to produce nickel carbonyl gas.</p>	<p>PROCESS: Incinerator, 3 field ESP</p> <p>FUGITIVE: LEV for nickel powder handling</p>	A feasibility study is underway to assess the atmospheric impacts of process and other local inputs for air quality in the vicinity.		Unknown until the feasibility study is complete although 3ng/m ³ for Ni is thought to be well beyond BAT limits for the site.	10	<p>As 1.5</p> <p>Cd 0.3</p> <p>Ni 16</p> <p>Hg 0.4</p>	<p>As</p> <p>Cd</p> <p>Ni 5</p> <p>Hg</p>
B, Nordic	<p>The site consists of a copper and nickel smelter.</p> <p>Concentrates, residues and scrap are used as raw materials in the smelters and nickel mattes and salts are used in the refinery.</p>	<p>PROCESS: Fumes from the slag and matte launders are collected in hoods and filtered in a bag house. Alkali is not used.</p> <p>FUGITIVE: Bagfilters</p>	None	None	Bagfilters for smelter fugitive gases.	18	<p>As 11 - 20</p> <p>Cd 0.7 - 1</p> <p>Ni 10 - 21</p> <p>Hg</p>	<p>As 5</p> <p>Cd 0.5</p> <p>Ni 10</p> <p>Hg</p>

6.3.6 Costs and Benefits of Complying with Potential Limit Values

Two sites have had the current 1999 emission data modelled to produce a dispersion model that has been checked against the measured ambient air quality values. Any planned plant modifications to comply with existing legislation have been fed into the model to produce the 2010 business as usual (BAU) scenario. Potential modifications beyond the 2010 BAU scenario to comply with the proposed limit values have been fed in to produce the 2010 compliance scenario. In general, the sites tend to have only one set of improvements (if any) additional to BAU improvements for the compliance scenario.

Site G, UK

Business as usual 2010

Based on business as usual (BAU) performance, the following table summarises the limit values which would be expected to be complied with in the vicinity of the site (beyond 1100m from the site).

Pollutant	Limit values to consider (ng/m ³)	Expected compliance? (Y/N)
Arsenic	20	Y
	13	Y
	5	Y
	4	Y
	1	N
Cadmium	15	Y
	5	Y
	0.5	Y
Nickel	50	Y
	30	Y
	10	N
	3	N

Limit value compliance 2010

The site's strategy for compliance with the proposed limit values would be developed following a feasibility study to assess the atmospheric impacts of process and other local contributors to air quality in the site vicinity. The outcome from this study will be used to evaluate the extent to which reducing the nickel refinery emissions could reduce ambient air quality levels of As, Cd and Ni. The site thinks that 3 ng/m³ is well beyond BAT limits for them. As site G uses the carbonyl process it is largely enclosed and it has relatively low fugitive emissions compared to other nickel production techniques. The estimated capital cost is €m 10 (Entec estimate based on Eurometaux capital cost data for gas cleaning techniques) with associated marginal operating costs of approximately €m 0.5 per annum (Entec estimate). This emission reduction reduces the ambient air values around the site from the business as usual scenario but does not achieve the next nickel limit value of 3ng/m³.

The following table summarises the limit values which would be expected to be complied with in the vicinity of the site (beyond 1100m from the site) taking into consideration the site's strategy for compliance.

Pollutant	Limit values to consider (ng/m ³)	Expected compliance? (Y/N)
Arsenic	20	Y
	13	Y
	5	Y
	4	Y
	1	N
Cadmium	15	Y
	5	Y
	0.5	Y
Nickel	50	Y
	30	Y
	10	Y
	3	N

The summarised benefits for implementing the compliance strategy at this site to reduce nickel emissions are detailed Table 6.19 (Arsenic and cadmium not included due to relatively small reductions compared to nickel).

Table 6.19 Health Benefits from Implementing Compliance Strategy at Site G

Pollutant	Current Emission Rates (kg pa)	Av reduction in conc ⁿ in area of interest due to compliance techniques (ng/m ³) (Note 2)	Radius of area of interest (m) (Note 3)	Distance of nearest housing (m)	Population within area of interest (Note 4)	Reduction in cancers per annum (Note 5)	Valuation of reduction in cancers (€m per annum) (Note 6)
Ni	1374	7.4	10,000	500	150,000	1.6x10 ⁻³ to 6.0x10 ⁻³	1.4x10 ⁻³ to 5.4x10 ⁻³ (low est) 2.9x10 ⁻³ to 0.011(best est) 7.0x10 ⁻³ to 0.026 (high est)

Notes

1. Quantified health effect benefits for the metals of interest relate to carcinogenic effects only as information on ambient concentrations in the vicinity of sites in this sector suggests that the non carcinogenic effect critical concentrations are not exceeded (See Section 10.1.2).
2. Assuming an overall reduction in ambient nickel concentrations from 16ng/m³ to 5ng/m³ from 2010BAU levels to 2010 compliance levels.
3. In general, elevated ambient concentrations due to industrial sources reduce to near background levels a few kilometers from the site. 10km has been selected to define the area of interest to ensure that good coverage is achieved of the most significant areas likely to experience benefits. Choosing a larger area is not expected to significantly impact on the results because the larger population would be counter-acted by a smaller average reduction in concentration across that population.
4. This is intended to be a generic population density suitable for scaling across the sector. Based on the average population of 150,000 within a radius of 10km for 7 non-ferrous metals sites.
5. These figures are based on unit risk factors for nickel of between $1 \times 10^{-4} (\mu\text{g}\cdot\text{m}^{-3})^{-1}$ (which is applicable to general exposure to nickel, not including exposure to nickel sub-sulphide which is only relevant to certain nickel processes) and 3.8×10^{-4} which is applicable to nickel refinery workers.
6. See Section 10.2 for details of the valuation methodology.

Site B, Nordic

Business as usual 2010

Due to this site having both copper and nickel smelting activities certain emission streams, eg stack for ventilation gases from both processes, are difficult to apportion specifically to one of the sites. The copper smelter is the dominant contributor to elevated arsenic and cadmium concentrations as considered in Section 6.2 (which takes into account modelling results). The nickel smelter is considered to contribute to ambient nickel concentrations in a similar ballpark to site G (10ng/m³ and 16ng/m³ respectively). Therefore the results for Site G have been used in scaling up potential benefits for this sector.

Overall

Analysis of the available data for sites within the nickel sub-sector indicates some variability in the average area concentrations for the BAU2010 case. An interpretation of the results is provided below:

Arsenic

For arsenic, of the two sites considered within the sub-sector (sites B and G), site B is expected to demonstrate compliance with the limit value of 20 ng/m³ for the BAU2010 case, and site G is expected to demonstrate compliance with the limit value of 4 ng/m³ for the BAU2010 case.

The potential reduction in concentrations due to compliance strategies indicates that of the two sites considered within the sub-sector (sites B and G), site B is expected to demonstrate compliance with the limit value of 4 ng/m³, and site G is expected to demonstrate compliance with the limit value of 5 ng/m³. The step change to 4 ng/m³ is not likely to be achievable for all sites, even when the compliance case is considered. Limit values of 4 ng/m³ or below are therefore not realistic.

Cadmium

For cadmium, of the two sites, site B is expected to demonstrate compliance with the limit value of 5 ng/m³ for the BAU2010 case, and site G is expected to demonstrate compliance with the limit value of 0.5 ng/m³ for the BAU2010 case.

The potential reduction in concentrations due to compliance strategies indicates that of the two sites, both sites are expected to demonstrate compliance with the limit value of 0.5 ng/m³.

Nickel

For nickel, of the two sites, site B is expected to demonstrate compliance with the limit value of 30 ng/m³ for the BAU2010 case, and site G is also expected to demonstrate compliance with the limit value of 30 ng/m³ for the BAU2010 case.

The potential reduction in concentrations due to compliance strategies indicates that of the two sites, both sites are expected to demonstrate compliance with the limit value of 10 ng/m³. The compliance strategy would result in a marked improvement compared to the average area concentrations for the BAU2010 case, although the step change to 3 ng/m³ is not likely to be achievable for all sites, even when the compliance case is considered. Limit values of 3 ng/m³ or below are therefore not realistic.

The variation in air quality between the sites within the sub-sector is a function of the the following:

- The relative age of the site installation;
- The relative contribution of fugitive emissions compared to direct emissions;
- The background concentrations of the three pollutants.

Determination of the cost of compliance is feasible, based on implementation of various strategies. However, the actual emissions performance of a site can only be predicted. On this basis an initial scale up of costs across the nickel production sector to comply with limits of 5ng/m³ for As, 0.5ng/m³ for Cd, and 10ng/m³ for Ni, based on data for Site G and a total of 4 sites is:

Capital costs for sector:

€m 40 (€m 3.1 pa @2% DR, €m 3.6 pa @4% DR, €m 4.1 pa @ 6% DR) (assumed average compliance cost of €m 10 per site. Whilst there is a total of 5 sites in the sub-sector, the costs for site B have already been covered in the copper sub sector)

Operating costs for sector:

€m 2 pa (assumed as 5% of capital costs)

Total costs for sector:

€m 5.1 pa (2% DR), €m 5.6 pa (4% DR), €m 6.1 pa (6% DR)

Taking into account the benefits that could be quantified for site G, an indication of the overall costs and benefits is given in Table 6.20.

Table 6.20 Costs and Health Benefits for Nickel Production

Compliance technique to meet 5ng/m ³ As, 0.5ng/m ³ Cd (where possible) and 10ng/m ³ Ni	Number of sites expected to adopt additional measures	Total costs (€m per annum) (Note 1)	Reduction in cancers per site due to As, Cd and Ni (per annum)	Total reduction in cancers due to As, Cd and Ni (per annum)	Valuation of reduction in cancers due to As, Cd and Ni (€m per annum)
To be determined followed detailed investigations by the sites	4	5 (@2%DR)	1.6x10 ⁻³ to 6.0x10 ⁻³	6.4x10 ⁻³ to 0.024	5.6x10 ⁻³ to 0.022 (low est)
		6 (@ 4%DR)			0.012 to 0.044(best est)
		6 (@ 6%DR)			0.028 to 0.10 (high est)

Note

1. Capital costs are based on the cost for Site G multiplied across the sector; operating costs assumed to be 5% of capital costs;

Whilst the above table shows that the costs outweigh the specific quantifiable benefits of the reduction in cancers due to Ni exposure there will be other important secondary benefits of the heavy metal air quality limit values. The benefits due to these other effects will clearly improve the balance towards the benefits, although by how much is not possible to fully quantify with the currently available information. These additional benefits include:

- Reduced carcinogenic effects associated with exposure to arsenic and cadmium (although these are less significant relative to nickel for this sector);
- Reduced adverse health effects due to reductions in exposure to other metals;
- Reduced mortality and morbidity effects due to reductions in exposure to PM₁₀;
- Reduced adverse impacts on ecosystems and crops; and
- Reduced occupational exposure to carcinogenic metal pollutants.

6.4 Primary Zinc (and Cadmium) Production

6.4.1 Profile of Sub-sector

Zinc is produced from a range of zinc concentrates by pyrometallurgical or hydrometallurgical processes. Some concentrates contain high proportions of lead and these metals are also recovered. Zinc is also associated with cadmium and the concentrates are a source of this metal. Secondary raw materials such as galvanising residues (ashes, skinnings, sludges etc), flue dust from steel plants and brass processing and die-casting scrap are also sources of zinc. Metal production from secondary sources accounted for more than 8% of the total EU refined zinc output in 1994. The recycling of zinc and zinc containing products is a key issue for the industry.

Table 6.21 shows the location and capacities of the sites in Europe.

Table 6.21 Location and Capacities of European Zinc Production Sites (Source IPPC BREF note)

Country	Company	Location	Process	Capacity (tpa)
Belgium	Union Minière	Balen-Wezel	E	200,000
Germany	Ruhr-Zink	Datteln	E	96,000
	MIM Hüttenwerke Duisburg	Duisburg-Wanheim	ISF-RT	100,000
	Metaleurop Weser Zink	Nordenham	E	130,000
Spain	Asturiana de Zinc	Sun Juan de Nieva	E	320,000
	Española del Zinc	Cartagena	E	60,000
France	Union Minière France	Auby	E	220,000
	Metaleurop	Noyelles Godault	ISF-Rt	100,000
Finland	Outokumpu Zinc Oy	Kokkola	E	175,000
Italy	Glencore	Porte Vesme (Sardegna)	ISF-RT	75,000
		Porte Vesme (Sardegna)	E	100,000
	Pertusola Sud	Crotone	E	80,000
Netherlands	Budelco (Pasminco)	Budel-Dorplein	E	210,000
Norway	Norzink		E	140,000
UK	Britannia Zinc (MIM Holdings)	Avonmouth	ISF-RT	105,000

Notes

1. E = electrolytic plant
2. ISF = imperial smelting furnace
3. RT = fire refining

6.4.2 Emission Sources

Emissions can escape the process either as stack or as fugitive emissions depending on storage/stockpiling arrangements and the type of technology used. Stack emissions are normally monitored continuously or periodically and reported. The sources of emissions from the process are:

- roasting (most emissions occur during unscheduled shutdown) (significant);
- other pre-treatment (battery breaking) (significant);
- transport and handling of material;
- smelting and refining (significant);
- leaching and purification;
- electrolysis;

- casting (significant).

Besides process emissions, fugitive emissions occur. The major fugitive emission sources are:

- dust from storage and handling of concentrates plus handling of internal materials;
- leakage from roasters and smelters;
- dust from the exhaust gases of leaching and purification vessels;
- exhaust gases of cooling towers of the leaching and purification units;
- exhaust gases of cooling towers of the electrolysis process;
- dust from the exhaust gases of casting furnaces.

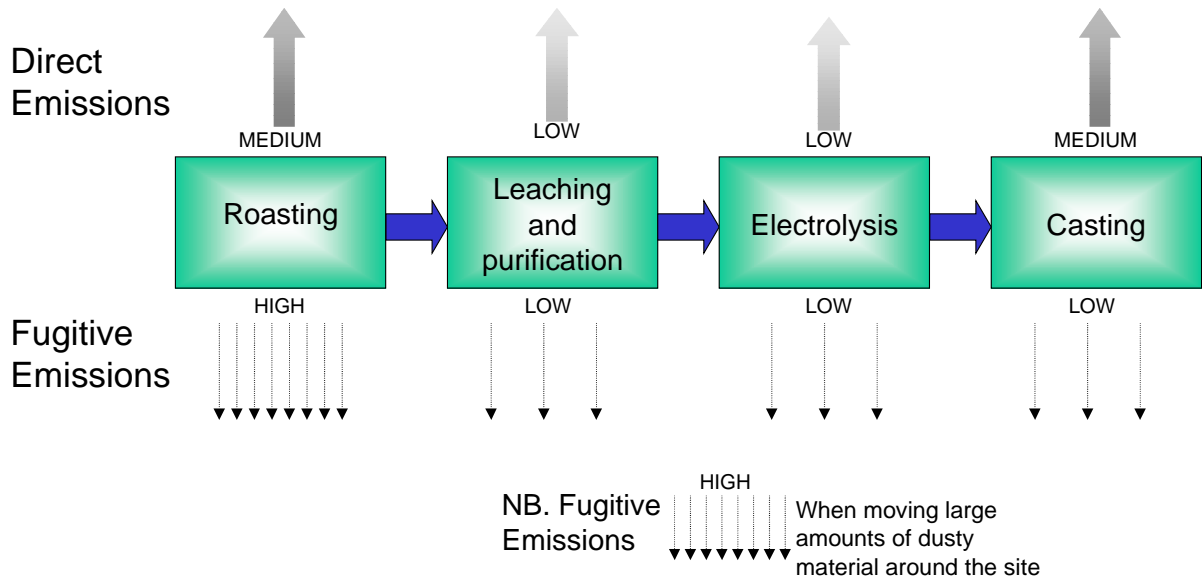
Dust carry over from the roasting and smelting processes are potential sources of direct and fugitive emissions of dust and metals. The gases are collected and treated in the gas cleaning processes of the sulphuric acid plant. Dust is removed and returned to the process.

The gases leaving splash condensers in the ISF, from distillation columns and from the tapping points are also potential sources. Good extraction and abatement is needed at these points to prevent fugitive emissions. Slag treatment and quenching also gives rise to dust. The range of dust emissions from these captured sources is <1 to $20\text{mg}/\text{Nm}^3$. De-aeration of vessels in the leaching and purification stages can emit dust and metals. Arsenic can be emitted from the purification stages of zinc. Cadmium can be emitted from the distillation stages and the cadmium plants.

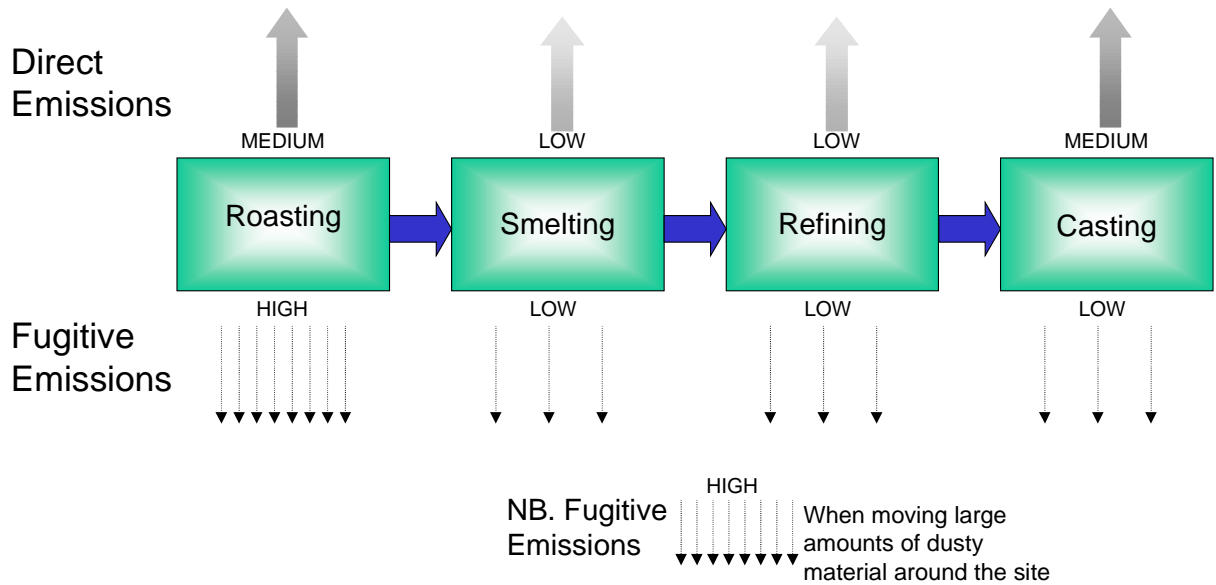
Emissions of aerosols take place in the cell room and battery breakers and can contain metals. The range of mist and dust emissions from these sources is 0.1 to $4\text{mg}/\text{Nm}^3$.

The melting, alloying, casting and zinc dust processes are potential sources of dust and metals. The range of dust emissions is reported to be 200 to $900\text{mg}/\text{Nm}^3$ in the crude gas. Fume collection and abatement systems are used and cleaned gas values are below $10\text{mg}/\text{m}^3$. Metals are associated with the dusts emitted, approximately 50% is zinc. Cadmium and lead are not present when pure zinc is melted, alloyed and cast.

The main process steps are summarised below and the relative importance of emissions from each step indicated as low, medium and high. The relative significance of the emissions relates to the process described and serves to indicate which process stages have the highest comparative metal emissions. The initial drawing summarises the process steps in hydrometallurgical production of zinc and cadmium.



Below is a summary block diagram for the pyrometallurgical production process.



6.4.3 Current Air Quality Data

Tables 6.22 to 6.25 summarise the available ambient air quality data for arsenic, cadmium, nickel and mercury for the zinc (and cadmium) production sector.

Table 6.22 Current Air Quality Data for Arsenic

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
Nordic	1.7	1993	K	1500m from zinc industry		Position paper
Nordic	1.2	1993	K	4000m from zinc industry		Position paper
Germany	9	1997	Datteln	Vicinity of Zinc smelter		Position paper
Germany	14.3	1998	Datteln	Vicinity of Zinc smelter		
UK	1.8	1999/00	L	Nearest sensitive receptor where max concs occur - 1300m downwind from the Britannia Zinc lead/zinc smelter		Preliminary results for the first 9 months of a 12 month project.
Germany	No data available	1999	M		1.7	Consultation with site

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality

Table 6.23 Current Air Quality Data for Cadmium

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
Nordic	0.2	1993	K	1500-4000m from zinc industry		Position paper
Germany	7.7	1998	Datteln	Vicinity of Zinc smelter		Position paper
UK	8	1999/00	L	Nearest sensitive receptor where max concs occur - 1300m downwind from the Britannia Zinc lead/zinc smelter	1252	Preliminary results for the first 9 months of a 12 month project.
Not specified	44	1996	Company 1	300m downwind of a hydrometallurgical zinc producer	54	Consultation with Eurometaux
Not specified	35	1996	Company 1	3000m downwind of a hydrometallurgical zinc producer	54	Consultation with Eurometaux

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
Not specified	78	1996	Company 2	600m downwind of a pyrometallurgical zinc producer	1683	Consultation with Eurometaux
Not specified	27	1996	Company 2	1200m downwind of a pyrometallurgical zinc producer	1683	Consultation with Eurometaux
Not specified	10	1996	Company 2	2400m downwind of a pyrometallurgical zinc producer	1683	Consultation with Eurometaux
Not specified	4	1994	Company 4	1000m from a hydrometallurgical zinc producer	3	Consultation with Eurometaux
Not specified	2.9	1994	Company 4	1500m from a hydrometallurgical zinc producer	3	Consultation with Eurometaux
Not specified	30	1996	Company 5	1200m SSE of a pyrometallurgical zinc producer	946	Consultation with Eurometaux
Not specified	30	1996	Company 5	1800m WSW of a pyrometallurgical zinc producer	946	Consultation with Eurometaux
Not specified	30	1996	Company 5	1400m ENE of a pyrometallurgical zinc producer	946	Consultation with Eurometaux
Not specified	1	1996	Company 6	2400m SW of a hydrometallurgical zinc producer	6 (all point sources)	Consultation with Eurometaux
Not specified	11	1996	Company 7	4000m S of a hydrometallurgical zinc producer	200 (all point sources)	Consultation with Eurometaux
Not specified	107	1996	Company 8	300m NE of a hydrometallurgical zinc producer	29	Consultation with Eurometaux
Not specified	0.2	1993	Company 9	2000m S of a hydrometallurgical zinc producer	110	Consultation with Eurometaux
Not specified	0.3	1993	Company 9	5000m SE of a hydrometallurgical zinc producer	110	Consultation with Eurometaux
Not specified	0.2	1993	Company 9	3900m SE of a hydrometallurgical zinc producer	110	Consultation with Eurometaux
Not specified	40	1996	Company 10	1000m SW from a hydrometallurgical zinc producer	3.3	Consultation with Eurometaux
Germany	No data available	1999	M		7.4	Consultation with site

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality.

Table 6.24 Current Air Quality Data for Nickel

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
UK	2.5	1999/00	L	Nearest sensitive receptor where max concs occur - 1300m downwind from the lead/zinc smelter	24	Preliminary air quality results for the first 9 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality.

Table 6.25 Current Air Quality Data for Mercury

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
UK	1.3	1999/00	L	Nearest sensitive receptor where max concs occur - 1300m downwind from the lead/zinc smelter		Preliminary air quality results for the first 9 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality.

6.4.4 Emission Reduction Techniques

The potentially dusty nature of concentrates and fluxes means that enclosed storage, handling and treatment systems may be needed in these instances. The dust generated by some crushing operations means that collection and abatement may be applicable. Enclosed conveyors or pneumatic transfer systems are used for dusty material. The drier and associated dust abatement stage depends on site-specific conditions such as the reliability of the steam supply. Fabric or ceramic filters achieve better dust removal efficiencies than ESPs when used at this stage of the process.

The abatement system to consider for primary smelting processes is dust removal and the removal of other metals followed by the recovery of sulphur dioxide. The gases are cooled (with heat/energy recovery) and cleaned before conversion. A combination of coolers and hot electrostatic precipitators or a combination of scrubbers (radial or jet) and wet ESPs are used. Mercury recovery systems are employed such as those described in Table 6.7 in Section 6.2.4. Steel belt, up-draught or fully enclosed down-draft sintering processes are techniques to be considered. Steel belt sintering has several advantages for certain metal groups and can minimise gas volumes, reduce fugitive emissions and recover heat.

For fume/gas collection and abatement, the use of secondary hoods is a technique to consider. The design of the hooding system needs to take account of access for charging and other furnace operations and the way the source of process gases change during the process cycle. This can be achieved by the use of a system of intelligent control to target fume emissions automatically as they occur during the cycle without the high-energy penalty of continuous operation.

The use of hoods for tapping and casting is also a technique to consider. Tapping fumes will consist mainly of oxides of the metals that are involved in the smelting process.

The fume collection systems used can exploit furnace-sealing systems and be designed to maintain a suitable furnace depression that avoids leaks and fugitive emissions. Examples are through hood additions of material, additions via tuyeres or lances and the use of rotary valves on feed systems.

Best Available Techniques for gas and fume treatment systems are those that use cooling and heat recovery if practical before a fabric filter except when carried out as part of the production of sulphuric acid.

BAT for dealing with heavy metal emissions and associated emission levels are summarised in Table 6.26.

Table 6.26 Summary of Emission Reduction Techniques for Zinc and Lead Production Plants

Process stage	Technique	Details of technique	Reduction efficiency
Raw materials handling	Correct storage Dust collection and fabric filter	The storage of fine dusts in enclosed buildings or in sealed packaging is used. Secondary raw materials that contain water-soluble components are stored under cover. The storage of non-dusty, non-soluble material (except batteries) in open stockpiles and large items individually in the open can be used. Fine dusts can be stored and handled in a manner that prevents the emission of dust. They are often blended and agglomerated to provide a consistent feed to the furnace. Secondary hoods Fabric filters that use modern high performance materials in a well-constructed and maintained structure	The metal content of the dust varies widely between processes. In addition for similar furnaces there are significant variations due to the use of varying raw materials. It is therefore not accurate to detail specific achievable concentrations for all metals emitted to air (BREF). Low concentrations of heavy metals are associated with the use of high performance, modern abatement systems such as a membrane fabric filter provided the operating temperature is correct and the characteristics of the gas and dust are taken into account in the design. The issue is therefore site specific.
Raw materials pre-treatment (mechanical de-coating /stripping) (thermal de-coating)	Correct pre-treatment Gas collection and fabric filter	Pre-treatment stages are often used to produce sinter or to remove casings or coatings and to separate other metals. Milling and grinding techniques are used with good dust extraction and abatement. The fine dust that is produced may be treated to recover other metals, pneumatic or other density separation techniques are used. Secondary hoods Fabric filters that use modern high performance materials in a well-constructed and maintained structure	
Primary roasting and smelting. Sintering	Process operation, gas collection, gas cleaning (dry and wet EP etc), cooling.	Sintering is used to prepare concentrates for some of the smelting processes - up draft and down draft sintering machines can be used and recent developments of a steel belt sintering process may be appropriate. Collection of fume and gases is important and the up draft sintering process is inherently easier for fume capture.	
ISF	Wet scrubbing (to cool gas) prior to use as LCV gas		
Secondary smelting	Process operation and gas collection, cooling and fabric filter.	Secondary hoods Fabric filters that use modern high performance materials in a well-constructed and maintained structure	
Chemical refining	Process operation and gas collection with oxidising scrubber		
Thermal refining	Process operation. Gas collection, cooling and fabric filter.	Secondary hoods Fabric filters that use modern high performance materials in a well-constructed and maintained structure	
Melting, alloying, casting and dust production	Process operation. Gas collection, cooling and fabric filter.	Secondary hoods Fabric filters that use modern high performance materials in a well-constructed and maintained structure	
Slag fuming and Waelz kiln processes	Process operation. Gas collection, cooling and fabric filter or wet EP if wet quenching is used.	Secondary hoods Fabric filters that use modern high performance materials in a well-constructed and maintained structure	

The abatement efficiency and approximate costs for various BAT are summarised in Table 6.8, Section 6.2.4. They are based on data for the copper industry but provide an indicative guide for zinc (including cadmium) and lead production processes.

6.4.5 Future Air Quality Under the Business as Usual Scenario

Table 6.27 summarises the investment plans sites have for complying with existing legislation and investment for complying with the proposed limit values. The sites forecast of 2010 business as usual (BAU) ambient air quality values and predicted air quality after additional investment beyond BAU investment for 2010 are also included. These values are estimates of what the ambient air quality will be at the location of the current ambient monitoring station based on 1999 ambient monitoring data and are a guide. More detailed modelling results have been used for the cost benefit analysis and these are presented in section 6.4.6.

Table 6.27 Predicted Future Ambient Air Quality for Business as Usual Scenario and after Implementing a Limit Value Compliance Strategy

Site	Process description	Existing air abatement techniques	Investment plans to comply with existing legislation	Capital cost (€m)	Strategy for compliance with proposed limit values	Capital cost (€m)	Business as usual air quality values for 2010 (ng/m ³)	Predicted air quality after additional investment for 2010 (ng/m ³)
Site I, Belgium	The site is a hydrometallurgical zinc production facility located in a rural area.	PROCESS: No data FUGITIVE: No data	None	None	Fugitive emissions are more significant than stack emissions (arising from materials handling, furnaces and wind dispersion from contaminated soils). Improvements in handling and road silo operation and a more robust furnace operation avoiding shutdowns would be likely to reduce fugitive emissions. The effect of soil remediation measures are thought not to be significant.	0.62	No data available	No data available
Site J, Unspecified	The site is a hydrometallurgical zinc production facility located near the sea and surrounded by mountains to the east and west.	PROCESS: No data FUGITIVE: No data	Ongoing work on the installation of mist/drop eliminators in the stacks from the leaching plant.				As No data available Cd 0.6 - 3.1 Ni No data available	As No data available Cd 0.6-3.1 Ni No data available

Site	Process description	Existing air abatement techniques	Investment plans to comply with existing legislation	Capital cost (€m)	Strategy for compliance with proposed limit values	Capital cost (€m)	Business as usual air quality values for 2010 (ng/m ³)	Predicted air quality after additional investment for 2010 (ng/m ³)
Site K, Nordic	The site is a hydrometallurgical zinc production facility located near the sea and near to a medium sized town.	PROCESS: No data FUGITIVE: No data	No additional measures needed				As 1.2 - 1.7 Cd 0.2 - 0.51 Ni No data available	As 1.2 - 1.7 Cd 0.2 - 0.51 Ni No data available
Site L, UK	The site is a hydrometallurgical zinc production facility located 1 km to the west of an estuary in a highly industrialised area.		Improvement plans are in place	50	To meet Cd levels of 5ng/m ³ would cost in the region of 33 m Euros. This cost is considered to be disproportionate to the environmental gain (particularly as the residential population is 1 km away)	33	As: 1.8 Cd: 8 Ni: 2.5	As: 1.2 Cd: 5 Ni: 1.5
Site M, Germany	The site consists of a zinc electrolytic plant which was built in 1973 and a lead plant which was rebuilt in 1996. Two plants are located on a site that has been used for metallurgical processes for more than 100 years. It is located on a large river, by the sea in Germany (flat terrain).	PROCESS: No data FUGITIVE: No data	No data		No data		No data available	As: Cd: <5 Ni: <3

6.4.6 Costs and Benefits of Complying with Potential Limit Values

Two sites have had the current 1999 emission data modelled to produce a dispersion model which has been checked against the measured ambient air quality values. Any planned plant modifications to comply with existing legislation have been fed into the model to produce the 2010 business as usual (BAU) scenario. Potential modifications beyond the 2010 BAU scenario to comply with the proposed limit values have been fed in to produce the 2010 compliance scenario. The sites tend to have only one set of improvements (if any) additional to BAU improvements for the compliance scenario.

Site M, Germany

The modelling of the 2010 BAU for Site M showed that they were already achieving their forecasted best achievable ambient air quality values. Therefore there would be no costs or benefits associated with the proposed limit values.

The cadmium limit of 0.5 ng/m³ is considered to be unachievable as it is the limit of the background, below any technical feasibility. The limit of 5 ng/m³ is likely to be achievable.

Site Q, France

Business as usual 2010

Based on business as usual (BAU) performance, the following table summarises the limit values which would be expected to be complied with in the vicinity of the site (beyond 750m from the site).

Pollutant	Limit values to consider (ng/m ³)	Expected compliance? (Y/N)
Arsenic	20	N
	13	N
	5	N
	4	N
	1	N
Cadmium	15	N
	5	N
	0.5	N
Nickel	50	No data available
	30	No data available
	10	No data available
	3	No data available

Limit value compliance 2010

Achieving Cd levels of 5 ng/m³ is considered to be unfeasible due to mining that has previously taken place in the area.

The following table summarises the limit values which would be expected to be complied with in the vicinity of the site taking into consideration the site's strategy for compliance.

Pollutant	Limit values to consider (ng/m ³)	Expected compliance? (Y/N)
Arsenic	20	No data available
	13	No data available
	5	No data available
	4	No data available
	1	No data available
Cadmium	15	Y
	5	N
	0.5	N
Nickel	50	No data available
	30	No data available
	10	No data available
	3	No data available

However, the wide range of ambient air quality measurements in the vicinity of this site means that the modelling results cannot be readily verified and hence a quantitative benefit analysis is not considered feasible for this site with the currently available information.

