Foundation Course on
Air Quality Management in Asia

# Emissions

2

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# Foundation Course on Air Quality Management in Asia

The Foundation Course on Air Quality Management in Asia is for adult learners studying the issue without the support of a class room teacher. It is aimed at students with some basic knowledge of environment and air pollution issues, acquired in a variety of ways ranging from conventional study, working in an environmental related field or informal experience of air pollution issues.

The course provides you with an opportunity to develop your understanding of the key components required to develop a programme to manage urban air pollution and to achieve better air quality. By working through the six modules you will gradually achieve a higher level of understanding of urban air pollution and the measures taken to monitor air quality and to prevent and control urban air pollution.

Clean air is recognised as a key component of a sustainable urban environment in international agreements and increasingly in regional environmental declarations in Asia. National and local governments have begun to develop air quality management strategies to address the deterioration in urban air quality. However, the scope and effectiveness of such strategies vary widely between countries and cities.

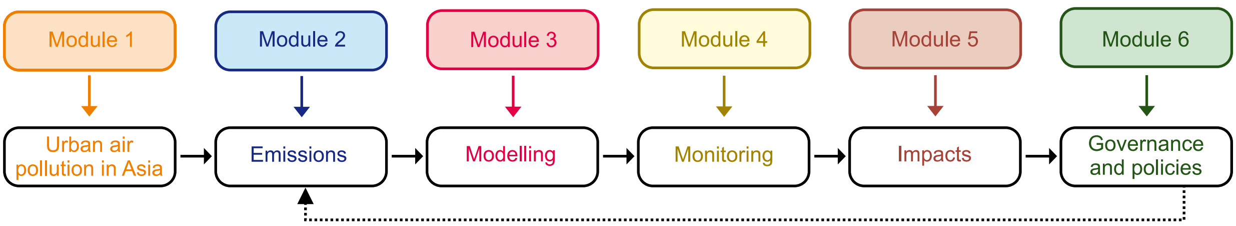
The aim of air quality management is to maintain the quality of the air that protects human health and welfare but also to provide protection for animals, plants (crops, forests and vegetation), ecosystems and material aesthetics, such as natural levels of visibility. In order to achieve this goal, appropriate policies, and strategies to prevent and control air pollution need to be developed and implemented.

## Urban Air Pollution in Asia

Urban air pollution affects the health, well-being and life chances of hundreds of million men, women and children in Asia every day. It is responsible for an estimated 537,000 premature deaths annually with indoor air being responsible for over double this number of deaths. It is often the poor and socially marginalized who tend to suffer disproportionately from the effects of deteriorating air quality due to living near sources of pollution.

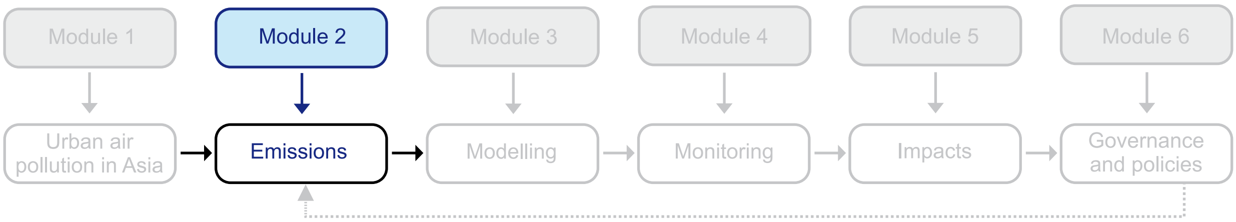
## Module Structure

The foundation course consists of six modules which address the key components of air quality management. An international team of air pollution experts have contributed to the the development of the course. Each module is divided into a number of sections each devoted to a different aspect of the issue, together with examples and key references.




*A simple air pollution pathway*

# Module 2 - Emissions




*A simple air pollution pathway*

## Learning objectives

In Module 2 *Emissions* you will examine the role of emissions inventories in air quality management and the different measures available to control emissions from different sources. At the end of the module you will have a better understanding of the:

- need for emissions inventories
- different types of pollution sources
- basic considerations required in developing an emission inventory
- computer programs available to compile an emission inventory
- measures available to control emission sources.

# List of Acronyms and Abbreviations

| | |
|---|---|
| ABC | Atmospheric brown cloud |
| ACFA | Asian Clean Fuels Association |
| ACS | American Cancer Society |
| ADAC | Automatic data acquisition system |
| ADB | Asian Development Bank |
| ADORC | Acid Deposition and Oxidant Research Center |
| AirQUIS | Air quality information system |
| ALAD | Aminolaevulinic acid dehydrase |
| AMIS | Air quality management information system |
| APHEA | Air Pollution and Health, A European Approach |
| API | Air pollution index |
| APINA | Air Pollution Information Network |
| APMA | Air pollution in the megacities of Asia project |
| APNEE | Air Pollution Network for Early warning and on-line information Exchange in Europe |
| AQG | Air quality guideline |
| AQM | Air quality management |
| AQMS | Air quality management system |
| AQO | Air quality objective |
| AQSM | Air quality simulation model |
| As | Arsenic |
| ASEAN | Association of South East Asian Nations |
| ASG | Atmospheric Studies Group |
| ATD | Arizona test dust |
| AWGESC | ASEAN Working Group on Environmentally Sustainable Cities |
| AWS | Automatic weather station |
| BaP | Benzo[a]pyrene |
| BBC | British Broadcasting Corporation |
| BMR | Bangkok Metropolitan Area |
| BRT | Bus rapid transit |
| BS | Black smoke |
| BTEX | Benzene, toluene, ethylbenzene and xylenes |
| CAI-Asia | Clean Air Initiative for Asian Cities |
| CAIP | Clean air implementation plan |
| CARB | Californian Air Resources Board |
| CAS | Chemical Abstract Service |
| CBA | Cost benefit analysis |
| Cd | Cadmium |
| CD | Compact disc |
| CDM | Clean development mechanism |
| CEA | Cost-effectiveness analysis |
| CER | Certified emissions reduction |
| CMAS | Institute for the Environment, Chapel Hill |
| CMB | Chemical mass balance |
| CNG | Compressed natural gas |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| COHb | Carboxyhaemoglobin |
| COI | Cost of illness |
| COPD | Chronic obstructive pulmonary disease |
| CORINAIR | CORe INventory of AIR emissions |
| CPCB | Central Pollution Control Board |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| CVM | Contingent valuation method |
| DALY | Disability-adjusted life years |
| DAS | Data acquisition system |
| DDT | Dichloro-Diphenyl-Trichloroethane |
| DETR | Department for Transport and the Regions |
| DQO | Data quality system |
| DQO | Data quality objective |
| DWM | Diagnostic wind model |
| EB | Executive board |
| EC | European Commission |
| EEA | European Environment Agency |
| EGM | Eulerian Grid Module |
| EIA | Environmental impact assessment |
| ETS | Environmental tobacco smoke |
| EU | European Union |
| FID | Flame ionisation detector |
| FOE | Friends of the Earth |
| FST | Foundation for Science and Technology |
| GBD | Global burden of disease |
| GDP | Gross domestic product |
| GHG | Greenhouse gas |
| GIS | Geographic information system |
| GTF | Global Technology Forum |
| HAP | Hazardous air pollutant |
| HC | Hydrocarbon |
| HCA | Human capital approach |
| HCMC | Ho Chi Minh City |
| HEI | Health Effects Institute |
| HEPA | Ho Chi Minh City Environmental Protection Agency |
| Hg | Mercury |
| HIV/AIDS | Human immunodeficiency virus/ Acquired Immunodeficiency Syndrome |
| I&M | Inspection and maintenance |
| IBA | Ion beam analysis |
| ICCA | International Council of Chemical Associations |
| IFFN | International Forest Fire News |
| IPCC | Intergovernmental Panel on Climate Change |
| IQ | Intelligent quotient |
| IR | Infrared |
| ISO | Organization for Standardization |
| IT | Interim target |
| IUGR | Intrauterine low growth restriction |
| IUPAC | International Union of Pure and Applied Chemistry |
| IVL | Swedish Environmental Research Institute |
| km | kilometre |
| LBW | Low birth weight |
| LCD | Less developed country |
| LPG | Liquid petroleum gas |
| LPM | Lagrangian particle module |
| MAPs | Major air pollutants |
| MCIP | Meteorology-Chemistry Interface Processor |
| MMS | Multimedia messaging service |
| MOEF | Ministry of Environment and Forests |
| MOPE | Ministry of Population and Environment |
| MT | Meteo-Technology |
| MW | Molecular weight |
| NAA | Neutron activation analysis |
| NAAQS | National Ambient Air Quality Standards |
| NASA | National Aeronautics and Space Administration |
| NDIR | Non-dispersive Infrared |
| NILU | Norwegian Institute for Air Research |
| NKBI | Neutral buffered potassium iodide |
| NMMAPS | National Morbidity and Mortality Air Pollution Study |
| NO | Nitric oxide |
| $NO_2$ | Nitrogen dioxide |
| $NO_x$ | Nitrogen oxides |
| NYU | New York University |
| $O_2$ | Oxygen |
| $O_3$ | Ozone |
| OECD | Organization for Economic Cooperation and Development |
| PAH | Polycyclic aromatic hydrocarbons |
| PAN | Peroxyacetyl nitrate |
| Pb | Lead |
| PbB | Level of blood lead |
| PCB | Polychlorinated biphenyl |
| PCD | Pollution Control Department |
| PDR | People's Democractic Republic |
| PESA | Proton elastic scattering analysis |
| PID | Photo ionisation detector |
| PIGE | Particle induced gamma ray emission |
| PILs | Public interest litigation |
| PIXE | Particle induced X-ray emission |
| PM | Particulate matter |
| $PM_{10}$ | Particulate matter less than 10 microns in diameter |
| $PM_{2.5}$ | Particulate matter less than 2.5 microns in diameter |
| PMF | Positive matrix factorisation |
| POP | Persistent organic pollutant |
| PPM | Parts per million |
| PRC | People's Republic of China |
| PSAT | Particulate matter source apportionment technology |
| PSI | Pollutant standard index |
| PSU/NCAR | Pennsylvania State University / National Center for Atmospheric Research |
| PVC | Polyvinyl chloride |
| QA/QC | Quality assurance/quality control |
| QEPA | Queensland Environmental Protection Agency |
| ROS | Reactive oxygen species |
| RBS | Rutherford backscattering spectrometry |
| SA | Source apportionment |
| SACTRA | Standing Advisory Committee on Trunk Road Assessment |
| SAR | Special Administrative Region |
| SMC | San Miguel Corporation |
| SMS | Short message service |
| $SO_2$ | Sulphur dioxide |
| $SO_x$ | Sulphur oxides |
| SPCB | State Pollution Control Board |
| TAPM | The Air Pollution Model |
| TEA | Triethanolamine |
| TEAM | Total Exposure Assessment Methodology |
| TEOM | Tapered element oscillating microbalance |
| TSP | Total suspended particulate |
| UAM | Urban airshed model |
| UCB | University of California at Berkeley |
| UF | Ultra fine |
| UK | United Kingdom |
| UNDESA | United Nations Department of Economic and Social Affairs |
| UNDP | United Nations Development Programme |
| UNECE | United Nations Economic Commission for Europe |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations framework on climate change |
| UN-Habitat | United Nations Habitat |
| US | United States |
| USEPA | United States Environmental Protection Agency |
| UV | Ultra violet |
| UVF | Ultra violet fluorescence |
| VOC | Volatile organic compound |
| VOSL | Value of statistical life |
| VSI | Visibility Standard Index |
| WAP | Wireless Application Service WHO World Health Organization |
| WMO | World Meteorological Organization |
| WRAC | Wide ranging aerosol collector |
| WTP | Willingness to pay |
| XRF | X-ray fluorescence |
| YLD | Years of life with disability |
| YLL | Years of life lost |

# List of Tables, Figures and Boxes

# Introduction

Air pollutant emissions inventories are the basic building blocks of air quality modelling and an integral part of air quality management (AQM) strategies. In Europe and North America there is official national reporting of emissions inventories for a number of pollutants. However, in Asia, Africa and Latin America, routine estimation and reporting of emission estimates of sufficient quality is either absent or only available in a few developing countries. If estimates exist they are often unreliable, contradictory and/or unrealistic. In most of the developing countries the capacity to undertake reliable estimations is generally lacking (CAI-Asia, 2004).

Without detailed and reliable emissions inventories, there is little opportunity to develop strategic plans to deal with air pollution and to monitor the effectiveness of such plans. In many cases the sources of pollution are obvious and are already being addressed in parts of Asia (e.g. the transformation of diesel-driven buses and three-wheelers to compressed natural gas (CNG) in New Delhi). However, the level of emission reduction achieved or achievable by these measures remains poorly understood due to the lack of high quality emission factors and inventory techniques. This fact has led to considerable debate as to whether a certain measure is really effective with respect to significantly reducing air pollutant concentrations.

Regional challenges such as acidic deposition, eutrophication of sensitive ecosystems, tropospheric ozone formation and increasing atmospheric loads of small particulate matter (especially those less than 2.5 μm in diameter) also require high quality emissions inventories in order to develop regionally coordinated abatement strategies.

This module examines the need for emissions inventories and the different sources of emissions. It provides an overview of the different types of computer programs available from different agencies that can be used to compile an emissions inventory. The module also addresses the control of emission sources of gaseous and particle compounds.

# 2

## Section 1 Emissions Inventories

An emissions inventory is generally defined as a comprehensive listing of sources and an estimation of the magnitude of air pollutant emissions in a geographic area during a specific time period. It can have different geographical scales ranging from global to individual plant level emissions. An inventory can be compiled at the national level, or emissions at the national level can be the sum of emissions compiled at smaller geographical scales (e.g. county, municipality or even facility level). An inventory can be given for a single year only, but inventories for more years (time-series) are needed for most applications. Emissions inventories should, therefore, be annually compiled and updated.

An emissions inventory can be used in a variety of ways as part of an integrated air quality management (AQM) programme. It can be used to:

- estimate the magnitude of local, regional or national emissions;
- evaluate emissions tendencies;
- serve as input in air quality models;
- assure compliance with regulatory/legal decisions (emission standards) and actions relating to emissions and/or air quality;

Box 2.1
**Why Produce an Emissions Inventory?**

An emissions inventory:

- estimates the magnitude of emissions to identify key sources;
- provides input data for modelling dispersion, ground level concentrations, deposition and effects of air pollutants;
- helps to inform policy makers and the public;
- helps to define priorities and set objectives for reducing emissions;
- assesses the potential efficiency of different reduction strategies;
- forecasts future emission levels to determine which emission sources might require further controls.

- estimate the impact of new sources of pollution (e.g. planning new industrial plants or changing processes in existing plants or allowing the use of different types of vehicles);
- support the setting of emission fees for sources;
- establish emission trading programmes;
- help revise current air quality regulations, policies and strategies; and
- initiate strategies and regulations for AQM.

Emissions inventories can be approached in two ways: top-down or bottom-up. The key decision on which approach to take is generally based on available resources.

### Top-down approach:

- national- or regional-level emission estimates allocated to state or county based on surrogate parameters such as population, employment, energy consumption, resource use, vehicle number growth in different sectors;
- used when local data are not available, cost to gather local data is prohibitive, and end use of data does not justify cost to collect;
- typically used to inventory area sources;
- requires modest resources.

### Bottom-up approach:

- collects source-specific information on individual sources, processes, activities and their levels, and estimates emission factors;
- typically used to inventory major sources;

- results in more accurate estimates than the top-down approach;
- requires more financial resources, depending on the requested level of detail and accuracy.

An emissions inventory addresses all relevant sources. It can often be labour-intensive to collect data, in particular when more sophisticated methods are applied. In this situation priority should be given to the key sources. Key sources are those that have a significant influence on the absolute level of emissions, the trend in emissions, or the reduction of uncertainty of estimated emissions. A key source is also determined by the toxicities of emitted compounds. For example, for two sources with equal mass emissions of compounds of different toxicity, the source which emits the more toxic compound has a higher relevance in a list of sources than the one which emits the less toxic compound. In turn, a source with low emission of a highly toxic compound may be more relevant than a source with high emission of a much less toxic compound. The consideration of key sources should be the priority for countries during inventory resource allocation for data collection, compilation, quality assurance/ quality control (QA/QC), and reporting.

## 1.1 Emission Data

Reliable emission estimates are often lacking in developing countries. However, where action is needed to improve air quality, absence of accurate information should not prevent the development of preliminary emission estimates. Basic information about the population, transportation, industry, fuels and other information can be used to calculate preliminary emission estimates (Kato and Akimoto, 1992), which can then be used to develop and implement AQM plans. In other cases, emissions can be calculated from estimates of process inputs. For example, emissions of sulphur dioxide ($SO_2$) from coal fired power plants can be estimated from the knowledge of the throughput and sulphur content of fuels, the process applied, operating conditions, the existence of emission-reducing equipment, and other information. In addition, reliable data may be available for some components of an emissions inventory (e.g. for some industrial sites from measurements of stack emissions).

The preliminary emissions inventory estimates can be revised as more accurate information becomes available. Sources of information on how to prepare rapid emissions inventories have been produced by the World Health Organization (WHO) (1993; 1995; 1997) and the Global Atmospheric Pollution Forum (GAPF) (2007).

In the past, most AQM goals have focused on emissions from major, and relatively well characterised, source categories. As major sources are addressed, remaining emissions will be more evenly distributed over source categories and will be more difficult to measure or model. Thus, errors in emission estimates from smaller individual sources will have a greater impact. Errors could range from wrongly identifying a pollutant that should be controlled to overlooking source categories whose control could result in a more cost-effective emission reduction. The Houston experience is an good example of the consequences of incomplete inventories (see Box 2.2).

Box 2.2

**The consequences of an incomplete inventory**

Houston, Texas has some of the most frequent violations of the US National Ambient Air Quality Standards. Emissions inventories in the late 1990s indicated that to meet the one-hour ozone standard it would be required to reduce nitrogen oxides ($NO_x$) emissions by 90 per cent. However, a 2000 study on the atmospheric chemistry affecting Houston's ozone problem found previously-unidentified sources of highly reactive volatile organic compounds (VOCs), and therefore a control strategy for $NO_x$-only would not achieve the desired reductions in ozone levels. The strategy was then revised to require more VOC control and only 79 per cent $NO_x$ emission reductions. Subsequent studies showed that the 90 per cent $NO_x$ control strategy would have resulted in the loss of 60,000 jobs and a US$ 9 billion smaller regional economy compared to the adopted 79 per cent $NO_x$ strategy. Obtaining accurate and complete emissions inventories is therefore extremely important and cost-effective (Corbett and Beskid, 2000).

## 1.2 Emission Sources

Pollutant air emissions can come from both man-made (anthropogenic) or natural (biogenic) sources. Table 2.1 provides a summary of the types of sectoral source categories that can be used in an emissions inventory.

Emissions can be identified on the basis of their sources which include the following:

- stationary (point) sources such as major industrial sites;
- area (non-point) sources such as domestic emissions and emissions from light industry and commercial areas;
- mobile (line) sources such as motor vehicles;
- biogenic or natural sources such as dust storms, forest fires, and volcanic eruptions.