Site L, UK

Business as usual 2010

Based on business as usual (BAU) performance, the following table summarises the limit values which would be expected to be complied with in the vicinity of the site.

Pollutant	Limit values to consider (ng/m ³)	Expected compliance? (Y/N)
Arsenic	20	Y
	13	Y
	5	Y
	4	Y
	1	N
Cadmium	15	Y
	5	N
	0.5	N
Nickel	50	Y
	30	Y
	10	Y
	3	Y

Limit value compliance 2010

Achieving Cd levels of 5 ng/m³ is considered to be just achievable for this site, with significant investment.

The following table summarises the limit values which would be expected to be complied with in the vicinity of the site taking into consideration the site's strategy for compliance.

Pollutant	Limit values to consider (ng/m ³)	Expected compliance? (Y/N)
Arsenic	20	Y
	13	Y
	5	Y
	4	Y
	1	N
Cadmium	15	Y
	5	Y
	0.5	N
Nickel	50	Y
	30	Y
	10	Y
	3	Y

The summarised benefits for implementing the compliance strategy at this site to reduce cadmium emissions are detailed in the following table (in comparison to cadmium, arsenic and nickel emissions are not considered significant for this site). The concentration reduction estimates are based on the dispersion patterns modelled for Site B (including stack emissions plus fugitive emissions) adjusted to the relevant absolute measured concentrations applicable to Site L.

Table 6.28 Health Benefits for Implementing Compliance Strategy at Site L

Pollutant	Current Emission Rates (kg pa)	Av reduction in conc ⁿ in area of interest due to compliance techniques (ng/m ³) (Note 2)	Radius of area of interest (m) (Note 3)	Distance of nearest housing (m)	Population within area of interest (Note 4)	Reduction in cancers per annum (Note 5)	Valuation of reduction in cancers (€m per annum) (Note 7)
Cd	1252	3.5	10,000	1,300	150,000	0.014	0.013 (low est) 0.025 (best est) 0.062 (high est)

Notes

1. Quantified health effect benefits for the metals of interest predominantly relate to carcinogenic effects only as information on ambient concentrations in the vicinity of sites in this sector suggests that the non carcinogenic effect critical concentrations are likely to be exceeded in only isolated cases (See Section 10.1.2).
2. Assuming an overall reduction in ambient cadmium concentrations from 8ng/m^3 to 5ng/m^3 from 2010BAU levels to 2010 compliance levels.
3. In general, elevated ambient concentrations due to industrial sources reduce to near background levels a few kilometers from the site. 10km has been selected to define the area of interest to ensure that good coverage is achieved of the most significant areas likely to experience benefits. Choosing a larger area is not expected to significantly impact on the results because the larger population would be counter-acted by a smaller average reduction in concentration across that population.
4. This is intended to be a generic population density suitable for scaling across the sector. Based on the average population of 150,000 within a radius of 10km for 7 non-ferrous metals sites.
5. These figures are based on a unit risk factor for cadmium of 1.8×10^{-3} .
6. See Section 10.2 for details of the valuation methodology.

Overall

Analysis of the available data for sites within the zinc sub-sector indicates some variability in the average area concentrations for the BAU2010 case. An interpretation of the results is provided below:

Arsenic

For arsenic, of the two sites for which data is available (sites K and L), both sites are expected to demonstrate compliance with the limit value of 4ng/m^3 for the BAU2010 case.

The potential reduction in concentrations due to compliance strategies indicates that of the two sites for which data is available, both sites are expected to demonstrate compliance with the limit value of 4ng/m^3 . The step change to 1ng/m^3 is not likely to be achievable for all sites, even when the compliance case is considered. Limit values of 1ng/m^3 or below are therefore not realistic.

However data from Table 6.22 indicates that a site in Germany currently has much higher concentrations, although only marginal improvements would be needed to comply with 13ng/m^3 .

Cadmium

For cadmium, of the three sites for which data is available (sites J, K and L), sites J and K are expected to demonstrate compliance with the limit value of 5ng/m^3 for the BAU2010 case, and site L is expected to demonstrate compliance with the limit value of 15ng/m^3 for the BAU2010 case.

The potential reduction in concentrations due to compliance strategies indicates that of the three sites, all three sites are expected to demonstrate compliance with the limit value of 5ng/m^3 . A limit value of 0.5ng/m^3 is not considered to be feasible. However, based on data in Table 6.23 for other sites (from 1996 and earlier) these cadmium levels would appear unlikely to be achievable for all sites.

Nickel

For nickel, very limited data is available. Data is available for one site (site L) only. Site L is expected to demonstrate compliance with the limit value of 3 ng/m³ for the BAU2010 case.

The potential reduction in concentrations due to compliance strategies indicates that Site L is expected to demonstrate compliance with the limit value of 3 ng/m³. The compliance strategy would, however, result in some improvement compared to the average area concentrations for the BAU2010 case. In the absence of more data, setting a limit value for nickel which sites could feasibly achieve is not possible without further consultation and information. A limit value of 30 ng/m³ is likely to be reasonable.

In the context of the potential cadmium limit values, further consultation and investigation should take place to confirm the likely BAU2010 situation for companies 1, 2, 5, 7, 8 and 10 listed in Table 6.23.

The variation in air quality between the sites within the sub-sector is a function of the following:

- The relative age of the site installation;
- The relative contribution of fugitive emissions compared to direct emissions;
- The background concentrations of the three pollutants.

Determination of the cost of compliance is feasible, based on implementation of various strategies. However, the actual emissions performance of a site can only be predicted. On this basis an initial scale up of costs across the zinc production sector to comply with limits of 4 ng/m³ for As for most sites, 5 ng/m³ for Cd for most sites and potentially 30 ng/m³ for Ni, based on data for Site L, a total of 14 sites in the sector, and one third failing to meet 5ng/m³ Cd under the BAU2010 scenario is:

Capital costs for sector:

€m 154 (€m 12.0 pa @2% DR, €m 13.8 pa @4% DR, €m 15.9 pa @ 6% DR)

Operating costs for sector:

€m 7.7 pa (assumed as 5% of capital costs)

Total costs for sector:

€m 19.7 pa (2% DR), €m 21.5 pa (4% DR), €m 23.6 pa (6% DR)

However, 4ng/m³ As and 5ng/m³ Cd could not be achieved for all sites with this investment.

Taking into account the benefits that could be quantified for site L, an indication of the overall costs and benefits is given in the Table 6.29.

Table 6.29 Costs and Health Benefits for Zinc Production

Compliance technique to meet 4 ng/m ³ As (most sites), 5 ng/m ³ Cd (most sites) and 30 ng/m ³ Ni	Number of sites expected to adopt additional measures	Total costs (€m per annum) (Note 1)	Reduction in cancers per site due to Cd (per annum)	Total reduction in cancers due to Cd (per annum)	Valuation of reduction in cancers due to As, Cd and Ni (€m per annum)
To be determined following detailed investigations by the sites	5	20 (@2%DR)	0.014	0.07	0.065 (low est)
		22 (@ 4%DR)			0.125 (best est)
		24 (@ 6%DR)			0.31 (high est)

Whilst the above table shows that the costs outweigh the specific quantifiable benefits of the reduction in cancers due to cadmium exposure there will be other important secondary benefits of the heavy metal air quality limit values. The benefits due to these other effects will clearly improve the balance towards the benefits, although by how much is not possible to fully quantify with the currently available information. These additional benefits include:

- Reduced carcinogenic effects associated with exposure to arsenic and nickel (although these are less significant relative to cadmium for this sector);
- Reduced adverse health effects due to reductions in exposure to other metals;
- Reduced mortality and morbidity effects due to reductions in exposure to PM₁₀;
- Reduced adverse impacts on ecosystems and crops; and
- Reduced occupational exposure to carcinogenic metal pollutants.

6.5 Primary and Primary/Secondary Lead Production

6.5.1 Profile of Sub-sector

Within the EU, the UK, Germany, France and Italy are the major lead producers and, on average, 49% of their output is based on secondary feed supplies. Within the EU there are 7 primary smelters/refiners whose production capacity ranges in size from 40,000 tonnes per year to 245,000 tonnes per year. The primary refineries are mostly multinational and are located in the UK (Britannia Refined Metals), France (Metaleurop), Germany (Ecobat, Metaleurop) and Italy (Enirisorse). Typically, plants smelt lead or lead/zinc concentrates before refining lead bullion and also refining crude bullion from other sources to recover precious metals. Britannia Refined Metals also refines crude lead bullion imported from its parent company MIM in Australia. All of these primary refiners are involved in secondary recycling/refining as well.

Table 6.30 summarises the annual European lead production capacities.

Table 6.30 Annual European Lead Production Capacities

Country	Lead blast furnace annual capacity (tpa)	Direct smelting annual capacity (tpa)
Belgium	110,000	
France	110,000	
Germany	35,000	220,000
Italy		90,000
Spain	14,000	
Sweden	50,000	65,000
UK		40,000 (200,000 tpa refining capacity)

Note

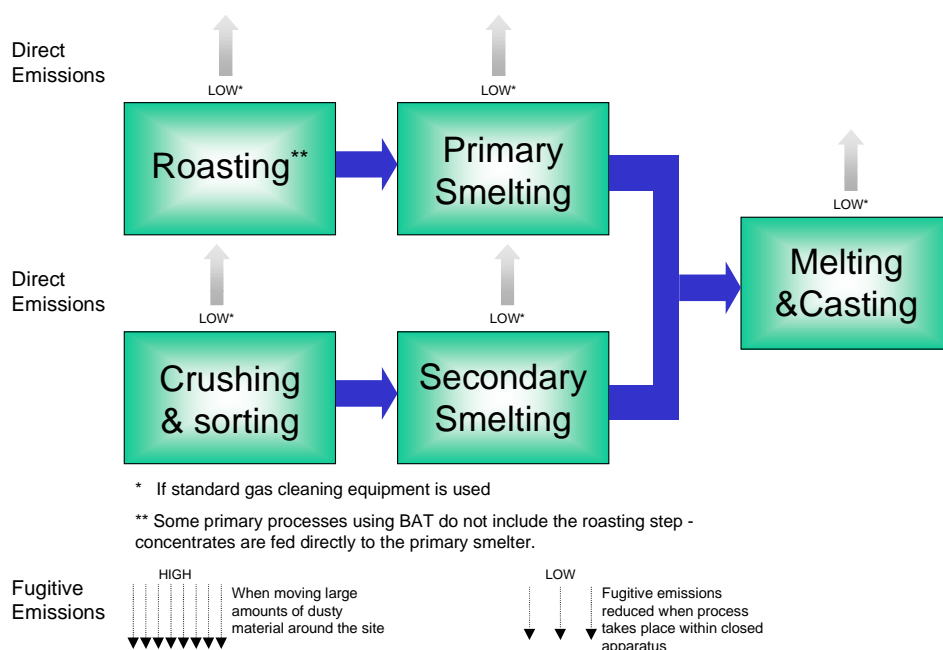
1. All above may use primary and/or secondary raw materials

In addition, there are approximately 30 secondary lead sites in the EU according to the BREF Document.

6.5.2 Emission Sources

In recent years several new technologies have been developed and implemented which offer more efficient methods of smelting lead concentrates. These processes have also reduced emissions to the environment. Existing processes have been improved by using up to date control and abatement systems.

The main process steps are summarised below and the relative importance of emissions from each step indicated as low, medium and high. The relative significance of the emissions relates to the process described and serves to indicate which process stages have the highest comparative metal emissions.



Metaleurop have completed investigations around all their major sites since 1990 to evaluate diffuse emissions from lead smelters as a fraction of total emissions. Lead has been used as the tracer, however it is indicative of the fraction of total emissions which relate to fugitive emissions for other elements. The average result for most of the sites studied has been that the fugitive emissions are generally 1 to 5 times the point sources, whatever the emission factor is. Two site results are given below as examples which provide an indication, however for individual sites the results will be heavily dependent on local factors.

Table 6.31 Example Lead Production Sites Showing the Ratio of Diffuse to Point Source Emissions

Site and source	Lead	Cadmium	Arsenic
Site 1, lead plant next to a zinc electrolytic unit (1990 data)			
Ratio of diffuse to point emissions	2.7	1.4	0.5
Diffuse source emissions (kg pa)	5 236	330	77
Point and line source emissions (roof openings) (kg pa)	1 955	242	141.5
Site 2, one lead and one zinc primary smelter (1999 data)			
Ratio of diffuse to point emissions	0.65-0.75		
Diffuse source emissions (kg pa)	11 710-18 090		
Point source emissions (kg pa)	18 000-24 000		

The ratio of diffuse to point appears to be lower than usual for the above Site 2, however Metaleurop comment that this may be due to this site containing two pyrometallurgical units emitting lead. For site 2 the diffuse lead emissions break down into:

- Storage 1 920 to 8 300 kg pa
- In site roads 5 850 kg pa
- Loading and unloading 3 200 kg pa
- Land fill dust emission 720 kg pa

Please see section 6.4.3 for further information on current emissions and abatement techniques for lead production.

6.5.3 Current Air Quality Data

Tables 6.32 to 6.35 summarise the available ambient air quality data for arsenic, cadmium, nickel and mercury for the lead production sector.

Table 6.32 Current Air Quality Data for Arsenic

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kg pa) ⁽¹⁾	Reference
Belgium	97	1998	N	'Industrial hotspots' in vicinity of lead/copper smelter		Position paper
Belgium	50	1998	N	10m from the lead/copper smelter in the prevailing wind direction		Consultation with site
Belgium	40	1998	N	110m from the lead/copper smelter in the prevailing wind direction		Consultation with site
Belgium	20	1998	N	330m from the lead/copper smelter in the prevailing wind direction		Consultation with site
Belgium	120	1999	N	100m from the lead/copper smelter in the prevailing wind direction	700 The site has fugitive emissions from stock-piles, roads, production units (rooves) that it cannot quantify Point sources included in the above figure are those which have a >10% impact on the total emission of the relevant metals.	Consultation with site
Germany	2.3	1998	P	600m from lead smelter after improvements		Position paper
Germany	5	1999	P	500m from lead smelter after improvements	7 (point sources)	Consultation with site
UK	1.8	1999/00	L	Nearest sensitive receptor where max concs occur - 1300m downwind from the zinc/lead smelter		Preliminary air quality results for the first 9 months of a 12 month project.
UK	1.8	1999/00	Derbyshire	Nearest sensitive receptor where max concs occur - 550m NE from the lead refiner (secondary lead)		Preliminary air quality results for the first 9 months of a 12 month project.
UK	1.4	1999/00	Kent	Nearest sensitive receptor where max concs occur - 1000m downwind from the zinc/lead smelter		Preliminary air quality results for the first 9 months of a 12 month project.

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality

Table 6.33 Current Air Quality Data for Cadmium

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
Germany	2.7	1998	P	600m from lead smelter after improvements		Position paper
Germany	5	1999	P	500m away from lead smelter	5 (Point sources)	Consultation with site
Belgium	20	1998	N	10m from the lead/copper smelter in the prevailing wind direction		Consultation with site
Belgium	20	1998	N	110m from the lead/copper smelter in the prevailing wind direction		Consultation with site
Belgium	10	1998	N	330m from the lead/copper smelter in the prevailing wind direction		Consultation with site
Belgium	40	1999	N	100m from the lead/copper smelter in the prevailing wind direction	88.8 The site has fugitive emissions from stock-piles, roads, production units (rooves) that it cannot quantify Point sources included in the above figure are those which have a >10% impact on the total emission of the relevant metals.	Consultation with site
UK	8	1999/00	L	Nearest sensitive receptor where max concs occur - 1300m downwind from the zinc/lead smelter	1252	Preliminary air quality results for the first 6 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
UK	0.5	1999/00	Derbyshire	Nearest sensitive receptor where max concs occur - 550m NE from the lead refiner (secondary lead)	<0.1	Preliminary air quality results for the first 6 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory
UK	0.6	1999/00	Kent	Nearest sensitive receptor where max concs occur - 1000m downwind from the zinc/lead smelter	135	Preliminary air quality results for the first 6 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory
Germany	No data available	1999	M		7.3	Consultation with site

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality

Table 6.34 Current Air Quality Data for Nickel

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
Belgium	30	1999	N	100m from the lead/copper smelter in the prevailing wind direction	30	Consultation with site
UK	2.5	1999/00	L	Nearest sensitive receptor where max concs occur - 1300m downwind from the zinc/lead smelter	24	Preliminary air quality results for the first 9 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory
UK	1.5	1999/00	Derbyshire	Nearest sensitive receptor where max concs occur - 550m NE from the lead refiner (secondary lead)		Preliminary results for the first 9 months of a 12 month project.
UK	3.4	1999/00	Kent	Nearest sensitive receptor where max concs occur - 1000m downwind from the zinc/lead smelter		Preliminary results for the first 9 months of a 12 month project.

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality

Table 6.35 Current Air Quality Data for Mercury

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa) ⁽¹⁾	Reference
UK	1.3	1999/00	L	Nearest sensitive receptor where max concs occur - 1300m downwind from the zinc/lead smelter		Preliminary air quality results for the first 9 months of a 12 month project. Emission rate from 1999 UK Environment Agency Pollution Inventory
UK	0.9	1999/00	Derbyshire	Nearest sensitive receptor where max concs occur - 550m NE from the lead refiner (secondary lead)		Preliminary results for the first 9 months of a 12 month project.
UK	0.2	1999/00	Kent	Nearest sensitive receptor where max concs occur - 1000m downwind from the zinc/lead smelter		Preliminary results for the first 9 months of a 12 month project.

Note

1. The emission rate generally reflects process emissions only, most sites have greater fugitive emission rates which are not measured but contribute significantly to the ambient air quality

6.5.4 Emission Reduction Techniques

Please see section 6.4.4 for information on Best Available Techniques associated with primary lead production.

6.5.5 Future Air Quality Under the Business as Usual Scenario

Table 6.36 summarises the investment plans sites have for complying with existing legislation and investment for complying with the proposed limit values. The sites forecast of 2010 business as usual (BAU) ambient air quality values and predicted air quality after additional investment beyond BAU investment for 2010 are also included. These values are estimates of what the ambient air quality will be at the location of the current ambient monitoring station based on 1999 ambient monitoring data and are a guide. More detailed modelling results have been used for the cost benefit analysis and these are presented in section 6.5.6.

Table 6.36 Predicted Future Ambient Air Quality for Business as Usual Scenario and After Implementing a Limit Value Compliance Strategy

Site	Process description	Existing air abatement techniques	Investment plans to comply with existing legislation	Capital cost (€m)	Strategy for compliance with proposed limit values	Capital cost (€m)	Business as usual air quality values for 2010 (ng/m ³)	Predicted air quality after additional investment for 2010 (ng/m ³)
Site M, Germany	The site consists of a zinc electrolytic plant and a lead plant. Two plants are located on a site that has been used for metallurgical processes for more than 100 years. It is located on a large river, by the sea in Germany (flat terrain).	PROCESS: No data FUGITIVE: No data	No data available		No data available		No data available	As Cd <5 Ni <3
Site N, Belgium	The copper smelter, blast furnace and lead refinery start-up dates were 1997, 1960 and 1967 respectively. Various primary and secondary non-ferrous metal containing products are used as raw materials for the copper smelter and lead refinery. Open and covered stock-piles, trucks and conveyors are used during handling of the raw materials. Lead bullion is used as the raw material for the lead refinery. It is handled using trucks. The copper smelter uses the ISA process. The blast furnace uses the ISA process downstream. The lead refinery has a Harris furnace followed by precious metal refining.	PROCESS: Wet electrofilter, scrubber, washing tower, electrofilter, sulphuric acid plant, demister for the copper smelter; baghouse with after burning system on the blast furnace, scrubber on the lead refinery (and a baghouse to be installed in 2001). FUGITIVE: Baghouses for the copper refinery and blast furnaces. Scrubber for the lead refinery (and a baghouse to be installed for the lead	Extra gas cleaning equipment for the lead refining is planned for 2001 Renewing of other gas cleaning equipment is planned for 2002. Ground and groundwater sanitation programme is ongoing. An extension of the sprinkling installations is planned for 2001 Applying BAT should result in a 10% decrease in Cd.	1 (Operating cost €10,000 /year) 2 (Operating cost €20,000 /year) 2 0.25 10	Unknown. In the immediate vicinity and under the prevailing wind of a large smelter/refinery, it is expected that the proposed standards will not be met.		As 20 - 120 Cd 10 - 40 Ni 20 - 30	As No data available Cd No data available Ni No data available

Site	Process description	Existing air abatement techniques	Investment plans to comply with existing legislation	Capital cost (€m)	Strategy for compliance with proposed limit values	Capital cost (€m)	Business as usual air quality values for 2010 (ng/m ³)	Predicted air quality after additional investment for 2010 (ng/m ³)
		refinery in 2001).	To reduce fugitive emissions there were plans to install more ventilation and filtration at some production units. For stockpiles, it is not thought possible to cover an area of 10ha with a roof. The fugitive reduction measures would lead to a further reduction of 10-20% cadmium.					
Site O, France	This secondary lead smelting site was established in 1973. It is located in an industrial area next to a river and to the north of a large town.	PROCESS: No data FUGITIVE: No data	No data		It is anticipated that compliance with the proposed values for nickel can be achieved at marginal cost. The cadmium limit of 0.5ng/m ³ is not considered to be achievable as it is at the limit of the background, below any technical feasibility. The limit of 5ng/m ³ is likely to be achievable		As No data available Cd No data available Ni No data available	As: Cd: <5 Ni: <3

Site	Process description	Existing air abatement techniques	Investment plans to comply with existing legislation	Capital cost (€m)	Strategy for compliance with proposed limit values	Capital cost (€m)	Business as usual air quality values for 2010 (ng/m ³)	Predicted air quality after additional investment for 2010 (ng/m ³)
Site P, Germany	The site has been in operation since 1848. In 1990 the QSL smelter was installed.	PROCESS: Sulphuric acid plant for gas cleaning	Roof for raw material storage is planned for 2001.	2			As: <5 Cd: <5 Ni:	As: <5 Cd: <5 Ni:
	Raw materials used are lead concentrates and secondary lead raw materials in the form of sludges, ashes, battery paste etc. They are stored in open stockpiles with moistening.	FUGITIVE: Fabric filters for dry gases and electric filters for wet gases from slag granulation.	More efficient emission capture and ventilation of the refinery is planned for 2002. It is expected that this will reduce As and Cd emissions by 95kg pa (from 117kg pa) and 5kg pa (from 15kg pa) respectively.	1.5				
	The QSL smelter is the main process stage, followed by a fully equipped lead refining process and Ag-Au alloy.		Improvements in the kettle ventilation are planned for 2004.	0.8				
Site Q, France	This site is in a marshland area in the North of France. This was a heavily industrialised area but the nearby coal mines have now been shutdown, urbanisation is taking place and there is a dense highway network. The lead plant was originally built in 1936 and extended during the sixties. A zinc ISF plant was built in 1962 and completed in 1970 for zinc refining.	PROCESS: No data FUGITIVE: No data	No data		Too meet is Cd levels of 5ng/m ³ is not feasible due to the mining that has previously taken place in the area.		As: 30 - 50 Cd: 1 - 50 Ni:	As: 1 - 15 Cd: 1 - 15 Ni:

6.5.6 Costs and benefits of complying with potential limit values

Two sites have had the current 1999 emission data modelled to produce a dispersion model which has been checked against the measured ambient air quality values. Any planned plant modifications to comply with existing legislation have been fed into the model to produce the 2010 business as usual (BAU) scenario. Potential modifications beyond the 2010 BAU scenario to comply with the proposed limit values have been fed in to produce the 2010 compliance scenario. The sites tend to have only one set of improvements (if any) additional to BAU improvements for the compliance scenario.

Site N, Belgium

Business as usual 2010

Based on business as usual (BAU) performance, the following table summarises the limit values which would be expected to be complied with in the vicinity of the site.

Pollutant	Limit values to consider (ng/m ³)	Expected compliance? (Y/N)
Arsenic	20	N
	13	N
	5	N
	4	N
	1	N
Cadmium	15	N
	5	N
	0.5	N
Nickel	50	Y
	30	Y
	10	N
	3	N

Limit value compliance 2010

The site has several investments planned to comply with existing legislation, ranging in value from €m 0.25 to €m 10. No additional investment suggestions which would aid compliance with the proposed limit values have been identified. The feedback from the site was that they would not be able to meet the proposed limit values in the immediate vicinity of the site in the prevailing wind direction.

The site would need to reduce fugitive emissions further. They have large areas of raw material stockpiles and they currently do not feel that there is technology available to reduce emissions further.

Site P, Germany

Based on business as usual (BAU) performance, the following table summarises the limit values which would be expected to be complied within the vicinity of the site.

Pollutant	Limit values to consider (ng/m ³)	Expected compliance? (Y/N)
Arsenic	20	Y
	13	Y
	5	Y
	4	N
	1	N
Cadmium	15	Y
	5	Y
	0.5	N
Nickel	50	No data available
	30	No data available
	10	No data available
	3	No data available

The site has several investments planned to comply with existing legislation and no additional investment suggestions which would aid compliance with the proposed limit values.

Overall

It is clear from the data that some historical industrial sites and geologically mineralised areas with high local background concentrations will not be able to comply with lower limit values. Feasibility for individual sites to successfully achieve these lower limit values must therefore be taken into consideration. Furthermore, achievement of limits is not necessarily guaranteed by the indicated levels of expenditure. This is because it is not feasible to provide a definitive indication of reduction in emissions for a specific level of capital expenditure.

Analysis of the available data for sites within the lead sub-sector indicates considerable variability in the average area concentrations for the BAU2010 case. In some cases site data is limited or no data is available. However, an interpretation of the results is provided below:

Arsenic

For arsenic, two of the three sites for which data is available (sites N and Q) are not expected to demonstrate compliance with the upper limit value of 20 ng/m³ for the BAU2010 case. The third site (site P) is expected to demonstrate compliance with the limit value of 5 ng/m³ for the BAU2010 case.

The potential reduction in concentrations due to compliance strategies indicates that site P is expected to demonstrate compliance with the limit value of 5 ng/m³. Site N is not expected to demonstrate compliance with the upper limit value of 20 ng/m³. The step change to 5 ng/m³ is not likely to be achievable for all sites, even when the compliance case is considered. Limit values of 5 ng/m³ or below are therefore not realistic.

Cadmium

For cadmium, two of the three sites for which data is available (sites N and Q) are not expected to demonstrate compliance with the upper limit value of 15 ng/m³ for the BAU2010 case. The third site (site P) is expected to demonstrate compliance with the limit value of 5 ng/m³ for the BAU2010 case.

The potential reduction in concentrations due to compliance strategies indicates that site Q is expected to demonstrate compliance with the limit value of 15 ng/m³. Sites M, O and P are expected to demonstrate compliance with the limit value of 5 ng/m³. The step change to 0.5

ng/m³ is not likely to be achievable for all sites, even when the compliance case is considered. A limit value of 0.5 ng/m³ is therefore not realistic.

Nickel

For nickel, very limited data is available. The highest concentrations are at Site N which is expected to demonstrate compliance with the limit value of 30 ng/m³ for the BAU2010 case.

No data is available that provides an indication of the potential reduction in concentrations due to compliance strategies. In the absence of data, setting a limit value for nickel which sites could feasibly achieve is not possible with further consultation and information. A limit value of 30 ng/m³ is likely to be reasonable.

In the context of the potential limit values, further consultation and investigation should take place with site N.

In the absence of more data, it is not clear whether more stringent limit values could be met compared to the level of compliance expected under the 2010 BAU scenario. Therefore an assessment of the costs and benefits of compliance is not feasible for this sector.

6.6 Foundries

It has not been possible to identify any significant relevant data for this sector, which will comprise of hundreds of processes that recast processed metals produced by the ferrous and non-ferrous production industry (as described in the previous sections) or that reprocess scrap metals.

However, based on recent ambient measurements in the vicinity of six relevant processes in the UK it is considered that under the 2010BAU scenario, compliance should be achievable for 4ng/m³ for As, 5ng/m³ for Cd and 30ng/m³ for Ni. Predictions of possible measures beyond 2010BAU are not possible with the current level of information.

6.7 References

1. European Commission, 2000. Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in Non Ferrous Metals Industries, Final BREF, May 2000
2. Finnish Environment Institute, Finnish Expert Report on Best Available Techniques in Nickel Production, Helsinki 1999
3. Finnish Environment Institute, Finnish Expert Report on Best Available Techniques in Copper Production and By-production of Precious Metals, Helsinki 1999
4. Finnish Environment Institute, Finnish Expert Report on Best Available Techniques in Zinc Production, Helsinki 1999
5. DETR, 2000. Preliminary results from heavy metals monitoring in the vicinity of 30 industrial sites.

7 Combustion Processes

7.1 Introduction

For coal fired combustion plant the metals being considered include arsenic, cadmium, nickel and mercury. However, for heavy fuel oil fired combustion nickel is the key metal of interest. For such processes it is considered that the achievement of any of the air quality limit values being considered for nickel will ensure that the values for the other metals will also be met.

Current Legislative Controls

Heavy metals from the combustion sector are not controlled directly. Controls on emissions of particulates will exert some control on heavy metals emissions. Controls on sulphur emissions can lead to accompanying reductions in heavy metals. Hence control legislation comprises:

- Regulation of emissions to atmosphere at a Member State level e.g. Integrated Pollution Control under the Environmental Protection Act, 1990 in the UK, Federal Law on Immission Control (*BImSchG*) in Germany, Air Pollution Act in The Netherlands.
- Large Combustion Plant Directive.
- Air Quality Standards regulations for particulate matter and SO₂.

Future Legislative Controls

Regulatory factors which will have an impact on heavy metal emissions from combustion processes in the future include:

- Proposed Revisions to the Large Combustion Plant Directive – with potentially stringent limit values on SO₂ and particulates (see Section 4).
- IPPC Directive – the need to meet BAT requirements (see Section 4).
- Sulphur Content in Liquid Fuels Directive (see Section 4).
- UNECE Heavy Metals Protocol – the need to meet BAT requirements plus emission limit values (see Section 4).
- Air Quality Daughter Directive limit values for PM₁₀, lead and SO₂ (see Section 4).

7.2 Power Generation - Coal-fired Plant

7.2.1 Profile of Coal-fired Power Stations

A number of different technologies are used for coal-fired power generation including pulverised fuel firing, circulating fluidised bed combustion and integrated coal gasification combined cycle (IGCC) processes. Of these technologies, the firing of pulverised coal is most

commonly used, however, other more advanced systems may be used in the future as a means of improving energy efficiency and reducing emissions.

Data on the current and future consumption of solid fuels (assumed to be mainly coal) for thermal power generation in each member state has been developed by the European Commission Shared Analysis Project (European Commission, 1999). A summary of relevant data is shown in Table 7.1.

Table 7.1 Current and Future Solid Fuel Inputs for Thermal Power Generation in the EU-15 (Note 1)

Country	Solid fuel inputs (Mtoe)	
	2000	2010
Austria	1.1	0.3
Belgium	2.6	1.1
Denmark	5.0	4.3
Finland	5.1	7.6
France	5.4	4.1
Germany	64.7	59.0
Greece	8.4	8.9
Ireland	2.1	1.8
Italy	5.4	8.9
Luxembourg	0	0
Netherlands	5.7	5.0
Portugal	3.0	4.2
Spain	14.2	13.6
Sweden	1.0	1.5
United Kingdom	26.6	16.7
TOTAL	150.1	137.0

Note

1. Mtoe = million tonnes oil equivalent

Similar data is not readily available for the Accession Countries, however data is available on the total electricity supplied by coal in the EU and accession countries in 1996 as given in Table 7.2 below (World Energy Council, 2000b).

Table 7.2 Total Electricity Supplied and Contribution of Coal (World Energy Council Data, 2000)

Country	Electricity supplied in 1996 (TWh)	
	Total supplied – all fuels	Total supplied by coal
Austria	56	5
Belgium	77	18
Czech Republic	64	47
Denmark	No data	No data
Estonia	8	9
Finland	74	22
France	444	31
Germany	551	303
Greece	44	29
Hungary	37	9
Ireland	19	9
Italy	282	25
Luxembourg	6	0
Netherlands	No data	No data
Poland	140	137
Portugal	36	13
Slovenia	10	4
Spain	175	55
Sweden	153	3
United Kingdom ¹	365	147
TOTAL	2541	866

The data in Table 7.2 above show how the reliance on coal varies throughout Europe. For example, in 1996 coal provided around 98% of the total electricity supplied in Poland. Coal is the dominant fuel source for power generation in a number of other countries such as the Czech Republic, Germany and Greece.

7.2.2 Emission Sources

The combustion of coal by the thermal power generation sector results in the significant emission of metals present in the coal. During combustion, the trace elements are distributed into the bottom ash, fly-ash and flue gases. Metals emitted in the flue gases are primarily associated with fine fly-ash particles but more volatile metals such as Hg are emitted in the

vapour phase. The quantity of metal emissions will depend on a number of important factors including the:

- concentration of As, Cd, Hg and Ni in the coal;
- the quantity of coal used;
- type of combustion process;
- extent of partitioning between the bottom ash, fly ash and gaseous phases;
- enrichment factor i.e. the condensation of metals on fine fly ash particulates;
- performance of emission control devices.

The concentration of As, Cd, Ni and Hg in coal can vary widely depending on a range of factors such as the geographical source and rank of coal. The average trace element contents of European, US and world-wide coals are compared in Table 7.3 below for bituminous, subbituminous and lignite.