**Table 2.1: Types of sectoral source categories used in an emission inventory**

| | Activities | Emissions from |
|---|---|---|
| 0 | Activities not adequately defined | • consumer solvent use<br>• surface coating |
| 1 | Agriculture, forestry and fishing | • crop and animal production<br>• forestry and logging<br>• fishing and aquaculture |
| 2 | Mining and quarrying | • mining of coal and lignite<br>• extraction of crude petroleum and natural gas<br>• mining of metal ores<br>• other mining and quarrying<br>• mining support service activities |
| 3 | Manufacturing | Manufacture of<br>• food, beverages and tobacco products<br>• textile, wearing apparel & leather and related products<br>• wood and products of wood and cork, except furniture; articles of straw and plaiting materials<br>• paper and paper products, printing and reproduction of recorded media<br>• coke and refined petroleum products<br>• chemicals and chemical products<br>• basic pharmaceutical products and preparations<br>• rubber and plastics products<br>• other non-metallic mineral products<br>• basic metals<br>• fabricated metal products, except machinery and equipment<br>• computer, electronic and optical products<br>• machinery and equipment<br>• motor vehicles, trailers and semi-trailers<br>• other transport equipment<br>• furniture<br>• other products<br>• repair and installation of machinery and equipment |

**Table 2.1: (continued)**

| | | |
|---|---|---|
| 4 | **Electricity, gas and water** | Production of<br>• electricity<br>• gas<br>• steam<br>• air conditioning supply. |
| 5 | **Water supply, sewerage, waste management and remediation** | • water collection, treatment and supply<br>• sewerage<br>• waste collection, treatment and disposal, and materials recovery<br>• remediation activities and other waste management services |
| 6 | **Construction** | • construction of buildings<br>• civil engineering<br>• specialized construction activities |
| 7 | **Wholesale and retail trade, repair of motor vehicles and motorcycles** | • wholesale trade<br>• retail trade<br>• repair of motor vehicles and cycles<br>• other retail trade |
| 8 | **Transportation and storage** | • land transport and transport via pipelines<br>• water transport<br>• air transport<br>• warehouses and support activities for transportation<br>• postal and courier activities |
| 9 | **Community, social and personal services** | • sanitary and similar services<br>• social and related community service<br>• recreational and cultural services<br>• personal and household services |
| 10 | **Accommodation and food service activities** | • hotels<br>• restaurants |
| 11 | **Information and communication** | • publishing activities<br>• motion picture, video and television programme production, sound recording and music publishing activities<br>• telecommunications<br>• computer programming, consultancy and related activities<br>• information service activities |

Source: Adapted from UN (2007)

## Stationary sources

A stationary source is a fixed-site emitter of pollution which usually involves industrial combustion processes. Emissions may be from large or small point sources or several single sources over a small area (e.g. several smokestacks in a copper smelter). Emissions may also be released from material transfers, equipment leaks, stacks or vents.

**Figure 2.1: Copper smelter in Ilo, Peru**

Source: Courtesy D. Schwela

Point sources (see Figure 2.1) typically emit key pollutants such as, carbon monoxide (CO), nitrogen oxides ($NO_x$), particulate matter (PM), sulphur oxides ($SO_x$) and volatile organic compounds (VOCs). Table 2.2 lists the different types of industrial activities which could be a stationary source of air pollution.

Toxic air pollutants, also called hazardous air pollutants, are known or suspected to cause serious health effects, such as respiratory and cardiovascular diseases, cancer, reproductive effects, or adverse environmental effects (USEPA, 2007a).

Point source emissions can be further divided into various sub-categories, depending on the industrial process. Examples of sub-categories

**Table 2.2: Emitted compounds from various industrial activities**

<table>
<tr><th>Activities</th><th>Emitted compounds</th></tr>
<tr><td>Electric utilities</td><td>PM, CO, $NO_x$, $SO_x$, lead (Pb), and toxic air pollutants</td></tr>
<tr><td>Petroleum refining</td><td>VOCs, PM, toxic air pollutants</td></tr>
<tr><td>Primary/Secondary metal production</td><td rowspan="2">PM, $SO_x$, Pb, toxic air pollutants</td></tr>
<tr><td>Cement production</td></tr>
<tr><td>Mining and quarrying</td><td rowspan="2">PM, Pb, toxic air pollutants</td></tr>
<tr><td>Mineral products</td></tr>
<tr><td>Waste disposal</td><td>VOCs, PM, CO, Pb, toxic air pollutants</td></tr>
<tr><td>Automobile industry</td><td>VOCs, PM, toxic air pollutants</td></tr>
<tr><td>Wood pulp and paper</td><td>PM, $SO_x$, toxic air pollutants</td></tr>
<tr><td>Oil and gas production</td><td rowspan="7">VOCs and toxic air pollutants</td></tr>
<tr><td>Surface coating</td></tr>
<tr><td>Bulk fuel terminals</td></tr>
<tr><td>Wood products manufacturing</td></tr>
<tr><td>Food and agriculture industry</td></tr>
<tr><td>Chemical manufacturing</td></tr>
<tr><td>Printing and publishing</td></tr>
</table>

include fugitive emissions, process emissions, combustion emissions, various solvent usage emissions, and storage tank emissions.

## Area sources

An area source refers to any source of air pollution emitted over an area, which cannot be classified as a point source. Area sources can be a large number of similar small stack point sources (e.g. household emissions) (see Figure 2.2) which can be difficult to estimate individually. Area sources might include emissions from household activities such as cooking and heating, small business activities, agricultural residue burning, waste combustion, fugitive dust from deposits and roads, forest fires, small activities from gasoline service stations, small paint shops, consumer use of solvents and biogenic (natural) sources. Waste deposits can also be a large area source of emissions (see Figure 2.3).

**Figure 2.3: Waste deposit in Lagos, Nigeria, as an example of a large area source**

Source: Courtesy D. Schwela

**Figure 2.2: Area source of household emissions in Alexandra, South Africa**

Source: Photo credit unknown

### Diffuse sources

Diffuse sources are sources that are not clearly delimited such as open windows, gates, doors, tube connections and flanges in a plant. They are also often summarized as area sources. According to the definition in the European PRTR Regulation (EC, 2006):

"diffuse sources are the many smaller or scattered sources from which pollutants may be released to … air …, whose combined impact ... may be significant and for which it is impractical to collect reports from each individual source".

Emissions from diffuse sources include evaporative emissions from motor vehicles and off-road mobile sources (e.g. hot soak emissions, running and diurnal losses) and emissions from areas with light industry, domestic and wood burning as well as biogenic emissions from natural sources. Area sources can be difficult and time-intensive to inventory and various screening techniques are often used to estimate their emissions.

## Mobile (line) sources

Mobile sources are on-road and off-road vehicles, ships and aircraft. Emissions from vehicles can be distributed over a large urban area and are normally near to where people live. In addition, the tail-pipe emissions are close to the level of the individual (e.g. breathing zone of children); thus exposure and impact of vehicle source emissions on human health may be higher than from stationary sources with elevated emission outlets.

### On-road sources

Mobile on-road sources include all vehicles which move on-roads. The category can be divided in sub-groups:

- passenger cars;
- light duty vehicles;
- heavy duty vehicles;
- urban buses and coaches; and
- two- and three-wheelers.

In an emissions inventory mobile sources on the roads in urban areas are considered to constitute line sources since it is not feasible to consider the emissions from each individual vehicle. Parameters that are important for estimating vehicle emissions include:

- type of the vehicles;
- year of conventional vehicle manufacturing;
- fuel consumption;
- cylinder displacement;
- type of catalytic converter, particle filter or conventional technology used;
- average trip length;
- ambient mean temperature.

The main pollutant categories associated with motorized vehicles are hydrocarbons (HCs) which contain a vast number of different hydrocarbon species including carcinogenic substances such as benzene and polycyclic aromatic hydrocarbons (PAHs). Other pollutants emitted from motor vehicles include PM, $NO_x$, CO, and ammonia ($NH_3$). PM includes black carbon species, metal oxides, sulphates, nitrates, and other particles.

**Off-road sources**

Non-road sources include a large number of different emission sources such as construction machines and equipment, tractors, lawn mowers, oil field equipment, boats, ships, aircraft, etc. Emissions from these sources are similar to those from on-road vehicles, but are much more difficult to estimate due to the fact that for most of the categories, no registration and activity rates are available in less developed countries (LDCs).

**Ships and aircraft**

Emissions from ships are important in harbours and on the shipping routes close to ports. Aircraft emissions are important for starting, landing and taxiing activities on airports.

## Emissions

The amount of emissions released into the atmosphere from any activity generally depend on a number of parameters such as (WHO, 1993):

- source type;
- unit of activity;
- source size;
- process;
- source age and technological sophistication;
- source maintenance and operating practices;
- type and quality of the raw material used;
- type, design and age of the control system employed;
- ambient conditions such as humidity and temperature; and
- other conditions.

These parameters are explained in Table 2.3.

**Table 2.3: Parameters influencing emissions of activities**

| Parameter | Impact on emissions |
|---|---|
| Source type | Type of pollution-generating activity such as cement manufacturing, vehicle traffic |
| Unit of activity | Measure of the activity, e.g. mileage of vehicles; number of aircraft take-offs and landings; amount of raw materials consumed or of products manufactured |
| Source size | Only indirectly related to the emission rate (defined as emission amount per unit of activity) if the process selected depends on the source size |
| Process | The quantities of emissions depend on the process chosen, e.g. different kinds of kilns in the production of lime and cement |
| Source age and technological sophistication | Both parameters affect emission loads. The ageing of a source leads to more frequent failure. Technological innovations may be more environmentally friendly. |
| Source maintenance and operating practices | These parameters affect emission loads, product quality and costs. Therefore, it is in the interest of manufacturers to ensure proper maintenance and operation. For vehicles, these parameters offer less emissions, lower fuel consumption and economic savings |
| Type and quality of the raw material used | In industrial processes, the type and quality of raw materials often dictate the process to be employed and, correspondingly, emissions. For motor vehicles, the type and quality of fuels affect the performance of the engines and their emissions |
| Type, design and age of the control system employed | These parameters determine the efficiency of emission removal |
| Ambient conditions such as wind velocity, humidity and temperature | Ambient conditions may significantly affect the emission rate, e.g. wind velocity and/or rainfall affect PM emissions from roads and material deposits. Temperature affects road traffic emissions |
| Topographic conditions such as altitude | Altitude may change the combustion efficiency due to rarefied atmospheric conditions and lower temperatures resulting in power loss |

## 1.3 Emission Factors

Often monitored source data such as the emission rate of the exhaust gas stream and concentrations of pollutants in the exhaust gas stream are missing. This is due to the fact that emissions would involve extensive monitoring in order to determine individual emission rates. Under these circumstances, it is common to model emissions by using general emission factors for point, area and line sources. Most emissions can be estimated using the simple relation:

**Emissions [mass/time unit] =**
**Emission factor [mass/activity unit] ·**
**Activity rate [activity unit/time unit]**

An emission factor provides emission as mass per unit activity, for example, kg $NO_x$ emitted per ton of coal or terajoule of fuel. Abatement of emissions is taken into account by the appropriate choice of the emission factor corresponding to the applied abatement technology. In other situations, abatement is taken into account by subtraction of a recovery term:

**Emissions = Emission factor · Activity rate – Recovery [mass/time unit]**

In this equation recovery is a measure of the efficiency of an abatement technology. Recovery depends on similar parameters to emissions such as the activity, type and age of technology. Industrial sources usually have several activities. Production processes therefore include more than one emission factor or type of activity data. Box 2.3 presents an example of emissions from power plants (Activity 1).

Air pollution inventories often include data from large point sources (LPS). Such data can be based on direct emission measurements, calculations from emission factors or mass balance considerations. In combining data from LPS with data estimated from aggregated emission factors and activity data (e.g. at the country level), it is particularly important to check that emissions are not double counted and that the inventory is complete. In applying emission measurements to determine emissions it is important to adhere to accepted standards for making such measurements (e.g. ISO 9096:2003; ISO 10396:2007; ISO 11942:1996).

Emission factors for area sources are calculated using the data specific for each type of source within the area. These are averaged over the sources. For line sources, motor vehicle emissions may be estimated by calculations involving the distance travelled by vehicles, number of vehicles, temperature, fuel consumption and the composition and properties of the fuels used (see Box 2.4, Activity 2).

General emission factors for many industrial processes are available from various published sources (WHO, 1993;1995; GAPF, 2007; UBA, 2004; USEPA, 2007b). However, emission factors need to be used with care, as adjustments in emission factors may need to take into account the differences in operating conditions, fuels and resource materials.

Box 2.3

**Activity 1: Estimating emissions from power plants**

Estimate the emissions of TSP, $SO_2$, $NO_x$, CO, VOC and $SO_3$ from three power plants in the study area:

(a) One is a utility boiler (UB) using natural gas (NG), the second one is an industrial boiler (IB) using distillate fuel oil, the third one is a power plant (PP) using anthracite coal in a pulverised coal furnace

(b) UB consumes 1,000,000 $Nm^3$/year

(c) IB consumes 200,000 tons/year

(d) PP consumes 50,000 tons/year in a pulverized coal furnace equipped with a cyclone.

Use the data of the rapid assessment technique in Appendix A (WHO, 1993), and the equation:

Release [t/y] = Emission factor [kg/U] $\cdot$ Activity rate [u/y]

| Source | Fuel/boiler parameters | Unit [U] | Source size [1000*U/y] | TSP | | $SO_2$ | | $NO_x$ | | CO | | VOC | | $SO_3$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Factor [kg/U] | Release [t/y] | Factor [kg/U] | Release [t/y] | Factor [kg/U] | Release [t/y] | Factor [kg/U] | Release [t/y] | Factor [kg/U] | Release [t/y] | Factor [kg/U] | Release [t/y] |
| **Utility boiler** | | 1000 $Nm^3$ | 1,000 | 0.048 | 48 | 15.6S | 9.6 | 8.8f | 6890 | 0.64 | 640 | 0.028 | 28 | | |
| S-content gas [%] | 0.000615 | | | | | | | | | | | | | | |
| Mean boiler load [%] | 0.87 | | | | | | | | | | | | | | |
| Load reduction coefficient f (see Appendix A) | 0.783 | | | | | | | | | | | | | | |
| **Industrial boiler** | | t | 200 | 0.28 | 56 | 20S | 12,000 | 2.84 | 568 | 0.71 | 142 | 0.035 | 7 | 0.28 | 56 |
| Sulphur content of fuel oil [%] | 3 | | | | | | | | | | | | | | |
| **Anthracite coal power plant pulverized coal furnace** | | | | | | | | | | | | | | | |
| Cyclone | | t | 50 | 1.25 | 587.5 | 19.5S | 3,900 | 9 | 450.00 | 0.3 | 15 | 0.55 | 27.5 | | |
| Sulphur content anthracite coal | 4 | | | | | | | | | | | | | | |
| Ash content in anthracite coal [%] (see Appendix A) | 9.4 | | | | | | | | | | | | | | |
| Subtotal | | | | | 691.5 | | 15,909.6 | | 4,063.10 | | 797 | | 62.5 | | 56 |

t: metric tonnes; y: year, S: Sulphur content, f: load reduction coefficient

Box 2.4

**Activity 2: Estimating exhaust emissions from heavy duty diesel powered trucks and buses in urban areas**

Description of vehicle fleet:

(a) Average speed = 25 km/h
(b) Average trip length = 8 km
(c) Cold/hot starts 75/25
(d) Mean ambient temperature 20⁰C
(e) S-content in diesel: 0.5%
(f) Number of trucks 3.5-16 tons: 1 000
(g) Number of trucks > 16 tons: 200
(h) Number of buses > 16 tons: 300
(i) Annual mileage trucks: 52000 km
(j) Annual mileage buses: 20000 km

Use the emission factors of Appendix B to estimate the emissions from this vehicle fleet., and the equation:

Release [t/y] = Emission factor [kg/U]▪Activity rate [u/y]

| Source | | Unit [U] | Activity rate [1000*U/y] | TSP | | $SO_2$ | | $NO_x$ | | CO | | VOC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Factor [kg/U] | Release [t/y] | Factor [kg/U] | Release [t/y] | Factor [kg/U] | Release [t/y] | Factor [kg/U] | Release [t/y] | Factor [kg/U] | Release [t/y] |
| 711 Land transport | | | | | | | | | | | | | |
| Sulphur content of diesel [%] | 0.5 | | | | | | | | | | | | |
| Annual mileage trucks 52000 km | 52,000 | | | | | | | | | | | | |
| Annual mileage buses 20000 km | 20,000 | | | | | | | | | | | | |
| Number of trucks 3.5-16 tons | 1,000 | 1000 km | 52 | 0.9 | 46,800 | 4.29S | 111,540 | 11.8 | 613,600 | 6 | 312,000 | 2.6 | 135,200 |
| Number of trucks > 16 tons | 200 | 1000 km | 52 | 1.6 | 16,640 | 7.26S | 37,752 | 18.2 | 189,280 | 7.3 | 75,920 | 5.8 | 60,320 |
| Number of buses > 16 tons | 300 | 1000 km | 20 | 1.4 | 8,400 | 6.6S | 19,800 | 16.5 | 99,000 | 6.6 | 39,600 | 5.3 | 31,800 |
| Subtotal | | | | | 71,840 | | 169,092 | | 901,880 | | 427,520 | | 227,320 |

t: metric tonnes; y: year, S: Sulphur content

# Section 2 Inventory for Different Source Types

In planning a source inventory the following issues should be considered:

1 the objective and the scope of the inventory;

2 the area to be covered;

3 the accuracy and precision needed for estimating emissions;

4 the implementation of quality assurance (QA) and quality control (QC);

5 previous efforts to establish emissions inventories and existing useful information, e.g. source apportionment;

6 source categories in the area;

7 sources within each source category;

8 relevant source parameters such as stack height, flue gas exit velocity, and temperature;

9 availability of relevant source parameters;

10 methodology to be used for emission estimates.

Objectives for an emissions inventory may include estimates of the contribution of individual sources to the overall concentrations at receptor sites; the prioritisation of source contributions; the assessment of compliance of individual sources with emission standards; the determination of stack heights; decisions on appropriate source control measures; estimation of exposure of the population. The scope of an emissions inventory refers to the inclusion of point, area and line sources and the extent to which these source types have to be considered.

A reliable, defensible emissions inventory needs a comprehensive QA plan and a thorough QA/QC system to ensure confidence in the inventory (USEPA, 2004a). Ingredients of QA/QC include:

- technical reviews;
- accuracy checks;
- use of approved standardized procedures for emissions calculations;
- external review and audit procedures conducted by personnel not involved in the inventory development process to assess the effectiveness of the QC plan and the quality, completeness, accuracy, precision, and representativeness of the inventory;
- devotion of adequate resources to QA/QC activities;
- implementation of data quality objectives (DQO) to ensure that the data in the emissions inventory will be sufficient for the intended use;
- balancing DQO with available resources including time constraints, resource (staff and funding) limitations, and lack of data;.
- describing data quality indicators such as accuracy (precision, systematic error), comparability of methods and data, completeness (amount of valid data obtained compared to the planned amount), and representativeness with respect to sources and the area to be covered;
- a standardized checklist that assesses the adequacy of the data and procedures at various intervals in the inventory development process and includes questions concerning completeness, use of approved procedures, and reasonableness;
- application of techniques such as reality check, computerized data checks, peer review, statistical checks, replication of calculations, and QA audits.

A key part of QC is recognising in the planning stage where errors typically happen and making a plan to avoid them. Typical errors found in inventories include (USEPA, 2004a):

- missing facilities;
- double counting of facilities;
- improper facility location data;
- missing operating or technical data;
- erroneous technical data including misinterpretation of data or transcription errors;
- inconsistent point, area and line source size designation or failure to designate inventory size cutoffs;
- errors in calculations such as transposition of digits; decimal errors; entering wrong numbers; and misinterpreting emission factor applications; and, finally,
- data entry, transposition and coding errors.

Data gaps in the inventory may be the result of:

- pollutants unaccounted for due to a lack of credible emission factors;
- sources that are missing or unaccounted for due to incomplete source lists;
- source categories that have not been considered due to a lack of credible emission factors or activity data;
- oversight of a facility or source category during inventory compilation; and
- data entry errors.

All QA/QC activities and results should be documented and reported, either as part of the inventory report, or as a separate document.

## 2.1 Stationary Source Inventories

The most basic type of emissions inventories in LDCs is the stationary source inventory.

The following steps should be considered in identifying source categories to determine emissions:

- examine any past emissions inventory efforts in the area, including those created by other agencies or levels of government;
- look at permit files, source and compliance tests;
- review emission characterisation documents;
- prepare a list of potential source categories based on the pollutants of interest;
- eliminate any source categories not found in the study area, or which no emission reduction methods are available;
- separate out stationary from area and line source categories;
- examine emission factor and estimation tools and decide on methodology;
- prioritise sources by amount of emissions in each category;
- refine prioritisation by weighting emission amounts with toxicity parameters such as air quality limits and guidelines (EC, 1999; 2000; 2002; 2004; USEPA, 2006a; WHO, 2005), threshold limit values and biological exposure indices (ACGIH, 2007), permissible exposure levels (OSHA, 2007), specified limits of toxicity (HSE, 2002), irreversible effects thresholds (Pichard, 2001), acute reference exposure limits (USEPA, 1998), or acute exposure guideline levels (NRC, 1993; NAC/AEGL 2001; 2002);
- consider budget and time constraints to conduct the inventory;

- document decisions to ensure transparency and consistency with future emissions inventories.