Table 7.3 Metal Content of Coals in ppm

Coal type	As	Cd	Hg	Ni
World-wide bituminous (average range) ¹	1.5-15	0.2-10	0.02-10	15-20
World-wide subbituminous (average range) ¹	15-55	0.9-2.6		2.0-44
UK bituminous ²	2-73	<0.3-3.4	<0.2-0.7	8-35
Polish bituminous ²	0-40	0-4		6-30
West German bituminous ²	1.5-50	<1.3-10	<0.7-1.4	15-95
US bituminous ³	5.0	0.5		15
EC bituminous ³	12	0.3		
US bituminous ^{4,5,6,7}	20	< 0.02-100 (mean 0.91)	<0.01-3.3 (mean 0.21)	20 (average for US coal)
US subbituminous ^{4,5,6}	6	0.04-3.7 (mean 0.38)	0.01-8.0 (mean 0.1)	
US Lignite ^{4,5,6}	23	<0.11-5.5 (mean 0.55)	0.03-1.0 (mean 0.15)	

Sources:

¹ Swaine, D.J. , 1990. Trace elements in coal. Butterworths, London.

² Swaine, D.J., 1985. Modern methods in bituminous coal analysis. CRC Critical reviews in Analytical Chemistry. Volume 15, issue 4.

³ Querol, X. et al, 1992. Trace elements in high-S subbituminous coals from the Teruel Mining District, NE Spain. Applied Geochemistry, Volume 7, 547-561.

⁴ US EPA, 1998. Locating and Estimating air emissions from sources of arsenic and arsenic compounds. EPA-454/R-98-013, June 1998.

⁵ US EPA, 1997. Locating and Estimating air emissions from sources of mercury and mercury compounds. EPA-454/R-97-012, December 1997.

⁶ US EPA, 1993. Locating and Estimating air emissions from sources of cadmium and cadmium compounds. EPA-454/R-93-040, September 1993.

⁷ US EPA, 1984. Locating and Estimating air emissions from sources of nickel and nickel compounds. EPA-450/4-84-007f, March 1984.

The average content of As and Cd in bituminous coals burned in the EC is reported to be 12 ppm As and 0.3 ppm Cd. The Hg content of coals used in Europe is usually less than 1 ppm (TNO Report, 1998). However, due to the variability in the trace element content, it is difficult to ascertain a typical range for the metals of interest in this study. A very general estimation can be made, based on the information in Table 7.1 above. A reasonable figure of the maximum metal content of bituminous coals burned in the EU-15 and Accession countries is considered to be up to:- 20ppm As, 10ppm Cd, 10ppm Hg and 40ppm Ni.

The metals content of coals used across Europe is likely to be lower in the future due to the increased use of internationally traded coals, with lower sulphur and mineral matter contents. Furthermore, the use of coal cleaning technologies, prior to combustion, can considerably reduce the trace element of the coal, and subsequently the trace element emissions. Processing techniques involving the removal of a proportion of the inorganic matter from the coal using physical property differences (e.g. density), are well-established. Significant progress is also being made in chemical and biological coal cleaning techniques.

Emission factors for As, Cd, Hg and Ni during coal combustion are summarised in Table 7.4 below. Measured emission factors are based upon the actual emissions generated during the testing of the boiler and information regarding the fuel heating value.

Table 7.4 Emission Factors for As, Cd, Hg and Ni from Coal-fired Combustion Plant

Fuel	Metal	Emission factor (g of metal emitted per tonne of fuel burned)	Comments
Hard Coal ¹	As	0.03-0.3	Assumes dust control and a clean gas particle concentration of 50mg/m ³
	Cd	0.003-0.01	
	Hg	0.05-0.2	
	Ni	0.03-0.4	
Brown Coal ¹	As	0.03-0.04	Assumes dust control and a clean gas particle concentration of 50mg/m ³
	Cd	0.002-0.004	
	Hg	0.05-0.2	
	Ni	0.02-0.04	

Fuel	Metal	Emission factor (g of metal emitted per tonne of fuel burned)	Comments	
Hard Coal ¹	As	0.01-0.1	Assumes FGD installed and a clean gas particle concentration of 20mg/m ³	
	Cd	0.0001-0.004		
	Hg	0.02-0.08		
	Ni	0.01-0.5		
Brown Coal ¹	As	0.008-0.01	Assumes FGD installed and a clean gas particle concentration of 20mg/m ³	
	Cd	0.0008-0.001		
	Hg	0.02-0.08		
	Ni	0.01		
Bituminous ²	Cd	0.05-3.9	Measured uncontrolled emission factor.	
		Subbituminous		0.05-42.0
Bituminous ²	Cd	0.0001-0.69	Measured Cd emission factor with ESP control.	
		Subbituminous		0.004-0.13
		Lignite		0.009-0.025
Bituminous ³	Hg	0.00015-4.0	Measured uncontrolled emission factor.	
		Subbituminous		0.0062-0.78
Bituminous ³	Hg	0.0055-0.29	Measured Hg emission factor with ESP control.	
		Subbituminous		0.0035-0.040
		Lignite		0.0016-0.0038

Sources:

¹ Emission inventory guidebook, 1996. B111-58, ps010101

² US EPA, 1993. Locating and Estimating air emissions from sources of cadmium and cadmium compounds. EPA-454/R-93-040, September 1993.

³ US EPA, 1997. Locating and Estimating air emissions from sources of mercury and mercury compounds. EPA-454/R-97-012, December 1997.

7.2.3 Current Air Quality Data

Ambient air quality data has been obtained for a range of coal-fired power stations as shown in Tables 7.5 to 7.7 below.

Table 7.5 Arsenic

Country	Conc. (ng/m ³)	Date	Location	Descr of loc	Emission rate (kgpa)	Ref.
UK	0.67	1999/2000	Longannet power station (2.4GWe) – no FGD installed. Dunfermline, Scotland	Nearest sensitive receptor where max concs occur - 2.3 km east of power station stack	-	DETR, 2000 (1)
UK	1.25	1999/2000	Drax power station (3.9GWe) – FGD installed. Selby, England	Nearest sensitive receptor where max concs occur - 2.6 km NE of power station stack. (Plant 3 in Section 7.1.3)	120	DETR, 2000 (1)
UK	0.47	1999/2000	Kilroot power station (0.4GWe) – no FGD installed. Antrim, Northern Ireland	Nearest sensitive receptor where max concs occur - 1km downwind of the power station	-	DETR, 2000 (1)

Notes

1. Preliminary results for the first 8 months of a 12 month project - running mean

Table 7.6 Cadmium

Country	Conc. (ng/m ³)	Date	Location	Descr of loc	Emission rate (kgpa)	Ref.
UK	0.29	1999/2000	Longannet power station (2.4GWe) – no FGD installed. Dunfermline, Scotland	Nearest sensitive receptor where max concs occur - 2.3 km east of power station stack	-	DETR, 2000 (1)
UK	0.34	1999/2000	Drax power station (3.9GWe) – FGD installed. Selby, England	Nearest sensitive receptor where max concs occur - 2.6 km NE of power station stack. (Plant 3 in Section 7.1.3)	66	DETR, 2000 (1)
UK	0.27	1999/2000	Kilroot power station (0.4GWe) – no FGD installed. Antrim, Northern Ireland	Nearest sensitive receptor where max concs occur - 1km downwind of the power station	-	DETR, 2000 (1)

Notes

1. Preliminary results for the first 8 months of a 12 month project - running mean

Table 7.7 Nickel

Country	Conc. (ng/m ³)	Date	Location	Descr of loc	Emission rate (kgpa)	Ref.
UK	1.97	1999/2000	Longannet power station (2.4GWe) – no FGD installed. Dunfermline, Scotland	Nearest sensitive receptor where max concs occur - 2.3 km east of power station stack	-	DETR, 2000 (1)
UK	2.11	1999/2000	Drax power station (3.9GWe) – FGD installed. Selby, England	Nearest sensitive receptor where max concs occur - 2.6 km NE of power station stack. (Plant 3 in Section 7.1.3)	180	DETR, 2000 (1)
UK	1.40	1999/2000	Kilroot power station (0.4GWe) – no FGD installed. Antrim, Northern Ireland	Nearest sensitive receptor where max concs occur - 1km downwind of the power station	-	DETR, 2000 (1)

Notes

1. Preliminary results for the first 8 months of a 12 month project - running mean

7.2.4 Emission Reduction Techniques

A significant proportion of heavy metals will be removed by the particulate control equipment installed, usually ESPs. Furthermore, particulate emissions will be significantly reduced (to below 25 mg/m³) for those existing coal fired power stations required to fit flue gas desulphurisation (FGD). This is illustrated in the table on emission factors. The behaviour of a range of elements was investigated at a plant installed with FGD in the Netherlands. The mean Hg content in the flue gases downstream of the FGD was 1.5 µg/m³ with an average removal of 52% of the total Hg achieved by the FGD scrubber (Meij, 1994).

Interestingly, the limestone used for FGD is likely to contain metals in trace quantities. Hence, the specification of limestone used may have an influence on the subsequent emissions of the more volatile trace elements.

The use of integrated coal gasification combined cycle systems for power generation can also offer significant improvements in emissions of potentially hazardous air pollutants. Experiments conducted at a gasification plant in the US suggest that virtually all volatile elements are captured and retained during the clean-up of the syngas (Baker, 1994).

7.2.5 Future Air Quality under the Business as usual Scenario

As discussed in Section 4, the Proposed Revisions to the Large Combustion Plant Directive (LCPD) are likely to have significant implications on heavy metal emissions from existing coal fired power stations, both as a result of controls on particulate and SO₂ emissions.

The ambient metal concentrations in the vicinity of the Drax power station in the UK (shown in Section 7.2.3, with the measurement point located where peak concentrations are expected to occur) are particularly useful in assessing the future concentrations that may be observed by 2010 following the installation of FGD at other coal-fired power stations in Europe. Factors influencing the significance of Drax include:

- It is the largest coal fired power station in Europe and operates at high load factors hence mass emissions of metals will be high compared with the majority of coal fired power stations fitted with FGD (for example data from a Belgian coal fired station fitted with FGD shows that emissions of As, Cd and Ni are over 100 times lower than for Drax (Electrabel, 2000)). Thus the ground level concentrations will be much higher than the majority of coal fired power stations fitted with FGD.
- The station is in close vicinity of two other major coal fired power stations, namely Eggborough and Ferrybridge, thus background metals concentrations will be relatively high.
- In comparison to the ranges of emission factors quoted in Table 7.4 for coal fired power stations fitted with FGD, Drax's emission factors (based on 9192ktpa coal consumption) do not compare in a straightforward way as follows:
 - As emission factor of 0.13g/t fuel is at the low end of the range for hard coal but above the high end of the range for brown coal;
 - Cd emission factor of 0.007g/t fuel is above the high end of the range for hard coal and brown coal; and
 - Ni emission factor of 0.02g/t fuel is at the low end of the range for hard coal but above the high end of the range for brown coal.

Overall, the combination of large quantities of coal burned and significant contributions to background concentrations from neighbouring power stations mean that ambient metal concentrations in the vicinity of the Drax station may be considered as being towards the high end of the range in comparison to other power stations. This is demonstrated by the fact that concentrations of As, Cd and Ni in the vicinity of Drax are higher than at the two other coal fired stations surveyed in Section 7.2.3 which don't even have FGD.

Under the business as usual scenario it is assumed that the station will improve from its current operation at around 85% overall efficiency of FGD to between 90 and 95% overall efficiency FGD. This would result in further reductions in metal emissions.

In order to comply with the Heavy Metals Protocol under the UN/ECE Convention on Long Range Transboundary Air Pollution, a number of power stations in Europe should have been upgraded by 2010 in order to meet the emission criteria for stationary combustion, as shown in Table 7.8. Plants must comply with a particulate emission value of 50 mg/m³, as also assumed with the IPPC Directive.

Table 7.8 Power Stations in Certain European Countries Requiring Up-grade in Order to Comply with the HM Protocol (TNO, 1998)

Country	Number of hard coal-fired plant in non-compliance	Number of brown coal-fired plant in non-compliance	Total number of plants to be upgraded
Czech Republic	8	27	39
Hungary	-	13	18
Poland	58	4	63
Slovenia	-	3	5

7.2.6 Costs and Benefits of Complying with the Potential Limit Values

From our investigation of emissions, ambient concentrations and trends in the coal fired power sector we conclude that it should be possible for a station fitted with high efficiency FGD (as assumed to be required under the business as usual scenario for stations operating at reasonable load factors) to meet even the lowest of the potential limit values under the business as usual scenario by 2010. Of the three metals, compliance with the lowest arsenic limit value is likely to be the most marginal. Therefore the application of the potential limit values to plants in this sector is not expected to lead to costs and benefits.

7.2.7 References

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7.3 Power Generation - Oil-fired Plant

7.3.1 Profile of Oil-fired Power Stations

Heavy fuel oil (HFO), also known as residual fuel oil, is the main type of oil used by the electricity generating industry. The combustion of HFO by the thermal power generation sector may result in the significant emission of gases and particulate matter. Particulates are produced from the incomplete combustion of the organic component of the oil as well as trace constituents.

Data on the current and future consumption of oil for thermal power generation in each member state has been developed by the European Commission Shared Analysis Project (European Commission, 1999). A summary of relevant data is shown in Table 7.9.

Table 7.9 Current and Future Oil Inputs for Thermal Power Generation in the EU-15

Country	Oil inputs (Mtoe)	
	2000	2010
Austria	1.1	0.9
Belgium	2.0	2.4
Denmark	2.3	1.6
Finland	1.4	1.1
France	7.9	9.5
Germany	13.2	14.7
Greece	3.1	3.8
Ireland	1.0	0.8
Italy	21.7	16.4
Luxembourg	0	0
Netherlands	5.3	6.6
Portugal	3.0	1.6
Spain	9.9	8.2
Sweden	1.7	2.2
United Kingdom	8.6	13.8
TOTAL	82.4	83.6

Similar data is not readily available for the Accession Countries, however data is available on the total electricity supplied by oil in the EU and accession countries in 1996 as given in Table 7.10 below (World Energy Council, 2000b).

The data show that the use of oil for electricity generation represents only a relatively small percentage of the total supplied across most EU and accession countries with the exception of Italy which supplies over 40% of its electricity using oil.

Table 7.10 Total Electricity Supply and Contribution of Oil (World Energy Council Data, 2000)

Country	Electricity Supply in 1996 (TWh)	
	Total – all fuels	Total supplied by oil
Austria	56	2
Belgium	77	1
Czech Republic	64	1
Denmark	No data	No data
Estonia	8	0
Finland	74	2
France	444	8
Germany	551	8
Greece	44	9
Hungary	37	5
Ireland	19	3
Italy	282	117
Luxembourg	6	0
Netherlands	No data	No data
Poland	140	2
Portugal	36	6
Slovenia	10	0
Spain	175	14
Sweden	153	5
United Kingdom	365	14
TOTAL	2541	201

7.3.2 Emission Sources

Significant emissions of nickel may be released as a result of HFO combustion, the predominant species being soluble Ni compounds (e.g. Ni sulphate) and complex metal oxides. Nickel exists as a low vapour pressure organo-metallic complex in crude oil and hence, will be more concentrated in the HFO than the crude source. The concentration of Ni in HFO can vary widely according to the source of the crude oil. Typical ranges of the Ni content are given in Table 7.11 below. As a result of the Directive on the Sulphur Content of Certain Liquid Fuels (1999/32/EC), the sulphur content of HFO will be limited to 1% from January 2003. The Ni content of lower sulphur crude sources has therefore been included in the Table for comparison.

Table 7.11 Range of Ni Content in Heavy Fuel Oils

Source of HFO	Typical Ni content (ppm)
Shell UK Ltd Stanlow oil refinery ¹	4-15
Sulphur content 1 % ²	20
Sulphur content 0.5 % ²	10
North Sea Crude ³	0.8-2 (content of crude)
West Africa Crude ³	up to 7 (content of crude)
US residual No.6 from low S sources ⁴	10
Fuel Oil (estimated concentration) ⁵	26

Sources of Data:

¹ Shell UK Ltd - Telephone conversation with John Fitzgibbon 12/06/00

² www.chemeng.ucl.ac.uk/research/;

³ Entec Report on the determination of the costs and benefits for England and Wales of transposing European Directive 1999/32/EC on the Sulphur Content of Certain Liquid Fuels (the SCLF Directive) into domestic legislation.

⁴ US EPA, 1984. Locating and Estimating air emissions from sources of nickel and nickel compounds. EPA-450/4-84-007f, March 1984.

⁵ US EPA Utility air toxics report at www.epa.gov/ttn/uatw/combust/utiltox/utoxpg.html

The quantity of Ni emissions from the combustion of HFO will depend on a number of factors such as the Ni content of the HFO, the grade and composition of the oil, and the performance of the particulate control device installed. The combustion of oil produces essentially no bottom ash, hence the type of boiler and the firing conditions do not particularly affect the emission of Ni (USEPA, 1984). However, Ni may be enriched on fine particles through the condensation of volatilised Ni. The removal efficiency of fine particulate matter from the combustion gases will therefore have a direct impact upon the level of Ni released through the stack. The levels of particulates emitted will largely depend upon the grade of oil used. The combustion of a heavy fuel oil, such as fuel oil no. 6, will generally result in the production of more particulate matter than the lighter fuel oils. However, the use of low sulphur heavy fuel oils can have a beneficial reduction on the emissions of particulate matter. The lower sulphur sources usually burn more efficiently as a result of the reduced inorganic content and the lower viscosity.

Emission factors for Ni during oil combustion are summarised in Table 7.12 below. Measured emission factors are based upon the actual emissions generated during the testing of the boiler and information regarding the fuel composition.

Table 7.12 Emission Factors for Ni for Heavy Fuel Oil-fired Combustion Plant

Fuel	Emission factor (g of metal emitted per tonne of fuel burned)	Comments
HFO ¹	35	General emission factor. Assumes a clean gas particle concentration of 50mg/m ³
Residual oil No.6 ²	9.9	Uncontrolled emission factor (measured)

Sources:

¹ Emission inventory guidebook, 1996. B111-58, ps010101

² US EPA, 1984. Locating and Estimating air emissions from sources of nickel and nickel compounds. EPA-450/4-84-007f, March 1984.

The emission factor for Ni for the Fawley site is calculated to be 12.8 g/t of oil burned (based upon 128 kg released and 10 ktonnes of oil). This value falls within the range of emission factors shown in Table 7.12 above. However, data for oil fired power stations in Italy fitted with FGD show that emission factors for Ni are in the region of 0.7g/t of oil burned (Enel, 2000a).

7.3.3 Current Air Quality Data

Nickel concentrations have been monitored in the vicinity of a number of oil-fired power stations. The ambient air quality data is summarised in Table 7.13 below.

Table 7.13 Nickel

Country	Conc. (ng/m ³)	Date	Location	Descr of loc	Emission rate (kgpa)	Ref.
UK	2.63	1999/2000	Coolkeeragh power station (0.4GWe), Campsey, Northern Ireland	Nearest sensitive receptor where max concs occur - 1km NE of the main stack	-	DETR, 2000
UK	2.1	1996 (3 week mean)	Fawley power station, Southampton (Note 1)	Monitoring location 1; 12.4 km from Fawley power station	128 (1998)	Environment Agency, 2000
	1.4	1996 (2 month mean)		Monitoring location 2; 9.6 km from Fawley power station		
	5.7	1997 (2 month mean)		Monitoring location 3; 11.7 km from Fawley power station	-	

Country	Conc. (ng/m ³)	Date	Location	Descr of loc	Emission rate (kgpa)	Ref.
	7.2	1997 (2 month mean)		Monitoring location 4; 12.4 km from Fawley power station	-	
	7.8 (6.8 background and 1.0 maximum process contribution based on dispersion modelling)			Location where maximum concentrations are estimated to occur		Environment Agency, 2000
UK	1.5	1996 (6 month monitoring period)	Minwear	Rural wooded area, 17 km NE of Pembroke Power Station. (Downwind of the plant - maximum ground level concentrations anticipated at this site)	-	PM ₁₀ and Trace Metals Monitoring in Pembrokeshire, June to December 1996. National Power Technology Report TECH/ECP/058/97
	2.0	1996 (6 month monitoring period)	Llanion	4km NE of Pembroke Power Station in a suburban area	-	
	2.0	1996 (6 month monitoring period)	Milford Haven	6km NW of Pembroke Power Station in a suburban area	-	
	1.6	1996 (6 month monitoring period)	Haverfordwest	15km N of Pembroke Power Station in a suburban area	-	
	2.2	1996 (6 month monitoring period)	Llangwm	10km NE of Pembroke Power Station in a rural location	-	
Italy	0.1	Modelling based on current emissions data	Typical Italian power station (4*320MW) fitted with FGD	2.5km downwind (location of peak concentration)	1,040	Enel, 2000a
	3 to 38	No date given	Range of figures covers several locations in Italy	Various distances downwind	Various	Enel, 2000a

Note

1. In 1998 the station was operating at a load factor of around 2% (for one flue operating). The plant generated a total of 18 GWh of electricity and burned 10,000 tonnes of oil. Current particulate emissions are approximately 140 mg/m³.

7.3.4 Emission Reduction Techniques

At many oil fired power stations, the combustion gases are passed to cyclone separators for the removal of a proportion of the particulates. Typical particulate emissions are in the region of 140mg/m³. ESPs should be capable of achieving particulate emissions of below 50mg/m³.

For many oil fired power stations operating with low load factors, it is considered unlikely that FGD will be adopted under the IPPC Directive or the Proposed Amendments to the LCPD. However, there will be a number of plant that would need to adopt FGD under these policies, for example in Italy where oil makes up a sizeable proportion of the fuel mix for power generation. With FGD, even lower particulate emissions would be achieved (<25mg/m³).

7.3.5 Future Air Quality Under the Business as Usual Scenario

In order to comply with the Heavy Metals Protocol under the UN/ECE Convention on Long Range Transboundary Air Pollution, a number of power stations in Europe should have been upgraded by 2010 in order to meet the emission criteria for stationary combustion, as shown in Table 7.14. Dust emissions from oil-fired combustion plant are typically 150 mg/m³ with lower values reached in more optimised boilers (TNO Report, 1998). An emission limit value of 50 mg/m³ will have to be attained, which corresponds to the emissions expected under the IPPC Directive. Hence, it is expected that the levels of Ni emitted will also be reduced due to the improved efficiency in the capture of particulate matter.

The average sulphur content of HFO used by the UK market for power generation is estimated to be 2.3% based on 1998 data from the UK Petroleum Industry Association. However, in order to comply with the Directive on the Sulphur Content of Certain Liquid Fuels (1999/32/EC), the sulphur content of HFO must not exceed 1% sulphur (by weight) from 1 January 2003. From the information sources reviewed for this study, the Ni content of lower sulphur fuel oils is generally lower. Hence, a reduction in Ni emissions is also anticipated as a result of the implementation of this Directive.

In addition, for a significant country with regard to oil fired power, Italy, there is decreasing reliance on oil in favour of gas and, in agreement with the above, the nickel content in the oils that are used is decreasing as oils with lower sulphur contents are being used (Enel, 2000b)

Table 7.14 Oil-Fired Power Stations in Certain European Countries Requiring Up-grade in Order to Comply with the HM Protocol (TNO, 1998)

Country	Number of residual-oil fired plant in non-compliance
Czech Republic	4
Hungary	5
Poland	1
Slovenia	2

The substitution of heavy fuel oil with orimulsion, an emulsion of bitumen in water, has taken place in some power stations and may continue to do so in the future. The Ni content of orimulsion is actually greater than that of heavy fuel oil, however the emissions are lower due to the requirement for FGD for power stations burning this fuel (DETR, 1997).

Based on this discussion and the information in Table 7.13, the future air quality in the vicinity of oil fired power stations in 2010 under business as usual commitments is likely to be similar to the concentrations in the vicinity of the Italian station with FGD that was modelled (process contribution of 0.1ng/n3) and the smaller station at Coolkeeragh in the UK operating at lower load factors without FGD – concentration of 2.6 ng/m³.

This would indicate that the lowest nickel limit value of 3 ng/m³ might be possible to be achieved. This is contradicted by other data for Italian oil power stations that rises significantly above 3 ng/m³ (ie up to 38 ng/m³). However it is known that some of the sites are in cities (with the potential for several background sources) and some are likely to be in the vicinity of oil refineries. Furthermore, it is not known which concentrations relate to stations with FGD (ie stations that would be representative of the business as usual scenario) and how up to date the data is.

7.3.6 Costs and Benefits of Complying with the Potential Limit Values

At the time of writing, from our investigation of emissions, ambient concentrations and trends in the oil fired power sector it is provisionally concluded that it should be possible for a station either operating at a low load factor or fitted with FGD (as assumed to be required under the business as usual scenario for stations operating at reasonable load factors) to meet even the lowest of the potential limit values for nickel (and hence for the other metals) under the business as usual scenario by 2010. Therefore the application of the potential limit values to plants in this sector is not expected to lead to costs and benefits.

However, due to the high ambient concentrations recorded at certain sites in Italy, further investigations are required prior to drawing firm conclusions regarding which of the potential limit values could be complied with under the business as usual scenario.

7.3.7 References

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7.4 Oil and Coal Fired Small Combustion Plant

7.4.1 Oil Fired Small Combustion Plant

Heavy Fuel Oil

Heavy fuel oil (HFO) is currently used in smaller boiler units (50 MW or less) throughout Europe. Applications will include schools, hospitals, office buildings, dairies (pasteurisation), distilleries, small industrial boilers (eg sugar processing) etc. Whilst each individual boiler is not a significant consumer of oil, the relatively low stack heights compared to larger industrial boilers and power stations makes these potentially significant contributors to elevated ambient nickel concentrations (the metal of most interest regarding HFO combustion).

However, by 2010 it is considered that this sub-sector will not be significant in terms of ambient nickel concentrations for the following reasons:

1. The decline in the use of HFO as a fuel source for small combustion plant

It is considered that due to environmental, economic and operational factors HFO consumption for small combustion plant is likely to decline in the period up to 2010. These factors include:

- the expansion of the supply network for natural gas;

- the controls on ambient SO₂ and PM₁₀ concentrations that will be imposed by the Air Quality Daughter Directive; and
- the handling, storage and heating requirements.

Taking the UK as an example, from an assessment of the latest available heavy fuel oil consumption statistics and projections and the findings of consultation with potentially affected sectors, forecasts of consumption for each year up to 2010 have been developed (Entec, 1999). These forecasts are summarised in Table 7.15 below. Deliveries of heavy fuel oil are expected to fall by approximately 18% by 2010 compared to 2000 data. This is set against a decline of more than 60% from 1990 to 1998 based on official statistics.

Table 7.15 Predicted Inland Delivery Trends for Heavy Fuel Oil in England and Wales up to 2010 (Entec, 1999). Data in thousand tonnes.

	1998	2000	2002	2004	2006	2008	2010
HFO	2706	2282	2189	2096	2013	1939	1865
Change compared to 2000			-93	-186	-269	-343	-417

2. The likely reductions in the nickel content of HFO in the future

The average sulphur content of HFO used by the UK market for power generation is estimated to be 2.3% based on 1998 data from the UK Petroleum Industry Association. However, in order to comply with the Directive on the Sulphur Content of Certain Liquid Fuels (1999/32/EC), the sulphur content of HFO must not exceed 1% sulphur (by weight) from 1 January 2003. From the information sources reviewed for this study, the Ni content of lower sulphur fuel oils is generally lower. Hence, a reduction in Ni emissions per unit of HFO burned is also anticipated as a result of the implementation of this Directive.

Gas Oil

As discussed in Section 8.1, heavy metals in crude oil are combined with organics in complex molecules that are essentially non-volatile. Consequently in the refining processes the heavy metals become concentrated in the residual streams, which are the major component of heavy fuel oils.

This lack of volatility means that heavy metals are not present in lighter distillates such as those used for production of gasoline and light fuel oils e.g. kerosines and gas oils used for domestic heating, industrial boilers, transportation etc. A search of over 100 literature references for heavy metals in distillate fuels has only produced information on nickel in commercial gasoline at up to 0.0004 ppm (Reimer, 1993). Concawe estimate that less than 1% of the nickel in crude feedstocks ends up in the distillate fuel fraction of the products (Concawe, 2000). Therefore distillate based fuels are not a significant source of emissions of nickel and the other heavy metals.

7.4.2 Coal Fired Small Combustion Plant

Coal has been an important fuel for industrial and residential combustion. According to the emissions inventory in Table 3.1, commercial, institutional and residential coal fired plants contributes 4% of EU-15 arsenic emissions (with lower percentages for other metals) and industrial coal fired plants contribute 20% of arsenic emissions (with lower percentages for other metals).

However, the current contributions to emissions are likely to differ somewhat from those in the inventory (which was based on 1990 emissions). For example, according to the Shared Analysis Project (European Commission, 1999) final energy demand for solid fuels across the EU-15 declined from 71Mtoe in 1990 to 36Mtoe in 2000. Further declines are expected with forecast demand by 2010 falling to 27Mtoe.

These historic and future significant reductions are no doubt as a result of national and EU-wide policies to reduce emissions of SO₂ and particulates, combined with the expansion in the supply of natural gas at competitive prices.

On the basis of these trends it is not expected that coal fired small combustion plant will be a significant contributor to elevated heavy metal concentrations by 2010.

7.4.3 References

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7.5 Transport

7.5.1 Profile of Nickel Emissions from the Transport Sector

The concentrations of Ni in ambient air are generally in the range 1.4-13 ng/m³ in urban background and traffic related sites in Europe. A range of data from the monitoring of Ni has been reviewed in the vicinity of sites of heavy traffic. Although the levels of Ni are elevated in urban sites compared to rural areas, it is not certain to what extent this can be directly attributed to the transport sector. Ambient levels of Ni are most likely to be elevated due to emissions from industrial sources, particularly from combustion plants (burning heavy fuel oils and coal), oil refineries, copper-nickel smelters and steel plants.

The emissions of Ni from the road transport sector have been observed to be rising gradually in the UK, as shown in Table 7.16 below, due to increased vehicle movements, amongst other factors. However, the releases of Ni from other transport sources have decreased considerably from 5.7 tonnes in 1970 to 0.1 tonnes in 1995.

Table 7.16 Emissions of Ni by the Transport Sector in the UK (Data from: DETR, 1997)

Sector	Nickel Emissions (tonnes)					
	1970	1975	1980	1985	1990	1995
Road Transport	0.7	0.8	0.9	1.0	1.2	1.3
Other Transport (Note 1)	5.7	2.0	1.8	1.1	0.1	0.1
Transport contribution to total emissions (%)	0.4	0.2	0.3	0.3	0.2	0.3

Note

1. Includes shipping, railways, aircraft etc

A literature review on the significance of Ni emissions from the transport sector was carried out, however very little information was found. Sources consulted include the US EPA (1984) and Concawe (1999a, 1999b, 2000). Emission factors for Ni from different vehicle categories have been estimated to be 0.07 mg/kg of fuel by Concawe (1999b). The emission factors for heavy metals are preliminary estimates only and further measurements are required in order to confirm the values.

Comparing the available ambient data for Ni in the Position Paper at traffic sites and urban locations, no significant differences in the range of Ni concentrations are observed. In general, Ni concentrations for sites influenced by traffic lie within the range identified for typical urban levels. This further indicates that Ni emissions from the transport sector are unlikely to contribute significantly to ambient levels across Europe.

7.5.2 Profile of Cadmium Emissions from the Transport Sector

A TNO report estimated that up to 18% (36.6 t) of the total Cd released in Europe in 1990 could be attributed to road transport (Berdowski et al, 1997). However, these levels are based upon the use of emission factors derived from studies conducted in the 1970's and early 1980's.

Cd emissions from the transport sector may potentially occur from trace quantities present in the petroleum crude oil feedstock used for fuel and motor oil. Uncontrolled vehicle emissions have decreased in recent years due to the use of catalytic converters and unleaded petrol. Older vehicles and non-maintained vehicles are likely to be the most significant sources of Cd emissions.

Tests on exhaust emissions have been carried out in order to characterise the trace metal concentrations. Cadmium was not present in detectable levels in a particular US EPA study, however the detection limit was not specified. The presence of Cd in vehicle exhaust gases cannot therefore be completely excluded (US EPA, 1993). Emission factors for Cd from different vehicle categories have been estimated to be 0.01 mg/kg of fuel by Concawe (1999b). The emission factors for heavy metals are preliminary estimates only and further measurements are required in order to confirm the values.

Where Cd is present as a trace impurity in tyres, this may also contribute to emissions through tyre wear and the emission of aerosols containing Cd. Contamination of the raw materials used in tyre manufacture could be derived from a number of sources including zinc oxide, steel wiring and the manufacture of carbon black. The most significant source of Cd contamination is likely to originate from the use of zinc oxide which has a typical Cd concentration of 300 ppm. The Cd levels in the tyres would subsequently be in the region of 5-15 ppm. However, taking the UK as an example, tyre wear is identified as contributing less than 1% of the total UK emissions of Cd in 1999 (data from UK National Atmospheric Emissions Inventory).

Comparing the available ambient data for Cd in the Position Paper at traffic sites and urban locations, no significant differences in the range of Cd concentrations are observed. In general, Cd concentrations for sites influenced by traffic lie within the range identified for typical urban levels. Based upon a review of this data, it suggests that Cd emissions from the transport sector do not contribute significantly to ambient levels across Europe.

7.5.3 References

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7.6 Emissions from Ships Burning Bunker Fuel

Shipping may have a significant contribution to nickel ambient air quality in port areas. A study of the contribution of shipping to ambient concentrations of sulphur dioxide (Concawe, 1994) has been used to estimate the accompanying nickel concentrations.

The Concawe report cited a modelling study for 11 major ports (Lowles, 1994). The ports were modelled on a fine gridscale of about 1 x 1 km, and for convenience the total port emissions of SO₂ were represented as a single source located at the centre of activity of the port. However representing the entire emissions from a port complex as a single source tends to overpredict concentrations near the source. As compensation for this the predicted concentrations of SO₂ were averaged based on the eight grid squares surrounding the source, and the results are shown in Table 7.17.

Table 7.17 “Near Source” Annual Mean Concentrations of SO₂ in-Port due to Shipping

	Predicted (point source), µg/m ³	Averaged (adjacent 8 grid squares), µg/m ³
Rotterdam	127	49
Antwerp	42	25
Le Havre	28	19
Europoort	32	15
Southampton	4	4

Note

Based on Figure 12, Concawe 1994

The five ports quoted in Table are those with petroleum refining activity nearby. The study also considered Dover, Felixstowe, Portsmouth and Calais, which had averaged SO₂ concentrations from 8 to 3 µg/m³. These lower values were due to the type of shipping, e.g. ferries, having low activity and quick turnaround. Southampton was said to fall in this category.

The SO₂ data has been translated herein into data for nickel as follows

Section 3.5 of the report (Concawe, 1994) gave sulphur contents and viscosities of bunker fuels at the ports. Those based on residual refinery components were interpreted as an equivalent heavy fraction of crude oil.

Nickel contents were obtained for the crude oils said to predominate the refining slate in The Netherlands (Stigter, 2000), each adjusted to the nickel content of the heavy fraction as bunker fuel, and averaged. This gave an average nickel content of the bunker fuel of 19 ppm.

The nickel ambient air concentrations contributed by shipping in-port were obtained pro rata to the SO₂ ambient concentrations and the bunker fuel sulphur contents, and are given in Table 7.18.

Table 7.18 Derived “near Source” Annual Mean Ambient Concentrations of Nickel in-Port due to Shipping

	Averaged (adjacent 8 grid squares), ng/m ³
Rotterdam	30
Antwerp	16
Le Havre	12
Europoort	9
Southampton	3

Even though the results in Table 7.18 have been adjusted for the sulphur content of the local port bunker fuel, they are based on a common nickel content of bunkers of 19 ppm. Whilst this is unlikely to be the case, nickel contents will generally be expected to be somewhat similar to 19 ppm. As appropriate the results can be pro-rated for alternative nickel contents.

Table has shown the potential for shipping to have a significant local effect on nickel ambient air quality in port areas. This data offers some explanation for the high nickel ambient air quality values of 4.7 to 16 ng/m³ given in Table 8.6 for three sites in the Rotterdam/Europoort area as being due to their proximity to shipping activity, see Table 7.19. These sites are also close to residential/business areas.

Table 7.19 Details of Monitoring Sites

Site	Annual ambient nickel concentration 1998/9, ng/m ³	Location detail
Vlaardingen	4.7	2km north of Maas waterway centreline. Docks and refineries south across waterway
Hoek van Holland	8.6	Adjacent to Maas waterway north bank. Europoort docks to S/SW across waterway
Schiedam	16	Adjacent to <i>Wilhelminahaven</i> dock and 1 km from Maas waterway centreline. Docks and refineries to south of waterway.

Hence ports having similar shipping traffic as Rotterdam, etc. will be expected to have comparable nickel contributions from the shipping. The similarities will include

- time in port e.g. typically 1.5 to 2.4 days
- type of shipping e.g. oil tankers, liquefied gas tankers, other tankers

- in-port fuel consumption by main engines for unloading purposes e.g. 40 – 70 % main engine fuel consumption for oil tankers depending on size, 100% for LNG tankers

For North Sea and Channel ports some improvement may be anticipated due to the limitation of sulphur in bunker fuel to 1.5%. This will be introduced in the NW Europe Special Area under Annex VI to MARPOL; whilst no implementation date has been fixed yet, industry sources anticipate its introduction by 2010. Reducing the sulphur may be accompanied by some reduction in nickel content but it is not possible at present to predict what the reduction, if any, might be. However the sulphur content in bunker fuel for other areas, e.g. Athens, will remain at the current worldwide limit of up to 4.5%, so no reduction in nickel content can be anticipated from this measure. However if the petroleum refineries adopt fuel oil desulphurisation widely to meet ambient nickel air quality requirements (as considered in section 8.1.9), there should be a similar improvement for bunker fuel and shipping would not contribute to an exceedance of a limit of 3 ng/m³.

Therefore, from the above analysis it is clear that whilst ports should be able to comply with a nickel limit value of 30ng/m³ by 2010 with no incremental costs, a limit value of 10ng/m³ may lead to additional costs and benefits, and a limit value of 3 ng/m³ is unlikely to be achievable. However, with the current state of available information it is not possible to quantify such costs and benefits with confidence.

References

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8 Other Processes

8.1 Petroleum Refining

8.1.1 Introduction

Nickel is the key metal of interest for the petroleum refining sector. As will be seen nickel is present in significantly greater quantities than arsenic, cadmium or mercury in those process streams which result in emissions to air from petroleum refining. Consequently achievement of any of the air quality limit values being considered for nickel will ensure that the values for the other metals will also be met by the petroleum refining sector. Hence, this section concentrates on nickel but provides supporting information on the other metals.

Current Legislative Controls

Heavy metals from the petroleum refining sector are not controlled directly. Controls on emissions of particulates will exert some control on heavy metals emissions. Controls on sulphur emissions can lead to accompanying reductions in heavy metals. Hence control legislation comprises:

- Regulation of emissions to atmosphere e.g. integrated pollution control under the Environmental Protection Act, 1990 in the UK, Federal Law on Immission Control (*BImSchG*) in Germany, Air Pollution Act in The Netherlands.
- Large Combustion Plant Directive.
- Air Quality Standards regulations for particulate matter and SO₂.

Future Legislative Controls

Regulatory factors which will have an impact on petroleum refineries in the future include:

- Auto Oil Programme - The EU Auto Oil Programme being brought in from 2000 includes a Directive (1999/32/EC) on the quality of gasoline (petrol) and diesel fuel to be used in vehicles, which introduces stricter specifications for these two fuels. This will result in different processing by petroleum refineries to achieve the new specifications. It is anticipated that some refineries will have to install new or additional processing plant and, as a consequence, their fuel consumption will increase leading in turn to more emissions to air.
- Sulphur Content of Liquid Fuels Directive - The Sulphur Content of Certain Liquid Fuels Directive, 1999/32/EC, reduces the sulphur content of heavy fuel oil from 2003 and of gas oil from 2008.

The heavy fuel oil specification for products can be achieved by selecting crude oils with lower sulphur contents than refined at present, and such a selection could result in a greater proportion of crude oils having lower metal contents being refined than is current. Hence the heavy metals in the petroleum refinery fuel could fall giving lower emissions to air. To meet the gas oil specification there will be some benefit from the lower sulphur crude oils

adopted for the heavy fuel oil, but it is anticipated that some additional process units will also be required. Hence fuel consumption will increase leading in turn to more emissions to air. However, as shown below, the availability of low sulphur crude oils is limited and is expected to decline so nickel contents will rise with the change in crude oil slate. Further not all low sulphur crudes have significantly lower metal contents, so this opportunity would apply only to some petroleum refineries, hence restricting the possibility of reductions in nickel emissions by this route.

It is also likely that due to non-exceedance of SO₂ critical loads, Member States in southern Europe will seek the derogation permitting use of the 3% higher sulphur limit fuel oil in all or part of their territories. Hence for these territories the ambient air nickel quality is unlikely to benefit from the SCLF Directive.

- IPPC Directive - The need to meet BAT requirements under the IPPC process may result in abatement equipment being fitted which carries with it an energy demand. This translates into a higher fuel demand leading in turn to more emissions to air, although conversely the abatement itself may reduce heavy metal emissions. Note that most petroleum refineries generate their own electric power, so if this was to increase, an increase in emissions would still result. In advance of IPPC, to be able to meet present emission obligations in respect of sulphur dioxide emissions, there are some petroleum refineries such as BP Amoco Grangemouth in Scotland that are switching to natural gas as a fuel, e.g. in CHP units, instead of using residual oil. For these refineries there may be a significant reduction in heavy metals emissions.
- Carbon Dioxide Emission Reduction - In view of the interest in reducing emissions of carbon dioxide, any measures taken to achieve reduction will have an impact on petroleum refining fuel usage and heavy metal emissions to air. Until details are clear e.g. whether they affect the fuels produced by the petroleum refining process, or the emissions from the petroleum refineries themselves, it is not possible to comment on the resulting trends in heavy metals emissions from the refineries. See also Section 4 - Kyoto Protocol.
- Proposed Revision to the Large Combustion Directive - See Section 4.
- Air Quality Daughter Directive - See Section 4.

8.1.2 Profile of Sector

Petroleum Refinery Products and Processes

The essential function of petroleum refineries is to produce marketable hydrocarbon-based products and intermediates, principally from crude oils. A petroleum refinery produces a wide variety of products of different specifications including fuels, petro-chemical feedstocks and other products.

In order to produce end products from its feedstocks, a petroleum refinery operates a number of processes. These processes are carried out in a number of installations, or plants, each of which has its own specific function, the output of one installation forming the input of other installations, as well as end products. These installations are supported by a number of other plants which supply utilities for the entire refinery - steam, power, water, hydrogen, etc. Since most of these refinery processes require a lot of energy, most have programmes for heat integration and energy saving.

The major categories of petroleum refinery installations are listed below:

Physical Separation Processes

- Atmospheric distillation
- Vacuum distillation
- High pressure distillation
- Aromatics extraction
- De-waxing/de-asphalting
- Gas separation plant

Processes Which Bring about Chemical Conversions

- Isomerisation
- Alkylation
- Etherification
- Reforming
- Catalytic cracking
- Hydrocracking
- Thermal cracking/visbreaking
- Petroleum coking
- Asphalt blowing

Purification or Treating Processes

- Desalting
- Hydrotreating/hydrodesulphurisation (HDS)/hydrofinishing
- Sour gas concentration (Acid gas removal)
- Sulphur recovery from hydrogen sulphide
- Sour water treatment

Lubricating Oil Refining**Utilities and General facilities**

- Steam and/or power supply
- Refinery liquid/gas fuel system
- Flare system for disposal of vapour releases
- Water, Air, Hydrogen, Nitrogen supply
- Cooling water system
- Wastewater and hydrocarbon slops treatment

Blending, Storage and Loading Facilities**Environmental Controls**

- Aqueous effluent treatment
- Combustion and other air emission controls
- Waste disposal
- Odour and noise control

[Based on an extract from Concawe, 1999a.]

Petroleum Refinery Feedstocks

Crude oils are the principal petroleum refinery feedstock. Crude oils are produced in many parts of the world, with the Middle East being a significant producer. Crude oils are produced in the EU, both onshore and in significant amounts offshore in the North Sea.

Crude oil is a mixture of many different hydrocarbons and small amounts of impurities. Nickel and vanadium are typically the metals with the highest concentrations in crude oils.

The composition of crude oil varies significantly depending on its source. Examples are given in Table 8.1, which also includes some heavy metals information. Information on the heavy metals of interest to this study is given in Table 8.2.

Table 8.1 Information on Crude Oils

Crude Oil	Density	Sulphur, % w/w	Vanadium, ppm	Nickel, ppm
Brent Blend, N Sea	0.835	0.38	3.8	0.8
Nigerian	0.89	0.23	<1	7
Iranian Light	0.853	1.35	34	15
Kuwait	0.868	2.52	30	9

Notes

Data from Concauwe, 1999b and Oil & Gas J, 1983.

Table 8.2 Heavy Metals in Crude Oils^a

Metal as element	Typical range in crude oils, ppm	Lowest value reported, ppm	Highest value reported, ppm
Arsenic	<0.01 – 0.1/0.2	Nil	2.3
	<0.01 – 0.037, average 0.014 ^b	--	--
	<0.0002 – 26.2 ^c		
Cadmium	Not detected	--	--
	0.0004 – 0.0053, 0.0016 average ^b	0.0004 (limit of detection)	--
	<0.0001 – 0.50, typical values 0.0024, 0.050 ^c	--	--
Mercury	<0.05	0.01	29 ^d
	0.0014-0.007 ^e	-	-
Nickel	3 – 25	0.01	150
Nickel in crudes run by surveyed petroleum refineries in Western Europe ^f	3.6 (non weighted average)	0.0	32.0

Notes

a Data from Jones, 1988.

b Data from measurements of eight crude oils (80% of The Netherlands consumption), Stigter, 2000.

c Data from literature cited by Stigter, 2000; includes some references cited by Jones, 1988.

d This is the atypical *Cymric* field, California, which was sited within a deposit of mercury ore.

e Liang, 2000; analyses of limited number of crude oils

f Concawe, 2000a (analyses of various crude oils also quoted)

Based on the petroleum refinery completely utilising their capacities given in Table 8.4 below, the total crude oil consumption of the EU is 586 Mtpa and that of the Accession States is 41 Mtpa, both for the survey year of 1999. The EU total compares with 585 Mtpa for the EU given in Table 6, Concawe, 1999b, and strongly suggests that the petroleum refineries are running very close to 100% capacity. Table 8.3 is a simplification of the actual consumptions and was developed by Concawe for planning purposes; it predicts the EU crude oil slate to change as follows :

Table 8.3 EU Crude Oil Slate Development, 1995 – 2015

Crude oil type	Density	EU Crude oil consumption, Mtpa				
		1995	2000	2005	2010	2015
Light, low sulphur e.g. N Sea	0.835	279	293	239	182	154
Light, naphthenic low sulphur e.g. Nigerian	0.89	28	29	60	91	93
Medium, medium sulphur e.g. Iranian	0.853	112	117	120	122	124
Heavy, high sulphur, e.g. Kuwait	0.868	140	146	180	213	247
Total :		559	585	599	608	618
N Sea crude, % of Total		50	50	40	30	25

Notes

Data from Concawe, 1999b

Whilst Table 8.3 gives an example of an EU slate used for modelling purposes by Concawe, the actual slates run by the individual petroleum refineries will vary considerably as many more crude oils are refined.

Different Types of Petroleum Refineries and Effect on Emissions to Air

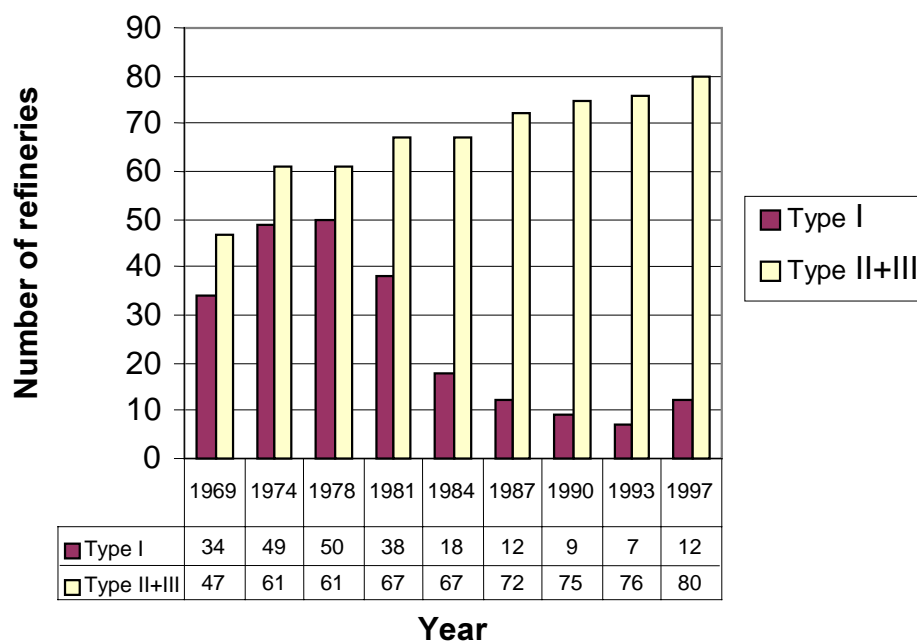
Petroleum refineries vary greatly in their complexity, that is, in the number of different types of operations carried out. The simplest type uses mainly physical separation processes such as distillation with only limited use of conversion processes such as mild hydrotreating and reforming to change the quality or yield of oils processed. These so-called "hydroskimming" refineries carry out very little conversion of products. This means that the types and quantities

of products are largely determined by the composition of the crude oils processed. They cannot be influenced to any great extent by modifying the operating mode of the refinery.

Many petroleum refineries are more complex than hydroskimming types and have "conversion" processes such as catalytic cracking, hydrocracking and visbreaking mentioned previously. These complex petroleum refineries will also retain the elements of a hydroskimming refinery. The principal reason for the use of conversion processes has been to reduce the production of fuel oil on economic and commercial grounds. Fuel oil competes with other fuels such as natural gas and coal, so its pricing is less than that of crude oil. Fuel oil is not a convenient fuel, particularly when compared with natural gas or distillate fuels, as, for example, it requires heating for handling even in summer.

As can be seen from Figure 8.1, the number of simple hydroskimming refineries (called type I) in the EU has decreased over the years. In making more efficient use of the crude, the increasingly deeper conversion units that have been installed in these petroleum refineries have incurred a higher energy consumption. This energy is provided by burning heavy fuel oil in both process heaters and in boilers. The consequence is an increase of atmospheric emissions, and since the majority of the heavy metals supplied in crude oils are contained in heavy fuel oil, their emissions are also increased. There is also a small emission of heavy metals from cat cracking processes.

The situation in the six accession countries is somewhat different. According to the survey used for Table 8.4, there are 11 petroleum refineries. Nine of these are of the hydroskimming variety, whilst two have cat cracking; one of the latter also has hydrocracking and a thermal operation.

Figure 8.1 Increases in the Complexity of European Petroleum Refineries**Notes:**

- Type I: Simple non-conversion refinery: composed of crude oil distillation, reforming, treatment of distillate products, including desulphurisation and/or other quality improvement processes (i.e. isomerisation or speciality manufacturing), e.g. see Figure 8.2.
- Type II: Mild conversion (Type I plus thermal cracking or visbreaking)
- Type III: Complex (Type II plus fluidised cat cracking and/or hydrocracking), e.g. see Figure 8.3.

Figure taken from Concawe, 1999a, Fig A1-5.

Petroleum Refining in the EU and Accession States

Table 8.4 gives the "production" rates for the petroleum refineries in the EU and the Accession States, expressed as feed rate of crude oil, the normal parameter for assessing the capacity of a petroleum refinery. The information was published in December 1999, so is applicable to 1999.

Whilst the table gives the numbers of petroleum refineries for each state it does not detail their size. The refinery capacities vary widely. Taking the UK as an example, and this pattern is reflected in most of the EU, there are a few very large refineries e.g. 2 in the range 12.5 to 15.6 Mtpa, a number of "average" size refineries e.g. five at or about 9 Mtpa, some smaller e.g. two at about 5 Mtpa, and several specialised refineries e.g. for bitumen at 1 Mtpa or smaller. In the Accession states there are fewer petroleum refineries. The larger states have some refineries of comparable capacity to the EU e.g. one of 8 Mtpa in Hungary and one of 13 Mtpa in Poland; the smaller states Cyprus and Slovenia have very much smaller refineries essentially to satisfy domestic consumption.

Table 8.4 Petroleum Refinery Capacities in EU and Accession States

	Number of Petroleum Refineries ^a	Total Capacity, of crude oil fed ^a	BPCD	Total Annual Capacity, Mtpa of crude oil fed ^b
EU Member States				
Austria	1	208,600		10.3
Belgium	5	719,000		35.4
Denmark	2	135,000		6.64
Finland	2	200,000		9.84
France	13	1,901,923		93.5
Germany	14	2,275,300		111.9
Greece	4	382,500		18.8
Ireland	1	71,250		3.51
Italy	17	2,340,600		49.2
Luxembourg	0	-		-
The Netherlands	6	1,187,842		58.4
Portugal	2	304,300		15.0
Spain	10	1,315,500		64.7
Sweden	5	427,000		21.0
UK	11	1,784,672		87.7
Accession Countries				
Cyprus	1	27,000		1.33
Czech Republic	3	186,055		9.15
Estonia	0	-		-
Hungary	3	232,000		11.4
Poland	3	382,000		18.8
Slovenia	1	13,500		0.66

Notes

a Worldwide Refining Survey, Oil & Gas Journal, 1999

b Conversion from BPCD - barrels per calendar day - to Mtpa based on an average density of 0.8496 for EU crude slate for 2,000, Table 6, Concawe, 1999b

Trends in Petroleum Refining

The trend for increasing complexity of the EU petroleum refineries has been described. It can be seen from Figure 8.1 that the move to greater complexity was diminishing in the early 1980s. It may be anticipated that similar drivers for greater complexity that applied in the EU will subsequently apply in the Accession States.

Recent years have seen consolidation of oil companies occurring e.g. the mergers of Chevron with Gulf, CFP Total with Fina and then with Elf, BP with Amoco, and Exxon with Mobil.

This has been accompanied by the closure of a number of petroleum refineries e.g. in the UK those of Gulf at Milford Haven and Shell at Shellhaven. There had been a wave of closures in the 1980s, and the changes in numbers can be obtained, if required, from Figure 8.1. It is not certain whether there will be more refinery closures in the period up to 2010. The EU petroleum refineries are running at close to full capacity, and there is a demand for their products. In such a situation further closures seem unlikely, but economics may dictate otherwise.

The economic situation is difficult to predict. The price of crude oil has been very volatile recently as shown in Table 8.5; and future trends are uncertain. The price for Brent crude in the fourth quarter of 2000 has been in excess of 30 \$/barrel, but has also fluctuated to below this level. The price is controlled on one hand by the level of crude oil production made available by the states in OPEC (*Organisation of Oil Producing Countries*), and on the other by demand or perceptions of upcoming demand.

Table 8.5 Variations in Price of Crude Oil

	1997	1998	1999	2Q99	3Q99	4Q99	1Q00	2Q00
IEA CIF average import	19.11	12.52	17.26	15.11	19.54	23.48	26.82	--
Brent, FOB spot	19.12	12.76	17.86	15.46	20.64	24.06	28.87	28.83
OPEC Basket, FOB spot	18.68	12.28	17.47	15.38	20.01	23.42	26.11	26.32

Notes

Prices in US \$/barrel

Data from IEA, 2000

Brent is a North Sea crude oil

As the petroleum refineries are running at a high utilisation of their capacity, additional demand for their products due to economic growth will eventually require an increase in the available capacity. This in turn would increase heavy metal emissions as a consequence of increased fuel usage by the petroleum refineries.

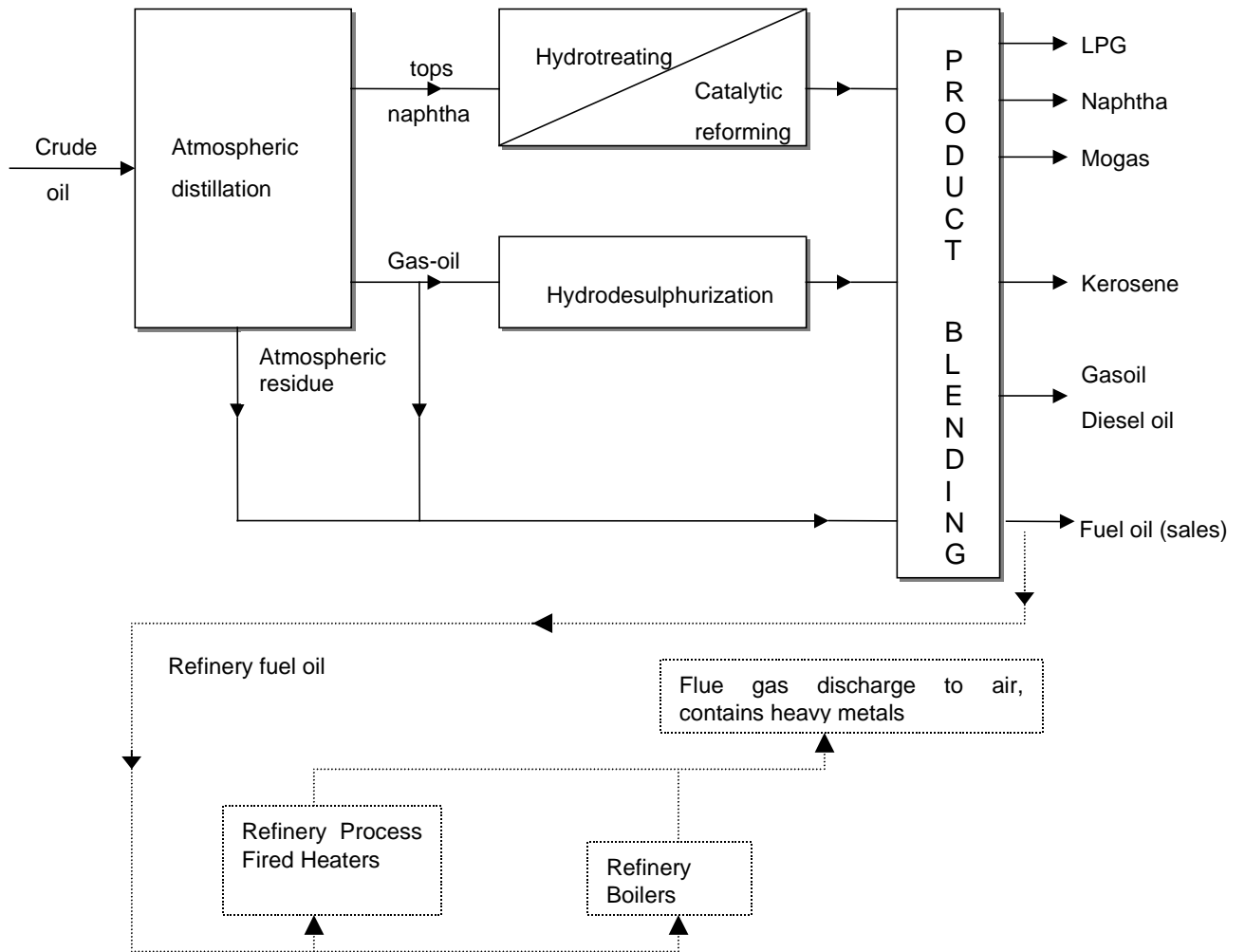
8.1.3 Emission Sources

As shown in Tables 8.1 and 8.2 heavy metals are present in crude oils. Vanadium and nickel are the predominant metallic elements, but a wide range of other heavy metals are also present. These other metals include zinc, titanium, calcium, magnesium, chromium and copper, but in much smaller quantities than vanadium and nickel. Arsenic and mercury are present in very small amounts, typically 0.1/0.2 ppm for arsenic and <0.05 ppm for mercury as shown in Table 8.2 according to the data of Jones, 1988. Cadmium has been quoted as *not detected* by Jones, 1988, but measurements and other literature values are also given. The measurements reported in the work of Stigter, 2000, led the work to suggest that other reported measurements may be too high.

The metals are combined with organics in complex molecules that are essentially non-volatile. Consequently in the refining processes the heavy metals become concentrated in the residual streams. Figures 8.2 and 8.3 (developed from Figures AI-2 and AI-4 in Concauwe, 1999a) show the residual streams. These residual streams are the major component of heavy fuel oils. Note that according to a recent reference cadmium is considered not to be a part of the hydrocarbon matrix, but is present in crude oil as an insoluble, probably inorganic, contaminant (Stigter, 2000); even so it is observed in emissions, see Table 8.9.

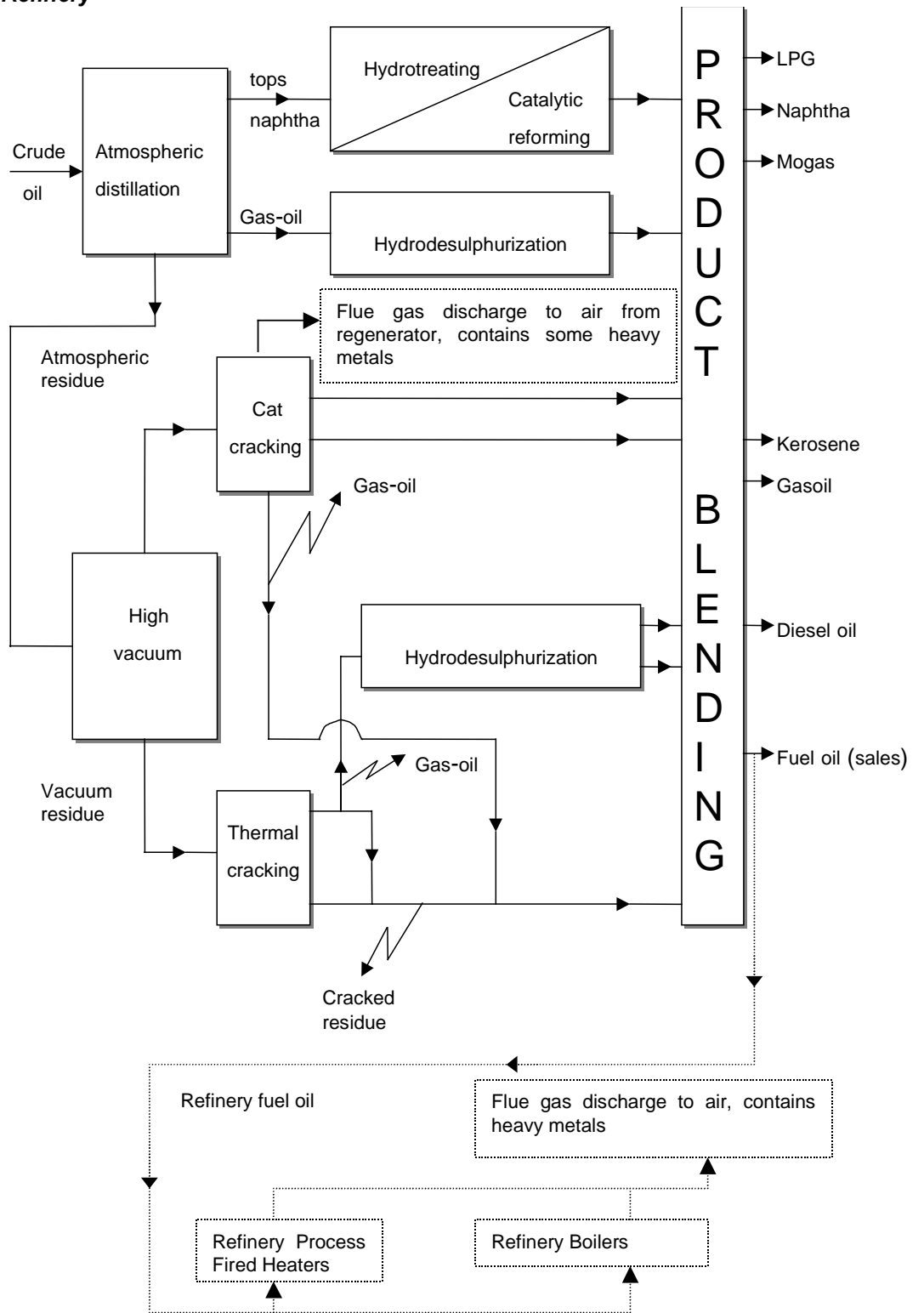
This lack of volatility means that heavy metals are not present in lighter distillates such as those used for production of gasoline and light fuel oils e.g. kerosines and gas oils. There is a little entrainment of residual material in the crude distillation process which will result in very small amounts being present in distillates, especially the gas oil light fuel; estimates by Concauwe, based on mass balances, expect less than 1% of the nickel in crude oil to be present in gas oil light fuel (Concauwe, 2000a). A search of over 100 literature references for heavy metals in distillate fuels has only produced information on nickel in commercial gasoline at up to 0.0004 ppm (Reimer, 1993). So distillate based fuels are not a significant source of emissions of nickel and the other heavy metals. In any case such fuels are not used in significant amounts by petroleum refineries.

Figure 8.2 Typical Flow Scheme for a Hydroskimming Petroleum Refinery



Developed from Figure AI-2, Concaew, 1999a

Figure 8.3 Complex Petroleum Refinery



Developed from Figure AI-4, Concawe, 1999a.

Petroleum refineries use some of their fuel oil production for internal fuel in process fired heaters and boilers. On combustion the heavy metals present are converted into ash and will be released to atmosphere as part of the particulates emission, see Figures 8.2 and 8.3. Ash contents are generally below 0.2% by mass, and apart from vanadium and nickel, sodium, iron and silica also predominate. The other metals originally in the crude oil will be present also and so include those of interest to this study.

The cat cracking process feedstock comprises vacuum distillates, so would contain those small quantities of heavy metal compounds which have some volatility. Atmospheric residue is also added to this feedstock (not shown in Figure 8.3) and it will contain more significant quantities of heavy metals. However as these metals are catalyst poisons, atmospheric residues with lesser quantities of heavy metals e.g. from North Sea crudes, are preferred. In the cracking process some of the feed is deposited as a carbonaceous material on the catalyst, and this deposition will also include some of the heavy metals. The catalyst is regenerated by burning off the carbonaceous deposit. The resulting flue gases are released to air and will contain catalyst fines (there is abatement, such as cyclones, for reduction of particulates emissions). Some of the heavy metals in the feedstocks will leave with these catalyst fines and this is a route for release of nickel to atmosphere (UOP, 2000).