Once the source categories have been identified, specific point sources within the study area should be identified. Useful data sources for identifying potential point sources include:

- existing inventories;
- inspection reports, compliance reports, and permit files;
- local information such as telephone directories or business license databases;
- professional organisations such as trade association membership, chamber of commerce membership, local section or chapter of the Air and Waste Management Association, and academic institutions;

Once the above have been examined, a list of potential sources, including name, address, size, and point source category can be created.

Finally, after identifying the categories and specific facilities to inventory, specific facility activity data for use in the emissions calculations should be determined. The following information sources should be considered:

- use of surveys, emissions declarations, and questionnaires;
- direct plant inspection reports;
- permit applications and files;
- industrial directories;
- commerce and labour statistics;
- national directories of manufacturers;
- data compiled by private research and development companies;
- trade and professional associations;
- similar facilities in other countries.

## Factors influencing emissions

There are several important factors that can influence the emissions from a specific facility or operation and must be factored into the emission calculations. Two facilities might have similar production activities, but entirely different emission levels based on the following factors:

- combustion characteristics influenced by firing configuration, operating conditions, fuel specifications;
- equipment age;
- operating practices;
- air pollution control equipment;
- raw materials used in processes or stored;
- meteorological conditions.

## Level of emission detail for point source facility inventories

There are several specific emissions inventory details that should be considered when determining what information to gather from a point source. Examples include:

- Plant level: denotes facility, and could contain several pollutant-emitting activities;
- Point source/stack level: denotes where emissions from point sources to ambient air occur;
- Process/segment level: denotes where emissions from individual processes within a facility may occur.

## Frequently overlooked processes

A common error in inventory development is that of not considering all aspects of a facility's emissions. There are numerous processes and emission locations beyond those emissions that are vented through a smoke stack, and the activity level of the facility's production may not account for them. Here are a few of the "frequently overlooked processes" of a stationary source:

- in-process fuel use;
- process additives;
- fugitive VOC component and dust emissions;
- devices that act as control devices and also emission sources;
- miscellaneous solvent usage;
- upset and start-up emissions.

Accidental releases of emissions are not part of a regular emissions inventory since they occur only in an emergency.

## Basic estimation formula for emissions from point sources

While emissions inventories frequently calculate source emissions through a software-computerized program, it is important to understand the basic formula to estimate emissions for a point source. The basic formula is as follows:

$$E = A \cdot EF$$

Where:

E = emission rate [mass of pollutant/time unit];

A = activity rate [activity unit/time unit];

EF = emission factor [mass of pollutant/activity unit].

The mass of pollutant may be expressed in g, kg, or tons. The emission factor (EF) is a representative value that attempts to relate the mass of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. In most cases, emission factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in a source category. EF is different for different process parameters such as "controlled" process, "uncontrolled" process, use of cyclones, etc.

An alternative formulation of this equation[1] is:

$$E = A \cdot EFU \cdot [1 - CE/100]$$

Where:

E = emission rate [mass of pollutant/time unit];

A = activity rate [activity unit/time unit];

EFU = emission factor of uncontrolled process [mass of pollutant/activity unit].

CE = Control Efficiency (per cent emissions reduction as measured across the control device times percent capture of the control device).

Control efficiency (CE) refers to the level of pollutant capture that a particular control device produces. Control efficiency should be considered when making rule effectiveness[1] determinations, as defects in the operation of equipment designed to capture emissions and route them through a control device can result in a substantial increase in emissions. Emission units that are dependent upon the operation of both capture and control device equipment should generally receive lower rule effectiveness[1] adjustments than units equipped with only control devices.

1 In the United States a more complicated formula is in use (USEPA, 2004b):

$$E = A \cdot EFU \cdot [1\text{-}(CE/100 \cdot RE \cdot RP)] \cdot T$$

In this formula, E, A, EFU, and CE have the same meaning as above. RE denotes "Rule Effectiveness", a correction factor to adjust for "real world" operating conditions (i.e. equipment breakdown, operator variance, compliance rate, etc.). It is a term that describes a method to account for the reality that not all facilities covered by a rule are in compliance with the rule 100 per cent of the time. In addition, RE accounts for the fact that control equipment does not always operate at its assumed control efficiency. Control efficiency, therefore, is related to RE determinations, as defects in the operation of equipment designed to capture emissions and route them through a control device can result in a substantial increase in emissions. Emission units that are dependent upon the operation of both capture and control device equipment should generally receive lower RE adjustments than units equipped with only control devices. RP denotes "Rule Penetration", a correction factor to adjust the degree a given regulation penetrates the totality of emission processes coming under the scope of the rule. RP is the extent to which a regulation may cover emissions from a geographical source category. T is an adjustment factor for temporal changes in emissions (e.g. the portion of the year that a particular source is operating.

### Checklist of point source emissions inventory development

It is useful to establish a planning review checklist for point source emissions inventory development. This checklist should include:

- objectives and end user requirements of the inventory;
- compatibility of defined source categories with available source and emission information;
- sufficient detailed source categories to facilitate control strategy projections;
- selection of an inventory data handling system
- definition of data reporting formats;
- staff and budget allocations;
- identification of the geographical inventory area;
- selection of the inventory base year ;
- adjustment of seasonal variations of emissions;
- determination of the temporal basis of emissions;
- compilation frequency of emissions;
- determination of the point source cut-off, depending on amount of pollutant emitted and its toxicity;
- estimation of the relative quantity of sources below the emissions cut-off level;
- determination of best collection methods for point source data;
- decisions made on emissions projections and projection period;
- identification of existing emissions estimates;
- consideration of all important sources including non-combustion industrial processes;
- selection and documentation of quality assurance procedures.

## 2.2 Area Source Inventories

Area sources can be geographically dispersed and are often aggregated by source category such as residential areas, waste deposits, forest fires, urban open burning, and commercial facilities such as service stations and dry cleaning facilities. This section will discuss how to apply emission factors to area sources, the level of detail to gather information, and identify those categories of area sources that might have potential interest in LDCs.

### Use of emission factors (local, national, or census-based)

As noted earlier, area source emission factors generally are based on a top-down approach. This approach frequently has a nationally-developed emission factor which is applied to the local level. Also, when there are national, regional or state/ provincial emission estimates, these can also be allocated to the local level on a population basis. The following are some examples of when to use national, local, or census-based emission factors:

**Nationally-based emission factors**

- National averages come from wide range of source tests, such as those found in AP-42 and CORINAIR guidebooks (see below).
- Useful when:
  - no local emission factors exist;
  - local mix of area sources is similar to the national average;
  - source category is of low priority.
- Geographical variability is not taken into account.

**Locally-based emission factors**

- Preferred when national-level emission factors do not account for local variation.
- Applicable to locally-significant source categories.

- May require representative source sampling.
- Considers existing uncertainty of estimate (e.g., mass balance for solvent emissions may be sufficiently accurate).

**Census-based emission factors**

- Often used when sources do not vary geographically or seasonally, such as consumer solvents and auto refinishing.
- May be highly uncertain due to socio-economic and cultural difference between regions of the country.
- Example of VOC emission factors:
  - Architectural surface coating: 2.9 kg/year/person
  - Consumer solvents: 3.56 kg/year-person.

### Level of detail

There are several specific emissions inventory details that should be considered when determining what information to gather from an area source:

- geographical level, such as city, district, province;
- magnitude of pollutant levels, such as only area source emission above 5 tons per year of pollutant; and
- source type, such as construction works with lower particle emission levels than wildfires

A key concern is the overlapping of area and point source categories. For example, point source inventories may include small sources such as dry cleaners and gas stations. However, these are often included in area source inventories and may thus lead to potential double counting of emissions.

### Area sources of potential interest

Several major area source categories need to be carefully assessed before estimating their emissions. These include the source categories shown in Table 2.4.

All these sources emit air pollutants such as PM, $SO_2$, $NO_x$, CO, VOCs and PAHs.

### Summary of area source emissions inventory development

Area sources are numerous sources of air pollution emitting over a relatively small area or extended sources which cannot be classified as a point source. Completing the area source inventory involves the following steps:

- Calculate emissions from the various area sources, using similar formulae as for point sources but with appropriately averaged emission factors.
- Avoid duplication between area source and point source inventories.
- Make temporal and spatial adjustments if necessary.
- Ensure quality assurance and quality control.
- Prepare documentation.

## 2.3 Mobile (On-road) Inventories

The following input data are required for an emission modelling:

- number of vehicles;
- vehicle fleet composition (share of light duty vehicles, separated gasoline, CNG, liquefied petroleum gas (LPG) and diesel, trucks differentiated between medium and heavy duty, buses differentiated between urban buses and coaches, other heavy vehicles);
- vehicle age distribution;
- number of vehicles meeting different emission standards;
- information on the inspection and maintenance level;
- annual mileage for the different vehicle categories;

**Table 2.4: Area source categories**

| Source category | Typical area sources |
|---|---|
| Fuel combustion | Small stationary source use of fossil fuel, e.g., diesel generators, residential wood burning, small utility boilers |
| Evaporative losses of fuels | Parking cars evaporation |
| | Gasoline and diesel distribution |
| | Petroleum vessel loading/unloading |
| | Aircraft refuelling |
| | Leaking underground storage tanks |
| | Catastrophic/accidental releases (Oil spills) |
| Open burning | Solid waste incineration (on-site, open burning) |
| | Slash burning and prescribed burning |
| | Agricultural field burning |
| | Forest fires |
| Fugitive particulate matter | Mining and quarrying |
| | Construction works |
| | Resuspended dust from paved roads |
| | Resuspended dust from unpaved roads |
| | Agricultural tilling |
| Solvents | Dry cleaning |
| | Surface cleaning (de-greasing) |
| | Surface coating |
| | Graphic arts |
| | Asphalt paving |
| | Commercial/consumer solvent use |
| | Barge, tank truck, rail car, and drum cleaning |
| Pesticides | Agriculture and indoors applications |
| | Bio process (bakeries, breweries, distilleries) |
| Ammonia | Agricultural fertilizer application |
| | Agricultural fertilizer manufacturing |
| | Animal husbandry |
| | Waste water treatment |

Source: Adapted from USEPA (2004b)

- vehicle speed information depending on the road category, urban, rural and highway;
- meteorological conditions, day/night fluctuations, seasonal changes;
- fuel characterisation, e.g. sulphur level, vapour pressure, aromatic and alcohol content;
- total fuel consumption.

These input parameters are the minimum to start an emissions inventory for the mobile sector. For other parameters such as average trip length, cylinder displacement, and the numbers of cold and hot starts, default values can be used. To further improve measured emission factors, information on driving behaviour and length of the trip should be developed. For heavy duty trucks information on the load and of the slope of the road should be evaluated. The altitude of the roads should also be made available.

## 2.4 Mobile (Off-road) Inventories

The estimation of off-road machinery emissions is much more complicated and inaccurate than for on-road vehicles. The problem is twofold. Firstly the emission factors have higher uncertainty due to the fact that this sector is very diverse and includes a large number of applications in:

- agriculture
- construction
- forestry
- household and garden
- sport boats
- passenger ships
- locomotives.

Secondly, the activity rates are much less-known than for on-road vehicles. The following information is needed to establish an inventory for the off road sector:

- number of engines
- size
- age distribution
- fuel quality
- duration of use
- average power used.

If this information is available, as a first approach the COPERT III non-road model can be used (EEA, 2000a). Due to the fact that the fuel quality and the engines used in LDC differs from those used in developed countries, results should be handled with caution. Further refinement of emission factors will require actual measurements of emissions of local vehicles.

## 2.5 Inventory for natural sources

Natural (non-anthropogenic) sources include emissions of pollutants from volcanoes, deserts, and biogenic emissions from swamps, forests, and other vegetation (USEPA, 2006b). This source category is difficult to control as processes based on natural phenomena and the source strengths occur unpredictably and therefore are not well established. Natural sources (see Table 2.5) are important sources of $H_2S$, $CH_4$, $CO_2$, VOCs and Radon (Rn) some of which are carcinogenic pollutants and precursors of regional tropospheric ozone.

Biogenic VOC emissions are thought to exceed anthropogenic VOC emissions on a national basis by up to a factor of two. In addition, many of these compounds, such as isoprene and methyl butenol, are highly reactive and control photochemistry in many locations. Model uncertainties range from ± 50 per cent for summertime isoprene emission estimates to over a factor of 10 for some oxygenated VOC such as hexenol (USEPA, 2007c).

**Factors influencing biogenic emissions**

To ensure the effectiveness of reducing anthropogenic emissions, it is necessary to utilize adequate datasets describing the environmental conditions that influence the photochemical reactivity of the ambient atmosphere. Compared to anthropogenic emissions from point and mobile sources, there are large uncertainties in the locations and amounts of biogenic emissions. For regional air quality modelling, biogenic emissions are not directly measured but are usually estimated with meteorological data such as solar radiation, surface temperature, land type, and vegetation data (Byun *et al.*, 2005). General and specific factors influence the results of modelling (LADCO, 2001; Byun *et al.*, 2005):

*General factors include:*

- diurnal and seasonal variations;
- species number and spatial distribution.

Specific factors include:

- type of vegetation cover;
- leaf biomass and area index;
- ambient temperature;
- photo-synthetically active radiation;
- humidity, wind speed, rainfall.

**Table 2.5: Types of natural sources and key pollutants**

| Types of natural sources | Pollutants | Reference |
|---|---|---|
| Trees and other vegetation | VOCs; isoprene | Geron and Pierce (2002) |
| Oil and gas seeps | $CH_4$, VOCs | Leifer *et al.* (2007); Marse and Tsoflias (2001) |
| Microbial action, e.g. soil de-nitrification | $NO_x$, $N_2O$, $CO_2$ | Hall *et al.*, (1996); Kitzler *et al.* (2005) |
| Volcanoes | PM, $SO_2$, VOCs | Thelocke *et al.* (2006) |
| Geothermal activities (geysers, seeps) | $H_2S$, $CO_2$, VOCs, Rn | Durand and Scott (2004); Guenther (2000) |
| Electrical storms (lighting) | NO, $O_3$ | Pierce (1999) |
| Wind blown dust | $PM_{10}$, $PM_{2.5}$ | Thelocke *et al.* (2006) |
| Vegetation fires | $NO_x$, $PM_{10}$, $PM_{2.5}$, CO, VOCs | Thelocke *et al.* (2006) |

*Basic estimation methods include:*

- computer models for the Biogenic Emissions Inventory System – BEIS (USEPA, 2006b) and Global Biosphere Emissions and Interactions System (GloBEIS); GLOBEIS estimates emissions from natural (biogenic) sources and is designed for use in combination with photochemical modelling systems for ozone and particulate matter such as CAMx (GLOBEIS, 2003);
- use of maps with land use and land-cover data;
- use of meteorological data;
- Global Emissions Inventory Activity (GEIA, 2007; Olivier, 2000).

## 2.6 Baseline Studies of Emissions in Regional and Transboundary Air Pollution

In Europe, the Regional Air pollution INformation and Simulation (RAINS) model is widely used for the calculation of regional and transboundary air pollution. The RAINS model combines information on expected trends in anthropogenic activities that cause transboundary air pollution with data on the available options for reducing emissions from these activities and their costs (IIASA, 2004). Dispersion models are used to calculate how these emissions are transported over Europe and how they influence air quality. With the resulting ambient concentrations and deposition fields of the various pollutants, RAINS estimates the impact on human health and ecosystems. These expected impacts can then be compared with environmental targets, highlighting areas where the assumed measures fail to meet the environmental policy objectives. A unique feature of the model is its ability to investigate the optimal distribution of further reduction efforts across the whole of Europe (from Norway to Italy and from Spain to the Ural) to meet air quality objectives. In this case the model provides estimates of regional costs and environmental benefits of alternative emission control strategies.

For $SO_2$, a RAINS model version for Asia exists. The problem of the extension to other pollutants is the lack of reliable emission data for the key emission sectors in many Asian countries (IIASA, 1999).

## Section 3 Compiling an Emissions Inventory

There are many good computer programs to develop emissions inventories produced by various environmental agencies, international organisations and the academic world. Some of these are all encompassing while others focus on a particular aspect or category of activities such as mobile sources. In selecting the emissions inventory method, one needs to carefully assess which approach best meets one's needs and can effectively form part of an overall AQM. A brief description of selected emissions inventory programmes available is given below.

### 3.1 EEA - EU EMEP/CORINAIR

The European Union's (EU) EMEP/CORINAIR emissions inventory (EEA, 2006) is similar to USEPA's Air CHIEF programme (USEPA, 2007d). It is the European air emissions inventory programme to collect, manage, maintain, and publish official national inventories on annual basis as required by EU legislation. Countries can use a software package, known as CERCERRER, to report their data (Lacour, 2003). Source types are harmonised using a detailed selected nomenclature for air pollution (SNAP). Emissions from some types of natural or biogenic sources are also included in CORINAIR.

The initial CORINAIR program was developed in 1985. During the early 1990s, revisions were made by the United Nations Economic Commission for Europe (UNECE) to allow it to be used for reporting transboundary air pollution. Additional modifications included covering emissions from more pollutants, including greenhouse gases.

The most recent edition of the EMEP/CORINAIR Emissions Inventory Guidebook was published in 2007, and provides a comprehensive guide to state-of-the-art atmospheric emissions inventory methodology (EEA, 2007). Its intention is to support reporting under the UNECE Convention on Long-Range Transboundary Air Pollution and the EU Directive on national emission ceilings (EC, 2001). The guidebook contains emission factors for various emission categories, and sub-categories. While the EMEP/CORINAIR guidebook provides a very extensive coverage of the stationary source category, the AP-42 document contains a more detailed set of emission factors.

An important aspect of EU emissions inventories is road transport. COPERT III is the programme used to develop relevant emission factors and is to be used by EU member countries to compile the mobile source portion of the CORINAIR annual emissions inventories (EEA, 2000b). COPERT III includes a software package to estimate national mobile source emissions. The methodology can be applied to calculate traffic emission estimates at a relatively high spatial and temporal aggregate level. Pollutants covered in COPERT III are ozone precursors (CO, $NO_x$, and NMVOC), greenhouse gases ($CO_2$, $CH_4$, and $N_2O$), acidifying substances ($NH_3$, $SO_2$), PM, carcinogenic species (PAHs, POPs), toxic substances (dioxins and furans) and heavy metals. Fuel consumption information can also be calculated.

### 3.2 Global Atmospheric Pollution Forum

A manual and workbook have been produced under the auspices of the Global Atmospheric Pollution Forum which is coordinated by the Stockholm Environment Institute (SEI), based at the University of York, UK and the International Union of Air Pollution Prevention Association (IUAPPA). The Forum Manual was based on a manual initially prepared for UNDP/UNDESA by SEI (GAPF, 2007) for use in Northeast Asia which has been subsequently modified for use by the Malé Declaration countries of South Asia and the Air Pollution Information Network for Africa (APINA).

The purpose of the Forum Manual is to provide a simplified and user-friendly framework for an emissions inventory preparation that is suitable for use in different developing and rapidly industrialising countries and which is compatible with other major international emissions inventory initiatives.

Inventory methods are provided for estimating emissions from the following sources: fuel combustion and transformation; fugitive emissions from fuels; industrial process emissions (non-combustion); emissions from solvent and other product use; emissions from agriculture (including savannah fires); emissions from other vegetation fires and forestry; and emissions $SO_2$, $NO_x$, CO, non-methane volatile organic compounds (NMVOC), ammonia ($NH_3$) and $PM_{10}$ and $PM_{2.5}$. An Excel workbook has been prepared as a companion to this Manual for use as an aid and tool in preparing emissions inventories.

## 3.3 NILU - AIRQUIS

The AirQUIS system developed by the Norwegian Institute for Air Research (NILU) in Norway has been based on the integrated AQM concept (see Figure 2.4)

The AirQUIS system uses modern information technology and geographical information systems (GIS). It contains the following modules (NILU, 2001):

- On-line measurement system
- Emissions inventory database
- Atmospheric dispersion models
- Exposure estimation
- Geographical information system
- Air quality planning.

The combination of on-line data collection, statistical evaluations and numerical modelling enable the user to obtain information, carry out forecasting and future planning of air quality. The

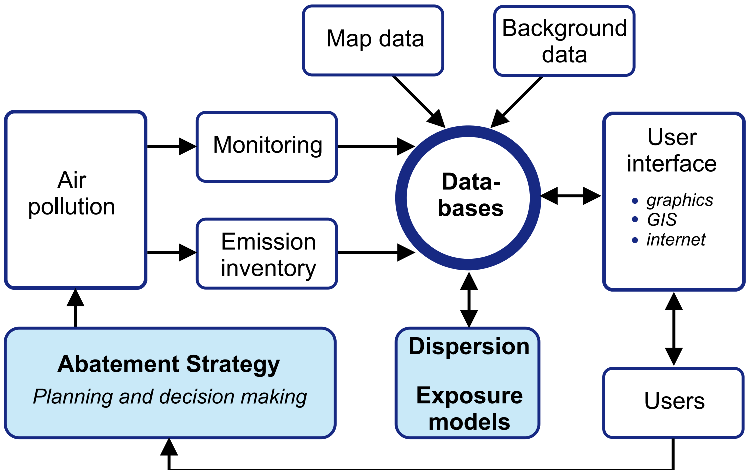



**Figure 2.4: The elements of the air quality management system AirQUIS**

Source: NILU (2001)

system can be used for monitoring and to estimate environmental impacts from planned measures to reduce air pollution.

## 3.4 The German-Swiss Emission Calculation System

The German-Swiss emission calculation system consists of a set of three emission models with a different level of complexity:

1. The Handbook of Emission Factors for Road Transport
2. Computer-aided Instrument for predicting the impact of Traffic measures on Air pollution Reduction (CITAIR)
3. TRansport Emission estimation MODel (TREMOD).

### Handbook of Emission Factors for Road Transport (UBA-BUWAL)

The Handbook of Emission Factors for Road Transport (HBEFA) was developed for the environmental agencies of Germany (UBA, Federal Environmental Agency) and Switzerland (BUWAL, Swiss Agency for the Environment, Forests and Landscape) by INFRAS, Switzerland. The HBEFA provides emission factors. These include specific emission factor in grams/ kilometre for all current vehicle categories (Personal cars, Light Duty Vehicles (LDV), Heavy Duty Vehicles (HDV) and motor cycles), each divided in different categories, for a wide variations of traffic situations. Version 2.1 contains the emission factors for Germany, Switzerland and Austria (HBEFA, 2004a).

The HBEFA is a Microsoft Access application, which is distributed as a CD and has to be installed as a run time version. The Model provides emission factors on a differentiated level (e.g. for different Euro standards and different traffic situations). An online version also exists (HBEFA, 2004b). The online version is a reduced version for occasional users and provides only aggregate values for Germany, Switzerland and Austria. The CD version includes also a forecast of the emission factors until 2020 based on adopted emission standards and proven technology.

## CITAIR

The computer-aided instrument for predicting the impact of traffic measures on air pollution reduction (CITAIR) has three modules: City Impact, Mobilev and Immis-Net/CPB. The interaction of the three modules is shown in Figure 2.5.

City Impact estimates the impacts of actions in the transport sector in reducing air pollution (UBA, 2002).

Mobilev allows air pollutant emissions to be quantified and makes prognoses about the development until 2020. Emission factors are estimated on the basis of road type, average daily traffic strength and vehicle distribution (UBA, 2007). Mobilev is designed to determine vehicle emissions:

- on the basis of scenarios for specific roads or road sections;
- throughout the main road network (as line sources); or
- for a single road section with lane-by-lane resolution;

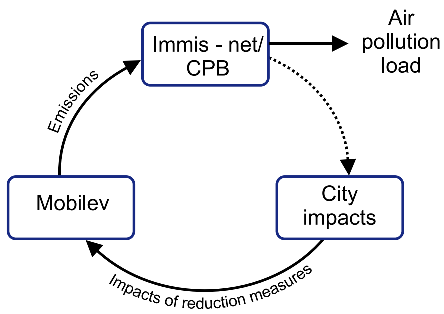



**Figure 2.5: The three modules of CITAIR**

Source: Friedrich (2002)

- in the form of exhaust and evaporation emissions of the secondary road network as area sources.

Mobilev contains and combines the following road network/traffic volume related elements:

- road category/traffic situation classification (urban, rural, motorway, free flowing traffic, dense traffic, congested traffic, road gradient class);
- vehicle category/subcategory classification (cars, trucks, buses, motorcycles);
- characteristic diurnal traffic load distribution curves for each vehicle category;
- shares for the contribution of each vehicle category to the whole vehicle fleet.

The model contains the following pollutants: methane and non-methane HC, benzene, $NO_x$, CO, PM for diesel vehicles, diesel soot, lead, $SO_2$.

Immis-Net/CPB calculates the pollutant concentrations in street canyons taking into account the following aspects:

- modelling the propagation of benzene, diesel soot and $NO_x$ in road spaces;
- limitation to concentration-relevant road classes;

- user-friendliness;
- practicable computation times;
- medium data input;
- proven model concepts; and
- integration in an overall system.

The CPB model is a two-dimensional analytical/ empirical propagation model for calculating concentrations of inert pollutants in road canyons. The CPB model is based on the Gaussian smoke plume equation and has been used successfully for many years.

Apart from the geometry of the road canyon, the CPB model requires only the hourly traffic emissions in the road canyon. These emissions are provided by using the Mobilev emission model. All other initial data records are provided directly by IMMIS-NET (Friedrich, 2002).

### TREMOD

The transport emission estimation model (TREMOD) is used to calculate the national or regional total emission in Germany (UBA, 2007). TREMOD consists of a database on personal passenger vehicles, motorcycles, buses, trucks, railways, ships and aircraft which has been updated annually since 1980. Data collected include trip lengths and frequencies, degree of usage of passenger and goods vehicles, energy consumption and emission factors. Air pollutants considered include $NO_x$, methane and non-methane HCs, benzene, CO, PM, $NH_3$, $N_2O$, $CO_2$ and $SO_2$. The model is used by German authorities, automobile and petroleum industries and the German Railways to estimate the national emissions from transport.

## 3.5 USEPA - AIR CHIEF

The USEPA has one of the most extensive programmes to develop emission factors for use in stationary and mobile source emissions inventories. The major repository for stationary and areas source emission information and updates can be found on its Air CHIEF programme (USEPA, 2007d). A subsection on emissions inventories contains all the official US, Mexican, and Canadian inventories.

The Emissions Factors and Policy Applications Center (EFPAC), a subsection of AirCHIEF, provides access to a recent USEPA update to the emissions factors program as well as various emission factors software and tools. EFPAC also contains information and access to AP-42, the classic compilation of emission factors that began with the US Public Health Service in 1968. The current fifth edition was published in January 1995.

Since December 2005, the USEPA provides an internet version of its FIRE (Factor Information REtrieval) Data System. This allows the user to search for the latest and best emission factors for most point and area source categories, including a rating on the quality of the particular emission factor. Users can browse through records in the database or select specific emissions factors by source category, source classification code (SCC), pollutant name, CAS number, or control device.

The latest emission model for mobile (on-road) sources is MOBILE 6. Until recently, mobile source emission factors were contained in a Volume II of AP-42. As the complexity of the MOBILE model had substantially increased, it was no longer feasible to provide documentation of the model in this format. MOBILE 6 is an emission factor model for estimating emissions [g/mile] of HC, CO, $NO_x$, $CO_2$, PM, and toxic air pollutants emitted by cars, trucks, and motorcycles under various conditions. For off-road mobile sources such as engines and equipment, USEPA's NONROAD 2005 model site, provides information on the NONROAD emissions inventory model, which is a software tool for predicting emissions of CO, HC, $NO_x$, PM, $SO_x$ from small and large non-road vehicles, equipment, and engines.

The National Mobile Inventory Model (NMIM) is a free, desktop computer application to estimate current and future emissions inventories for on-road motor vehicles and non-road equipment. NMIM uses current versions of MOBILE6 and NONROAD, based on multiple input scenarios that can be entered into the system. NMIM can be used to calculate national, regional, or provincial inventories. Because of the large amount of computing necessary to calculate a national inventory, the NMIM model is designed to utilize multiple computers over a computer network. NMIM will also work on a single computer, but much more slowly.

Finally, USEPA is currently developing a new generation model called MOVES (Motor Vehicle Emission Simulator) to estimate emissions produced by on-road and non-road mobile sources and covers a broad range of pollutants. When fully implemented, MOVES will serve as the replacement for MOBILE6 and NONROAD.

## 3.6 WHO: RIAS

WHO has published various books on how to rapidly assess and develop management systems on air, water, and land pollution. The aim was to use these techniques in developing countries to enhance their capacity to address pollution issues. In 1993 WHO published a rapid inventory guide, part one of which discusses rapid inventory techniques in environmental pollution and part two describes approaches for consideration in formulating environmental control strategies (WHO, 1993). The emissions inventory methodology used in this publication has been used in numerous countries including Chile, India and Mexico. Furthermore, the technique, generally referred to as Rapid Inventory Assessment Technique (RIAS), is frequently used as part of AQM training courses. A computer program called "Decision Support System for Industrial Pollution Control" has also been developed and is available on CD-ROM (WHO, 1997; 1998). A Tutor's Guide is also available (WHO, 1996a), which addresses workshop organisation, course agenda, and provides transparency charts and lecture notes, as well as the training of participants through the solution of selected environmental problems (WHO, 1996b). Moreover, it offers evaluation questionnaires to be used before and after the workshop. For motor vehicle emission estimates, a Teacher's Guide gives practicable examples of the estimation methods (WHO, 1996c).

For a country or region with very limited resources the use of rapid assessment techniques can provide a good indication of the magnitude and type of air pollutant emissions as well as identifying some initial control strategies for consideration. RIAS can provide the country with an initial decision support system.

This relatively simple and straightforward approach to emissions inventories is based on existing information on a facility's activity, quantity of emissions, application of existing or proposed control equipment and estimations of released pollution load. The RIAS contains various emission factors for both stationary and mobile sources of pollution (WHO, 1993). Many of these factors have since been updated in AP-42 or in CORINAIR corresponding to the implementation of new technologies for stationary and mobile sources. One must therefore use them with caution or substitute them with newer factors. However, for the technologies still in place in many developing countries, the 1993 emission factors may represent reality more closely than the new emission factors developed for modern technologies in developed countries. There are several advantages to the use of the WHO rapid assessment approach which include:

- convenience of use;
- limited time and little resources required;
- effectiveness of alternative control measures can be assessed.

The RIAS is useful for initial emissions inventories but may need adjustment once more detailed emissions inventories are conducted.

## 3.7 SIM-AIR

The Simple Integrated Model for Better Air Quality (SIM-AIR) is a relatively new interactive model to examine emissions, ambient air quality, and health. While it relies on some of the basic approaches and emission factors contained in AP-42, CORINAIR, and RIAS, it is based on an integrated AQM approach like AirQUIS and provides a user-friendly visualisation of rapid assessment of pollution data and control options.

The SIM-AIR integrated approach has a number of advantages:

- allows definition of all major types of urban emission sources, such as point, mobile, and area;
- provides default emission factors where available (users can change these factors based on local context, or use CORINAIR, AP-42 or RIAS emission factors);
- interfaces an emission computation model with key technology and management options (e.g. fuel change, conversion of two stroke to four stroke engines etc.);
- links emissions to ambient air quality through an externally created or supplied source-receptor matrix (this allows user to apply an urban air quality model of their choice. SIM-AIR is thus independent of the air quality model);
- allows estimation of economic impacts on health. The user can edit exposure-damage relationships according to local knowledge;
- allows input of cost data for a broad range of air quality management options;
- encourages rapid assessment of management options in terms of cost effectiveness;
- provides an optimization scheme to identify most cost-effective option combinations.

SIM-AIR uses a "main" worksheet and eight other "theme" worksheets to display the output in Excel format. The eight themes include emission distribution of non-transport sources, vehicle data, emissions inventory, a menu of options, health impacts, transfer coefficients to compute ambient concentrations, ambient concentrations, and, finally, a help worksheet. The result is that for any grid of the study area, the input data contains information on emission distribution, ambient concentration, health impacts, and management options.

The SIM-AIR model is primarily a training tool and should not be used as the only support system for decision making. However, as a training tool, it helps to understand how different management options can influence health impacts.

## 3.8 Other International Emissions Inventory Programs

In addition to the emissions inventory approaches discussed above, there are several other similar programs that should be briefly mentioned.

The Organisation for Economic Co-operation and Development (OECD) has had a project since 1983 known as the OECD/MAP Project. The MAP Project was designed (EEA, 2006) to:

- assess pollution by large scale photochemical oxidant episodes in Western Europe; and
- evaluate the impact of various emission control strategies for such episodes.

The MAP emissions inventory covered the following pollutants: $SO_2$, $NO_x$, and VOCs, including natural emissions. The inventory quantified point and area source emissions in nine main source sectors from 17 European OECD countries - the current 15 Member States (excluding the former German Democratic Republic) plus Norway and Switzerland. The nine main source sectors were:

1 mobile
2 power plant
3 non-industrial combustion
4 industry
5 organic solvent evaporation
6 waste treatment and disposal
7 agriculture and food industry
8 nature
9 miscellaneous

In most but not all cases the inventory was compiled from emission estimates submitted officially by each country.

Another OECD emissions inventory programme is the Pollutant Release and Transfer Registry (PRTR). A PRTR provides publicly accessible data about quantities of releases and/or transfers of a set of potentially harmful substances, the origin of these releases and transfers and their geographic distribution on a timely, regular periodic basis (OECD, 1996).

NARSTO (formerly North American Research Strategy for Tropospheric Ozone) has had considerable experience in evaluating and recommending improvements to emissions inventories in North America. NARSTO's third assessment examines the current state of emissions inventories for Canada, the US and Mexico, and offers suggestions for improvement (NARSTO, 2006).

The International Sustainable Systems Research Center (ISSRC) is a relatively new organisation that focuses on assisting cities in developing countries assess their air pollution program. The key model used is the International Vehicle Emissions (IVE) Model, which focuses on control strategies and transportation. The IVE model predicts how different strategies will effect local emissions, and measures progress in reducing emissions over time. Local air pollutants, greenhouse gases, and toxic pollutants can be estimated with the IVE Model (ISSRC, 2005). Existing US and European models take into account the modern technologies and conditions that exist in most developed countries. These technologies and conditions do not prevail in developing countries. A model applicable for developing countries must consider the local toxic emissions that are needed to fully evaluate the impact of motor vehicles. The IVE Model is designed to have the flexibility needed by developing nations in their efforts to address mobile source air pollutant emissions. Reports on IVE vehicle activities exist for Almaty, Kazakhstan; Beijing, PR China; Lima, Peru; Mexico City, Mexico; Nairobi, Kenya; Pune, India; Santiago, Chile; Sao Paulo, Brazil; and Shanghai, PR China. A report on the measurement of in-use passenger vehicles in three urban areas of developing nations describes the gasoline emissions testing results and applications of the IVE model in Mexico City ; Sao Paulo; and Nairobi.

## 3.9 Basic Considerations In Emissions Inventory Development

### Adoption of emission models

None of the emission factor models can be used without adaptation to local conditions and with the help of an experienced expert. Emission standards, the age distribution of the vehicles, maintenance quality, fuel quality and enforcement are very different in LDCs. Only by considering the local situation and the support of an expert can a reliable emissions inventory for all mobile sources, including aircraft and ships, be developed. Quality control of the results can be achieved by simulating the concentrations related to a multitude of sources and comparing them with measurements.

**General planning considerations**

The most important step in initiating an emissions inventory is determining the objectives of, and the major planning considerations for, the inventory. Factors which need to be considered include:

- ultimate use of and background and basis for the inventory;
- identification of point, area, and mobile source categories;
- responsibility for the inventory;
- staff and budget requirements/constraints;
- geographical coverage;
- selection of base year;
- variation of source emissions: daily, seasonal, annual;
- rule effectiveness;
- minimal source size;
- data collection methods;
- emission estimate approach, including selection of sources for emission factors;
- status of existing emissions inventories;
- inventory data handling system;
- quality control (QC) and quality assurance (QA) measures, including naming a quality assessment coordinator;
- use of the inventory modelling purposes, e.g. as input to a photochemical dispersion model.

**Characteristics**

Key characteristics of an emissions inventory include the base year for which the emissions will be estimated and the geographic domain for the inventory. The area selection determines the sources to be included; the political boundaries for setting regulations when applying control strategies; and the potential area (which may be different from the source area) to simulate the impact of the emissions on the atmosphere, human health and the environment.

**Stages in estimating an emissions inventory**

There are six stages in calculating an emissions inventory:

1 establishing a list of sources by category;

2 contacting source operators for information;

3 compiling data on activity levels and process parameters;

4 review data on its suitability for use in the calculations;

5 develop alternative strategies or activity levels, if necessary;

6 process source and activity level information to provide a spatially disaggregated inventory.

**Methods to assess/conduct emissions inventory**

There are several methods to gather the necessary information to develop an emissions inventory. Some of these include:

- direct or indirect source sampling (e.g., testing the stack emissions);
- surveys of industrial sources;
- use of modelling to simulate emissions from point, area, and line sources;
- use of the national census to determine number of registered vehicles, distinguished by type and eventually other characteristic parameters;
- material balance: collection of information on raw materials and fuel consumption;
- information transfer or extrapolation from similar sources;
- use of relevant meteorological information;
- application of appropriate emission factors;
- ensure quality of the inventory by QA/QC plan.

**Resource needs**

The level of detail or sophistication of an emissions inventory is directly dependent upon the level of human and financial resources. This needs to be carefully considered before launching into an inventory development process as it is necessary to complete the full inventory on a consistent base year basis. A team leader with broad environmental management experience is important. Some of the internal resource considerations include:

- availability of staff and staff expertise, team can vary from 2-3 persons up to 10;
- outside experts/specialists knowledgeable of particular sources such as power plants, smelters, etc.;
- budget allocations;
- administrative and training support;
- computer/data management capabilities;
- data handling systems;
- availability of emissions inventory-related data;
- coordination of efforts within the agency.

**External resource considerations include:**

- consider assistance from national or regional air pollution control agencies if conducted at a local level;
- obtain training and funding from national and/or international agencies;
- using emission data compiled on national basis;
- using outside experts to provide guidance.

**Time requirements**

The time required to conduct and analyze the emissions inventory varies with the complexity of the inventory. A fairly uncomplicated area might take a couple of months, while a more complex metropolitan region could take six months or longer.

**Use of rapid assessment techniques**

In LDCs emissions inventories should be compiled by use of rapid inventory assessment techniques such as the GAP Forum model (GAPF, 2007) or the WHO model (WHO, 2003). These models provide an indication of the magnitude of emissions and can be implemented with relatively limited resources. Staff applying these models should be made aware of the uncertainties in the estimates which are larger than those of more sophisticated models.

## Section 4 Control of Emission Sources

Decades of AQM in developing countries have shown that prevention of air pollution in the planning phase of stationary sources or in the inspection and maintenance of mobile sources is less expensive that taking remedial action to clean the air of polluting emissions.

Two approaches to address the problem of air pollution have been applied in the past:

- reduction of emissions;
- reduction of the impact of emissions.

For the reduction of emissions from all types of sources, planning tools have been developed to:

- evaluate the magnitude of a potential reduction of emissions using emission factors; and
- apply dispersion models for estimating ambient air pollutant concentrations before and after the implementation of control options (see Module 3 *Modelling*).

In broad terms, control options for point sources include:

**Reduction of emissions**

- selection of type and quality of raw materials;
- changes in processes;
- programmes of inspection and maintenance;
- replacement of obsolete factories;
- closing down of very obsolete factories;

**Reduction of impacts of emissions**

- increase of stack heights;
- compounding of gases of adjacent stacks into single stacks;
- modification of exit gas volume;
- modification of exit gas temperature;
- increase of distance between sources and sensitive areas.