There are 11 petroleum refineries in the EC with petroleum coke plants; there are none in the Accession States (Oil & Gas Journal, 1999). The production of petroleum coke uses residual materials as feedstocks, so heavy metals will be present in the coke product. Fugitive emissions of coke fines and dust are controlled, so this is not a route to ambient air for heavy metals from petroleum refining. If the coke is calcined, there will be abatement controls to limit particulate emissions in the off-gas which is incinerated, and hence heavy metals will be controlled.

Nickel is an active ingredient in fixed bed catalysts used by the petroleum refining industry. The only opportunity for nickel emissions to atmosphere would be on regeneration of these catalysts, which is a short term event that occurs at intervals of at least 6 to 12 months. However, this regeneration is normally undertaken by companies external to the refinery sites, using plant with abatement controls. Hence this is not a route from petroleum refining.

No other potential routes for emissions of heavy metals, with nickel in particular, have been identified. This is supported by discussions with a world wide licensor of a range of petroleum refining processes (UOP, 2000).

Thus it can be seen that the main source of heavy metals emissions from petroleum refining is the flue gases from process fired heaters and boilers, and that they are carried by the particulate matter in the flue gases.

However not all the particulate matter formed in the combustion of fuel oil is emitted. Furthermore, the distribution of heavy metals according to particulate size is not known. Estimates made by Concawe, based on analyses of fuel and stack gases, for their report on nickel emissions (see 8.1.4) suggest that about 50% of the nickel present in the fuel is actually emitted to the surrounding atmosphere (Concawe, 2000). Nickel emission factors given by others have been quoted for fuel oil combustion (Lepicard, 1997). Some of these factors assume that most (90%) or all of the nickel in the fuel is emitted, whilst other factors are based on actual stack gas measurements. Whilst there is comment on various parameters affecting emissions e.g. type of atomisation system, there is insufficient information quoted for the measurements to establish the fraction of nickel in the fuel that is emitted.

8.1.4 Current Air Quality Data

Table 8.6 Nickel

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa)	Reference
Greece	4.5 (average of various daily measurements over 9 months)	1995	Athens	City centre. Hellenic Petroleum Aspropyrgos Refinery ca 20 km SW.		Ministry of Environment, 2000
Greece	9.1 (average of daily measurements in 1 month)	1995	Thesaloniki	City centre. Eko Hellenic refinery/chemical complex ca 15 km W.		Ministry of Environment, 2000
Netherlands	8.6	1998/9	Hoek van Holland, Rotterdam	W of Rotterdam, Approx 4 km North of a number of petroleum refineries		RIVM, 1999
Netherlands	4.7	1998/9	Vlaardingen, Rotterdam	W of Rotterdam, Aprox 3kmN and E of a number of petroleum refineries		RIVM, 1999
Netherlands	16	1998/9	Schiedam, Rotterdam	Further inland in Rotterdam, Approx 4 km NE and E of a number of petroleum refineries		RIVM, 1999
UK	2.99 (1)	1999/2000	Esso Fawley refinery	Nearest sensitive receptor where max concs occur – Residential area 2 km downwind of refinery	177	DETR, 2000
UK	1.69 (1)	1999/2000	Shell Stanlow refinery, neighbouring industrial complex	Fringe of residential area ca 1 kmt to refinery boundary. Downwind of refinery and other industries. Power station and fertiliser plant adjacent but emissions not carried to receptor by prevailing wind	1700	DETR, 2000
UK	1.5 (6 month average)	1996	Texaco Pembroke refinery (2)	Minwear, NE of refinery	453	National Power, 1997

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa)	Reference
UK	2.0 (6 average)	month 1996	Texaco Pembroke refinery (2)	Llanion, refinery near	453	National Power, 1997
UK	1.2 (1 average)	month 1996	Elf Milford Haven refinery	Haverfordwest, near refinery	771	National Power, 1997
UK	1.6 (5 average)	month 1996	Elf Milford Haven refinery	Milford Haven, near refinery	771	National Power, 1997
UK	2.2 (6 average)	month 1996	Texaco Pembroke refinery (2)	Llangwm, N of refinery	453	National Power, 1997
UK	0.95, 0.95, 0.76 Modelled process contributions (peak, 1 km downwind and 2 km downwind respectively)	2000	Texaco Pembroke refinery (2)		453	Estimates from dispersion modelling, excludes background

Notes

1. Preliminary results for the first 8 months of a 12 month project - running mean
2. Texaco in Pembroke is of particular interest because: it has a comparable degree of complexity to many EU refineries, including a cat cracking process and thermal treatment of bottoms products from vacuum distillation; it has an average processing capacity; and it is reasonably modern so should have as good a degree of compliance with BAT as other petroleum refineries.

A report on air quality in the vicinity of oil refineries related to heavy metals, particularly nickel, is being prepared by Concawe. A draft of this report has been made available to the study.

8.1.5 Emission Reduction Techniques

Table 8.7 presents techniques and costs for reducing heavy metal emissions from petroleum refineries. For combustion applications, as discussed in section 8.1.6, abatement of particulates is unlikely to be an appropriate option.

Table 8.7 Summary of Techniques for Reducing Heavy Metal Emissions from Petroleum Refineries

Process	Emission reduction technique	Reduction efficiency	Capital cost	Operating cost
Process fired heaters	Particulate abatement	Not applied to process fired heaters, as particulate loads are generally low.		
	Reburning	To improve burner efficiency and minimise non-ash particulate formation	€m 3 (40 burner installation) (a)	Not applicable
	Lower metals containing fuel oil (as an incidental consequence of meeting lower fuel sulphur content requirements) ^(c)	Depends on crude oil selection to have reduced sulphur content	Not applicable	Depends on higher cost margin for lower sulphur crudes
	Change fuel to natural gas (as an incidental consequence of meeting other limits e.g. lower sulphur oxides emission requirements) ^(c)	100%	Depends on installation costs for supply, may require feeder pipeline.	Depends on differential between purchased natural gas and sale of displaced fuel oil
Boilers	Particulate abatement	<50 mg/m ³ particulates in release, heavy metals undefined	€m 2.5 (1.2 x 10 ⁹ m ³ gas year ⁻¹) (a)	€m 0.2 year ⁻¹ (a)
			€m 6 (5.2 x 10 ⁹ m ³ gas year ⁻¹) (a)	€m 0.2 year ⁻¹ (a)
			€m 4 – 6 (10 ⁹ m ³ gas year ⁻¹) (b)	€m 0.25-0.5 year ⁻¹ (b)
	Lower metals containing fuel oil (as an incidental consequence of meeting lower fuel sulphur content requirements)	Depends on crude oil selection to have reduced sulphur content	Not applicable	Depends on higher cost margin for lower sulphur crudes
Change fuel to natural gas (as an incidental consequence of meeting other limits e.g. lower sulphur oxides emission requirements) ^(c)	100%	Depends on installation costs for supply, may require feeder pipeline.	Depends on differential between purchased natural gas and sale of displaced fuel oil	
Catalytic cracking regenerator flue gas ^(d)	Particulate abatement, Multi-cyclones	50-70%, 60-250 mg/m ³ particulates in release, heavy metals undefined	€m 1-2 (10 ⁹ m ³ gas year ⁻¹) (b)	€m 0.1 year ⁻¹ (b)
	Particulate abatement, Electrostatic precipitator	90-95%, <50 mg/m ³ particulates in release, heavy metals undefined	€m 2.5 (1.2 x 10 ⁹ m ³ gas year ⁻¹) (a)	€m 0.2 year ⁻¹ (a)
			€m 4 – 6 (10 ⁹ m ³ gas year ⁻¹) (b)	€m 0.25-0.5 year ⁻¹ (b)
Particulate abatement (and sulphur oxides control), Wet gas scrubbing	Up to 95%, <50 mg/m ³ particulates in release, heavy metals undefined	€m 4 – 6 (10 ⁹ m ³ gas year ⁻¹) (b)	€m 2-5 year ⁻¹ (b)	

Process	Emission reduction technique	Reduction efficiency	Capital cost	Operating cost
Coke calciner off-gas ^(e)	Particulate abatement for off-gas incinerator, Electrostatic precipitator	90-95%, <50 mg/m ³ particulates in release, heavy metals undefined	€m 2.5 (1.2 x 10 ⁹ m ³ gas year ⁻¹) (a) €m 4 – 6 (10 ⁹ m ³ gas year ⁻¹) (b)	€m 0.2 year ⁻¹ (a) €m 0.25-0.5 year ⁻¹ (b)
	As above, Fabric Filter	<25 mg/m ³ particulates in release, heavy metals undefined	€m 5 (10 ⁹ m ³ gas year ⁻¹) (b)	€m 0.25-0.5 year ⁻¹ (b)

Notes

- Environment Agency, 1999.
- Concawe, 1999a
- The use of natural gas by petroleum refineries is increasing and hence displacing refinery fuel oil, which then has to be sold so the emissions of heavy metals (and other pollutants) are distributed to other locations. The natural gas is used in both combined heat and power plant, which replaces boiler plant, and process fired heaters. The prime environmental benefit of the change to natural gas is the essentially complete removal of sulphur oxides emissions, but heavy metals emissions from fuel oil will also be eliminated.
- Particulate emissions in catalytic cracking regenerator offgas are widely controlled by tertiary cyclones or multi-cyclones. The use of either ESPs or hot ceramic filters is slowly gaining ground. Wet scrubbing is used mainly in the USA. Fabric filters are not suitable for this application due blinding problems, size and inability to cope with upset conditions.
- Coke plants with calciners usually employ ESPs or fabric filters for particulate abatement downstream of the off-gas incinerator.

8.1.6 Future Air Quality Under the Business as Usual Scenario.

Section 8.1.1 presents a summary of future legislative controls that are likely to impact upon heavy metal emissions from petroleum refineries. This section considered some specific issues as discussed below.

Actual particulate emissions from petroleum refinery process heaters are already relatively low e.g. typically 50 mg/Nm³ at 3% oxygen (Environment Agency, 1999). Alternatively, good performance has been quoted as being well below 200 mg/Nm³ (Concawe, 1999a), arguably not very different to ca 50. Older furnaces however may have emissions in the range of 500 to 1000 mg/Nm³ (Concawe, 1999a). It is reasonable to assume that under the business as usual scenario there will be pressure for particulate emissions performance to converge towards the best current performance.

As noted in section 8.1.1 the lower sulphur content crude oils expected to be refined to comply with the SCLF Directive are likely to have lower metal contents than refined at present. However the reduction will not be as great as, or even approaching, an order of magnitude. A proportion of these crude oils are refined already, but the proportions are not uniform across the EU. For example 80% of the crude oil volume refined in The Netherlands comprises many Middle East and other higher metal content crudes, with only one lower metal content North Sea crude (Stigter, 2000). Therefore this aspect could contribute an improvement. It is likely to be

one of the reasons for the differences in emissions observed in Table 8.6. between the UK and The Netherlands.

In addition to a switch to lower sulphur crudes, the SCLF Directive and other policies aimed at reducing SO₂ emissions will ensure that the trend towards displacing residual oil combustion with gas combustion will continue into the future. One refinery in the Rotterdam area expects that by 2007 the nickel emissions from the refinery will have reduced sharply and will equate to emissions from burning gas rather than residual oil. If this trend is repeated for the other refineries in the area then the ambient concentrations of nickel will have declined significantly by 2010. Based on the current air quality in the vicinity of the petroleum refineries in the UK and the significant reductions achievable by displacing residual oil with gas we assume that ambient Ni concentrations of less than 10 ng/m³ could be achieved in the Rotterdam area under the business as usual scenario by 2010. Further consultation with the industry will be required to confirm this viewpoint.

8.1.7 Costs and Benefits of Complying with the Potential Limit Values.

Arsenic and Cadmium

For the petroleum refineries where data is available (Shell Stanlow in UK, Esso Fawley in UK and Rotterdam in NL), arsenic and cadmium concentrations are approximately equal to or below the lowest limit values being considered. Even for sites with higher arsenic or cadmium concentrations, nickel is clearly expected to be the metal of most concern with regard to the potential limit values. Therefore compliance with the lowest nickel limit values should enable compliance with the lowest arsenic and cadmium limit values.

This conclusion is due to their much smaller presence in material leading to emissions in comparison with nickel. For example see the comparison of heavy metal contents in crude oil given in Table 8.2, which shows that arsenic is typically at least one thirtieth of nickel, whilst cadmium is at least one sixtieth. Further support is given by the data in Table 8.8, namely the UK annual emissions from petroleum refining and the observed annual releases for one petroleum refinery which burns fuel oil and has a catalytic cracker.

Table 8.8 Observed Annual Releases of Heavy Metals from Petroleum Refining

Metal	Petroleum refinery combustion emissions for UK, 1996 (t)^a	Emission from a single petroleum refinery (g/year)^b
Arsenic	0.064	7,430
Cadmium	0.019	1,260
Mercury	0.031	<100
Nickel	67.37	453,000

Notes

- a. Environment Agency, 1999
- b. Data from Texaco, 2000

Nickel

The indications from the relatively limited ambient air quality data presented in Table 8.6 are that petroleum refineries could achieve the potential air quality limit values as given in Table 8.9.

Table 8.9 Achievement of Limit Values for Nickel by Petroleum Refineries under the Business as Usual Scenario

Limit Value, ng/m ³	Locality	Comments
3	Fawley, UK	
	Milford Haven, UK	Achievement will be subject to any housing being nearer to source than monitoring sites
	Pembroke, UK	Achievement will be subject to any housing being nearer to source than monitoring sites
	Stanlow, UK	
10	West of Rotterdam and Rotterdam, NL	Hoek van Holland, Vlaardingen and Schiedam – achievement will be subject to any housing being nearer to source than monitoring sites. Extent of natural gas/fuel oil combustion unknown. This is assuming future BAU reductions from displacing fuel oil with gas burning, use of lower sulphur crudes and reductions in shipping emissions (See section 7.6).
30	-	Lower limit value(s) than 30 are expected to be achieved
50	-	Lower limit value(s) than 50 are expected to be achieved

As noted in the table, the extent of fuel oil combustion is not known for the refineries in the Rotterdam area. It is known that natural gas is imported to petroleum refineries in The Netherlands as a significant source of fuel due both to meeting SO_x limits and for economic reasons.

The unpublished report of Concawe is understood to hold the view that a limit value of 30 ng/m³ is reasonable for the majority of petroleum refineries. The extent of fuel oil combustion

versus natural gas imported to these refineries is not known for this conclusion. The degree of abatement is anticipated to be as described by Concauwe (Concauwe, 1999a).

Aspects of Meeting Nickel Limit Values

There are a number of aspects to consider when deriving costs for the petroleum refining industry to achieve the potential limit values for nickel, including :

The Availability of Ambient Air Quality Data for Nickel.

This data is very limited for assessing all the EC and Accession States, for example :

- Some of the data are remote from petroleum refineries, e.g. Greece, so may have other influences e.g. shipping in the Greek case.
- The Rotterdam area data describes an area with a high concentration of petroleum refining, four in number, plus some other energy intensive industries such as petrochemicals. Further, this area potentially has a significant nickel contribution from ships bunker fuel, see section 7.6.

Hence in the absence of more information, this results in an uncertainty which needs to be considered when formulating policy.

Variations in Petroleum Refinery Type and Crude Oil Slate

Petroleum refineries are varied in their complexity i.e. the extent and types of processes operated. They also vary in the types of crude oils run (the crude oil "slate"), and the crude oils themselves are variable in quality e.g. nickel contents. Consequently the ambient air quality data for nickel reported in Table 8.10 shown to meet 3 ng/m^3 will not necessarily be replicated by other petroleum refineries in the EU or the Accession States. These aspects have been given consideration as described in Appendix 3. The trends in nickel ambient air quality due to changes in petroleum refinery type and crude oil slate are summarised by Table 8.10 (Table A7 of Appendix 3).

The variations in petroleum refinery type are accompanied by variations in the percentage of oil fuel fired by the refinery; complex refineries (e.g. Type III of Figure 8.1) have less oil firing than simple refineries and so have the potential for lower nickel emissions. Table 8.10 also includes some directional influence based on dividing Western Europe into four regions (see Appendix 3).

Table 8.10 Factors Influencing Nickel Emissions from Petroleum refineries and Resulting Ambient Air Quality

	Low nickel (low sulphur) crude	High nickel (high sulphur) crude	Regional variation ↓ Mediterranean
Complex refinery	Low nickel emissions	Higher nickel emissions	
Simple refinery	Low/moderate nickel emissions	Highest nickel emissions	
Regional variation	Some Atlantic/some Others, e.g. Scandinavia →	Mediterranean	Mediterranean

To apply quantification to Table 8.10, Appendix 3 has analysed petroleum refinery types, their oil fuel fired, together with the nickel contents of crude oils and their vacuum residua (an oil fuel component). Factors have been derived to compare nickel emissions for different scenarios and so predict nickel ambient air qualities for the scenarios, as given in Table 8.11 (Table A10 of Appendix 3), from a base case of a complex refinery with a low nickel crude meeting a nickel air quality limit of 3 ng/m³, with a background of 1 ng/m³.

Table 8.11 Nickel Ambient Air Qualities for Different Refinery Scenarios

	Low nickel crude oil	High nickel crude oil
Complex petroleum refinery		
Ambient air nickel concentration, ng/m ³	3	5.8 – 19.8
Limit value compliance, ng/m ³ (Note 1)	100% meet 3	30% meet 10 100% meet 30
Simple petroleum refinery		
Ambient air nickel concentration, ng/m ³	6.6	14.4 – 53.6
Limit value compliance, ng/m ³ (Note 1)	100% meet 10	40% meet 30 100% meet 50 (Note 2)

Notes

1. Assuming performance is evenly spread across quoted ranges.
2. A limit of 50 would be expected to be achieved on the basis of proportion of non N Sea in the base case, see discussion below

Table 8.11 shows how the various refinery scenarios result in a wide range of possible ambient air nickel concentrations, and consequent differences in limit values which could be achieved. Whilst the approach to Table 8.11 has been somewhat simplistic and necessarily has been based on averaging of data, it demonstrates that the potentially good performance shown in Table 8.9 for some petroleum refineries in the UK does not necessarily apply uniformly across the EU. The position for the Accession States is anticipated to be represented by the data for the higher nickel crude oil in Table 8.11.

In considering Table 8.11 it should also be noted that the UK crude oil slate is not exclusively based on North Sea crudes as in recent years about 50% has been imported (DUKES, 2000). Some of these imports will be higher nickel content crudes e.g. from the Middle East, but the actual proportions run by the refineries near to the monitoring sites are not available. Consequently the factors used in Table 8.11 may predict a nickel ambient air qualities that are somewhat on the high side. However this aspect does not alter the variability of performance expected across the EU and Accession States. Furthermore, the factors assume, perhaps pessimistically, that there will not be a significant switch to natural gas as a combustion fuel under business as usual commitments.

Reductions Achieved by Abatement

Abatement for control of nickel from petroleum refining is essentially the reduction of particulates in combustion flue gases. Selective removal of nickel from the fuel is not a general realistic option at present. In simple terms, with all other factors being equal, to move from a limit value of 30 to 10 will require a threefold reduction in particulate emissions. Similarly to achieve 3 from 30 requires a tenfold reduction. Actual particulate emissions performance from process heaters is typically 50 mg/Nm³ at best as discussed earlier.

Therefore the best reduction performance that might be expected for process heaters already performing well for particulate emissions would be ca threefold by use of filtration, and achieving an emission of ca 15 mg/m³ is a possibility with fabric or ceramic filters. This is probably too low a limit for use of electrostatic precipitators. However there are process constraints. Many process heaters will have flue gas temperatures at best close to or in excess of those accepted for fabric filters; such temperatures are needed to avoid the sulphuric acid dew point, and heat recovery will often not cool the flue gases sufficiently to even approach these temperatures. Ceramic filters are not appropriate for the flue gas capacities.

The situation is similar with boiler plant, which are said on average to have lower particulate emissions than process heaters (Concawe, 1999a).

It is concluded therefore that particulate abatement would not be a practicable option for process heaters and boilers that are currently performing well, whilst older, poorer performers would be better retrofitted/replaced than by adding abatement. Such measures would be foreseeable under business as usual commitments.

Reductions achieved by change of crude oil

Since the metals contents of crude oils vary, e.g. as shown in Table 8.1, a change of crude oil can achieve a reduction in nickel emission. Generally crude oils with lower sulphur contents have lower metals contents. As described in section 8.1.1 a move to refine more lower sulphur crude oils is anticipated to meet the requirements of the Sulphur Content of Liquid Fuels Directive (SCLF), and this is expected to anticipate any requirements on nickel emissions. However such lower metals containing crude oils are not necessarily sufficiently available or suitably priced (see below) to enable all petroleum refineries who wish to take advantage of them. For example Table 8.3 gives a projected European crude oil slate development which shows a decline in low sulphur crudes refined between 2000 and 2015; note that it was prepared in a study for the effects of Auto Oil 2000 and has not allowed for the SCLF Directive.

If nickel air quality limits were to be achieved by choice of crude oil alone a number of important issues would be raised, namely

- There would be the restrictions on the numbers/types of crude oils which could be run
- The flexibility of petroleum refineries to change crude oils to assist in meeting changes in product slate demand would be reduced, with detriment to economics and the viability of petroleum refining
- There could be significant consequences arising from security of supply of crude

Consequently it is anticipated that for many of the petroleum refineries reductions in nickel emissions will have to be achieved by the other methods outlined herein.

Use of a Replacement Fuel – Natural gas

Natural gas is imported into some petroleum refineries already for use as internal fuel instead of heavy fuel oil e.g. as a means of achieving SO₂ bubble emission limits. However, natural gas supplies may not be adequately available in quantity or location for all petroleum refineries that may wish to use this fuel; this is reviewed below. Furthermore, whilst it does not follow that all the refinery fuel oil has to be replaced, there is the issue of disposing of that refinery fuel which is displaced and the consequent relocation of its nickel emissions. Consumption of such heavy fuel oils by industrial, etc. consumers has declined significantly in recent years in those countries where natural gas is available, whilst smaller industrial and similar users prefer distillate fuels due to advantages in handling, etc., although they are more costly.

Natural gas is an attractive proposition as a replacement fuel as its price is comparable to heavy fuel when compared on a *tonne of oil equivalent* basis. Natural gas is available in most EC member states and some of the Accession States, whether from indigenous production or from imports. Imports are by pipeline and shipments of liquefied natural gas (LNG). Provision for future imports is also in hand e.g. pipelines from North Africa. However, at present Greece, Portugal, Sweden, Cyprus and Slovenia (possibly, no data) have limited or no supplies. (Eurogas, 2000; BP, 2000)

The availability of natural gas for potential use by petroleum refineries and the proximity of a pipeline supply to each refinery has not been investigated in detail. The forecast total demand for natural gas in the EU in 2010 is 425 MTFOE (million tonnes fuel oil equivalent) compared with the 1999 demand of 324 MTOE. Of this increase of 101 MTFOE, 50 MTFOE are additional supplies yet to be defined. (Eurogas, 2000). Petroleum refinery internal fuel oil consumption in 1995 (the most recent survey data) was 1.92% FOE of refinery intake.

(Concawe, 1998) This is a consumption of 11.2 Mtpa of fuel oil for the EU petroleum refineries. This appears to be a relatively small fraction of anticipated growth in demand for natural gas, but a higher fraction of the undefined supplies. In view of the anticipated growth in demand it appears that a demand by petroleum refining in the future could be met.

Alternatively, in the absence of natural gas, it can be argued that a petroleum refinery could use another non-metals containing fuel, such as gas oil or LPG, from its own production. The significantly higher costs of these fuels, approximately twice that of heavy fuel oil, would obviously impose a greater economic burden.

Costs for Meeting Nickel Limit Values

The following options, their consequences and resulting costs, for meeting nickel limit values by petroleum refineries are considered.

- Use of natural gas and displacement of refinery fuel oil
- Implication for selling displaced high sulphur refinery fuel oil
- Sales and desulphurising the refinery oil to SCLF Directive limits
- Additional benefit of desulphurising refinery fuel oil
- Use of the refinery fuel oil in a gasification plant
- Use of lower sulphur crude oil with low nickel content

These options, their consequences and the nature of their costs are summarised in Table 8.14 in the final sub-section.

It should be noted that some of the options will also reduce SO_x emissions, so some of the costs may be incurred for other reasons, e.g. meeting the SCLF Directive, or the new Large Combustion Plant Directive.

Use of Natural Gas

Natural gas and fuel oil have similar pricing structures. However both vary seasonally and fuel oil can be influenced by fluctuations in crude oil pricing. Natural gas can cost in the region of 10 – 20 \$/tFOE more than fuel oil. On the basis of a higher price for natural gas of 10 \$/tFOE, the cost for replacing the 11.2Mtpa of fuel oil used by EU petroleum refineries (see above) would be €m 112 pa for the EU. Similarly for the Accession States the amount for disposal would be approximately 0.79 Mtpa, with a replacement cost of €m 7.9. (For comparison a margin of 10\$/t is typical of that between 1% sulphur fuel and 3.5% sulphur fuel (Entec, 1999). 1% sulphur fuel oil is more competitive with alternative fuels than is 3.5%).

Depending on the source point for the supply of natural gas a delivery pipeline may be required. Typically installation of a pipeline for a distance of 100km and local refinery installation will have a capital cost of €m 15 nd an annualised capital cost of €m 1.4pa (with mid-range discount of 4% and 15 year economic life). The actual requirements will vary significantly according to the circumstances of each petroleum refinery. Without the benefit of a detailed analysis of these circumstances, it is proposed that these capital costs be estimated as applying only to 15% of the refineries or one per state with refineries i.e. 14 for EU and 5 for the Accession States. Hence capital costs become

EU – €m 210 total capital, €m 19.6 annualised

Accession States - €m 75 total capital, €m 7 annualised

Disposal of displaced refinery fuel oil – potential sale costs

The fuel oil market has been declining over the years so it is unlikely that the quantity of displaced refinery fuel oil will be readily marketable in the EC. One disposal prospect is export outside the EC provided that there are no quality constraints such as sulphur content limits. Fuel oils are exported from the EC and in some cases up to 45% of production has been exported (Concawe, 2000a). The disposal of significantly increased volumes in the marketplace would be expected to be at a lower unit price than the purchase of natural gas. For this report a differential in the unit prices equal to US\$10/t has been taken, and differences in calorific value per unit mass for the two fuels have been ignored. (For comparison this margin is typical of that between 1% sulphur fuel and 3.5% sulphur fuel (Entec, 1999). 1% sulphur fuel oil is more competitive with alternative fuels than is 3.5%).

For the 11.2 Mtpa of fuel oil used by EU petroleum refineries (see above) this disposal cost amounts to €m 112 pa for the EU. Similarly for the Accession States the amount for disposal would be approximately 0.79 Mtpa, with a disposal cost of €m 7.9.

Disposal of displaced refinery fuel oil – meeting sulphur content limits

Any sale of refinery fuel oil will have to meet prevailing quality standards. In the EC the SCLF Directive will limit the sulphur content of fuel oil to 1% from 2003, except for those territories able to obtain a derogation from this limit, as described previously. To meet this limit for sales of refinery fuel oil the most likely technical option would be to desulphurise the refinery fuel oil, for which the appropriate process would have to be installed for use by probably all petroleum refineries affected. Currently there is very little fuel oil desulphurisation capacity installed in the EC; there are a number of plants in the USA and Japan. The technology is expensive as high pressures are involved, the plants are constructed in special alloys, and the demand for hydrogen usually requires installation of a hydrogen production plant which is also an expensive item.

To provide guidance on the implication of displacing refinery fuel to satisfy nickel ambient air limits and meeting SCLF Directive requirements for sulphur content costs have been developed for the desulphurisation of the fuel oil. The basis is that all the refinery fuel that is displaced needs to meet SCLF Directive limits; this does not apply to all petroleum refineries. The numbers of petroleum refineries are based on an estimate of those complex refineries which would not be running significant amounts of North Sea crude, using crude oil consumption for 2010, and all simple petroleum refineries. This basis for numbers corresponds to petroleum refineries which are not described by the base case of Table 8.11, i.e. not meeting 3 ng/m³ nickel limit value. The basis of the costs is published information for residue desulphurisation (Concawe, 1993). The capital and operating costs have been adjusted to present day costs, but the commercial benefits values were not adjusted being relatively similar to current margins. The costs are approximate and do not fully take into account the effect of plant capacity on capital costs (larger plants are cheaper on a unit basis expressed as feed). One aspect of this is whether the refinery would also be desulphurising its “normal” sales of production fuel oil. This would increase the individual plant capacity and so reduce the unit capital costs. The consumption of refinery fuel has been derived by allocating the EC and Accession States the same proportion of complex and simple petroleum refineries as used in Appendix 3, fuel consumption for the two types is also taken from Appendix 3 in conjunction with published refinery consumption

(Concawe, 1998). The capital and operating costs, together with commercial benefits that accrue, are given in Table 8.12. The commercial benefits quoted arise because in the desulphurisation process some of the fuel oil is converted to lighter, more valuable products; the commercial benefits values derive from the better prices obtained for these products.

Some Member States may seek the derogation of the SCLF Directive allowing production of fuel oil at a higher sulphur content, as described above. Thus some petroleum refineries in those states may not need to desulphurise their internal fuel oil for sales purposes. This aspect has been included in the costs given in Table 8.12 by a reduction in the number of petroleum refineries.

**Table 8.12 Costs for Desulphurising Refinery Fuel Oil for Sale for Petroleum Refineries
Anticipated not to Currently Meet 3ng/m³ Nickel Air Quality Limit**

	Number of refineries	Capital costs, €m	Operating costs, €m pa	Commercial Benefits, €m pa
EU				
Complex petroleum refineries	35	1348	131	81
Simple petroleum refineries	22	1925	188	115
Totals	93	4914	479	294
Accession States				
Complex petroleum refineries	6	165	16	10
Simple petroleum refineries	5	263	26	16
Totals	11	428	42	26
EU with SCLF Directive derogation permitting higher sulphur fuel oil				
Complex petroleum refineries	16	671	65	40
Simple petroleum refineries	6	527	51	32
Totals	22	1198	116	72

It should be noted that with the requirements of the SCLF Directive applying in 2003, any improvements made to meet the requirements of that Directive may reduce the need to incur to these costs. Similarly there may be obligations under the new Large Combustion Plant Directive. No estimate has been made herein of any such reduction in costs.

Disposal of displaced refinery fuel oil – additional benefit of desulphurisation

The process for desulphurising refinery fuel oil reacts the oil with hydrogen in the presence of a catalyst. The available technology uses either fixed beds of catalyst or “ebullated” beds. In both types the heavy metals are retained in the pores of the catalyst. In the fixed bed arrangement the catalyst will become deactivated by accumulation of the metals over time and will then need to be replaced. The ebullated bed arrangement allows some of the catalyst to be

removed and replenished without interrupting the plant operation. In both types the net result is a high degree of de-metallisation of the fuel oil product. The nickel would leave with the spent catalysts for disposal off-site.

Consequently if the residue desulphurisation process was adopted there would not appear to be any need to sell the treated fuel oil as it would now be much lower in nickel content and so could be used for fuel within the refinery, and the refinery would be expected to meet an ambient air nickel limit value of 3 ng/m³, provided the neighbouring background level is acceptably low.

Due to the production of some lighter more valuable products by the desulphurisation process, mentioned above, there would be a shortfall of about 18% in the quantity of desulphurised, de-metallised refinery fuel oil produced. This could be compensated for by desulphurising additional fuel oil intended for sale; this in turn would require a larger process unit capacity and result in higher costs. However there would be a significant advantage with this option as the potential difficulties associated with selling displaced refinery fuel oil are removed and additional gas supplies would not be required.

Disposal of displaced refinery fuel oil – gasification

The displaced refinery fuel oil could be fed to an on-site gasification unit to produce synthesis gas, which could be used as fuel gas by the refinery e.g. in heaters, boilers, co-generation of electricity via gas turbines, or as a feedstock for chemicals manufacture. The principle of the gasification process is partial combustion of the oil in a restricted oxygen atmosphere. There are various processes available. The heavy metals constituents of the fuel oil, including the nickel, would be released from the process in a reject solid waste stream for disposal. Thus if the gas were used in combustion processes there would be no emission of nickel. However there would be significant amounts of sulphur as SO_x and, typically, the gas steam would be treated for its removal.

Gasification processes are expensive in terms of capital and operating costs, so they are considered to have little or no cost benefit in comparison with the fuel oil desulphurisation option described above. However there would be a significant advantage with this option as, with the use of the gasification product within the refinery, the potential difficulties associated with selling displaced refinery fuel oil are removed.

Lower Sulphur Crude Oil

Refining a lower sulphur crude oil will usually have the benefit of a reduction in metals content. A premium cost for lower sulphur crude oil in 1999 was 0.5\$/barrel or ca €3.5/t (Entec, 1999). Hence operating costs for a petroleum refinery of 6 Mtpa capacity would be €m 21pa.

With the increase in crude oil prices the margin will increase. As shown in Table 8.5 in 2000 the margin between Brent, a North Sea low sulphur, low nickel crude, and the higher sulphur OPEC Basket is ca \$2.5/barrel. Hence the operating costs for the above complex petroleum refinery would rise to €m 105pa and to €m 53pa for the simple refinery.