There are fewer control options for area sources:

**Reduction of emissions**

- keeping wet raw and waste material deposits;
- housing/encapsulating raw and waste material deposits;
- use of modern incineration facilities for wastes.

**Reduction of impacts of emissions**

- increasing distance between sources and sensitive areas.

For line sources control options include:

**Reduction of emissions**

- fuel type and quality improvements;
- oxygenated fuels for CO reduction;
- reduce age of car fleet;
- enforce vehicles to have catalytic converters;
- renewal of old diesel-powered fleet;
- inspection and maintenance programme for vehicles;
- develop aggressively hydrogen/solar driven cars;
- remove fugitive dust from roads;
- develop mass transportation (e.g. bus rapid transport systems);
- Limit vehicle licensing;
- Introduce congestion charges.

**Reduction of impacts of emissions**

- Increasing of distance between sources and sensitive areas;
- Plan roads outside residential areas.

## 4.1 Selection of Control Devices

The selection of control devices is determined by what is required to limit polluting emissions from a point source. The selection depends on the processes applied in the source, the effluent characteristics, the capacities and limitation of control devices, and the capital investment and operation costs.

Emissions are usually limited by regulations on emission standards and their enforcement. Tables 2.6 and 2.7 provide examples of emission standards in Thailand for old and new power plants using coal and cement factories, respectively.

Control equipment must be designed to meet the emission standards. A central concept in the reduction of emissions into the atmosphere is control efficiency.

Control efficiency η is defined as the ratio of the amount of emissions prevented from entering the atmosphere by the control equipment to the amount of emissions $E_{in}$ that would have entered the atmosphere without control equipment (Spaite and Burckle, 1977). The amount of emissions prevented from entering the atmosphere is the difference between $E_{in}$ and the emission standard $E_{out}$ (also see Activity in Box 2.5):

$$\eta\,[\%] = (E_{in}-E_{out})/E_{in} \cdot 100$$ [1]

The capital investment is the amount of money which is required to put a plant and its equipment in operation. The capital investment is composed of two parts (Armer *et al.*, 1974):

- fixed capital investment to provide the physical facilities;
- working capital investment to provide a revolving fund to keep the facility in operation.

The operating costs is a repeated cost covering the cost of keeping the facility running every day, every month and every year.

Fixed capital investment cost include expenditures for land acquisition, buildings, utilities, process units, storage facilities, auxiliary facilities and spare parts. Working capital investment includes raw materials in stock or storage, finished products in storage, semi-finished products in process, accounts receivable and payable, and taxes. Operation costs include recurring costs such as raw-materials costs; labour, supervision, and payroll charges; factory supplies, maintenance and power costs. Armer *et al.* (1974) discuss extensively the methodology for estimating capital investment costs and operating costs, sources and representation of cost data, pitfalls in estimating capital investment and operation costs. Figure 2.6 presents a comparative estimate of costs of PM control devices as a function of the gas flow in actual cubic feet per minute (acfm, 472 L/s).

Box 2.5

**Activity 3: Estimation of the requested efficiency of control devices**

The $SO_2$ emission measured from a stack is 7,000 mg/m³.

What is the control efficiency required to meet the emission standard of 300 mg/m³?

Answer: $\eta$ = (7000-300)/7000 · 100% = 95.7%.

1 Note: This formula does not apply to PM collectors since the collection efficiency depends on the size of the particles. For this case a set of fractional collection efficiencies corresponding to particle fractions has to be used and combined to a total collection efficiency (Spaite and Burckle (1977).

## 4.2 Properties of Particles

Some of the most important physical properties of particles include:

- number and number size distribution;
- mass and mass size distribution;
- surface area;
- shape;
- hygroscopicity;
- volatility;
- electrical charge.

### Table 2.6: Emission standards for coal power plants in Thailand

| Compounds | Capacity [MW] | Standard |
|---|---|---|
| Old power plant | | |
| Total particulate matter [mg/Nm$^3$] | Any | 320 |
| $SO_2$ [ppm] | | 700 |
| $NO_2$ [ppm] | | 400 |
| New power plant | | |
| Total particulate matter [mg/Nm$^3$] | Any | 120 |
| $SO_2$ [ppm] | < 300 | 640 |
| | 300-500 | 450 |
| | > 500 | 320 |
| $NO_2$ [ppm] | Any | 350 |

Source: Ministry of Industry (2004a)

### Table 2.7: Emission standards for cement plants in Thailand

| Sources | Compound | Limit [mg/Nm$^3$] |
|---|---|---|
| **Old cement plant** | | |
| Grey cement kiln | Total Particulate matter [mg/Nm$^3$] | 300 |
| | $SO_2$ [ppm] | 50 |
| | $NO_2$ [ppm] | 600 |
| White cement kiln | Total Particulate matter [mg/Nm$^3$] | 300 |
| | $SO_2$ [ppm] | 600 |
| | $NO_2$ [ppm] | 600 |
| Clinker, cooler, clinker grinding mill, coal grinding mill | Total Particulate matter [mg/Nm$^3$] | 200 |
| **New cement plant** | | |
| Grey cement kiln | Total Particulate matter [mg/Nm$^3$] | 120 |
| | $SO_2$ [ppm] | 50 |
| | $NO_2$ [ppm] | 500 |
| White cement kiln | Total Particulate matter [mg/Nm$^3$]] | 120 |
| | $SO_2$ [ppm] | 500 |
| | $NO_2$ [ppm] | 500 |
| Clinker, cooler, clinker grinding mill, coal grinding mill | Total Particulate matter [mg/Nm$^3$] | 120 |

Source: Ministry of Industry (2004b)

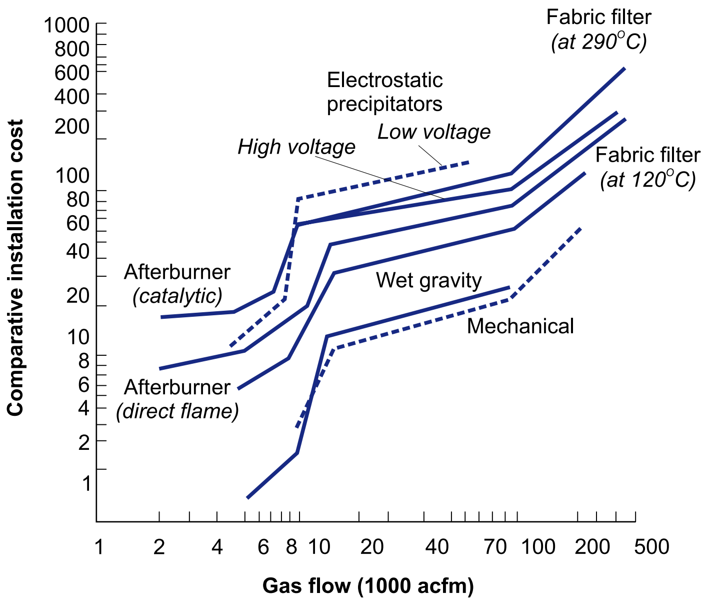



**Figure 2.6 Comparative cost of PM control devices as a function of gas flow**

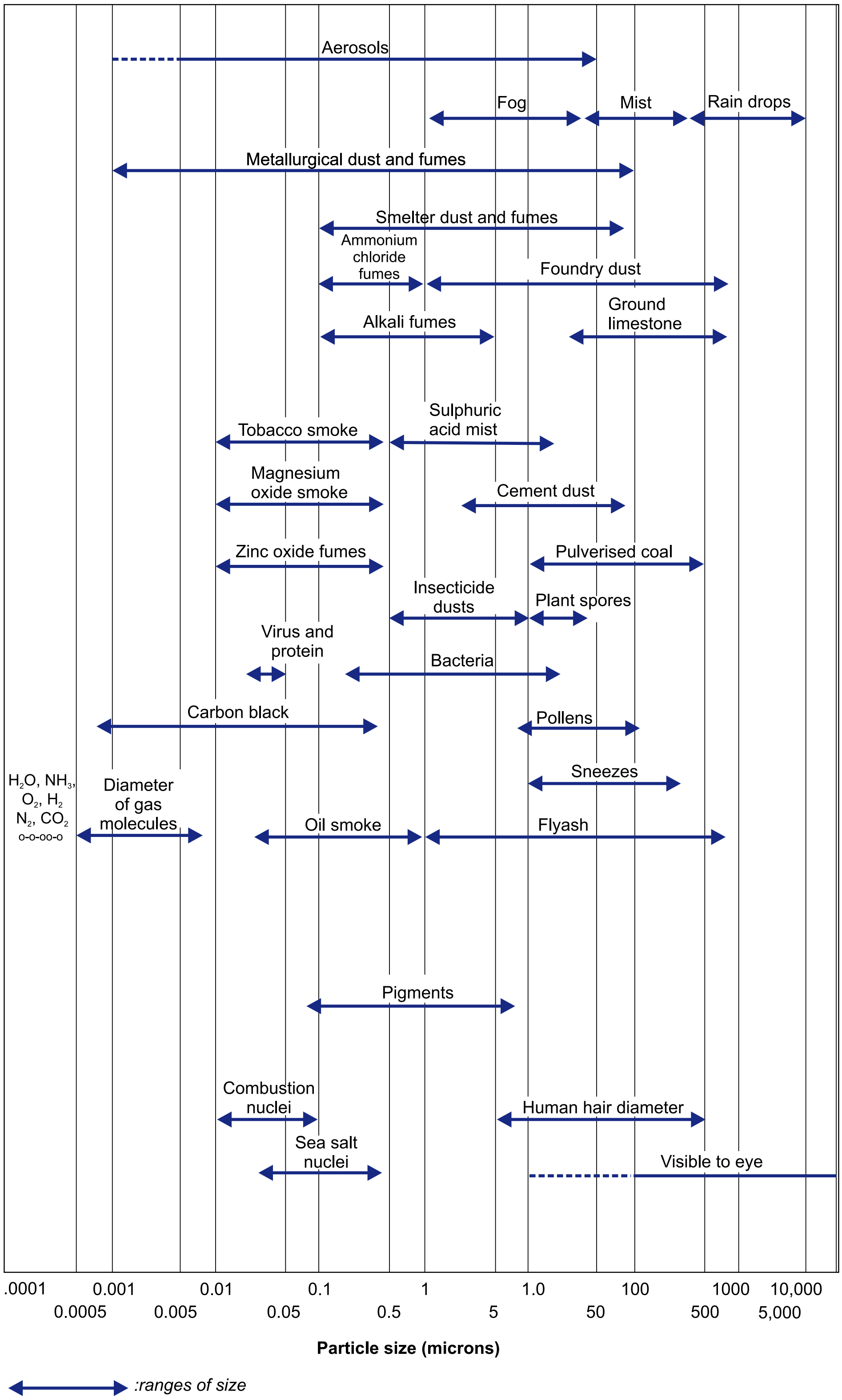
Source: Unknown

While each of these characteristics is important in terms of playing a role in affecting particle dynamics and thus behaviour and fate in the air, the first two are always important (Schwela *et al.*, 2002). Figure 2.7 illustrates the large variance of different particle sizes.

Particle size is often characterised by particle diameter. Diameter is a characteristic of spherical objects, but in fact, only a small fraction of particles is spherical. Figure 2.8 presents examples of the non-spherical size of particles. Particle equivalent diameter is a way of representing irregular shapes of particles. Particle equivalent diameter is the diameter of a sphere having the same value of a physical property as the irregularly shaped particle being measured.

An important characteristic of airborne particles is their size distribution as it strongly affects particle behaviour and fate in atmospheric systems and their deposition in the human respiratory tract, and also determines the instrumentation to be used for particle detection. Almost all of the sources of particles in outdoor air generate particles with some distribution of the sizes. The spread of particle size distribution is characterised by an arithmetic or geometric (logarithmic) standard deviation.

Particles generated by most sources have a lognormal size distribution, which means that the particle concentration versus particle size curve is "normal" (bell shaped) when the particles are plotted on a logarithmic scale. The geometric standard deviation characterises the width of the peak in the distribution. Particle size distributions often do contain one or more distinct peaks, called modes of the distribution. Figures 2.9 and 2.10. provide examples of the typical size distributions of emissions from diesel vehicle emissions (Morawska *et al.*, 1998a) and from environmental tobacco smoke (ETS) (Morawska *et al.*, 1997). The distributions show that different emission sources are characterised by different size distributions.




## Figure 2.7: Characteristic sizes of various particles

Source: Adapted from Armer *et al.*, 1974: 508)

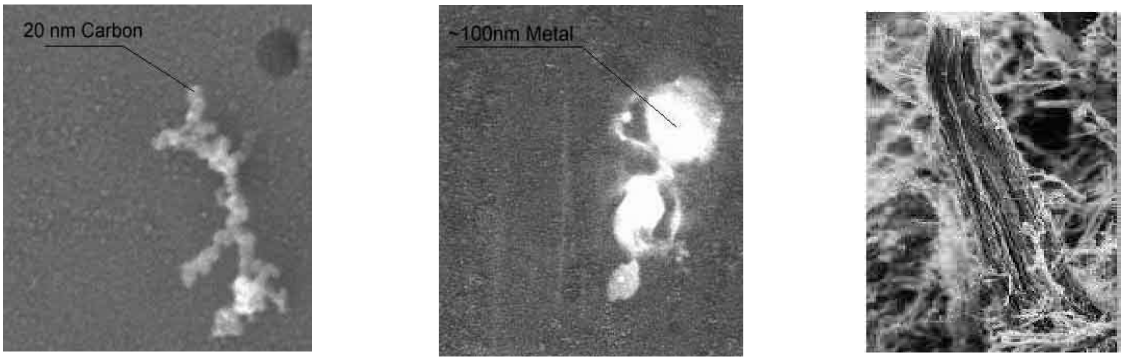



**Figure 2.8: Petrol particles and asbestos fibre particle**

Source: Courtesy L. Morawska, Queensland University of Technology

**Figure 2.9 Size distribution of particles from a diesel bus running on low power**

Source: After Morawska *et al.* (1998).

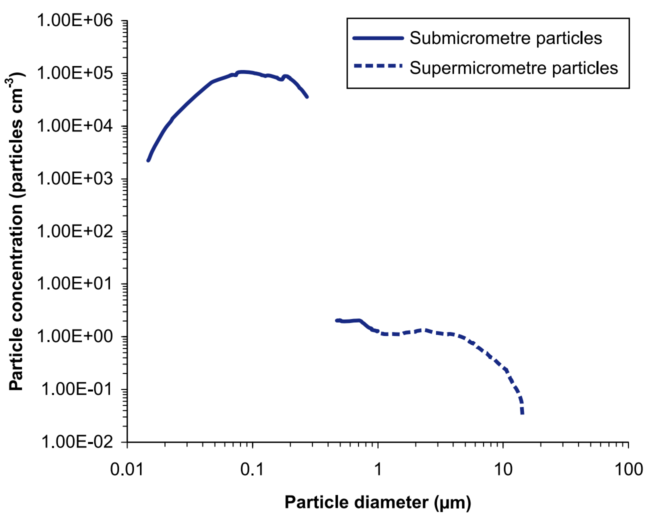
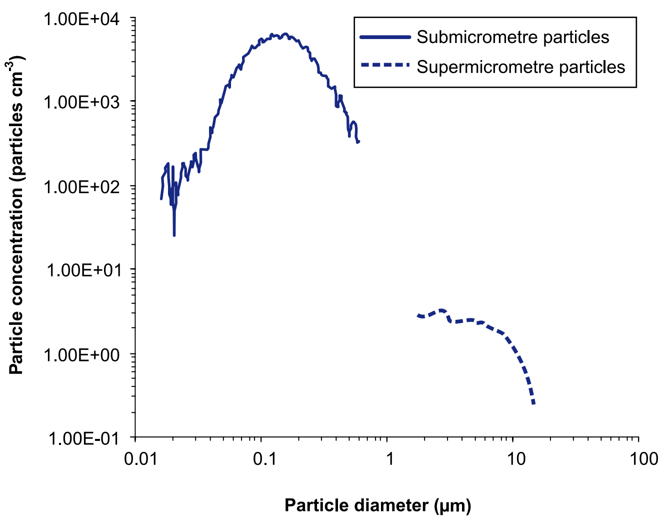



**Figure 2.10 Size distribution of side stream smoke produced by a human smoker.**

Source: After Morawska *et al.* (1997)



It should be kept in mind that size distributions change their shapes due to various factors affecting emissions from the sources or after the particles have been emitted. These factors are therefore important for understanding particle behaviour (Schwela *et al.*, 2002).

## 4.3 Control Of Particulate Matter

Different devices based on different particle collection processes are used to control particle air pollution. These include (Spaite and Burckle, 1977):

- inertial dust separators;
- cyclones or centrifugal dust collectors;
- wet scrubbers;
- filters;
- electrostatic precipitators.

Inertial dust separators are the simplest type of dust collector. When the dust filled air stream is slowed down heavier particles settle out from the air stream by gravity and fall into a hopper. There are two types of inertial separators: settling collectors and baffle collectors (BPA, 2006-2007).

Settling dust collectors separate dust from the dust filled air stream by using a settling chamber (see Figure 2.11). When the air stream enters the large settling chamber its speed decreases considerably. Heavier dust particles settle out due to gravity from the slow air stream and are collected.

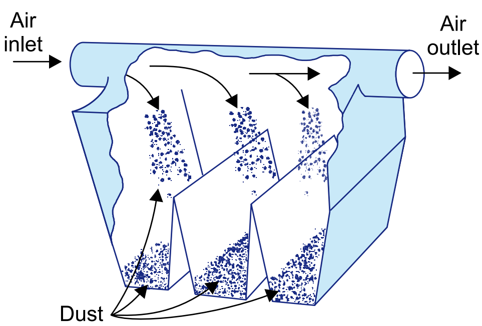



**Figure 2.11: Settling chamber**

Source: Adapted from OSHA (1987)

Baffle dust collectors have a baffle plate (a flat plate) in the path of the dust filled air stream to slow it down. The air stream strikes the baffle plate and undergoes a sudden change in direction (see Figure 2.12). The air stream flow and the baffle are designed in a way that the stream is first forced in a downward direction, followed by an upward 180 degree turn. With such abrupt changes in direction, the air flow slows down sharply. The heavier dust particles either strike the baffle plates due to their inertia or settle out by gravity when the flow slows down and slide into the hopper where they are collected.

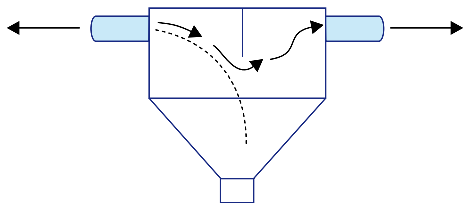


**Figure 2.12: Baffle chamber**

Source: OSHA 1987

Inertial separators are normally used as a pre-cleaner or a pre-filter for collectors since their main function is to separate large particles.

A cyclone collector is a structure without moving parts in which the velocity of an inlet gas stream is transformed into a confined vortex. Centrifugal forces tend to drive the suspended particles to the wall of the cyclone body (Caplan, 1977). Cyclone dust collectors, named after the cyclone weather phenomenon, are large funnel shaped sheet metal tubes (see Figure 2.13). The common cyclone has a tangential inlet with axial dust discharge into a hopper or dust bin. Other types of cyclones have a tangential inlet with peripheral discharge, or an axial inlet through swirl vanes, with either axis or peripheral dust discharge (Caplan, 1977)

Collection efficiency of cyclones increases with dust particle size (see Figure 2.14) or density, gas inlet velocity, cyclone body or cone length, and ratio of body diameter to gas outlet diameter. Efficiency will decrease with an increase in gas

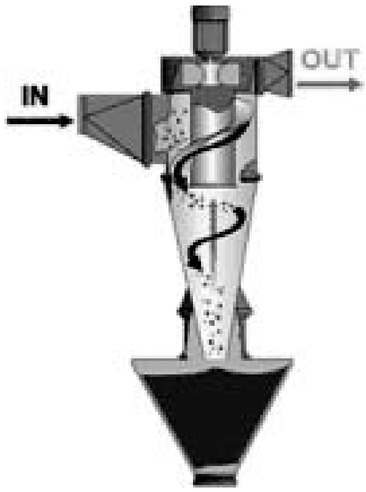



**Figure 2.13: Operation diagram of a common cyclone**

Source: BPA (2006-2007)

This is a simplified drawing showing only the "main vortex".

viscosity or density, cyclone diameter, gas outlet diameter, and inlet width (Caplan, 1977).