However, it is assumed that any switches to lower sulphur crude oil will already have been undertaken to comply with the fuel oil and gas oil sulphur limits in the SCLF Directive. Furthermore, as discussed above, the ongoing availability of low nickel (and low sulphur crudes) will be insufficient to enable compliance with the limit values for all petroleum refineries. Consequently potential total costs for the EC and Accession States have not been calculated.

Summary of options, consequences and costs

Table 8.13 Summary of options, consequences and costs for petroleum refineries to meet nickel limit values.

Option	Consequence	Cost aspects
Replace refinery fuel oil with natural gas	Need to sell displaced refinery fuel oil	Potential higher cost of natural gas compared to fuel oil Capital costs of natural gas pipeline connection
	May need to desulphurise displaced refinery fuel oil for sale to meet sulphur limits e.g. SCLF Directive. Fuel oil becomes de-metallised	Capital and operating costs incurred, some benefits arise due to yield in process of some lighter, more valuable products
Use desulphurised refinery fuel oil in petroleum refineries	Additional fuel oil needed due to yield loss in process, and larger process units	Desulphurisation costs rise due to need for larger process units
	Eliminates problems with selling displaced volumes of refinery fuel oil	
Gasification of refinery fuel oil	Potential use as fuel in refineries	Capital and operating costs incurred
	Eliminates problems with selling displaced volumes of refinery fuel oil	
Low nickel crude oil	Crude oil supply insufficient for all petroleum refineries and declining in quantity so majority of petroleum refineries will need to adopt another option	Potential marginal higher cost of low nickel crude compared to other crudes

On the basis of our investigations and for the purposes of this study a somewhat simplified assumption for the most likely compliance technique selected to comply with potential air quality limit values for nickel will be the desulphurisation of the refinery fuel oil followed by on-site combustion. Due to the unique circumstances of each refinery, in practice a range of compliance techniques would be likely; however these assumptions are considered to provide a reasonable indication of potential compliance costs. These costs are given in Table 8.14 on an annualised basis; an allowance has been made for the larger capacity of process unit required to supply the required refinery fuel oil demand and avoid any shortfall as described above.

Table 8.14 Annualised costs for desulphurising refinery fuel oil in EC and Accession States (Note 1)

	Low nickel crude oil		High nickel crude oil		Total costs, €m
	Costs, €m pa	Refinery numbers	Costs, €m pa	Refinery numbers	
Discount rate 2%					
Complex petroleum refineries	0	36	217 (Note 3)	41	217
Simple petroleum refineries	120	8	193 (Note 2)	19	313
Totals	120	44	410	60	530
Discount rate 4%					
Complex petroleum refineries	0	36	235 (Note 3)	41	235
Simple petroleum refineries	131	8	210 (Note 2)	19	341
Totals	131	44	445	60	576
Discount rate 6%					
Complex petroleum refineries	0	36	254 (Note 3)	41	254
Simple petroleum refineries	141	8	227 (Note 2)	19	368
Totals	141	44	481	60	622

Notes

1. Based on a 15 year economic life. For a 20 year economic life multiply the costs by 0.83.
2. Apply factor of 0.6 to derive compliance cost for meeting 30 ng/m³ and 1.0 for lower limit values (See Table 8.12).
3. Apply factor of 0.7 to derive compliance cost for meeting 10 ng/m³ and 1.0 for meeting 3ng/m³ (See Table 8.12).

The benefits as a result of the above investments can be estimated from the results of modelling a representative complex refinery located in the UK and using low nickel crude. For this refinery the average contribution from the refinery to ambient nickel concentrations within 10km of the site (to ensure that good coverage is achieved of the most significant areas likely to experience benefits) is approximately 1.1 ng/m³.

The summarised benefits for the above investments to reduce nickel emissions, considering the same size area of interest, are detailed in the following table:

**Table 8.15 Quantified Benefits of Desulphurising Refinery Fuel Oil in EC and Accession States
(Note 1)**

Low nickel crude oil				High nickel crude oil			
Refinery numbers	Average reduction in Ni conc ⁿ within area of interest due to compliance techniques (ng/m ³) (Note 2)	Total reduction in cancers per annum (Note 3)	Valuation of reduction in cancers (€m per annum) (Note 4)	Refinery numbers	Average reduction in Ni conc ⁿ within area of interest due to compliance techniques (ng/m ³) (Note 2)	Total reduction in cancers per annum (Note 3)	Valuation of reduction in cancers (€m per annum) (Note 4)
Complex petroleum refineries	36	No additional techniques to comply with 3ng/m ³ nickel	0	0	41	11.2 (to comply with 3ng/m ³)	0.09 (low est) 0.18 (best est) 0.44 (high est) (Note 6)
Simple petroleum refineries	8	5.1 (to comply with 3ng/m ³)	8.7x10 ⁻³	7.8x10 ⁻³ (low est) 0.016 (best est) 0.038 (high est)	19	35.2 (to comply with 3ng/m ³)	0.13 (low est) 0.25 (best est) 0.62 (high est) (Note 5)
Totals	44		8.7x10 ⁻³	7.8x10 ⁻³ (low est) 0.016 (best est) 0.038 (high est)	60		0.22 (low est) 0.43 (best est) 1.06 (high est)

Notes

1. Quantified health effect benefits for the metals of interest relate to carcinogenic effects only as information on ambient concentrations in the vicinity of sites in this sector suggests that the non carcinogenic effect critical concentrations are not exceeded (See Section 10.1.2).
2. Assuming that the majority of nickel emissions from the refinery are abated by this compliance technique. The concentration is based on the modelled result of 1.1 ng/m³ for the complex refinery using low nickel crude oil and scaled according to the mid-range relative ambient nickel concentrations in Table 8.12, and accounting for the background contribution (assumed equal to 2 ng/m³).
3. Assuming a generic population density suitable for scaling across the sector of 150,000 within a radius of 10km – based on average data for 7 industrial sites considered in this study. These figures are based on a unit risk factor for nickel of 1x10⁻⁴ (which is applicable to general exposure to nickel, not including exposure to nickel sub-sulphide which is only relevant to certain nickel processes).
4. See Section 10.2 for details of valuation methodology.
5. Apply factor of 0.6 to derive valuation for meeting 30 ng/m³ and 1.0 for lower limit values (See Table 8.12).
6. Apply factor of 0.7 to derive valuation for meeting 10 ng/m³ and 1.0 for meeting 3ng/m³ (See Table 8.12).

Whilst the above table shows that the costs outweigh the specific quantifiable benefits of the reduction in cancers due to Ni exposure there will be other important secondary benefits of the heavy metal air quality limit values. The benefits due to these other effects will clearly improve the balance towards the benefits, although by how much is not possible to fully quantify with the currently available information. These additional benefits include:

- Reduced carcinogenic effects associated with exposure to arsenic and cadmium (although these are less significant relative to nickel for this sector);
- Reduced adverse health effects due to reductions in exposure to other metals;
- Reduced mortality and morbidity effects due to reductions in exposure to PM₁₀;
- Reduced adverse impacts on ecosystems and crops; and
- Reduced occupational exposure to carcinogenic metal pollutants.

8.1.8 References

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8.2 Cement Manufacture

8.2.1 Introduction

The metals being considered for the cement manufacturing sector are arsenic, cadmium, nickel and mercury. The bulk of the analysis will be based on the first three metals because potential limit values have been proposed for those metals.

Current Legislative Controls

Heavy metal emissions from cement processes can be controlled directly, or through controls on emissions of particulates or other pollutants they can be controlled indirectly. Current control legislation includes:

- Regulations of emissions to atmosphere at a Member State level e.g. Integrated Pollution Control under the Environmental Protection Act, 1990 in the UK, Federal Law on Immission Control (*BImSchG*) in Germany, Air Pollution Act in The Netherlands.
- Air Quality Standards regulations for particulate matter and lead.
- For cement kilns burning certain types of wastes: the current Municipal Waste Incineration Directive and the current Hazardous Waste Incineration Directive.

Future Legislative Controls

Regulatory factors which will have an impact on heavy metal emissions in the cement sector in the future include:

- IPPC Directive – the need to meet BAT requirements (see Section 4).
- For cement kilns burning any types of wastes - the proposed Waste Incineration Directive will apply (see Section 4). Limit values are set for all the metals of interest to this study as well as particulates. A comparison of particulate limit values is shown in Table 8.8
- UNECE Heavy Metals Protocol – the need to meet BAT requirements plus emission limit values (see Section 4).
- Air Quality Daughter Directive limit values for PM₁₀ and lead (see Section 4).

Table 8.16 Comparison of Emission Limit Values for Cement Co-incineration Processes

Country and national law	Particulates (mg/m ³)
Proposed Waste Incineration Directive	30 Daily
The Netherlands - Process authorisation limits	30 (100% compliance) 18 (97% compliance)
Germany - 17 th BImSchV and process authorisation limits	20 to 40
Denmark - Process authorisation limits	50
Sweden - Process authorisation limits	50

8.2.2 Profile of Sector

Cement production was carried out in 252 installations in the European Union in 1995, with a total production of 172 million tonnes. The table below shows the current or recent number of cement plants in EU and accession countries.

Table 8.17 – Cement Plants in EU and Accession Countries

Country	Cement plants (with kilns)	Year
Austria	9	2000
Belgium	8	2000
Cyprus	8	2000
Czech Rep		
Denmark	1	2000
Estonia		
Finland	2	2000
France	42	2000
Germany	77	2000
Greece	8	1995
Hungary	5	1999
Ireland	2	2000
Italy	94	2000
Luxembourg	1	2000
Netherlands	1	2000
Poland	21	2000
Portugal	6	1995
Slovenia		
Spain	37	1995
Sweden	3	1995
UK	23	1995

(Source: European Commission, 2000; and information collected by Entec)

There are a number of different kiln types used in cement manufacture, the choice of which has traditionally been based on raw material availability. These kiln types are wet, dry and semi-wet and semi-dry. Wet kilns feed their raw materials as a slurry. Additional heat is required to drive off the moisture, which increases the energy requirement of the process. As cement kilns

are very energy-intensive, with fuel costs typically 30-40% of production costs, a large number of kilns have converted to the dry process, which uses less energy. In Europe at present, 78% of the cement production is in dry kilns, 16% in semi-wet and semi-dry kilns, and only 6% in wet kilns. It is expected that all the non-dry kilns will convert to the dry method when they are renewed, and the use of a dry kiln is considered to be BAT (European Commission, 2000).

8.2.3 Emission Sources

All cement processes (whether wet or dry) use the same basic principles for cement manufacture. The raw materials, such as chalk and limestone, are ground and blended. They are then heated to 800-900°C, at which temperature calcination occurs. The calcium carbonate in the raw mix is dissociated into calcium oxide (lime), which remains in the mix, and carbon dioxide (CO₂), which is driven off as a gas. Following calcination, further heating increases the temperature to 1300-1400°C, at which point clinkering occurs, when the calcium oxide reacts with various materials to form cement clinker. The cement clinker is then cooled and ground with gypsum and other additives to form finished cement.

The major pollutants of concern at cement works are nitrogen oxides (NO_x), sulphur dioxide (SO₂) and dust/particulates. Heavy metal emissions are not considered to be as much of a priority, although they are still of concern. All raw materials and fuels at cement works contain metals, which can be categorised into three classes:

- Non-volatile metals, including arsenic and nickel
- Semi-volatile metals, including cadmium
- Volatile metals, including mercury

These three types of metals behave differently in a cement kiln. The cement clinker acts as a dry scrubber and is very alkaline, meaning that acid gases and non-volatile heavy metals will combine with it and exit the system bound into the cement. Semi-volatile metals can become a gas during the clinkering phase, but condense on the raw material, meaning that they remain within the system and are mainly removed in the clinker. Volatile metals become a gas at lower temperatures and can either condense on raw materials or be emitted with the flue gases. A small proportion of mercury is retained in the clinker.

It is not considered that there is a major difference in heavy metal emissions between the different process types (e.g. wet or dry kilns), or between kilns burning different fuels (e.g. conventional fuels or waste derived fuels). This is because it is the raw material input and not the process type which has the greater effect on heavy metal emissions (Cembureau, 2000).

Emissions data for cement kilns operating in Europe are shown in the table below. This information is taken from the BREF note. The table also includes the range of emissions experienced in UK kilns in 1998, as shown on the Environment Agency public register. The two data ranges have been combined to produce a consolidated range of emissions typically experienced in European cement kilns, shown in the right-hand column:

Table 8.18 Range of Metal Emissions from European Cement Kilns

Metals	Europe			UK	Assumed range for Europe
	mg/Nm ³	mg/tonne clinker	kg/year	kg/year	kg/year
Hg, Cd, Tl	0.01-0.3	20-600	20-600	1-70	1-600
Cd (1)	0.002-0.07	5-138	5-138	0.2-16	0.2-138
Hg (1)	0.008-0.23	15-456	15-456	0.8-53	0.8-456
Tl (1)	0.0001-0.003	0.2-6	0.2-6	0.01-0.7	0.01-6
As, Co, Ni, Se, Te	0.001-0.1	2-200	2-200	1-200	1-200
Sb, Pb, Cr, Cu, Mn, V, Sn, Zn	0.005-0.3	10-600	10-600		10-600

Source: European Commission, 2000

Note

- 1) Hg and Cd/Tl have been separated based on a pro rata approach using a sample of Cd, Hg and Tl emissions at 11 European cement works using a range of processes and fuel types

8.2.4 Current Air Quality Data

Table 8.19 Arsenic

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa)	Reference
EU	Modelled process contributions (peak concentrations with min and max heavy metal emissions of European plants) 0.003 to 0.5	2000	Generic site	Generic European site with minimum and maximum heavy metal emissions	1-200	Estimates from dispersion modelling, excludes background
EU	Modelled process contributions (peak concentrations complying with Waste Incineration Directive) 1.1 – although actual max is 0.5	2000	Generic site	Generic European site with maximum heavy metal emissions complying with Waste Incineration Directive	438 WID Concentration limit 0.5 mg/m ³ (in combination with Nickel plus Sb, Pb, Cr, Co, Cu, Mn and V)	Estimates from dispersion modelling, excludes background
Germany (1)	Modelled process contributions (peak concentrations) 0.012	1998	Rüdersdorf	Estimates from dispersion modelling carried out by the company	0.002 mg/Nm ³	Readymix Zement, 2000, from their dispersion modelling, excludes background
UK (2)	1.1 (3)	1999/2000	Castle Cement, Padeswood	Nearest sensitive receptor where max concs occur- Small residential area 1.35 km East of cement stack	1.6	DETR, 2000

Notes

- 1) Dry process kiln using a range of alternative fuels in addition to conventional fuels
- 2) Plant with two wet kilns and one dry kiln using conventional fuels
- 3) Preliminary results for the first 7 months of a 12 month project - running mean

Table 8.20 Cadmium

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa)	Reference
EU	Modelled process contributions (peak concentrations with min and max heavy metal emissions of European plants) 0.0007 to 0.35	2000	Generic site	Generic European site with minimum and maximum heavy metal emissions	0.2-138	Estimates from dispersion modelling, excludes background
EU	Modelled process contributions (peak concentrations complying with Waste Incineration Directive) 0.11	2000	Generic site	Generic European site with maximum heavy metal emissions complying with Waste Incineration Directive	44 WID Concentration limit 0.05 mg/m ³ (in combination with TI)	Estimates from dispersion modelling, excludes background
Germany (1)	Modelled process contributions (peak concentrations) 0.014	1998	Rüdersdorf	Estimates from dispersion modelling carried out by the company, excludes background	0.003 mg/Nm ³	Readymix Zement, 2000
UK (2)	0.35 (3)	1999/2000	Castle Cement, Padeswood	Nearest sensitive receptor where max concs occur- Small residential area 1.35 km East of cement stack	5.87	DETR, 2000

Notes

- 1) Dry process kiln using a range of alternative fuels in addition to conventional fuels
- 2) Plant with two wet kilns and one dry kiln using conventional fuels
- 3) Preliminary results for the first 8 months of a 12 month project - running mean

Table 8.21 Mercury

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa)	Reference
EU	Modelled process contributions (peak concentrations with min and max heavy metal emissions of European plants) 0.002-1.14	2000	Generic site	Generic European site with minimum and maximum heavy metal emissions	0.8-456	Estimates from dispersion modelling, excludes background
EU	Modelled process contributions (peak concentrations complying with Waste Incineration Directive) 0.11	2000	Generic site	Generic European site with maximum heavy metal emissions complying with Waste Incineration Directive	44 WID Concentration limit 0,05 mg/m ³	Estimates from dispersion modelling, excludes background
Germany (1)	Modelled process contributions (peak concentrations) 0.252	1998	Rüdersdorf	Estimates from dispersion modelling carried out by the company	0.040 mg/Nm ³	Readymix Zement, 2000, from their dispersion modelling, excludes background
UK (2)	0.36 (3)	1999/2000	Castle Cement, Padeswood	Nearest sensitive receptor where max concs occur- Small residential area 1.35 km East of cement stack	5.7	DETR, 2000

Notes

- 1) Dry process kiln using a range of alternative fuels in addition to conventional fuels
- 2) Plant with two wet kilns and one dry kiln using conventional fuels
- 3) Preliminary results for the first 7 months of a 12 month project - running mean

Table 8.22 Nickel

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa)	Reference
EU	Modelled process contributions (peak concentrations with min and max heavy metal emissions of European plants) 0.003 to 0.5	2000	Generic site	Generic European site with minimum and maximum heavy metal emissions	1-200	Estimates from dispersion modelling, excludes background
EU	Modelled process contributions (peak concentrations complying with Waste Incineration Directive) 1.1 – although max actual is 0.5	2000	Generic site	Generic European site with maximum heavy metal emissions complying with Waste Incineration Directive	438 WID Concentration limit 0,5 mg/m ³ (in combination with Arsenic plus Sb, Pb, Cr, Co, Cu, Mn and V)	Estimates from dispersion modelling, excludes background
Germany (1)	Modelled process contributions (peak concentrations) 0.050	1998	Rüdersdorf	Estimates from dispersion modelling carried out by the company	0.006 mg/Nm ³	Readymix Zement, 2000, from their dispersion modelling, excludes background
UK (2)	0.92 (3)	1999-2000	Castle Cement, Padeswood	Nearest sensitive receptor where max concs occur- Small residential area 1.35km East of cement stack	<10	DETR, 2000

Notes

- 1) Dry process kiln using a range of alternative fuels in addition to conventional fuels
- 2) Plant with two wet kilns and one dry kiln using conventional fuels
- 3) Preliminary results for the first 8 months of a 12 month project - running mean

The emissions data and ambient concentrations shown in the tables above are considered to be representative of the cement sector in Europe. They include actual emissions from both wet and dry kilns and from kilns burning a variety of fuel types as well as hypothetical data based on information in the BREF note.

8.2.5 Emission Reduction Techniques

All cement plants will be required to use BAT, although methods specifically for heavy metals are not specified in the BREF note as they are not considered to be a major pollutant from the cement process. The best way to reduce heavy metal emissions is to avoid using feed materials with a high content of volatile metals such as mercury. Mercury can build up over time in the cement kilns dust, which is usually returned to the kiln system. When high build-ups occur in the dust, emissions may increase. This can be remedied by discarding the cement kiln dust rather than returning it to the raw meal.

As metals are often bound to dust, particulate abatement methods will help to reduce emissions. Particulate abatement is an important issue for cement plants. The table below shows the abatement methods described in the BREF note. Using electrostatic precipitators and bag filters ensures dust releases can be reduced to levels where they cease to be significant, with some plants achieving emission levels below 10 mg/m³ (European Commission, 2000).

Table 8.23 Techniques for Controlling Emissions

Process	Emission reduction technique	Reduction efficiency	Capital cost (in €m)	Operating cost (in € per tonne of clinker)
All kiln systems	Electrostatic precipitators	To reduce particulate emissions from 500 g/m ³ to 10-50 mg/m ³	2.1-4.6	0.1-0.2
Clinker coolers	Electrostatic precipitators	To reduce particulate emissions from 500 g/m ³ to 10-50 mg/m ³	0.8-1.2	0.09-0.18
Cement mills	Electrostatic precipitators	To reduce particulate emissions from 500 g/m ³ to 10-50 mg/m ³	0.8-1.2	0.09-0.18
All kiln systems	Fabric filters	To reduce particulate emissions from 500 g/m ³ to 10-50 mg/m ³	2.1-4.3	0.15-0.35
Clinker coolers	Fabric filters	To reduce particulate emissions from 500 g/m ³ to 10-50 mg/m ³	1.0-1.4	0.1-0.15
Cement mills	Fabric filters	To reduce particulate emissions from 500 g/m ³ to 10-50 mg/m ³	0.3-0.5	0.03-0.04
All plants	Fugitive dust abatement	To reduce particulate emissions from 500 g/m ³ to 10-50 mg/m ³	-	-

Source: European Commission, 2000

8.2.6 Future Air Quality Under the Business as Usual Scenario

The ambient data shown above indicate that even the lowest limits for arsenic and nickel should be met by all cement plants, although there may be difficulty for some plants in meeting the lowest limit for cadmium. The three metals are discussed below.

Arsenic

The lowest proposed limit in ambient air for arsenic is 1 ng/m^3 . It is estimated that compliance with the Waste Incineration Directive would require less than 438 kg of arsenic to be emitted each year, based on typical exhaust gas flowrates. However, actual emissions from European plants (as shown in Table 8.10 above) are shown to be below 200 kgpa. This figure would cause contributions to ambient air of 0.003 to 0.5 ng/m^3 , which are well within the limit. The contributions from the German plant are also calculated to be very low, at 0.012 ng/m^3 . Actual ambient concentrations measured near to the Castle Cement plant in the UK have averaged 1.1 ng/m^3 with emissions of only 1.6 kgpa, hence it is assumed that the background contribution is relatively high. However, with only modest progress in particulate abatement over the period to 2010 compliance with 1 ng/m^3 should be easily achievable. Such improvements would be expected for older kilns such as at Padeswood. In practice, the kiln is due to be replaced with a new dry kiln with a fabric filter instead of an ESP, which is designed to achieve high levels of particulate abatement.

Cadmium

The lowest proposed limit in ambient air for cadmium is 0.5 ng/m^3 . The contributions from the German plant, at 0.014 ng/m^3 (excluding background), and the ambient concentration near the UK plant, at 0.35 ng/m^3 (including background), both meet the lowest proposed limit. It is estimated that compliance with the Waste Incineration Directive would require less than 44 kg of cadmium to be emitted each year, based on typical exhaust gas flowrates. This would contribute 0.11 ng/m^3 to ambient levels. Only those plants burning waste fuels are required to meet the requirements of this Directive, meaning that higher levels may be emitted at plants using conventional fuels.

The actual emissions of the sum of cadmium, mercury and thallium from European plants (as shown in Table 8.10 above) are between 1 and 600 kgpa. This is substantially higher than the 44 kg maximum emission of cadmium under the Waste Incineration Directive. However, the BREF note states that of the 1-600 kg of cadmium, mercury and thallium, this is made up of "mainly Hg". A sample of the relative proportions of cadmium, mercury and thallium emissions at 11 European cement works gave an estimated ratio of the three metals of 23% cadmium, 76% mercury and 1% thallium. Therefore an estimation of cadmium emissions from European plants (as shown in Table 8.10 above) is between 0.2 and 138 kgpa. This would give an estimated ambient concentration of between 0.0007 and 0.35 ng/m^3 , which indicates that the lowest limit of 0.5 ng/m^3 should be achievable based on current performance of European plants.

Nickel

The lowest proposed limit in ambient air for nickel is 3 ng/m^3 . It is estimated that compliance with the Waste Incineration Directive would require less than 438 kg of nickel to be emitted each year, based on typical exhaust gas flowrates. However, actual emissions from European plants (as shown in Table 8.10 above) are again shown to be below 200 kgpa. This figure would cause contributions to ambient air of 0.003 to 0.5 ng/m^3 , which are well below the 3 ng/m^3 limit. The contributions from the German plant are again calculated to be very low, at 0.05 ng/m^3 , and

the actual ambient air concentration near the UK plant are 0.9 ng/m³, which is well within the limit.

8.2.7 Costs and Benefits of Complying with Potential Limit Values

From our investigation of emissions, ambient concentrations and trends in the cement sector we conclude that it should be possible to meet even the lowest of the potential limit values under the business as usual scenario. Therefore the application of the potential limit values to plants in this sector is not expected to lead to costs and benefits. In cases where high background concentrations are observed, the contributors to such concentrations are expected to be addressed directly by the potential limit values and would be covered in other sections of this report.

8.2.8 References

- Cembureau, 2000. Telephone conversation with Lars Hjorth, 12/5/00
- DETR, 2000. Preliminary results from heavy metals monitoring in the vicinity of 30 industrial sites.
- European Commission, 2000. Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries, February 2000
- Readymix Zement, 2000. Letter received from Peter Scur, 3/7/00
- ZKG International, 2000. Limiting and determining mercury emissions in the cement industry. M Schneider and M Oerter. No.3/2000 (Volume 53) (Volume 53)

8.3 Incineration

8.3.1 Introduction

The metals being considered for this sector are arsenic, cadmium, mercury and nickel.

Current Legislative Controls

At present, European municipal waste incinerators are covered by two Municipal Waste Incineration Directives - for new plant 89/369/EEC and existing plant 89/429/EEC. Hazardous waste incinerators are covered by the Hazardous Waste Incineration Directive 94/67/EC.

Future Legislative Controls

These Directives will shortly be replaced by the proposed Waste Incineration Directive, which is expected to apply in 2005 for existing plant and 2002 for new plant and will cover emissions from all incinerators in the European Union.

Table 8.24 below shows the proposed Waste Incineration Directive limits in comparison with the national limits of certain Members States with relatively stringent current controls.

Table 8.24 Comparison of Emission Limit Values for Incineration Processes

Country and national law	Particulates (mg/m ³)	Cd and Tl (mg/m ³)	Hg (mg/m ³)	Other metals (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V) (mg/m ³)
Waste Incineration Directive limits	10 Daily 30 Half hourly	0.05	0.05	0.5
The Netherlands - Dutch Waste Incineration Decree 1993	5 Hourly	0.05 (Cd only)	0.05	1
The Netherlands - Special Arrangement for Sewage Sludge	5 Half hourly	0.05 (Cd only)	0.05	1
The Netherlands - Special Arrangement for Hazardous Waste	10 Daily 10 Half hourly	0.05 (new) 0.1 (existing)	0.05	0.5 (new) 1 (existing)
Germany - 17 th BImSchV	10 Daily 30 Half hourly	0.05	0.05	0.5
Austria - Incineration Ordinance - for dedicated incinerators	10 Daily 10 Half hourly	0.05	0.05	0.5

Additional regulatory factors which will have an impact on heavy metal emissions in the incineration sector in the future include:

- IPPC Directive – the need to meet BAT requirements (see Section 4).
- UNECE Heavy Metals Protocol – the need to meet BAT requirements plus emission limit values (see Section 4).
- Air Quality Daughter Directive limit values for PM₁₀ and lead (see Section 4).
- The 1991 Batteries Directive (the Batteries and Accumulators Containing Certain Dangerous Substances Directive 91/157/EEC) and its proposed amendments - aim to limit the levels of heavy metals from batteries that are landfilled or incinerated.

8.3.2 Profile of Sector

The municipal waste incineration sector has changed substantially in recent years, as legislation at European and national levels required much more stringent emissions limits than previously, resulting in the closure of many incinerators, although some chose to upgrade. Municipal waste incinerators in the European Union are covered by the Municipal Waste Incineration Directive. Many recover heat for combined heat and power schemes.

Following the recent decline in incinerator numbers, an increase is expected in the future. This is a result of waste strategies and legislation such as the Landfill Directive, which require the diversion of significant amounts of biodegradable waste from landfill towards more sustainable waste management methods, such as energy recovery or composting.

An example of the potential increase in capacity is in the UK, where current incineration capacity is approximately 2,700 kt of municipal solid waste per year, and predicted capacity for 2010 is approximately 10,000 kt (with 6,400 kt of this already planned or proposed) (Energy from Waste Association, 2000).

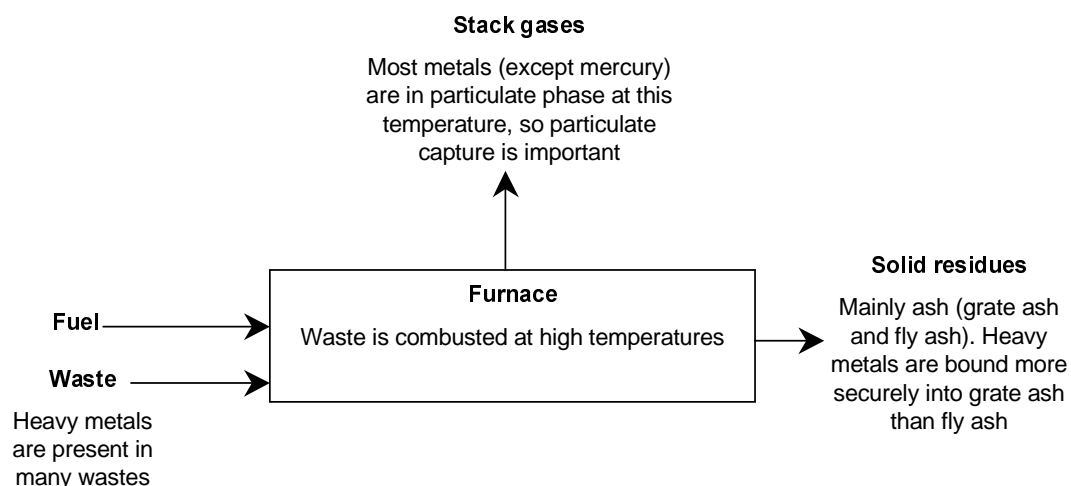
This situation is likely to be repeated across Europe, especially in countries with a high reliance on landfill. For example France and Germany are both predicted to have large increases in the amounts of waste incinerated. France is predicted approximately 16,000 kt pa in 2000 and 19,000 kt pa in 2010; and Germany 16,000 kt pa in 2000 and 23,000 kt pa in 2010 (ETSU, 1996).

As well as municipal waste incinerators, other incinerators may be affected by the proposed heavy metal limits for ambient air. These include hazardous waste incinerators; clinical waste incinerators; and sewage sludge incinerators. La Fédération Européenne des Activités du Déchet (FEAD) has been contacted for details of these sectors across Europe, however they do not collect that type of information at present (FEAD, 2000).

8.3.3 Emission Sources

Many wastes contain heavy metals, in the form of the metal itself or as the metal compound. During incineration, heavy metals will either be bound into the ash and leave as a solid residue, or will be volatilised into the flue gas to condense there as the gas cools. The flue gases are usually around 300 degrees C. At this temperature, most metals have condensed and are in the particulate phase, except mercury, which is more volatile. This means that particulate capture methods are important to prevent heavy metals being emitted from the stack. Other abatement methods are more suitable for mercury reduction.

Other heavy metals will be bound into the ash leaving the process, either grate ash or the finer fly ash. Metals are bound more securely into grate ash than fly ash. It is more likely that metals will become grate ash when there are relatively low peak temperatures and effective combustion occurs.



8.3.4 Current Air Quality Data

Table 8.25 Arsenic

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa)	Reference
UK	Modelled process contributions (peak, 1km downwind and 2km downwind respectively) 0.004, 0.004, 0.002	2000	Cleveland (Municipal Waste Incinerator)	Peak concentrations occur 1km downwind.	<1	Estimations from dispersion modelling, excludes background
UK	3.54 (1)	2000	Wolverhampton (Municipal Waste Incinerator)	Nearest sensitive receptor where max concs occur- In grounds of local community centre, next to residential properties	<1	DETR, 2000
UK	4.07 (2)	2000	Knostrop (Leeds) (Clinical Waste Incinerator plus neighbouring Sewage Sludge Incinerator)	Nearest sensitive receptor where max concs occur- The site is 400m south of the stacks in a sparsely populated area	<1 (Clinical Waste Incinerator) <1 (Sewage Sludge Incinerator)	DETR, 2000

Notes

- 1) Preliminary results for the first 5 months of a 12 month project - running mean
- 2) Preliminary results for the first 7 months of a 12 month project - running mean

Table 8.26 Cadmium

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa)	Reference
UK	Modelled process contributions (peak, 1km downwind and 2km downwind respectively) 0.06, 0.06, 0.03	2000	Cleveland (Municipal Waste Incinerator)	Peak concentrations occur 1km downwind.	15.66	Estimations from dispersion modelling, excludes background
UK	0.85 (1)	2000	Wolverhampton (Municipal Waste Incinerator)	Nearest sensitive receptor where max concs occur- In grounds of local community centre, next to residential properties	1.5	DETR, 2000
UK	0.74 (2)	2000	Knostrop (Leeds) (Clinical Waste Incinerator plus neighbouring Sewage Sludge Incinerator)	Nearest sensitive receptor where max concs occur- The site is 400m south of the stacks in a sparsely populated area	1.54 (Clinical Waste Incinerator) 1.8 (Sewage Sludge Incinerator)	DETR, 2000

Notes

- 1) Preliminary results for the first 6 months of a 12 month project - running mean
- 2) Preliminary results for the first 8 months of a 12 month project - running mean

Table 8.27 Mercury

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa)	Reference
UK	Modelled process contributions (peak, 1km downwind and 2km downwind respectively) 0.08, 0.08, 0.4	2000	Cleveland (Municipal Waste Incinerator)	Peak concentrations occur 1km downwind.	21.40	Estimations from dispersion modelling, excludes background
UK	0.27 (1)	2000	Wolverhampton (Municipal Waste Incinerator)	Nearest sensitive receptor where max concs occur- In grounds of local community centre, next to residential properties	26.4	DETR, 2000
UK	0.33 (2)	2000	Knostrop (Leeds) (Clinical Waste Incinerator plus neighbouring Sewage Sludge Incinerator)	Nearest sensitive receptor where max concs occur- The site is 400m south of the stacks in a sparsely populated area	1.84 (Clinical Waste Incinerator) 1.8 (Sewage Sludge Incinerator)	DETR, 2000

Notes

- 1) Preliminary results for the first 5 months of a 12 month project - running mean
- 2) Preliminary results for the first 7 months of a 12 month project - running mean

Table 8.28 Nickel

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Emission rate (kgpa)	Reference
UK	Modelled process contributions (peak, 1km downwind and 2km downwind respectively) 0.05, 0.05, 0.03	2000	Cleveland (Municipal Waste Incinerator)	Peak concentrations occur 1km downwind.	12.90	Estimations from dispersion modelling, excludes background
UK	2.23 (1)	2000	Wolverhampton (Municipal Waste Incinerator)	Nearest sensitive receptor where max concs occur- In grounds of local community centre, next to residential properties	<10	DETR, 2000
UK	2.80 (2)	2000	Knothrop (Leeds) (Clinical Waste Incinerator plus neighbouring Sewage Sludge Incinerator)	Nearest sensitive receptor where max concs occur- The site is 400m south of the stacks in a sparsely populated area	<10 (Clinical Waste Incinerator) <10 (Sewage Sludge Incinerator)	DETR, 2000

Notes

- 1) Preliminary results for the first 7 months of a 12 month project - running mean
- 2) Preliminary results for the first 8 months of a 12 month project - running mean

8.3.5 Emission Reduction Techniques

All incinerators will be required to use BAT, although the BREF note has not yet been developed. Heavy metal emissions can be reduced by avoiding burning materials with high metal contents such as nickel-cadmium batteries. As metals are mainly in the particulate phase in flue gases (with the exception of mercury), particulate abatement methods will help to reduce emissions. Additional abatement methods are also applicable to reduce heavy metals. These are shown in the table below.

Table 8.29 Emission Reduction Techniques

Process	Emission reduction technique	Reduction efficiency	Capital cost (€)	Operating cost (€ pa)
Municipal waste incineration	Fabric filter, lime and carbon	Particulate emissions 10-30 mg/m ³ (but nearer lower figure)	1,640,000 For a capacity of 350,000 tpa	1,500,000
Municipal waste incineration	Two ESPs, lime and carbon	Particulate emissions 10-30 mg/m ³ (but nearer higher figure)	2,300,000 For a capacity of 350,000 tpa	1,925,000
Municipal waste incineration	Semi dry scrubber		Total annualised cost: 1,300,000 For a capacity of 300,000 tpa	
Municipal waste incineration	Bag filter		Total annualised cost: 1,000,000 For a capacity of 300,000 tpa	
Municipal waste incineration	Carbon injection		Total annualised cost: 260,000 For a capacity of 300,000 tpa	
Clinical waste incineration	Upgrade of existing flue gas treatment	To meet WID limits	410,000 For "a typical CWI"	4920
Clinical waste incineration	Replacement of existing flue gas treatment	To meet WID limits	1,640,000 For "a typical CWI"	24,600
Clinical waste incineration	Total pollution control system - assumed to include fabric filter, lime and carbon		980,000 For a capacity of 1 tph	117,000
Sewage sludge incineration	Bag filter	Particulate emissions 10 mg/m ³	492,000	N/A
Sewage sludge incineration	2 field ESP, polishing bag filter	Particulate emissions 10 mg/m ³	780,000	N/A
Sewage sludge incineration	3 field ESP	Particulate emissions 30 mg/m ³	1,040,000	N/A
Sewage sludge incineration	Activated carbon bed	Mercury reduction	328,000 For capacity of 17,600 tds pa	147,600 pa
Hazardous waste incinerator	Scrubber		1,640,000 For capacity of 30,000 tpa	1,150,000
Hazardous waste	WESP		980,000	106,600

Process	Emission reduction technique	Reduction efficiency	Capital cost (€)	Operating cost (€ pa)
incinerator			For capacity of 30,000 tpa	
In-house chemical waste incinerator	Bag filter		164,000	N/A
			For capacity of 10,000 tpa	
In-house chemical waste incinerator	Wet scrubber		490,000	N/A

8.3.6 Future Air Quality Under the Business as Usual Scenario

The process emissions from an incinerator currently meeting the Waste Incineration Directive (WID) limits were modelled and were well within the lowest proposed limits for arsenic, cadmium and nickel. This is important as all existing incinerators are expected to have to meet the WID limits by 2005.

The actual ambient levels of arsenic, cadmium, mercury and nickel were measured in the vicinity of a municipal waste incinerator (MWI) and a clinical waste incinerator (CWI) with a neighbouring sewage sludge incinerator (SSI). There were found to be unexpectedly high levels of arsenic and cadmium near these plants, although nickel levels were below the lowest proposed limits. Further discussion is included below.

Arsenic

The modelled process contributions from the MWI meeting the WID limits are low, at 0.004 ng/m³. This excludes background levels but is well below the lowest proposed limit of 1 ng/m³.

The incinerators for which ambient data are available have low process emissions of under 1 kg of arsenic emitted per year. Despite the low process emissions, relatively high levels of arsenic have been measured, i.e. 3.5 ng/m³ near the MWI and 4.1 ng/m³ near the CWI and SSI. The lowest proposed limit for arsenic is 1 ng/m³, with the next proposed limit being 4 ng/m³.

Discussion with the operators and/or inspectors of these plants has failed either to link the elevated arsenic levels to the incinerators or to provide alternative explanations for the results. The ambient concentrations of arsenic relative to other metals are out of proportion to the relative emission rates, indicating that other sources are likely to be contributing significantly to the background. Both the ambient monitoring points are in industrialised areas. The MWI in Wolverhampton is located near a metals works, a rubber plant and is on the site of a previous incinerator (operating up to 1997) with higher pollutant emissions than at present that would have caused deposition of heavy metals in the local area. The CWI and SSI near Leeds are located near a plant that makes copper tubing and a recently demolished power station which would have caused historic deposition.

Cadmium

The modelled process contributions of cadmium from the MWI currently meeting WID are very low, at a maximum of 0.06 ng/m³ (excluding background concentrations), compared to the lowest proposed limit of 0.5 ng/m³.

The incinerators for which ambient data are available have lower emissions than the modelled MWI (which emits 16 kg of cadmium per year), as they emit 1.5 kg, 1.5 kg and 1.8 kg per year. However, the measured ambient concentrations of cadmium are both above the lowest proposed limit, at 0.85 ng/m³ and 0.74 ng/m³. As with arsenic, discussion with the regulatory inspectors of the sites has failed to link the high cadmium levels to the incinerators, although again both monitoring sites are in industrialised areas.

In the future, cadmium emitted from MWIs should decrease as a result of the 1991 Batteries Directive and its proposed amendments. A large proportion of global cadmium use is in rechargeable nickel-cadmium (NiCd) batteries, the demand for which is increasing owing to the popularity of power tools and mobile communications. This in turn is causing an increase in levels of these batteries in the waste stream. The 1991 Directive required separate collection and disposal of batteries containing cadmium, mercury or lead, and a reduction in their arisings. The proposed amendments include restricting the marketing of NiCd batteries and devices in which they are used by 2008, and setting recycling targets to divert NiCd batteries from landfill and incineration.

Therefore, together with incremental declines in background levels of cadmium and more efficient abatement plant in certain cases under the business as usual scenario, it is considered that the lowest potential limit values for cadmium could be complied with in the vicinity of incinerators under the business as usual scenario by 2010.

Nickel

Both the modelled process contributions from a municipal waste incinerator, which were a maximum of 0.05 ng/m³, and the ambient concentrations measured in the vicinity of a municipal and a clinical waste incinerator, which were 2.23 ng/m³ and 2.80 ng/m³, were below the lowest proposed limit for nickel of 3 ng/m³. In the future, nickel emissions from municipal incinerators may decrease following the removal of nickel-cadmium batteries from the waste stream as a result of the 1991 Batteries Directive and its proposed amendments, as discussed above.

8.3.7 Costs and Benefits of Complying with Potential Limit Values

From our investigation of emissions, ambient concentrations and trends in the incineration sector we conclude that it should be possible to meet even the lowest of the potential limit values under the business as usual scenario. Therefore the application of the potential limit values to plants in this sector is not expected to lead to costs and benefits. In cases where high background concentrations are observed, the contributors to such concentrations are expected to be addressed directly by the potential limit values and would be covered in other sections of this report.

8.3.8 References

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8.4 Chlor-alkali

8.4.1 Introduction

The only metal emission of significance for the chlor-alkali industry is mercury. This is because a number of chlor-alkali plants in Europe use mercury-cell (or amalgam) technology, which has the potential to emit mercury.

Current Legislative Controls

The current legislation for mercury-cell chlor-alkali plants includes the PARCOM decision (Decision 90/3 of 14 June 1990 of the Commission for the Protection of the Marine Environment of the North-East Atlantic).

Future Legislative Controls

In the future, chlor-alkali plants will be required to use Best Available Techniques under the IPPC Directive.

See Section 8.4.6 for further information.

8.4.2 Profile of Sector

The chlor-alkali industry produces chlorine by the process of electrolysis. Production in Western Europe is around 9 million tonnes per year, compared with world-wide production of around 38 million tonnes. The chlor-alkali sector in Europe has developed over a long time period and is well scattered geographically.

A number of technologies are used within the chlor-alkali industry, including mercury cell, diaphragm and membrane technology. Mercury cell technology (also known as an amalgam process) is the only technology important to this project as it is the only process to emit mercury. The industry is not responsible for any other significant heavy metal emissions. The mercury cell process has been used in Europe since 1892, however it is gradually being phased out.

Although all new plants built in Europe since the early 1980s have been membrane cell plants (which represent BAT for new plants), there are still a large number of older mercury cell installations in Europe which have not yet converted or closed down, and 64% of chlorine production in Western Europe in 1997 was by the mercury cell method. The table below shows the number and capacity of installations in the EU and accession countries covered by this study.

Table 8.30 – Chlor-alkali Plants in EU and Accession States

County	Number of mercury cell plants	Capacity (kt chlorine/year)
Austria	0	0
Belgium	5	662
Cyprus	0	0
Czech Rep	2	170
Denmark	0	0
Estonia	0	0
Finland	1	40
France	7	874
Germany	14	2062
Greece	1	37
Hungary	0-5	
Ireland	0	0
Italy	9	812
Luxembourg	0	0
Netherlands	2	210
Poland	1-3	
Portugal	1	48
Slovenia	0	0
Spain	9	761.5
Sweden	2	220
UK	3	856

Source: Euro Chlor, 2000; European Commission, 2000

8.4.3 Emission Sources

The basic process involved at mercury cell chlor-alkali plants is electrolysis, where an electric current is passed through a chloride-salt solution. At the anode, chloride ions are oxidised and chlorine is formed. At the cathode, a sodium/mercury amalgam is formed and hydrogen and hydroxide ions are formed by the addition of water to the amalgam. The main raw materials required are electricity and salt.

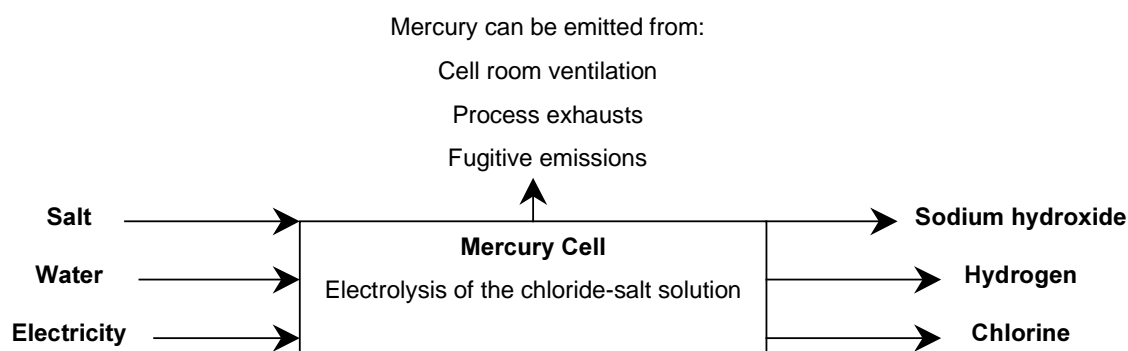
Mercury can be emitted from the process from a number of areas:

- Cell room ventilation - this is one of the main sources to air and emissions can be up to ten times more than process exhausts. The cell room contains hot mercury cells and is naturally

ventilated, with the air being changed frequently. The quantities of mercury emitted range from 0.17 to 1.93 grams per tonne of chlorine capacity.

- Process exhausts - these emissions include all gaseous streams by which mercury can be emitted to atmosphere except cell room air and product hydrogen. The quantities of mercury emitted here range from 0 to 1 gram per tonne of chlorine capacity.
- Fugitive emissions may also be released, including from mercury storage and from the recovery retort.

The diagram below shows the key flows in and out of the mercury cell process.



Mercury emissions were a major concern about the process in the past, but have substantially decreased in recent years. In 1989, average mercury emissions were 5.1 grams per tonne of chlorine capacity. By 1997, average emissions were 1.5 grams, and by 1998 1.4 grams, which is the approximate level today. The total European mercury emissions from the chlor-alkali sector in 1977 were 97 tonnes, compared with 9 tonnes in 1997 (Euro Chlor, 2000).

8.4.4 Current Air Quality Data

Table 8.31 Ambient Mercury Concentrations

Country	Ambient concentration (ng/m ³)	Date	Site	Sampling location	Reference
UK	27.8 (based on 26.3 in vapour phase and 1.5 in particulate phase)	2000	ICI Chemicals and Polymers, Runcorn	Nearest sensitive receptor where max concs occur - located on the roof-top of a single-storey building within the grounds of a local school. The site lies 650m East from the site boundary	DETR, 2000. Preliminary results from first 8 months of a 12 month project

8.4.5 Emission Reduction Techniques

The methods for mercury abatement include primary abatement (especially good housekeeping) and secondary abatement techniques applied to emissions. The table below shows methods that could be used further to reduce mercury emissions, and their costs if known.

Table 8.32 Mercury Abatement in the Chlor-alkali Sector

Process	Emission reduction technique	Reduction efficiency	Capital cost (in €)	Operating cost (in €)
Cell room ventilation	Minimisation of mercury emissions from the cell room by containment and good housekeeping			
Removal from process exhausts	Adsorption on impregnated activated carbon	Close to zero mercury emissions.	1.4 million	195,160
Removal from process exhausts	Calomel reaction	Emissions of 0.006-0.01 g mercury per tonne of chlorine capacity, or 0.05-0.1 mg/m ³	1.3 Euros/tonne chlorine capacity (for a plant with 100,000 tonnes chlorine capacity per year, with waste gas volume 2000 m ³ /hour)	
Removal from process exhausts	Scrubbing with chlorinated brine or hypochlorite	Emissions of 0.006-0.01 g mercury per tonne of chlorine capacity, or 0.05-0.1 mg/m ³	16.4 million 0.9 Euros/tonne chlorine capacity (for a plant with 100,000 tonnes chlorine capacity per year, with waste gas volume 2000 m ³ /hour)	984,000 pa
Removal from hydrogen gas	Adsorption on impregnated active carbon		0.45-0.5 million Euros (including heat exchanger, equipped tower and filter) (for a plant with 166,000 tonnes chlorine capacity per year)	
Removal from hydrogen gas	Chemical reaction with cupric oxide	Emissions of 0.003 g mercury per tonne of chlorine capacity		
Removal from hydrogen gas	Adsorption on copper/aluminium or silver/zinc oxides	Emissions at under 0.001 mg Hg/m ³ hydrogen gas		
Conversion to membrane technology	Excluding clean-up costs	Membrane technology has zero mercury emissions	226.5-260 Euros/tonne chlorine capacity	
Conversion to membrane technology	Including clean-up costs	Membrane technology has zero mercury emissions	290-610 Euros/tonne chlorine capacity	

Sources: Entec, 1996; European Commission, 2000

8.4.6 Future Air Quality Under the Business as Usual Scenario

As stated above, the application of BAT in this sector for new plant will mean that mercury cell plants will be eventually phased out. The PARCOM decision (Decision 90/3 of 14 June 1990 of the Commission for the Protection of the Marine Environment of the North-East Atlantic) recommended that all mercury cell plants be phased out as soon as practicable, with an objective of phasing them out by 2010, although a final decision on this date has not yet been made.

The PARCOM decision also required plants to meet a limit of 2g Hg/tonne chlorine capacity by December 1996. This has been met and emissions are now considerably lower (an average of 1.4g Hg/tonne chlorine capacity), with an expectation that by 2007, this figure will be 1 gram, with further reductions in the future. Euro Chlor (the European trade association for the chlorine production industry) aims to meet this average figure of 1 gram in 2007, reducing to 0.7 grams in the future, should operation be allowed post-2010.

Euro Chlor has also estimated that between 1998 and 2010, there will be a 21% reduction in mercury cell capacity, providing that natural phasing out occurs and the PARCOM decision does not require a complete shut-down. It is also estimated that all plants should disappear by 2025 (Euro Chlor, 1999).

The final decision on the date for mercury cell plant closure is expected by 2002 (ICI, 2000). Euro Chlor believes that, should closure be forced by this 2010, total mercury emissions from the sector would be greater than if gradual plant closure were allowed to occur naturally, as mercury reduction measures would not be implemented due to costs. Conversion to membrane technology costs approximately ten years' capital costs (ICI, 2000). Should the industry be allowed to convert plants over a longer time period, mercury emissions reduction measures would continue to be implemented.

As no potential limit values for mercury have so far been proposed it is clearly not possible at this stage to assess compliance costs or benefits.

8.4.7 References

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8.5 Glass Production

Consultation with the International Crystal Federation has confirmed that the contribution of this sector to emissions of arsenic, cadmium, mercury and nickel does not warrant further analysis.

9 Sources of Heavy Metal Concentrations in Urban Locations

This report has systematically covered what are considered to be the most important contributors to ambient concentrations of As, Cd and Ni. This will inherently consider compliance with the limit values at industrial, urban and rural locations. However, due to certain locations with elevated urban concentrations identified in the Position Paper the issue of compliance at urban locations has specifically been raised. From our investigations in the previous sections it is clear that many key emission sources of As, Cd and Ni are located in or at the edge of urban areas and hence will naturally contribute to elevated urban concentrations. For example nickel concentrations in the region of 16 ng/m³ have been identified in the Rotterdam area due to contributions from four nearby petroleum refineries.

This section is intended to identify whether the emission source groups considered in the previous sections will give satisfactory consideration to compliance with the limit values at urban locations.

A recently reported study, based on sampling in Rome from October 1995 to September 1996 (D'Innocenzio et al, 1998), has investigated PM₁₀, PM_{2.5} and total suspended particulate (TSP) at a sampling site in the centre of Rome. The work included analysis of the distribution of toxic metal concentrations in the various particle fractions to gather information on their toxic components content.

Cd was found to be distributed predominantly in finer particules while Ni was more equally distributed in all fractions (As was not covered in this study). An enrichment in airborne finer particles during the winter-autumn periods was noted, probably due to the enhanced activity of combustion sources (traffic, heating etc). Annual mean concentrations are shown in Table 9.1.

Table 9.1 Annual Mean Concentrations of Metals Based on Sampling in Rome in 1995/6 (ng/m³)

Metal	Coarse	Fine (PM _{2.5})	PM ₁₀	TSP
Nickel	4	3	8	13
Cadmium	below limit of detection	0.3	0.4	0.5

For Cd, a general finding is that in urban areas Cd originates from combustion sources (traffic, heating etc). A different trend has been found for Ni which is generally more equally distributed and more slightly favoured towards fine particles. Ni showed single episodes with peak values in the coarse fraction, probably because of the influence of temporary local sources which contribute to the emission of this metal.

An earlier study investigated the sources and atmospheric concentrations of heavy metals in two Italian towns, Genoa and La Spezia (Valerio et al, 1992). Relatively high concentrations of nickel were observed in La Spezia and were attributed to the nearby stainless steel works.

Research reported on the contribution of metallic sources to suspended particulate matter in the Paris area (Person et al, 1993) was inconclusive. The effect of nearby and potentially important emitters (a municipal waste incinerator and a coal fired power station) was difficult to detect for relevant tracers such as cadmium (in the case of incineration). It was reported that significant emitters of heavy metals are relatively limited in number in the Paris area and it is not impossible that long range transport is affecting the ambient metals concentrations in this area. High levels of sodium were observed, attributable to air movements from the sea.

Furthermore, in certain areas with potentially significant industrial sources, high ambient concentrations are not always easy to trace to particular sources. For example nickel concentrations at Siegen, Germany in 1998 have been reported at 23ng/m^3 , however the monitoring point is not in the prevailing wind direction from the nearby stainless steel works and other unspecified sources are thought to be significant contributors (VDEh, 2000). VDEh have been assessing the ambient measurement data at measurement sites near steelworks against their knowledge of emissions from these sites and have so far not been able to see a good link between the two. One view is that certainly at traffic locations, re-suspension of historically deposited metals may be a significant source.

In Rotherham, UK, ambient nickel measurements are just over 8ng/m^3 in the vicinity of a stainless steel works although the site manufactures leaded steels rather than nickel containing steels. They do not believe that their site is the key contributor and point to other nickel sources in the area such as another stainless steel plant and a non ferrous metals process (Corus, 2000).

Combustion and transport sources that are relevant to urban locations are discussed in Section 7.

As a result of this analysis it is considered that the investigations of the emission sources covered in the previous sections will address the emission sources that are primarily important to elevated urban concentrations, either through localised or long distance transport of pollutants. It is noted that in the business as usual scenario, significant reductions in all metals will have been achieved from coal and oil fired power stations, which will be important contributors to long range pollution.

Furthermore, the business as usual scenario will take into account measures to comply with the AQDD limit values for PM_{10} , such as controlling the use of coal as a domestic fuel (in favour of gas), which will have a beneficial impact on ambient heavy metal emissions.

As more research is undertaken in this area, it will be possible to estimate with greater confidence the key contributors that elevate urban concentrations of heavy metals.

References

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10 Benefit Analysis Methodology

10.1 Quantifiable Human Health Benefits

10.1.1 Carcinogenic Effects of Arsenic, Cadmium and Nickel

Carcinogenic effects are assessed using unit risk factors and the general form of the exposure-response function, according to the EC 'ExternE Externalities of Energy' methodology, is as follows for all cancer effects;

No. of additional cancers = Δ Concentration [$\mu\text{g.m}^{-3}$] * unit risk [$(\mu\text{g.m}^{-3})^{-1}$] * population/70.

Some points relevant to the above equation are as follows:

- The ' Δ Concentration' function is the reduction in average concentration of the metal of interest (within the key area expected to experience health benefits) from the future business as usual case to the compliance case (i.e. after complying with specific limit values). In general, elevated ambient arsenic, cadmium and nickel concentrations due to industrial sources reduce to near background levels a few kilometers from the site according to information in the Position Paper and observation of monitoring and modelling results. A radius of 10km from the site has been selected to define the key area of interest to ensure that good coverage is achieved of the most significant areas likely to experience benefits. Choosing a larger area is not expected to significantly impact on the results because the larger population ('stock at risk') would be counter-acted by a smaller average reduction in concentration across that population.
- The unit risk factor is an estimate of the likelihood of a cancer occurring within a population. For each of the metals being considered in this study, cancer of the lung, brought about through inhalation, has been identified as the most likely carcinogenic effect. The unit risk, as defined in the Position paper (section 2.6.1.2, pp.2), is the additional risk due to lifetime exposure to a chemical compound at a mean concentration of $1 \mu\text{g.m}^{-3}$. The unit risk factors chosen for use in this study are discussed below.
- The factor of 70 annualises lifetime risk (assuming an average longevity of 70 years).
- The population is the population in the area defined under the first bullet point.

Arsenic

Unit risk factor: $1.5 * 10^{-3} (\mu\text{g.m}^{-3})^{-1}$.

This value is based on WHO figures (1997), as described in section 2.6.2.2 in the Position paper. This unit risk factor has been revised down from the 1994 WHO estimate ($3 * 10^{-3}$) due to consideration of recent European data.

Cadmium

Unit risk: $1.8 * 10^{-3} (\mu\text{g}\cdot\text{m}^{-3})^{-1}$.

This value, taken from the Position paper (section 2.6.3.2) is from a 1985 (Thun et al) study using human data. The US-EPA and WHO also quote this risk factor, so it is deemed suitable for this study.

Nickel

It is proposed that two unit risk factors are used when calculating the cancer risks associated with nickel compounds. This approach can be justified based on the variation in toxicity with nickel speciation.

Processes emitting nickel are summarised in the following table, taken from the position paper (section 1.1.3, p.20).

Table 10.1 - Nickel Emitting Processes

Process	Nickel species produced
Oil-fired combustion units	Soluble nickel compounds (Ni sulphate) Nickel oxides
Metallurgical operations (stainless steel and nickel alloy)	Soluble Ni salts Metallic Ni Nickel alloys Insoluble Ni oxides
Nickel primary production (mining, grinding, smelting and refining)	Mining and grinding: Ni dusts Smelting: Metallic Ni, soluble Ni compounds, complex Ni oxides Refining, matte grinding: Ni sub-sulphide Refining, other operations: soluble Ni sulphate and chloride, Ni hydroxide, complex Ni oxides

Of the various species of nickel emitted, nickel sub-sulphide has been identified as the most toxic form that could be released into the environment under normal production conditions. The position paper states however that the assumption that 50% of refinery dust contains Ni sub-sulphide is based on processes that have not been used since the 1950s, so the unit risk factor associated with this ($4.8 * 10^{-4}$) is not considered appropriate.

In addition, ores containing nickel sub-sulphide are processed at only two sites in Europe. Given improved processing technology and the rapid solubilisation of nickel sub-sulphide on release to the atmosphere, the unit risk factor used to predict excess cancers within the population should reflect the diminished presence and use of nickel subsulphide.

The unit risk factors to be used in this study are based on values produced by the WHO (taken from the Position paper - Section 2.6.4.2, p.24) and an additional value derived by the CEPN (p.79). Brief summaries of the origins of these factors are included below:

- CEPN: Unit risk factor = $1 * 10^{-4} (\mu\text{g}\cdot\text{m}^{-3})^{-1}$. This value has been derived from the unit risk factor for occupational exposure ($2.5 * 10^{-4}$), which was based on a large number of studies by different organisations (WHO, CARB, US-EPA, NiPERA). This figure was revised down for exposure to the general population through consideration of the fact that nickel sub-sulphide will be much reduced in ambient air. It is also recognised in the Position paper that the WHO and US-EPA risk factors **do not** consider the reduced exposure of the general population to nickel sub-sulphide. This risk factor has been used for sectors apart from nickel production, where it has been used to provide a lower range estimate.
- Position paper: WHO: Unit risk factor = $3.8 * 10^{-4} (\mu\text{g}\cdot\text{m}^{-3})^{-1}$. This value is based on a study of nickel refinery workers from Falconbridge in Norway, where a significant excess risk was found for workers exposed to nickel. This risk factor has been used for nickel production to provide a higher range estimate.

10.1.2 Non-Carcinogenic Effects of Arsenic, Cadmium and Nickel

Within the Position paper both human epidemiological and animal toxicity data have been used to derive air concentration limits to prevent non-cancer effects. Three values have been used to produce this limit value and each is briefly described below:

- Lowest Observed Adverse Effect Level (LOAEL). This is the lowest concentration at which an adverse effect has been observed
- No Observed Adverse Effect Level (NOAEL). This is a theoretical concentration at which no adverse effect will occur. The value itself cannot actually be measured, so it is calculated from the LOAEL using safety factors based on experience and judgement.
- Limit Value. The limit value itself is derived from the NOAEL and again uses safety factors based on experience and judgement.

There is a methodology for the application of safety factors to produce the various values, as described in the Position paper (Section 2.6.1.1, p.1). Although this could be discussed in more detail, a review of toxicological data is considered beyond the scope of work for this project. In addition, the general approach to deriving the values within the Position paper is regarded as sound and the same values should be used for purposes of consistency.

The three values for each of the metals are given below, along with a brief summary of how they have been derived.

Arsenic (Position paper, section 2.6.2.1)

LOAEL: $50 \mu\text{g}\cdot\text{m}^{-3}$, based on cardiovascular effects and peripheral neuropathy in workers

NOAEL: $1 \mu\text{g}\cdot\text{m}^{-3}$, based on averaging LOAEL for the general population (factor of 5) and consideration of the vascular effects of arsenic (factor of 10).

Limit Value: $0.1 \mu\text{g}\cdot\text{m}^{-3}$, based on a safety factor to account for intra-species variation (factor of 10).

Cadmium (Position paper, section 2.6.3.1)

The most important pathway for non-cancer effects associated with cadmium is oral uptake, leading to renal effects. The critical dose in the human body for renal effects has been identified as $1\mu\text{g}\cdot\text{kg}^{-1}$ of body weight per day (JECFA 1996). The Position paper actually describes a model for assessing the uptake pathways for cadmium, based on a worst case scenario, the aim of which is to derive an acceptable deposition value according to critical dose. There is however no simple link between air concentrations and deposition itself so, using the model described, it is not possible to assess the amount of cadmium taken up into the human body based on air concentrations alone.

An analysis of occupational exposure data, detailed in the Position paper, has resulted in the derivation of an LOAEL in air, and it is this value that has been used in the study.

LOAEL: $270\text{ ng}\cdot\text{m}^{-3}$, based on renal effects.

NOAEL: $54\text{ ng}\cdot\text{m}^{-3}$, based on a safety factor for potentially reversible effects (factor of 5).

Limit Value: $5\text{ ng}\cdot\text{m}^{-3}$, based on a safety factor to account for intra-species variation (factor of 10).

Nickel (Position paper, section 2.6.4.1)

LOAEL: $1\mu\text{g}\cdot\text{m}^{-3}$, based on chronic active inflammation of the respiratory tract in rats, using an inter-species safety factor (factor of 10) and an uncertainty factor for the exposure time (factor of 6) to modify animal toxicity data.

NOAEL: $100\text{ ng}\cdot\text{m}^{-3}$, based on an uncertainty factor applied to the LOAEL (factor of 10).

Limit Value: $10\text{ ng}\cdot\text{m}^{-3}$, based on a safety factor to account for intra-species variation (factor of 10).

Summary

Although the non-cancer effect limit values have been set to protect human health, it is the No Observed Adverse Effect Level (NOAEL) that is deemed to be more appropriate for quantifying actual human health effects. Note that this point is clearly not relevant to carcinogenic effects.

The basis of this assumption is that the uncertainty associated with the original data is reflected in the factors used to generate the NOAEL from the LOAEL, and that the NOAEL is the intended critical point. The limit value itself incorporates an additional uncertainty factor to protect the general population by a margin. Exceeding the limit value in itself therefore is not necessarily going to lead to non-cancer effects on the population. Given the uncertainty, this can also be said of the NOAEL but this value, although theoretical, is likely to be considerable closer to the threshold level of effects.

Consequently it is the values presented in Table 10.2 that will be used in this study to assess the non-cancer effects on the general population.

Table 10.2 – Non-Carcinogenic Effect Critical Concentrations

Metal	Concentration
Arsenic	1 $\mu\text{g.m}^{-3}$
Cadmium	54 ng.m^{-3}
Nickel	100 ng.m^{-3}

10.1.3 Health Effects of Other Pollutants

Other metals

Abatement technology used for arsenic, cadmium and nickel may also result in reductions to lead, mercury and other metal emissions.

For lead, the UK Air Quality Strategy states that, whilst it is not possible to identify a threshold for effects on health, an ambient annual average concentration $0.25 \mu\text{g.m}^{-3}$ will provide a good measure of health protection. The most sensitive receptor for lead has been identified as intelligence in children. A reduction of approximately 1 IQ point has been associated with an atmospheric concentration of $1 \mu\text{g.m}^{-3}$. The UK Air Quality Strategy value of $0.25 \mu\text{g.m}^{-3}$ has been recommended as it is not possible to discern effects attributable to lead below this concentration. Consequently this level has been included as an objective to be achieved by 31 December 2008. Based on recent research by Entec there is expected to be a substantial level of compliance against this objective under the business as usual scenario. As the many of the key processes of interest will be covered by the IPPC Directive a similar level of compliance might be expected across the EU. Hence incremental benefits associated with exposure to lead arising from measures that go beyond the 2010 business as usual scenario are not expected to be significant.

However, the reductions in other metals (eg mercury) achieved by reductions in arsenic, cadmium and nickel are likely to give rise to certain incremental health benefits.

Particulates

The measures to reduce emissions of the metals of interest are essentially particulate abatement techniques. Therefore measures targeted at these metals will clearly lead to reductions in particulate emissions. Health effects due to exposure to particulates (in particular PM_{10}) include both acute and chronic mortality and morbidity effects. Whilst quantification of chronic effects due to particulates may introduce some double counting due to the carcinogenic effects of metals of interest potentially included in the particulates, there would certainly be some incremental acute effects of particulates to additionally consider, as secondary health benefits of the heavy metal limit values. It is recognised that business as usual commitments include the air quality limit values for PM_{10} under the Air Quality Daughter Directive (1999/30/EC) which includes the stringent indicative annual average limit of $20 \mu\text{g.m}^{-3}$ to be met by 2010.