High efficiency cyclones are usually operated in a larger number as multiple cyclone separators arranged in parallel in order to achieve a practical gas volume. Multiple cyclone separators consist of a number of small diameter cyclones (15 cm diameter) and have a common inlet and outlet for air and a common dust bin (Caplan, 1977; BPA, 2006-2007). Multiple cyclones are more efficient than single cyclones because they are longer and smaller in diameter. The longer length provides longer residence time while the smaller diameter creates greater centrifugal force. These two factors result in better separation of dust particles (OSHA, 1987). Figure 2.15 presents a multiple cyclone.

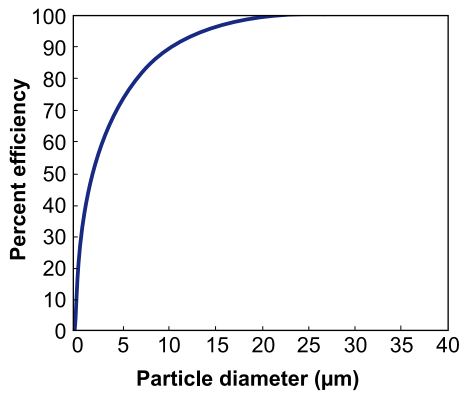



**Figure 2.14: Collection efficiency of a cyclone as a function of particle size**

Source: Caplan (1977)

A wet scrubber is a device that removes contaminants in either gaseous or particulate state from an effluent gas stream by means of a liquid. The removal process depends on the contacting process. Three schemes of contact are distinguished:

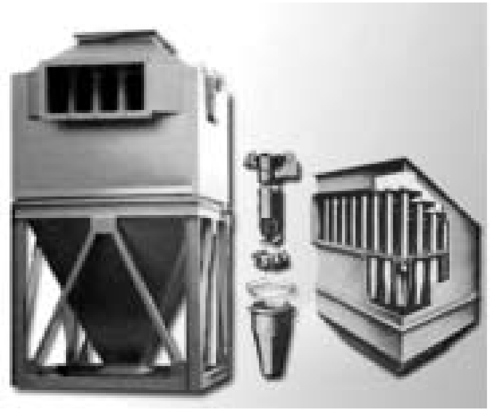


**Figure 2.15: Multiple cyclone separator**

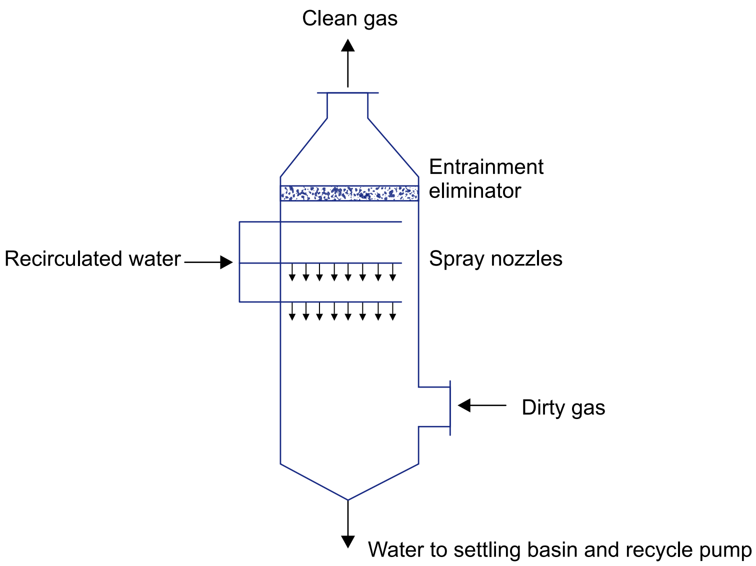
Source: Shin Pung (1999-2004)

1 counter-current, if the liquid enters the top of and passes down a vertical column and the effluent gas enters the bottom of and passes upward through the column;

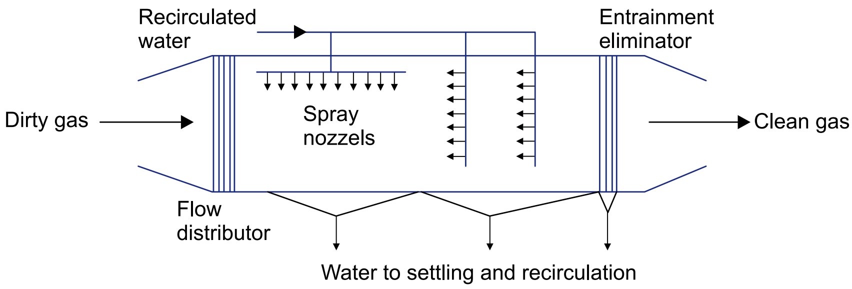
2 co-current, if liquid and gas enter the top of the column and pass downward through the column;

3 crosscurrent or cross flow, if the gas stream flows in a direction perpendicular to the liquid.

Combinations of these contacting processes may occur (Calvert, 1977). Figure 2.16 shows some of these arrangements.




(a) Vertical spray chamber (counter current flow)




(b) Horizontal spray chamber (cross-flow)

**Figure 2.16: Counter-current (a) and cross flow (b) scrubbers**

For PM, wet scrubber collection mechanisms include inertial impaction, gravitational force, interception, electrostatic, and Brownian and turbulent diffusion processes. The purpose of the liquid is to provide the collecting surface and/or to wash a solid collecting surface (Calvert, 1977). Figure 2.17 illustrates the mechanisms of inertial impaction and interception.

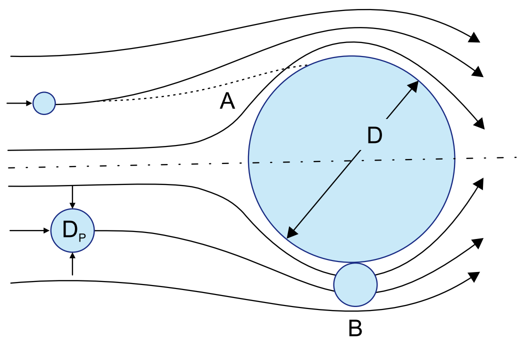



**Figure 2.17: Inertial impaction (A) and direct interception (B) of particles on a liquid droplet.**

**D = liquid droplet diameter; DP = particle diameter.**

Filter separators are among the most reliable, efficient and economic methods of removing particles from effluent gases. Gas filters may be classified into fabric, or cloth, filters and in-depth, or bed, filters. Fabric filters are characterised by various fabric bag arrangements while bed filters are mostly fibrous packings or paper-like mats. Fabric filters are utilized with effluent gas streams of particle loading of 1 g/$Nm^3$; fibrous packings, paper filters, and packed beds are applied at particle concentrations of approximately 1 mg/$Nm^3$ (Iinoya and Orr, 1977). Performance criteria for particle filtration are pressure loss, collection efficiency and lifetime.

Fabric filters are extensively employed to control harmful or noxious emissions of abrasives, irritating chemical dusts, and effluents from electric furnace, oil-fired boilers, and oxygen-fed converters for steel making (Iinoya and Orr, 1977). Fibrous-mat filters are extensively used in air conditioning, heating and ventilating systems. High-efficiency filters are used as after-cleaners, and less efficient fibrous mat filters are pre-cleaners for the protection of more efficient and sensible equipment (Iinoya and Orr, 1977).

**Figure 2.18: Bag filter dust collecting system**

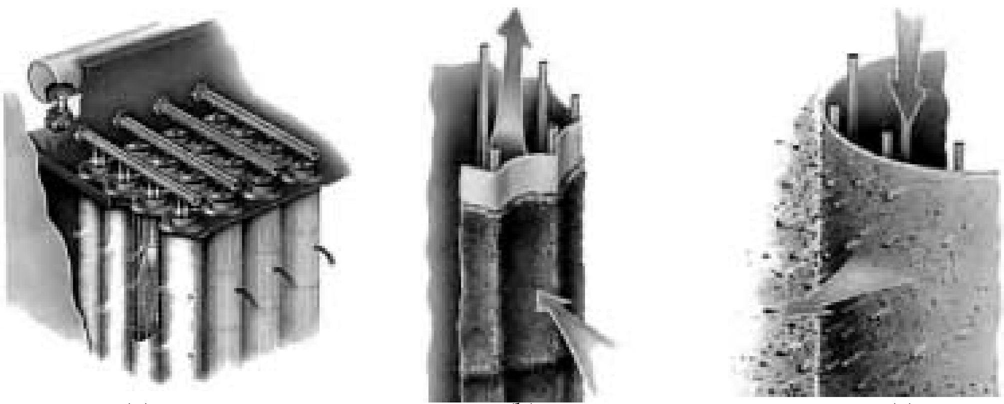
Source: Boarke (2007)

In a bag house, filter bags hang vertically inside the unit and are firmly held in place by clamps, snap-bands or hold-downs and the bag bottoms are enclosed. In some systems, the bags are supported internally by wire cages. Dust-laden gas enters the system through the inlet and is filtered through the bag, depositing dust on the outside surface of the bag.

Figure 2.18 shows a typical bag filter system while Figures 2.19a and 2.19b illustrates how it works. Cleaning of the filter system is achieved by reversing the air stream (see Figure 2.19c). Figure 2.19d shows a dust-loaded filter.

Filter material may be woven or non-woven. Figure 2.20 shows examples of both types of filters. Woven and non-woven filter materials include polyamide, polyester, polypropylene, polyethylene and others.

In a pulse jet bag house, the dust is removed by a blast of compressed air injected into the top of



(a) (b) (c)

**Figure 2.19a-c Bag filter system (a), operation mode of bag filter (b) and cleaning of bag filter (c)**

Source: Photo credit unknown

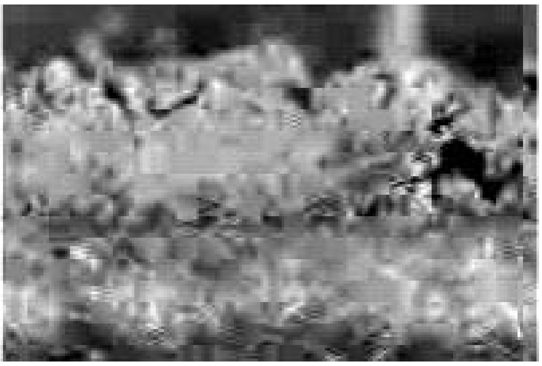


**Figure 2.19d: Dust-loaded filter**

Source: Photo credit unknown

the opening of the filter bags. The air is supplied from a blowpipe which feeds into Venturi tubes located at the top of each filter bag. The blast of high pressure air creates a shock wave that stops the normal flow of air though the filter and causes the bag to flex as the air wave travels down the length of the filter bag. As the bag flexes, PM is released into the hopper below. Figure 2.21 shows a pulse jet bag house.

The key steps of operation in an electrostatic precipitator are:

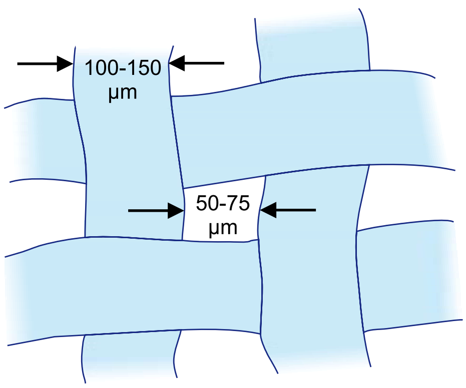
1. electrical charging of suspended particles;
2. collection of the charged particles on an electrode; and
3. removal of the collected material to a hopper or dustbin.

The simplest arrangement to charge suspended particles is that of a fine wire with negative polarity in a grounded cylindrical or plate electrode. A high-voltage direct-current flowing through the wire forms a corona which produces positive and negative ions in the effluent gas. The positive ions are attracted to the wire while the negative ions are attracted to the ground electrode. The gas space is mostly filled with negative ions which bounce on particles in the gas stream which in turn become quickly charged.

Particles are collected on the grounded electrode by either the field of the corona (one-stage precipitator) or an additional electrostatic field (two-stage precipitator) between the electrodes exerting the Coulomb force. Figure 2.22 shows a schematic diagram of a wire and tube precipitator.

The last step in an electrostatic precipitator is the removal of the particles into a hopper. While sticky solid particles and liquid droplets can be easily removed this is not the case for dry solid particles which are susceptible to re-entrainment in the gas stream. For such dry particles and large effluent gas flow rates plate type systems with baffles are

(a)




(b)

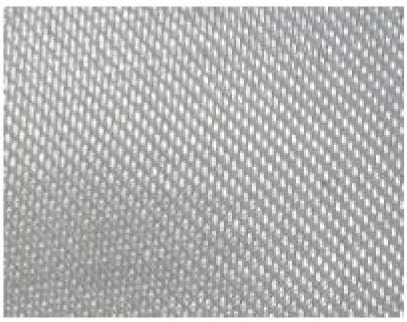


**Figure 2.20: New, clean, woven filter (a) and new, clean, non-woven filter (b)**

Source: TF (2007)

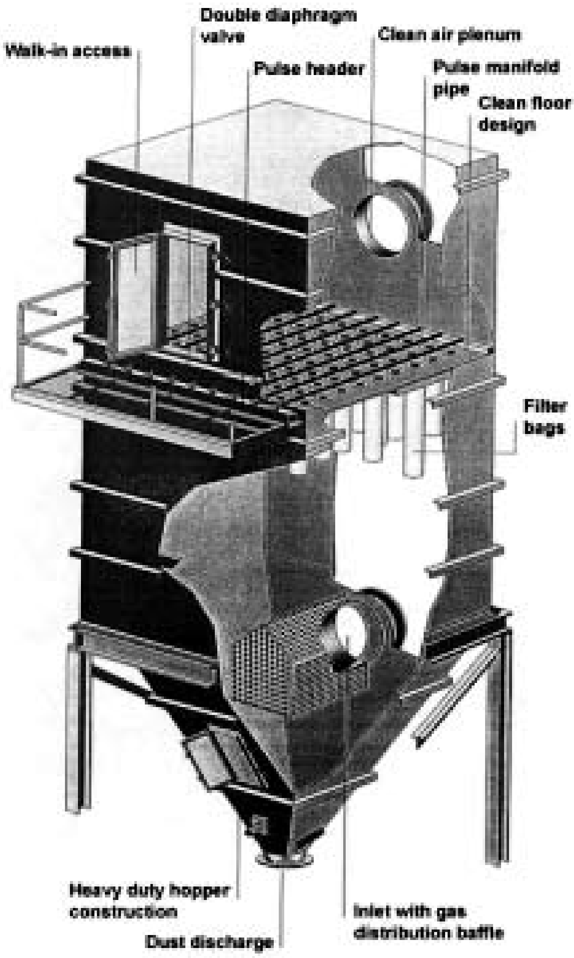



**Figure 2.21: Pulse jet bag house**

Source: Menardi (2003)

used while for liquid droplets and for smaller flow rates pipe type electrodes are applied (Armer *et al.*, 1974). Dry solid particles can also be removed in a "wet electrostatic precipitator" by irrigation of the collecting electrode with some fluid (Oglesby and Nichols, 1977).

The size and type of electrostatic precipitator are determined by the:

- physical properties of the effluent gas;
- physical properties of the particles;
- gas flow rate; and
- required collection efficiency.

The operation of precipitators is largely governed by the:

- magnitude of the charge transferred to the particles;
- electric field; and
- extent of re-entrainment of collected particles in the gas stream (Oglesby and Nichols, 1977).

Figure 2.23 shows a conventional electrostatic precipitator.

Figure 2.24 shows a single gas passage in a typical electrostatic precipitator. The fine wire electrode

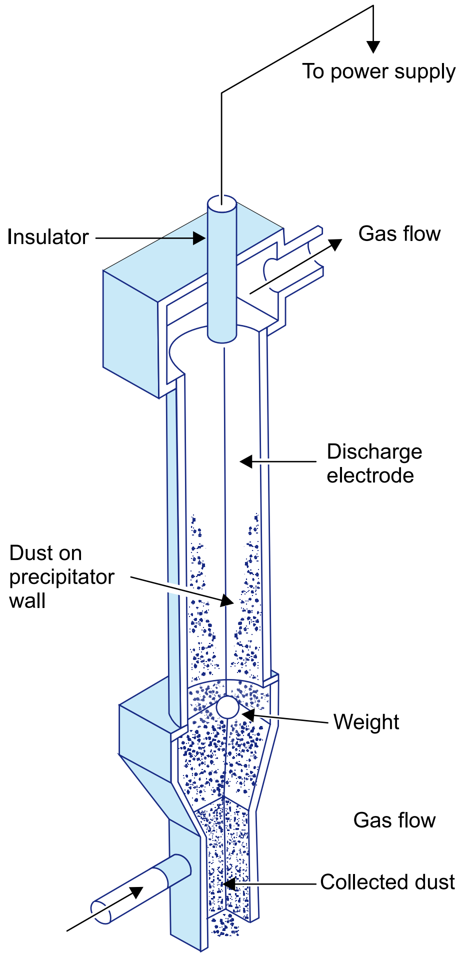



**Figure 2.22: Schematic diagram of a wire and pipe precipitator**

Source: Oglesby and Nichols (1977)

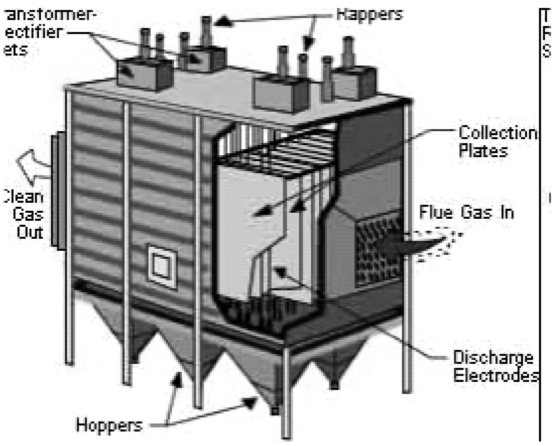



**Figure 2.23: Typical electrostatic precipitator used at a coal-fired boiler**

Source: USEPA (2006)

**Figure 2.24: Single gas passage in a typical electrostatic precipitator**

Source: USEPA (2006)

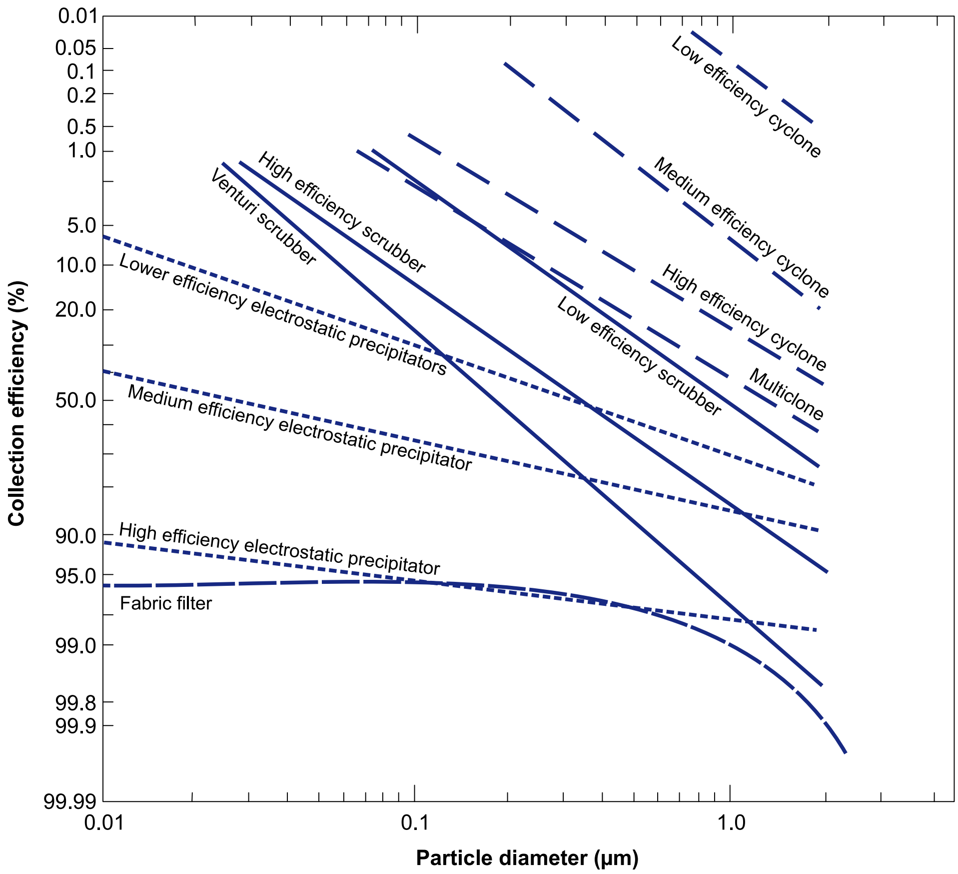



**Figure 2.25: Particle collection efficiency as a function of particle diameter**

Source: Spaite and Burckle (1977)

of negative polarity is in the centre of the gap defined by grounded vertical surfaces on both sides of the electrode. The gas stream is moving horizontally through the unit. Particles moving with the gas stream become charged by collisions with ions created in the corona and then move to either side.

Figure 2.25 gives an impression of the wide variation of particle collection efficiencies of equipment for particle equivalent diameters between 0.01 and 2 μm.

## 4.4 Control of Gaseous Emissions

Table 2.8 shows the typical air pollutants emitted from point sources.

Gaseous emissions are controlled by the following physical/chemical/biological processes:

- combustion
- absorption
- adsorption
- condensation
- biofiltration
- flaring

**Table 2.8: Sources of typical gaseous compounds**

| Key element | Pollutant | Source |
|---|---|---|
| S | $SO_2$ | Boiler flue gas |
| | $SO_3$ | Sulphuric acid manufacturing |
| | $H_2SO_4$ vapours | Sulphuric acid manufacturing, pickling operations |
| | $H_2S$ | Natural gas processing, pulp and paper mills, sewage treatment |
| | R-SH (mercaptans) | Petroleum refining, pulp and paper mills |
| N | NO, $NO_2$ | Nitric acid manufacturing, boiler flue gas |
| | $HNO_3$ vapours | Nitric acid manufacturing, pickling operations |
| | $NH_3$ | Ammonia manufacturing |
| | Other N compounds (i.e. amines, pyridines) | Sewage, rendering, solvent processes |
| C | Inorganic CO | Boiler flue gas |
| | Organics: Volatile Organic Compounds | Solvent uses, gasoline marketing, petrochemical plants |
| | Hydrocarbon<br>• paraffins<br>• olefins<br>• aromatics<br>Oxygenated hydrocarbons<br>• aldehydes<br>• ketones<br>• alcohols<br>• phenols | Surface coating operations, petroleum processing, plastics manufacturing |
| | Chlorinated solvent | Dry cleaning, degreasing |
| F | HF | Phosphate fertilizer plant, aluminium plant |
| | $SiF_4$ | Ceramics, fertilizer plant |
| Cl | HCl | HCl manufacturing, PVC combustion |
| | $Cl_2$ | Chlorine manufacturing |

**Figure 2.26: Direct flame incinerator**

Source: IF (2007)

For the purpose of cleaning effluent gases from gaseous pollutants, combustion processes require:

- a combustible fuel which can be the pollutant;
- oxygen which can be carried by the flue gas;
- a high enough temperature;
- sufficient turbulence;
- a sufficiently long residence time of the gaseous pollutants in the combustion unit;
- combustion products not to be pollutants.

There are three processes of incineration of gaseous pollutants:

- direct flame incineration;
- thermal incineration; and
- catalytic combustion.

Direct flame incinerators burn the effluent pollutants without any additional fuel at temperatures around or above 1370 $^0$C (Armer *et al.*, 1974). Components of these incinerators include a combustion chamber, a combustion system of one or more burners, and accessories for control of temperature and safety. Direct incineration is not applicable for:

- oxides;
- pollutants that are stable under combustion conditions;
- pollutants whose combustion products are chemically altered into obnoxious combustion products.

Figure 2.26 provides an example of a direct flame incinerator.

Thermal incinerators involve the burning of a fuel (natural gas, propane) and mixing the effluent polluted gas stream with the hot combustion products at temperatures between 650 and 820 $^0$C (Armer *et al.*, 1974). In order to achieve complete oxidation of waste gases thorough mixing of the pollutant with the burning fuel must be achieved. Figure 2.27 shows the schematic diagram of a thermal incinerator.

Catalytic incinerators use a catalyst which adsorbs gaseous pollutants on its active surface and initiates a chemical reaction between the adsorbed

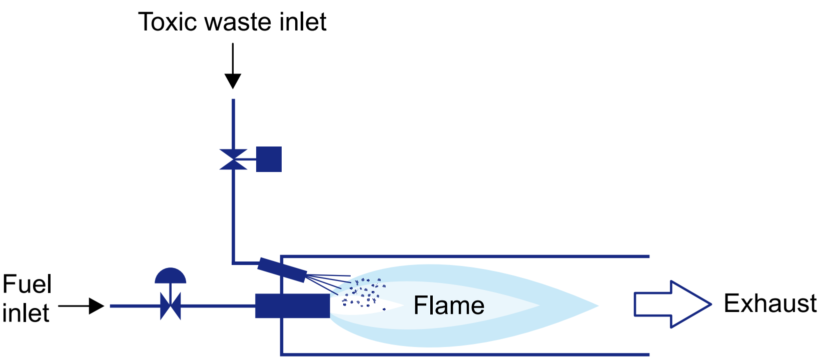



**Figure 2.27: Schematic diagram of the thermal incinerator**

Source: FEEE (2007)

oxygen and pollutant gas to yield $CO_2$ and water as the primary products which will be desorbed from the catalyst's surface and entrained into the main gas stream. Catalytic combustion works at temperatures between 340 and 540 $^0$C (Armer *et al.*, 1974). Catalytic combustion is primarily used to control VOCs. Figure 2.28 shows the catalytic afterburner in two parts: a chamber in which the waste gas is preheated and a chamber in which the waste gas is brought into contact with a bed of catalyst, often a finely divided metal such as platinum or nickel.

Waste gas absorption is the main process for gas scrubbing. Diffusion and absorption of the gas in the liquid provides the mechanism for the transfer of the contaminant succeeded by a separation of the cleaned gas and the contaminated liquid. There are physical or chemical constraints to the solubility of gaseous material in liquid regardless of how intimate the contacting of phases is or how long the time of contact. An example of physical equilibrium is the solution of $SO_2$ in water which is governed by Henry's law. The absorption of $SO_2$ in sodium hydroxide is an irreversible chemical reaction (Calvert, 1977). Figure 2.29 presents a flue gas desulphurisation limestone scrubber

Adsorption is the process where a gaseous pollutant is removed from flue gas by the binding forces of the molecules on a solid surface to which the gas comes in contact. For example, $SO_2$ brought in contact with activated charcoal at temperatures between 40 and 150 $^0$C (Alpert *et al.*, 1974) is first absorbed to the porous charcoal surface, oxidized to sulphuric acid in the presence of water vapour and oxygen in the waste gas, and then desorbed by steam or a liquid. Figure 2.30 presents the process.

Gaseous pollutants in high concentrations and with dew points above 30 $^0$C can also be removed by condensation through cooling or compression of the gas stream. Two types of condenser designs exist: surface or contact.

In surface condensers the pollutant gas does not come into contact with the coolant while in contact

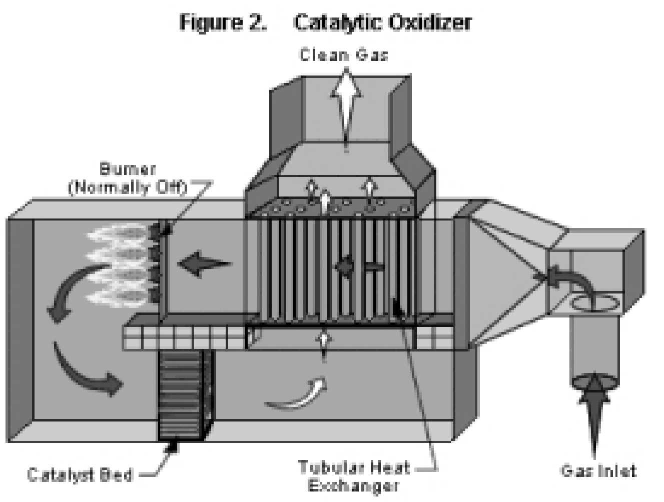



**Figure 2.28: Schematic diagram of a catalytic oxidizer using its waste to preheat the gaseous pollutant stream.**

Source: USEPA (2006)

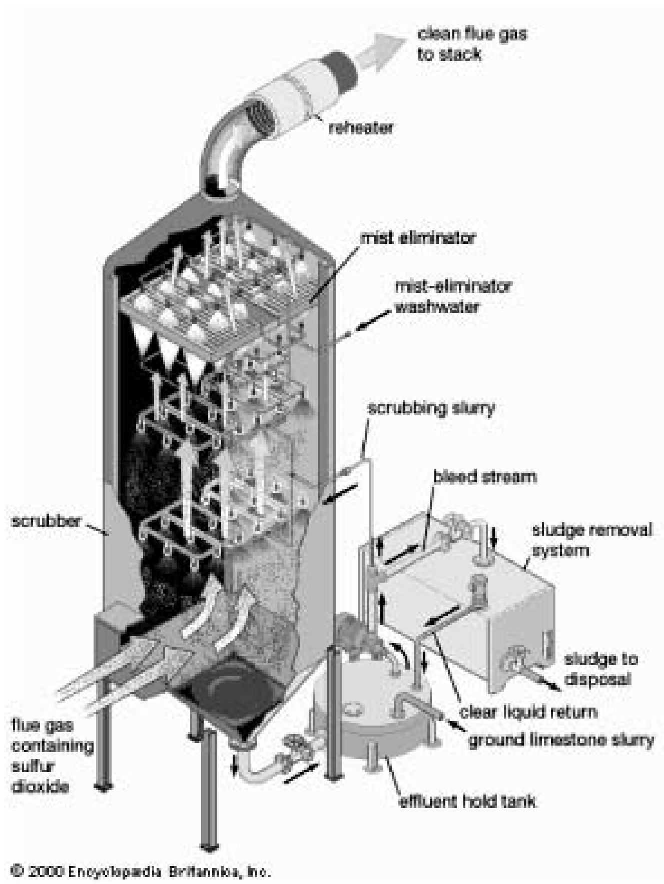



**Figure 2.29: Flue gas desulphurisation limestone scrubber**

Source: EBO (2007)

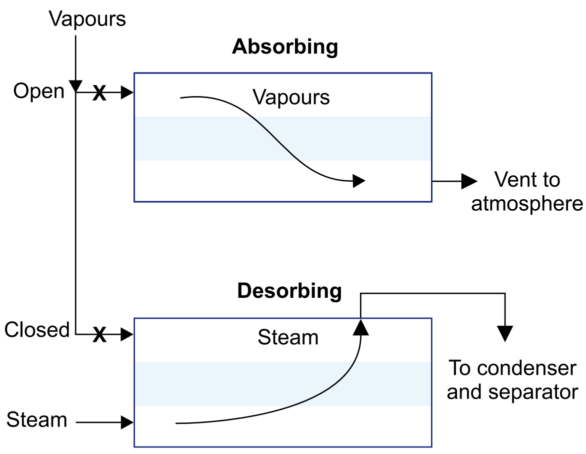



**Figure 2.30: Process of absorption and desorption in a catalyst**

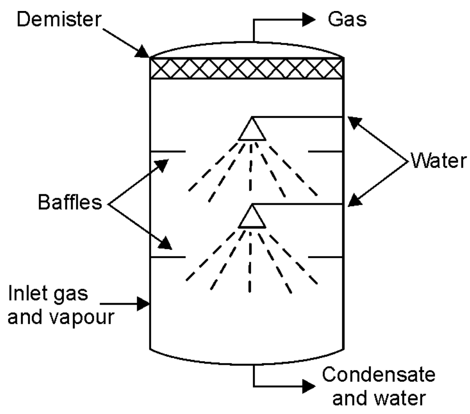



**Figure 2.32: Schematic diagram of a spray contact condenser**

Source: Armer *et al.* (1974:737)

condensers the coolant and polluted gas are mixed. Figure 2.31 shows a schematic design of a surface condenser.

Contact condensers can be the spray scrubber and jet condenser types (Armer *et al.*, 1974). In the vessel of the spray scrubber type the effluent gas-pollutant-vapour stream is in contact with the liquid coolant injected into the vessel through spray nozzles. Baffles increase the contact between the liquid spray and the gas stream. Figure 2.32 shows a schematic diagram of the spray contact condenser. In the jet condenser type the gas-vapour mixture is brought in contact with a high-speed water jet.

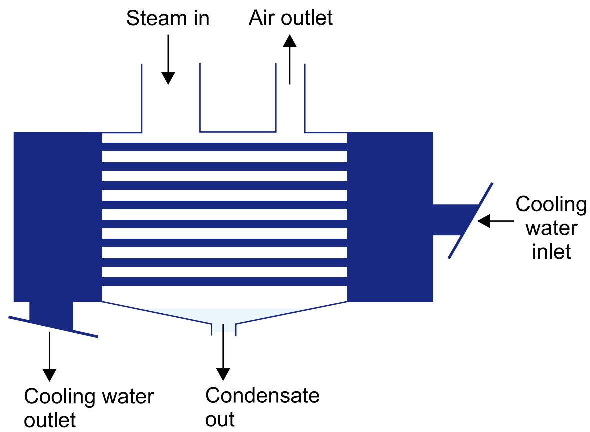



**Figure 2.31: Schematic design of a surface condenser**

Source: Roymech (2007)

Biofiltration is a relatively new pollution control technology for the removal of malodorous gas emissions and of low concentrations of VOCs.

Biofilters are essentially large tanks filled with a porous medium such as soil or compost. The microorganisms live in a thin layer of moisture, the "biofilm", which surrounds the constituents of the filter medium. When contaminated air is slowly passed through the medium, contaminants are transferred to and adsorbed by the biofilm, where they can be biologically degraded. This micro-organisms degrade the pollutants to produce energy and metabolic by-products according to (Anit and Artuz, 2006):

Organic Pollutant + $O_2$ => $CO_2$ + $H_2O$ + Heat + Biomass

Figure 2.33 depicts an arrangement of a biofilter to remove noxious organic gases from air.

Flaring of combustible gases is performed in the petroleum refining and chemical processing industries to dispose of:

- small continuous hydrocarbon waste gas streams from the process units; and/or
- huge quantities of process gases released under off-design operating conditions by pressure relief valves due to compressor

failures, loss of cooling water, vessel overpressure, power failures, fires, etc. (Armer *et al.*, 1974).

Flares are either elevated or ground combustion flares or burning pits. Elevated flares are emitted at elevations between 30 and 100 m; flow rates are between 30 $Nm^3$/hour to more than 30,000 $Nm^3$/hour (Gottschlich, 1977). Figure 2.34 shows an elevated flare and Figure 2.35 a burning pit in Africa. Armer *et al.* (1974) noted that such pits are generally unacceptable except as a device to handle catastrophic emergency situations.

**Figure 2.33: Biofiltration device for removal of air pollutants**

Source: Anit and Artuz (2006)

**Figure 2.34: Elevated gas flaring in Russia**

Source: Amsterdam (2007)

**Figure 2.35: Shell gas flare at Rumuekpe, Rivers State, Nigeria**

Source: ENS (2006) Friends of the Earth

## 4.5 Best Available Control Technology (BACT)

Best available control technology (BACT) is the currently available technology which achieves a maximum reduction for each regulated air pollutant emitted from any new or modified stationary source. BACT represents an achievable emission limit that is determined on a case-by-case basis and takes into account energy, environmental and economic impacts, and other costs (adapted from USEPA, 2006c). Table 2.9 summarizes typical control devices that correspond to BACT in industrial pollution sources.

**Table 2.9: Industrial pollution sources and typical control devices**

| Industry | Source | Control System | Typical Gas Temperature [$^oC$] |
|---|---|---|---|
| **Asphalt roofing** | Saturator and storage tanks | Scrubber<br>Precipitator<br>Afterburner | 26.7-148.9 |
| **Basic oxygen furnace** | Basic oxygen furnace<br><br>Charging hood | Precipitator<br>Scrubber<br>Bag house | 1926.7-2204<br><br>65.6-204.4 |
| **Benzene handling and storage** | Vents, storage tanks | Afterburner<br>Adsorber<br>Refrigeration | 21-37.8 |
| **Brick manufacturing** | Tunnel kiln<br>Crushers<br>Dryer<br>Periodic kiln | Scrubber, Bag house | 93.3 – 315.6<br>21<br>121.1<br>93.3 – 315.6 |
| **Castable manufacturing** | Electric arc<br>Crushers<br>Dryer<br>Periodic kiln | Scrubber, Bag house | 1648.9 –2204<br>21<br>148.9<br>65.6 |
| **Chemical manufacturing waste disposal** | Miscellaneous sources | Afterburner<br>Flare | As required |
| **Clay refractories** | Shuttle kiln<br><br>Calciner<br>Dryer<br>Crusher | Bag house, Precipitator<br>Scrubber<br><br>Baghouse Precipitator | 66 - 427<br>66 - 427<br>121.1<br>21 |
| **Coal fired boiler** | Stream generator | Precipitator<br>Scrubber<br>Bag house | 148.9 – 371.1 |
| **Conical incinerator** | Incinerator | Scrubber | 204.4 – 371.1 |
| **Cotton ginning** | Incinerator | Scrubber | 260 – 371.1 |
| **Degreasing** | Degreasing tanks | Adsorber Refrigeration | 21 |
| **Detergent manufacturing** | Spray dryer | Scrubber<br>Bag house | 82.2-121.1 |
| **Direct smoking of meat** | Smoke house | Afterburner<br>Electrical precipitator | 48.9 – 65.6 |

**Table 2.9: (continued)**

| Industry | Source | Control System | Typical gas temperature [$^oC$] |
|---|---|---|---|
| **Distilled Whiskey Processing** | Distillation process | Adsorber Afterburner | As required |
| **Dry Cleaning** | Washer, extractor, tumbler | Adsorber | 21 |
| **Electric arc furnace** | Arc furnace (direct exhaust)<br>Charging and tapping | Bag house, Scrubber, Precipitator | 1649<br>65.6 (canopy) |
| **Feed mills** | Storage bins<br>Mills/grinders<br>Flash dryer<br>Conveyors | Scrubber, Bag house | 21.1<br>21.1<br>76.7 – 121.1<br>65.6 |
| **Ferroalloys plants HC, Fe, Mn**<br><br>**50%Fe, Si**<br><br>**HC, Fe, Cr** | Submerged arc furnace (open)<br><br>Submerged arc furnace (close)<br><br>Tap fume | Scrubber, Bag house, Precipitators<br><br>Scrubber<br><br>Same collector or baghouse | 204.4 - 260<br><br>537.8 – 648.9<br><br>65.6 hood |
| **Gasoline Bulk Terminal Storage** | Vents, storage tanks | Afterburner,<br>Adsorber,<br>Refrigeration | 21 – 37.8 |
| **Glass Manufacturing** | Regenerative tanks furnace<br>Weight hoppers and mixers | Bag house,<br>scrubber,<br>Precipitator | 315.6 – 454.4<br><br>37.8 |
| **Graphic Arts** | Presses<br><br>Lithographics, metal decor. ovens | Adsorber,<br>Afterburner<br>Afterburner | 37.8<br><br>204.4 – 315.6 |
| **Gray Iron Foundries** | Cupola<br><br>Electric arc furnace<br><br>Core Oven<br>Shakeout | Afterburner-baghouse for closed cap. Afterburner-precipitator for closed cap.<br>Scrubber, Baghouse, Precipitator<br><br>Afterburner<br>Baghouse | 21 – 37.8<br><br>- 1407direct exhaust.<br>- 240 hood.<br><br>65.6 -101.1 |

Table 2.9: (continued)

| Industry | Source | Control System | Typical gas temperature [$^{o}$C] |
|---|---|---|---|
| **Industrial and Utility Boiler** | Boiler | Precipitator<br>Bag house | 37.8 – 426.7 |
| **Insulation Wire Varnish** | Spray booths<br>Flow coating machines<br>Dip tanks<br>Roller coating machines | Adsorbers<br>Absorbers<br>afterburners | 37.8 |
| **Iron Ore Beneficiation** | Crushing<br>Sinter Machine | Bag house<br>Scrubber | As required |
| **Iron & Steel (Sintering)** | Sinter machine<br>• sinter bed<br>• ignition fee<br>• wind boxes<br>• sinter crusher<br>• conveyors<br>• feeders | Precipitator<br>Bag house<br>Scrubber<br>Baghouse<br>Scrubber | 65.6 – 204.4 Sinter machine<br>21, conveyors |
| **Kraft Recovery Furnace** | Recovery furnace and direct contact evaporator | Precipitator<br>Scrubber | 176.7 |
| **Lime Kilns** | Vertical kilns<br>Rotary sludge kilns | Baghouse<br>Scrubber<br>Precipitator<br>Scrubber<br>Precipitator | 93.3 – 648.9<br>93.3 – 648.9 |
| **Maleic Anhydrid** | Benzene storage tanks Process vent and vacuum. Refinery vent | Adsorbers, afterburners | 21 – 37.8 |
| **Miscellaneous Refinery Sources** | Vents<br>Storage tanks | Afterburner<br>Flare<br>Absorbers<br>Refrigeration | As required |

Source: USEPA (2006c)

## 4.6 Reducing Emissions from Mobile Sources

In recognition of the major importance of vehicle emissions in determining the quality of air in a city, numerous Asian countries have implemented legislation to reduce vehicle emissions. There is a trend towards the introduction of increasingly strict standards. Four elements can help to reduce emissions from mobile sources (ADB, 2003):

- emissions standards and vehicle technology;
- cleaner fuels;
- inspection and maintenance;
- transportation planning and demand management.