10.2 Economic Valuation of Health Effects

This section presents the approach adopted for the valuation of human health benefits associated with carcinogenic effects of arsenic, cadmium and nickel. The latest available and most relevant data for this assessment is derived from the DG Environment's recommended **interim** values for the value of preventing a statistical fatality (VPF). The VPF refers to small changes in risk over large populations. Values were developed on the basis of a DG Environment workshop for experts held in November 2000.

Reference Values

Based on contingent valuation studies of the value of preventing a statistical transport fatality, uprating to 2000 prices, applying Purchasing Power Parity, and adjusting for the age of mortality victims usually associated with environmental pollution produces a best estimate figure of around €m 1 (2000 prices).

The upper estimate is €m 2.5 and the lower estimate is €m 0.65.

Adjusting for Context

Latency: In the case of chronic or latent effects (as applicable to carcinogenic emissions) there is a delay between the emission and the impact. It is appropriate to value future impacts at a lower rate than contemporaneous impacts. The central discount rate to be used in discounting the value of future impacts is 4% real. However, the sensitivity analysis should be carried out using a value of 2% real. Assuming a 10 year time until impact would occur leads to the following discount factors:

- 67.6% - central rate of 4% real
- 82.0% - sensitivity analysis based on rate of 2% real

Carcinogenic pollutants: People may be willing to pay more to reduce their risk of dying of cancer than to reduce their risk of a fatal heart attack, because death from cancer may be preceded by a long period of serious illness. In other words, the value attributed to the risk of mortality from cancer equals the standard reference value plus a "cancer premium". A central estimate for the value of the "cancer premium" is equivalent to 50% of the standard reference values.

Age: The reference values are based on an elderly population and relatively small reductions in life expectancy. If the population affected included all ages then multiplying by 1.43 would correct for the original age adjustment factor of 0.7.

Health status: It is not considered appropriate to adjust for the health status of the population at risk.

Adjusting for different populations within the EU: It is not recommended that values be changed according to the income of the population affected.

Values to Use in this Study

On the basis of the abovementioned factors, the factor to multiply the reference values with comprises:

- latency: 0.676 (low estimate), 0.820 (central estimate)

- carcinogenic pollutants: 1.5
- age: 1.43
- overall: 1.45 to 1.76

Therefore the VPF figures to use in this study are considered to be:

- lower estimate: €m 0.9
- best estimate: €m 1.8
- upper estimate: €m 4.4

However, as elevated ambient arsenic, cadmium and nickel concentrations due to industrial sources reduce to near background levels reasonably close to the source as discussed earlier, the size of population that will experience health benefits may not be large. Therefore as the abovementioned method for determining a VPF is based on small changes in risk over large populations it's applicability to this study will be reduced. The willingness to pay by a smaller population to reduce risk of fatality may exceed the VPF figures that have been derived, although quantifying such adjustments in value is not readily achievable within the scope of this study.

Finally, the valuations calculated in the earlier sections are based on the pessimistic assumption that a carcinogenic effect leads to a fatality, albeit after a latency period. In practice, improvements in health care should reduce the likelihood of fatality.

10.3 Environmental Benefits

10.3.1 Effects on ecosystems

Ideally the impact of atmospheric concentrations on the environment would be considered as part of the benefit analysis. A summary of the information available covering the effects of arsenic, cadmium and nickel on terrestrial ecosystems is given in the Position paper (section 2.4), but it does conclude that the current state of knowledge of possible effects on terrestrial ecosystems is limited. In addition, it can be stated that the impacts of metals on all ecosystems, whether terrestrial or aquatic, is not understood well enough to allow for an assessment of benefits through reduced airborne concentrations.

There are numerous studies looking at specific dose-response relationships between metals and particular organisms, but these can only be applied at a site-specific level. Due to the specific nature of individual sites, these data cannot be extrapolated to full ecosystem level with confidence.

In addition to actual effects noted in specific organisms, it is necessary to look at the origin of contaminants and relate airborne concentrations to the levels found in ecosystems. Owing to the lack of data on the specific nature of emissions to the atmosphere, this is not currently possible. With particulate size profiles of each emission and corresponding deposition velocity data, it will be possible to model the extent of deposition around each emission source. Given knowledge of the speciation of the metals in the release, it will eventually be possible to predict potential ecosystem impacts. One of the main problems of this approach however is the cost of generating data in the first instance. Nickel speciation, for example, is expensive to carry out

and is not routinely monitored for. Offsite the problem becomes even greater as the amount of time required to collect a large enough sample to fractionate may actually affect the metal species.

An alternative approach to the problem is to look at critical loads within a system and to assess its vulnerability to pollution. Work at the Institute of Terrestrial Ecology (ITE) at Bradford University is aimed at developing critical load maps for heavy metals. This, ultimately, will provide a means with which to assess the vulnerability of each site and to identify those most at risk. This, in turn, will act as a means of identifying emission sources that need to be considered in more detail. In essence, this approach is starting with the environmental impact and working back towards the source.

Ideally both of the above methods would be used in the future to reach an appropriate solution. Emission sources would be modelled to see if there is potential for environmental harm, and ecosystems would be characterised according to their sensitivity to particular pollutants. Together those parts of the environment most at risk would be identified, along with those emission sources with the potential to cause problems, and action would be taken accordingly.

10.3.2 Effects on Crops

Although the available literature concerning heavy metal damage to crops is extensive, particularly regarding laboratory studies, there are few studies relating effects to reductions in crop yield.

Of those that have been carried out, the focus tends to be on metal concentrations in the soil rather than air. It could be argued that deposition rates should be used to predict soil metal concentrations from concentrations in air. This however involves additional complexities that carry too many unknown variables, such as those identified below:

- The nature of different processes means that each release to atmosphere will comprise of different metal species, each of which has its own deposition characteristics. To model deposition the speciation of metals in each release is required. Very few studies have been undertaken to examine metal speciation at this level, which needs to take place on a site by site basis. This lack of data means that any deposition modelling that does take place will generate results with potentially large errors that cannot be used with confidence.
- Data are required on the behaviour and toxicity of each metal species. Once released to the environment it is necessary to establish how the metal moves through different pathways to potential receptors, such as crops. Although laboratory studies provide an indication of how metals might react in specific compartments of the natural environment (e.g. uptake by certain organisms from a specific soil type), there is a lack of knowledge when it comes to predicting the movement of metals through all of the various paths and the impact on the receptor.
- Site-specific data are needed, identifying the surrounding environment, in terms of geology, meteorology and land use. Coupled with the information on the type of each release and the behaviour and toxicity of the compounds present, it will then be possible to predict the effects of heavy metals on crop yields, and to present the data in financial terms.

Various aspects of the above three points are covered for some sites, but the need for additional academic research and site-specific data is demonstrated. Owing to the costs of sampling for metal speciation and data collection on a site-by-site basis, crop damage and environmental impacts as a whole cannot be considered as part of this study.

Cadmium

The amount of literature available varies substantially between the three metals considered in this project. Few studies were found for nickel and arsenic, whereas a large number were found for cadmium. The reason for this is that the presence of cadmium in the environment at potentially toxic levels has been well documented.

The position paper itself makes reference to the impact of cadmium on crops. Several laboratory studies are referred to in which reductions in crop yields of 12% were recorded during exposure to deposition levels of 100 to 230 $\mu\text{g}\cdot\text{m}^{-2}\cdot\text{day}^{-1}$ for between 17 and 45 days. Given that annual average cadmium deposition values quoted in the position paper are typically less than 1 $\mu\text{g}\cdot\text{m}^{-2}\cdot\text{day}^{-1}$, with only one site recorded as exceeding 100 $\mu\text{g}\cdot\text{m}^{-2}\cdot\text{day}^{-1}$, the use of such high deposition values cannot be considered relevant.

Summary

It is considered that the effects on crops arising through heavy metals in air cannot currently be quantified or assessed with any accuracy. Although numerous studies exist looking at different aspects of the pathway from the point of release to the ultimate effect on the crop, the high variability between different sites means that only site specific studies are suitable for trying to quantify crop damage. It should be noted that similar conclusions were drawn for analysis of environmental effects as a whole.

Appendix 1

Heavy Metal Emissions Inventory

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Table 1 - Heavy Metal Emissions Inventory in 1990 for EU-15

Sector	Arsenic emissions		Cadmium emissions		Mercury emissions		Nickel emissions	
	tpa	% of tot	tpa	% of tot	tpa	% of tot	tpa	% of tot
Iron and steel	35	6%	37	18%	7	3%	142	3%
Sinter plants	4	1%	5	2%	1	0%	27	1%
Pelletisation plants		0%		0%		0%		0%
Coke oven plants	2	0%	3	1%	2	1%	4	0%
Blast furnaces	16	3%	1	1%	1	1%	19	0%
Basic oxygen steelmaking	2	0%	2	1%	0	0%	5	0%
Electric steelmaking and casting	11	2%	26	13%	3	1%	88	2%
Ferrous metal processing	0	0%	0	0%	0	0%	0	0%
Non-ferrous	16	3%	29	14%	3	1%	13	0%
Aluminium	0	0%	0	0%	0	0%	13	0%
Copper production	7	1%	2	1%	0	0%	0	0%
Nickel production	-		-		-		-	
Metallurgical processes (ni alloys)		0%		0%		0%		0%
Cobalt		0%		0%		0%		0%
Lead production (primary)	9	2%	8	4%	3	1%		0%
Zinc production (primary)	-		19	9%	1	0%	-	
Cadmium & mercury		0%		0%		0%		0%
Petroleum refineries	-		-		-		1	0%
Chlor-alkali production	-		-		28	12%	-	
Cement and lime production	4	1%	2	1%	38	15%	20	0%
Glass production	7	1%	1	0%	0	0%	10	0%
Waste treatment and disposal	3	0%	16	8%	39	16%	27	1%
Waste incineration	3	0%	16	8%	36	15%	27	1%
Cremation	-		0	0%	2	1%	-	
Hg thermometers and vapour lamps	-		-		1	1%	-	
Transport	2	0%	44	22%	0	0%	1759	36%
Road transport combustion	-		34	17%	0	0%	270	6%
Road transport non-combustion	-		3	1%	-		9	0%
Other transport combustion	2	0%	8	4%	0	0%	1480	30%
Public power, cogen and d. heating	277	48%	19	9%	43	18%	1681	35%
Public power etc. brown coal	20	4%	3	2%	9	4%	24	0%
Public power etc. hard coal	130	23%	4	2%	21	9%	94	2%
Public power etc. fuel oils	117	20%	10	5%	1	1%	1560	32%
Public power etc. other fuels	10	2%	1	1%	12	5%	3	0%
Comm, instit and res combustion	38	7%	10	5%	13	5%	129	3%
Commercial etc. brown coal	2	0%	0	0%	4	2%	16	0%
Commercial etc. hard coal	23	4%	1	1%	3	1%	38	1%
Commercial etc. fuel oils	9	2%	2	1%	0	0%	73	2%
Commercial etc. other fuels	3	0%	6	3%	6	2%	2	0%
Industrial combustion	177	31%	29	14%	33	13%	970	20%
Industrial combustion brown coal	66	11%	9	4%	14	6%	81	2%
Industrial combustion hard coal	52	9%	2	1%	9	4%	70	1%
Industrial combustion fuel oils	51	9%	12	6%	2	1%	805	17%
Industrial combustion other fuels	9	2%	6	3%	9	4%	15	0%
Other sectors	17	3%	17	8%	39	16%	108	2%
Total	575	100%	203	100%	245	100%	4860	100%

Source: UBA-TNO report "The European Atmospheric Emissions Inventory of Heavy Metals and Persistent Organic Pollutants for 1990".

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Appendix 2

Air Quality Modelling Approach

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Introduction

The current ground level concentrations of the metals arsenic, cadmium, mercury and nickel resulting from process emissions have been estimated by dispersion modelling. This chapter describes the approaches and tools conducted in this project. Dispersion models are used to predict the ambient atmospheric concentrations of metals at defined receptor points some distance from a source of emissions. The major inputs required by the model for this type of assessment are:

- 1) emission characteristics that determine the rate at which the metals are introduced to the atmosphere;
- 2) meteorological parameters that determine how the metals are dispersed and diluted in the atmosphere over time, and;
- 3) the existing concentrations of metals in the ambient atmosphere (background concentrations) to which the emitted metals additionally contribute.

In addition to these inputs, other site specific factors such as large buildings or steep terrain gradients can influence the dispersion of metal emissions. These factors are dealt with in this chapter in section 1.2.

The dispersion model used throughout this project was the Advanced Dispersion Model System version 3 (ADMS3). The input information described in the previous paragraph was obtained from various sources to be described in this chapter.

The ADMS3 model and model assumptions

The Atmospheric Dispersion Modelling System Model version 3 (ADMS-3) was used to predict ground level concentrations resulting from the plant emissions. The Environment Agency has an active programme validating this model and has found this an acceptable modelling tool; as have local authorities in the UK. It has been widely used for assessing air quality impacts from new and existing plant/processes throughout the UK.

For modelling required so far under this study, ADMS is considered as applicable as any other 'new generation' model such as AERMOD at a European level.

ADMS-3 is capable of modelling the ground level concentrations over an area of several km² resulting from buoyant releases from up to 50 sources accounting for meteorological, terrain and building parameters that affect atmospheric dispersion. Therefore, the model is an ideal tool for this project.

Using the model, long-term impacts of the stack emissions have been assessed for those emissions that are expected to occur during normal operation of the plant. (based on 100% utilisation).

The model uses a range of input parameters including, among others, meteorological measurements, emissions data and stack flow rate parameters. The data used in modelling the dispersion of emissions in this assessment are described below.

Surface roughness

This parameter provides a measure of the vertical mixing and dilution that takes place in the atmosphere due to the land-use in the site locality. Since the results from single plant are to be

applied in different situation in a number of countries the dispersion of stack emissions was modelled using two different surface roughnesses. The first was 0.5 m which is representative of rural situations while the second was 1.5 m which is representative of urban situations¹.

Terrain

Topographical land features such as hills can have a significant effect on the dispersion of pollutants, generally when ground level within 1km of an emission stack varies by more than a third of the stack height². However, this assessment has considered only flat terrain.

Building downwash

Air passing over a building tends to move downwards in its lee; an effect known as downwash. The potential for building downwash to affect plume dispersion is an important consideration, particularly where the stack is less than 2.5 times the height of nearby buildings. The EA stack height assessment methodology³ takes into consideration building sizes when calculating appropriate stack heights. Therefore, building downwash effects are unlikely to be significant for stacks whose heights were calculated using this or similar methodologies in other countries.

Receptor grid

The ground level concentrations of pollutants resulting from process stack emissions were modelled over a polar grid centred on the emission point in each case. Where there was more than one emission point, a point centrally among them was selected as the grid centre. Rings of grid receptors were placed in radial fashion around the emission point, each receptor separated from its neighbours by 22.5 around the ring. The rings of receptors began at 500m from the emission point and subsequent rings of receptors were separated by further increments of 500m radial distance up to a total of 50km.

Meteorological data

The Meteorological Office provides sequential hourly measurements of wind speed, wind direction, boundary layer depth, temperature, and stability class for specific use with ADMS-3.

Meteorological data from RAF Wyton airfield 1993 was selected as a suitable generic data set for this assessment. This data is not overly biased towards any wind direction and the measurement site is in a situation where the surrounding terrain is flat for several kilometres. Therefore, the influence of terrain on this data should be minimal.

¹ Suggested default values from the Air Quality Modelling Assessment Unit of the UK Environment Agency.

² US EPA Guidance on Air Quality Models (Revised) (1986), Pages 8-10.

³ Guidance for estimating the air quality impact of stationary sources, Environment Agency, GN24, November 1998.

Appendix 3

Profile of Petroleum Refining and Crude Oil Slates - Effect on Nickel Ambient Air Quality

Regional Variation of Crude Oils

As described in section 8.1.2 a variety of crude oils are refined in the EU and this will apply also to the Accession States. There is a regional variation which can be typified by sulphur content in crude oils, in products, and for the refinery fuel burnt by the SO₂ emissions from refinery stacks, as shown in Table A1.

Table A1 Sulphur Contents of Crude Oils and Fuels by Region in Western Europe

Region ^c	Northwest Europe	Atlantic	Mediterranean	Others
Weighted average % sulphur in crude oils, 1995 ^a	1.17	0.91	1.2	0.64
Weighted average % sulphur in crude oils, 1992 ^b	1.1	1.0	1.3	0.6
Weighted average % sulphur in heavy fuel oils, 1992 ^b	1.8	2.4	2.5	0.9
Weighted average % sulphur in bunker fuels, 1992 ^b	3.3	2.7	3.0	2.0
Average SO ₂ concentration at refinery stacks ^d , mg/m ³	838	1560	2071	194

Notes

a Concawe, 1998

b Concawe, 1994

c Regions defined as

Northwest Europe – Belgium, The Netherlands, Germany, Denmark

Atlantic – Ireland, UK, Portugal, Atlantic coasts of France and Spain

Mediterranean – Mediterranean coast of Spain, southern France, Italy, Greece

Others – Norway, Sweden, Finland, Austria, Switzerland

The higher sulphur contents are associated with a greater proportion of Middle East crude oils. The lowest sulphur contents of the “Others” region results from the high proportion of North Sea crudes refined in Scandinavia.

As already indicated higher sulphur contents are accompanied by higher nickel contents, although not on a pro rata basis. Thus, based on the sulphur contents of the crude oil, higher nickel emissions may be anticipated from petroleum refineries in the Mediterranean region followed by Northwest Europe compared to the other two regions. However this pattern is not fully replicated by the data on sulphur contents of heavy fuel oil or SO₂ emissions, although both of these criteria rank the Mediterranean region as the potentially highest emitter of nickel.

Petroleum Refinery Type

The type of petroleum refinery is also an important factor influencing its nickel emissions. The more complex refineries will have more refinery fuel gas available and so will burn less fuel oil, even though the total fuel demand of the refinery has been increased by the greater number of process units, demand for utilities, and supporting facilities such as storage requiring heating, etc. Consequently the more complex refineries will emit less nickel than simpler refineries of comparable capacity.

An analysis of petroleum refinery types by region is given in Table A2. It shows that simple refineries are in the minority, whilst complex refineries vary in the type of conversion process used with cat cracking being the most prevalent. Regional variations in refinery type are also seen.

Table A2 Number of Petroleum Refineries in 1998 by Region and Type^a

	Scandinavia	UK Ireland	Benelu x	Germany Austria	France	Iberia	Italy Greece	Total
Simple ^b	4	2	2	2	1	3	10	24
Cat Cracking (CC) ^c	1	7	3	10	11	6	6	44
Hydrocracking (HC) ^d	0	1	3	3	0	1	2	10
Both CC & HC	2	1	1	1	1	1	5	12
Total Numbers	7	11	9	16	13	11	23	90

Notes

a Based on Table 1 of Concawe1999

b Typically Type I, see Figure 8.1

c Typically Type III based on cat cracking, see Figure 8.1

d Typically Type III based on hydrocracking, see Figure 8.1

For interpretation of the refinery type with fuel type data given in Table A5, Table A2 has been converted to the four regions basis of Table A5 as shown in Table A3. It should be noted that this conversion is approximate as neither precise details of the boundaries of the Atlantic and Mediterranean regions nor of the locations of the individual refineries has been given.

Table A3 Number of Petroleum Refineries by Type in 1998 Allocated to Four Regions^a

	Northwest Europe		Atlantic		Mediterranean		Others		Total Number
	Number	%	Number	%	Number	%	Number	%	
Simple	4	18	6	19	10	37	4	40	24
Cat Cracking (CC)	11	50	20	65	10	37	3	30	44
Hydrocracking (HC)	5	23	2	6	2	7	1	10	10
Both CC & HC	2	9	3	10	5	19	2	20	12
Total Numbers	22	100	31	100	27	100	10	100	90

Notes

a derived from Table1 of Concawe 1999

Oil Firing in Petroleum Refineries

The range in the amount of fuel oil burnt by petroleum refineries in Western Europe compared with fuel gas and other fuels, such as natural gas, based on surveys in 1995, 1992 and 1989 has been reported (Concawe 1998, 1994, 1991), see Table A4. The 1992 data was broken down also on the four regions basis, as shown in Table A5. A similar breakdown was not given for the years 1989 and 1995. The percent oil fired for individual refineries in 1995 is shown in Figure A1. (Note that Tables A4, A5 and Figure A1 are based on survey returns so do not include all petroleum refineries, e.g. those included in Table A2). In Figure A1 the balance of fuel consumed by the refineries is gas i.e. refinery gas, a by-product of the refining processes, and “other fuels” for 23 of the refineries. These “other fuels” will include natural gas.

Table A4 Oil Firing in Petroleum Refineries in Western Europe

	1995	1992	1989
Weighted average of oil fired in petroleum refineries, %	32.0	37.2	29.8
Petroleum refineries firing less than 50% of oil, %	87	75	87

Notes

- a Concawe, 1998
- b Concawe, 1995
- c Concawe, 1991

Table A5 Oil Firing in Petroleum Refineries by Region in Western Europe^a

	Northwest Europe	Atlantic	Mediterranean	Others
Total fuel fired, Mtpa	11.8	10.0	6.7	1.9
Percent oil fired in region, weighted average	26.0	49.0	46.0	16.0

Notes

- a Based on Figure 10 of Concawe, 1994

Figure A1 Percent Oil Fuel Fired for Individual Petroleum Refineries in 1995 (based on Figure 2, Concawe, 1998)

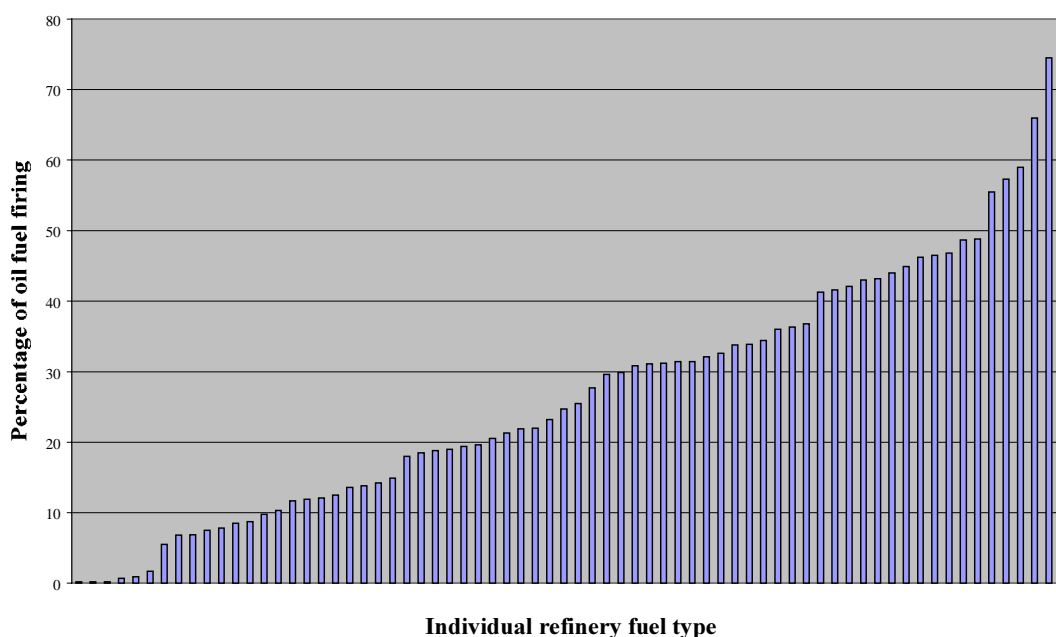


Table A4 and Figure A1 show that the majority of petroleum refineries do not burn a large proportion of oil fuel. This is because there are many more complex refineries than simple refineries e.g. as shown in Table A2. The reference for this Table anticipated an increase in complexity due to additions to the numbers of cat cracking and hydrocracking refineries by 2010 due to demand increases and the requirements of the Auto Oil programme.

Trends due to Petroleum Refinery Complexity

The analysis in Table A3 shows that the Mediterranean and Others regions have a greater proportion of “simple” petroleum refineries than the other two regions. Consequently it would be expected from the arguments above that these two regions would have the higher amounts of oil fuel firing. This is not supported by the information available in Tables A3, A5 as summarised in Table A6.

Table A6 Comparison of Petroleum Refinery Oil Fuel Firing with Refinery Type

	Northwest Europe	Atlantic	Mediterranean	Others
Simple refineries in region, %	18	19	37	40
Oil firing in refineries, %	26	49	46	16

This information does not show the trends anticipated. It is based on averages and there are wide variations in refinery types, configurations and local circumstances. For example, some of the refineries shown as “complex” burn little refinery gas with large amounts of other fuels such as natural gas and so should be considered to be “simple”. In some complex refineries the demand for hydrogen for use in treating processes has depleted the amount of refinery fuel gas available and more oil has been fired; it should be noted this trend for firing more oil could continue due to demands for additional treatment. Further the refineries have been analysed on a numerical basis, whereas the fuel data is from quantities and in this analysis has not been related to refinery capacities in e.g. tpa.

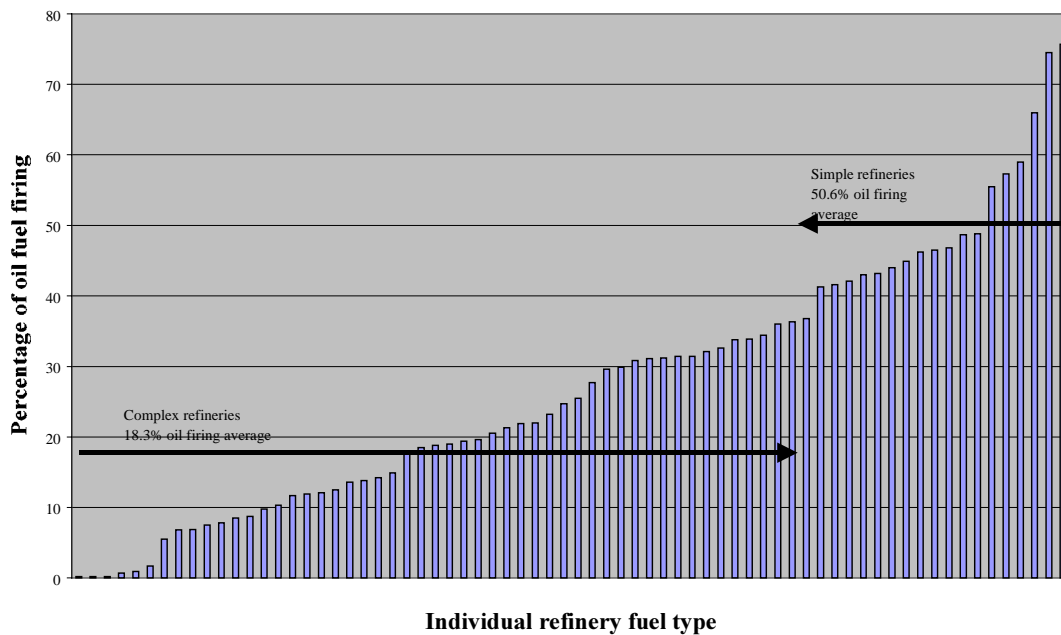
The variability of refinery circumstance is shown by the data reported by Concawe for the percent of oil fuel firing in Figure A1. Figure A1 also shows that the majority of petroleum refineries burn a relatively small proportion of oil. The numbers of refineries listed in Table A2 have been used to pro-rate a breakdown of Figure A1 to estimate the average oil fuel fired by simple and complex refineries respectively, viz.

27% of refineries in Table A2 are **simple** refineries, equivalent to the top 19 in Figure A1. These have an average oil fuel fired of 50.6%, with a range of 41 to 76%.

73% of refineries in Table A2 are **complex** refineries, equivalent to the lower 51 in Figure A1. These have an average oil fuel fired of 18.3%, with a range of 0 to 36%.

This is shown also in Figure A2.

Figure A2 Percent Oil Fuel Firing for Complex and Simple Petroleum Refineries in 1995




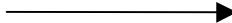
Interpretation and Conclusions

The implications of the foregoing on nickel emissions from petroleum refineries is summarised as follows

- Petroleum refineries are varied in their process configuration
- “Complex” petroleum refineries are in the majority compared to “simple” petroleum refineries.
- The proportion of crude oils refined with higher nickel contents (higher sulphur crudes) is greater than those with low nickel contents, and will continue to increase. This leads to higher nickel emissions from oil fuel firing in petroleum refineries.
- Complex petroleum refineries have a lower percentage of oil fuel firing than simple petroleum refineries.
- There are regional variations in the complexity of refineries and in the nickel contents of the crude oils refined.

On a simplified basis these points can be shown directionally as in Table A7.

Table A7 Factors Influencing Nickel Emissions from Petroleum Refineries

	Low nickel (low sulphur) crude	High nickel (high sulphur) crude	Regional variation
Complex refinery	Low nickel emissions	Higher nickel emissions	
Simple refinery	Low/moderate nickel emissions	Highest nickel emissions	
Regional variation	Some Atlantic/some Others, e.g. Scandinavia 		Mediterranean

To take these influencing factors further the following is an approach to quantify their variations on expected ambient air concentrations of nickel. It must be understood that this exercise involves some simplification and approximation. Even so it shows that there will be variations from one petroleum refinery to another.

Crude Oil Nickel Contents

Nickel contents of four crude oils are given in Table 8.1. To consider a wider range the nickel contents of crude oils given by Concawe has been used (Concawe, 2000a). A range of seven typical Middle East crudes were compared with North Sea crudes. For each crude the nickel content was given as a range; the “average” for this work was derived by taking the value at the lower one third of the range rather than the arithmetic mean. This was to compensate for the heavier crudes with proportionately higher nickel contents being refined in lower volumes. A factor was derived from the “averages” to arrive at the higher nickel emissions from Middle East crudes compared to North Sea crudes. Factors were similarly obtained based on vacuum residues using Concawe data and for crude oils using published data (Oil & Gas Journal, 1983). The factors are given in Table A8.

Table A8 Factors for Nickel Emissions from Middle East Crude Oils Compared to North Sea Crude Oils

	North Sea	Middle East	Nickel Emission Factor (Middle East nickel emission / North Sea nickel emission)
Crude oil (Concawe data)			
"Average" nickel content, ppm	2.5	11.1	4.4
Range of nickel contents for crudes considered, ppm	0.4 – 6.8	0.3 – 55	
Vacuum residue (Concawe data)			
"Average" nickel content, ppm	19.4	45.8	2.4
Range of nickel contents for vacuum residua considered, ppm	5.6 – 47	3.2 – 179	
Crude oil (Oil & Gas J data)			
"Average" nickel content, ppm	1.2	11.3	9.4
Range of nickel contents for crudes considered, ppm	0.6 – 2.9	0.3 – 50	

Oil Fuel Firing

A further factor to consider is the influence of petroleum refinery type and the consequent extent of oil fuel firing. This was taken simply as the ratio of the average oil fuel firing in simple and complex refineries derived above and shown in Figure A2. This factor for simple refineries compared to complex refineries is 50.6/18.3 i.e. 2.8.

Ambient Air Nickel Concentrations

The factors are combined in Table A9 to give comparative factors to convert nickel emissions and hence ambient air nickel concentrations from a scenario of a complex petroleum refinery running North Sea crude to other scenarios of refinery type and crude oil feed. In Table A9 the lower factor in the ranges is from Concawe vacuum residue data, whilst the higher factor is from Oil and Gas Journal crude oil data.

Table A9 Comparison Factors for Ambient Air Nickel Concentrations

	Low nickel crude oil	High nickel crude oil
Complex petroleum refinery	1	2.4 – 9.4
Simple petroleum refinery	2.8	6.7 – 26.3

The factors in Table A9 are used to predict ambient air nickel concentrations based on the achievement of a 3 ng/m³ limit value by a complex refinery running low nickel crude oil, and taking a background nickel concentration of 1 ng/m³, see Table A10. The ranges given in Table A10 are the same as Table A9.

Table A10 Ambient Air Nickel Concentrations Predicted for Different Refinery Scenarios

	Low nickel crude oil	High nickel crude oil
Complex petroleum refinery		
Ambient air nickel concentration predicted, ng/m ³	3 ^a	5.8 – 19.8
Limit value compliance, ng/m ³	3	10 – 30
Simple petroleum refinery		
Ambient air nickel concentration predicted, ng/m ³	6.6	14.4 – 53.6
Limit value compliance, ng/m ³	10	30 - > 50

Notes

a base value used for predictions

Table A10 shows how the various refinery scenarios result in a wide range of possible ambient air nickel concentrations, and consequent differences in limit values which could be achieved. Whilst the approach to Table A10 has been somewhat simplistic and necessarily has been based on averaging of data, it does demonstrate that the potentially good performance demonstrated in Table 8.10 for some petroleum refineries in the UK does not necessarily apply uniformly across the EU. The position for the Accession States is anticipated to be represented by the data for the higher nickel crude oil in Table A10.

In considering Table 8.12 it should also be noted that the UK crude oil slate is not exclusively based on North Sea crudes as a recent years about 50% has been imported (DUKES,1999). Some of these imports will be higher nickel content crudes e.g. from the Middle East, but the actual proportions run by the refineries near to the monitoring sites are not available. Consequently the factors used in Table 8.12 may predict a nickel ambient air qualities that are somewhat on the high side. However this aspect does not alter the variability of performance expected across the EU and Accession States.

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