### Emissions standards and vehicle technology

Regulations have been developed and enforced to require that new vehicles satisfy increasingly strict emissions standards in most Asian nations. The lag time with European and US standards has been considerably reduced since the mid-1990s when Asian countries started to introduce vehicle emission standards. Table 2.10 presents the current emission standards in Asian countries for new light-duty vehicles.

Modern vehicle technology is characterised by the use of catalytic converters, three-way catalysts, and $NO_x$ traps in petrol-driven and catalysts, filters and $NO_x$ absorbers in diesel-driven vehicles. These devices serve to reduce emissions of $NO_x$, CO and HC in petrol-driven vehicles. In addition, diesel filters and catalysts help to reduce emissions of PM. Table 2.11 illustrates the reduction potential of these devices depending on the sulphur content of gasoline and diesel fuel.

### Cleaner fuels

To support the introduction of stricter vehicle emissions standards, fuel quality is required to meet tighter standards. With the exception of a limited number of countries, Afghanistan, Lao PDR, Mongolia, and Myanmar— all Asian

**Table 2.10: Vehicle Emissions Standards in Asia and the European Union, 1995-2010**

| Country | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| European Union | Euro 1 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 3 | Euro 3 | Euro 3 | Euro 3 | Euro 4 | Euro 4 | Euro 4 | Euro 5 * | Euro 5 * | Euro 5 * |
| Bangladesh[a] | | | | | | | | | | | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 |
| Bangladesh[b] | | | | | | | | | | | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 |
| Hong Kong, SAR | Euro 1 | Euro 1 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 3 | Euro 3 | Euro 3 | Euro 3 | Euro 3 | Euro 4 | Euro 4 | Euro 4 | Euro 4 | Euro 4 |
| India[a] | | | | | | | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 3 |
| India[b] | | | | | Euro 1 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 3 | Euro 3 | Euro 3 | Euro 3 | Euro 3 | Euro 3 |
| Indonesia | | | | | | | | | | | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 |
| Malaysia | | | Euro 1 | Euro 1 | Euro 1 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 4 * | Euro 4 * |
| Nepal | | | | | | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 |
| Pakistan | | | | | | | | | | | | | | | | |
| Philippines | | | | | | | | | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 2 * | Euro 2 * | Euro 2 * | Euro 4 * |
| PRC[a] | | | | | | | Euro 1 | Euro 1 | Euro 1 | Euro 2 | Euro 2 | Euro 2 | Euro 3 | Euro 3 | Euro 3 | Euro 4 |
| PRC[e] | | | | | | | Euro 1 | Euro 1 | Euro 2 | Euro 2 | Euro 3 | Euro 3 | Euro 4 * | Euro 4 * | Euro 4 * | Euro 4 * |
| Singapore[a] | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 |
| Singapore[b] | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 2 | Euro 4 | Euro 4 | Euro 4 | Euro 4 | Euro 4 |
| Sri Lanka | | | | | | | | | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 |
| Thailand | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 1 | Euro 2 | Euro 2 | Euro 2 | Euro 3 | Euro 3 | Euro 3 | Euro 3 | Euro 3 | Euro 3 | Euro 4 |
| Vietnam | | | | | | | | | | | | | Euro 2 | Euro 2 | Euro 2 | Euro 4 * |

Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5

Source: CAI-Asia (2006)

Notes: [a]gasoline, [b]diesel; [c]Entire country; [d]New Delhi and other cities - Euro 2 introduced in Mumbai, Kolkata, and Chennai in 2001 - Euro 3 in Bangalore, Hyderabad, Khampur, Pune, and Ahmedabad in 2003 - Euro 3 to be introduced; [e]Beijing and Guangzhou adopted Euro 3 standards as of 01.09.2006 - Shanghai requested the approval of the State Council for implementation of Euro 3; *Under discussion

**Table 2.11: Pollutant reduction through modern technological devices**

| Optimum/required fuel quality | Vehicle technology | Pollutant reduction |
|---|---|---|
| **Gasoline** | | |
| Unleaded gasoline | Catalytic converters | $NO_x$, HC and CO |
| < 50 ppm sulphur | Three-way catalyst (TWC) | $NO_x$, HC and CO |
| < 30 ppm sulphur | Advanced TWC | $NO_x$, HC and CO |
| < 15 ppm sulphur | $NO_x$ Trap | $NO_x$ |
| **Diesel** | | |
| < 150 ppm sulphur | Diesel oxidation catalyst | PM, HC and CO |
| < 50 ppm sulphur | Diesel particulate filter | PM, HC and CO |
| < 50 ppm sulphur | Selective catalytic reduction | $NO_x$ |
| < 15 ppm sulphur | $NO_x$ absorber | $NO_x$ |

countries—have phased out Pb. An issue following the phase-out of leaded gasoline is the use of octane enhancing fuel additives (CAI-Asia, 2006). Table 2.12 and Table 2.13 show gasoline specifications in EU and Asian countries.

Key issues and recommendations for emissions standards, vehicle technology and cleaner fuels include the following:

- institutionalising a clear roadmap for introducing vehicle emissions standards and fuel quality;
- developing a comprehensive fuel quality monitoring system;
- promoting fuel efficiency/ economy standards;
- introducing alternative fuel (NGVs) vehicles, whenever possible, especially for public transportation;
- improving vehicle engines and fuel technology to improve the energy efficiency of individual vehicles, to increase the distance travelled per unit of fuel;
- introducing low carbon-footprint fuels, with lower GHG emissions.

## Inspection and Maintenance

Effective inspection and maintenance (I&M) programmes can reduce vehicle emissions by 30 to 50 per cent compared to emissions without I&M (ADB, 2003). The main objective of I&M is to ensure that benefits of emission control technologies are not lost through poor maintenance and tampering with emission controls. Many Asian countries have introduced inspection and maintenance requirements for in-use vehicles, but the success of efforts to implement these requirements have been mixed. Many Asian countries are still struggling to develop effective inspection and maintenance systems (CAI-Asia, 2006).

Regular I&M controls can:

- help identify vehicles with high emissions caused by maladjustments or other mechanical problems; and
- discourage tampering with emission control equipment so that emission controls

remain effective over useful life of the vehicle.

Key Components of I&M include:

- public awareness;
- link between registration and emission testing;
- carefully designed programme in centralised high-volume testing facility;
- automated reading of emission measurements and computerization of pass/fail decisions;
- information management and analysis;
- routine checking;
- adequate repair facilities and mechanics;
- effective enforcement (i.e. no exceptions).

The testing facility should be centralised in order to reduce the potential for fraud. For the same reason, repair facilities should be separated from emission testing facilities. I&M facilities operated by a small number of private contractors facilitate the role of the Government to supervise and oversee the I&M process.

**Table 2.12: Sulphur content in diesel in Asian countries, the European Union and the United States**

| Country | 96 | 97 | 98 | 99 | 2000 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bangladesh | | | | | | | 5000 | | | | | | | | | |
| Cambodia | | | | | 2000 | | | | | | | | | | | |
| Hong Kong, China | | 500 | | | | | 50 | | | | | 10 | | | | |
| India (nationwide) | 5000 | | | | 2500 | | | | | 500 | | | | | 350 | |
| India (metros) | 5000 | | | | 2500 | 500 | | | | 350 | | | | | 50 | |
| Indonesia | 5000 | | | | | | | | | | | | | | | |
| Japan | 500 | | | | | | | | | 50 | | 10 | | | | |
| Malaysia | 5000 | | 3000 | | | | 500 | | | 500 | | | | | 50 | |
| Pakistan | 10000 | | | | | | 5000 | | | | | | | | | |
| Philippines | 5000 | | | | | 2000 | | | 500 | | | | | | | |
| PRC (nationwide) | 5000 | | | | | | 2000 | | | 500 | | | | | | |
| PRC (Beijing) | 5000 | | | | | | 2000 | | 500 | 350 | | | | | | |
| Republic of Korea | 500 | | | | | | | 430 | | | 30 | | | | 10 | |
| Singapore | 3000 | | 500 | | | | | | | | 50 | | | | | |
| Sri Lanka | 10000 | | | | | | | 5000 | 3000 | /500 | | 500 | | | | |
| Taipei, China | 3000 | | | 500 | | | 350 | | | 50 | | | | | | |
| Thailand | 2500 | | | 500 | | | | | 350 | | | | | | 50 | |
| Viet Nam | 10000 | | | | | | | 2500 | | | 500 | | | | | |
| European Union | | | | | 500 | | | | | 50/10 | | | 10 | | | |
| United States | 500 | | | | | | | | | | 15 | | | | | |

Source: ADB (2003)

**Table 2.13: Specification of Gasoline in Asian Countries and the European Union**

| | Lead | Sulphur ppm | Benzene % v/v, max | Aromatics % | Olefins % | Oxygen % m/m, max | RVP summer kPa, max |
|---|---|---|---|---|---|---|---|
| **Linked to Euro 3 Vehicle Standards Effective 2000** | Lead free | 150 | 1.0 | 42 | 18 | 2.7 | 60 |
| **Linked to Euro 4 Vehicle Standards Effective 2005** | Lead free | 50 | 1.0 | 35 | 18 | 2.7 | 60 |
| **Bangladesh** | Lead free | 1000 | - | - | - | - | 0.7kg/m$^2$ |
| **Bhutan** | Lead free | - | - | - | - | - | - |
| **Cambodia** | Lead free | - | 3.5 | - | - | - | - |
| **Hong Kong SAR PRC** | Lead free | 5- | 1 | 42 | 18 | 2.7 | 60 |
| **India** | Lead free | 1000 | 5 | - | - | 2.7 | 35 - 60 |
| **Indonesia** | 0.30 g/l | 2000 | - | - | - | 2.0 (premix) | 62 |
| **Laos** | Lead free | - | - | - | - | - | - |
| **Japan** | Lead free | 100 | 1 | - | - | - | 78 |
| **Malaysia** | Lead free | 1500 | 5 | 40 | 18 | - | 70 |
| **Pakistan** | Lead free | 10000 | 5 | 40 | - | - | 9 - 10 psi |
| **Philippines** | Lead free | 1000 | 2 | 35 | - | 2.7 | 9 psi |
| **PRC** | Lead free | 500 | 2.5 | 40 | 35 | - | 74 |
| **Singapore** | Lead free | - | - | - | - | - | - |
| **Sri Lanka** | Lead free | 1000 | 4 | 45 | - | 2.7 | 35 - 60 |
| **Taipei, China** | Lead free | 180 | 1 | - | - | 2.7 | 8.9 psi |
| **Thailand** | Lead free | 500 | 3% | 35 | - | 1 - 2% | - |
| **Viet Nam** | Lead free | 5000 - 10000 | 5 | - | - | - | - |

Source: ADB (2003)

Most Asian countries/cities with I&M facilities have centralised systems, however, most emissions testing centres also offer repair facilities which can fix the vehicles to pass the emissions test; most emissions testing facilities are not also linked to a central repository of data on vehicles.

## Transportation management and travel demand management

Transportation management and travel demand management includes four basic elements (ADB, 2003):

- transportation planning;
- traffic engineering;
- traffic management;
- traffic law enforcement.

Transportation planning is a continuing, comprehensive and collaborative process to encourage and promote the development of a multimodal transportation system to ensure safe and efficient transportation of people and goods while balancing environmental and community needs. This process can include market mechanisms such as fees for registration, congestion charges, and road pricing.

The urban transport planning process for a certain study area incorporates several steps:

- Preparation of land use, transport and travel inventories of the study area;
- Analysis of present land use and travel characteristics;
- Forecast of the tendency of land use and travel demands;
- Setting of goals and the formulation of transport alternatives designed to accommodate the projected travel demands and land use changes; and
- Testing and evaluation of alternative transport plans.

Travel demand analysis is one of the most important elements of the transportation planning process. Travel demand is expressed as either person trips or commodity (freight) trips. Table 2.14 provides an overview over attributes for person and commodity trips.

The key challenges for urban transport in Asia include (ADB, 2003):

- providing mobility for goods and persons in support of economic growth and poverty alleviation;
- mitigating traffic congestion;
- responding to air quality, climate change, road safety, congestion challenges resulting from increased motorization;
- reducing urban $CO_2$ emissions;
- maintaining a (high) share of NMT not withstanding almost complete lack of government investment and the desire for individual motorized transport;
- understanding and integrating motorcycles and three-wheelers in urban transport strategy;
- modernizing transit and public transport to provide attractive alternative to individualized transport.

Box 2.6

**Public Transport Policy in China**

The National Reform and Development Commission (NRDC) Guideline (2006) prioritised public transportation:

- mass rapid transit (MRT) as a key transport mode in megacities;
- integrated modal systems (normal buses, BRT buses and railways);
- cities as appropriate to develop BRT system and rebuild the urban street network;
- increase of bus density and shortening of waiting times;
- safe, comfortable, energy-efficient and environment-friendly buses;
- scrapping of highly polluting and low-technology buses;
- economic subsidy and compensation policy for public transportation in cities;
- fares should consider economic and social benefits, business cost of enterprises, and paying capacity of the public.

Source: ADB (2003)

**Table 2.14: Person trip attributes and commodity attributes**

| Person trip attributes | Commodity trip attributes |
|---|---|
| Purpose | Purpose |
| Time of the day | Handling |
| Origin | Volume |
| Destination | Packaging |
| Travel mode | Storage |
| Travel route | Weight |
| Trip frequency | Shelf-life |

The key recommendations to improve urban transport include:

- promoting urban reform and land use planning to ensure urban design that reduces the need to travel, requiring fewer passenger- or freight-kilometres travelled;
- adopting an integrated transportation planning to ensure modal shift that promotes lower fuel consumption per passenger- or freight-kilometre travelled.

Box 2.7
**Transport Policy in India**

The 2006 Indian National Urban Transport Policy vision recognises that all plans would be for the common benefit and well-being of people:

- incorporation of urban transportation in the urban planning stage;
- integrated land-use and transport planning to minimise travel distances and improve access;
- equitable allocation of road space to people, rather than vehicles;
- investing in transport systems that encourage greater use of public transport and non-motorized modes instead of personal motor vehicles;
- financing frameworks for project development and implementation.

Source: ADB (2003)

## Summary

In this module you have learnt how an emissions inventory can be used as part of an integrated AQM programme. You have gained an understanding of the:

- top-down and bottom-up approaches;
- consequences of an incomplete emissions inventory;
- need for quality assurance and quality control in the development of an emissions inventory;
- different sources to be considered in an emission inventory (point, area, and line (mobile));
- parameters influencing emissions of activities;
- emission factors used to estimate emissions.

You have become knowledgeable of the various sophisticated computer programs used in developed countries (e.g. EEA, NILU, USEPA and WHO) to compile an emissions inventory and the rapid assessment methods which are more suitable for developing countries.

This module has introduced you to the most important devices available to control particulate and gaseous emissions. You have learnt about the best control technologies and measures available for mobile sources (cleaner fuels, inspection and maintenance programmes, transport demand management).

The key messages you should take away from this module on emissions are:

- ▶ Emissions inventories must be as accurate as possible.
- ▶ Emissions inventories much consider all relevant sources of air pollutants and their potential of affecting human health and the environment.
- ▶ Rapid assessment of emissions is the most cost-effective way to obtain a fairly reliable emissions inventory.
- ▶ Best available control technologies exist for stationary sources.
- ▶ For mobile sources cleaner fuels and engines, inspection and maintenance programmes and transport and demand management are suitable measures to limit air pollution and greenhouse gas emissions.

In Module 3 *Modelling* you will examine the basic components of an air simulation model which is used to estimate air pollutant concentrations in space and time. You will gain an understanding of the application of dispersion models and the key data requirements. You will also examine the different approaches to source apportionment in determining the contribution of different pollution sources.

## Information sources

ACGIH (2007) *TLVs and BEIs*. American Conference of Governmental Industrial Hygienists, Cincinnati, OH, ISBN 978-1-882417-69-8

ADB (2003) *Vehicle Emissions - Cleaner Fuels. Guidelines, Handbooks, and Manuals.* Asian Development Bank, Manila. http://www.adb.org/documents/guidelines/Vehicle_Emissions/cleaner_fuels.asp

Amsterdam, R. (2007) *The soft power of Russian energy imperialism.* May 2007 Archives. http://www.robertamsterdam.com/2007/05/

Anit, S.B., Artuz, R.J. (2006) *Biofiltration of air.* Rensselaer Polytechnic Institute (RPI), Troy, NY http://www.rpi.edu/dept/chem-eng/Biotech-Environ/MISC/biofilt/biofiltration.htm

Armer, R.A., Bennett, R.L., Black, J.H., Cole, D.E., Dimitriades, B., Essenhigh, R.H., Ferretti, J.W.T., Gantz, R.G., Hatcher Jr., W.J., Hirscher, D.A., Liu, D.H.F., Santhanam, C.J., Shah, I.S. (1974) General Air pollution Control Techniques – Air Pollution Control Estimating. In: Liptak BG, *Environmental Engineers' Handbook*, Volume II, Air Pollution´, pp. 471-906. Chilton Book Company, Radnor, PA

Boarke (2007) *Bag filter dust collection system.* Boarke Machinery Co., Ltd., Taiwan. http://www.boarke.com.tw/e_html/woodworking.15.02-1.htm

BPA (2006-2007) *What you never knew about your cyclone dust collector.* BPA Air Quality Solution LLC, Charleston, SC. http://www.dustcollectorexperts.com/cyclone/

Byun, D.W., Kim, S., Czader, B., Nowak, D., Stetson, S., Estes, M. (2005) Estimation of biogenic emissions with satellite-derived land use and land cover data for air quality modelling of Houston-Galveston ozone nonattainment area. *Journal of Environmental Management* 75: 285-301.

CAI-Asia (2006) *Country Synthesis Reports on Urban Air Quality Management in Asia,* Clean Air Initiative for Asian Cities, Manila, Philippines. http://www.cleanairnet.org/caiasia/1412/channel.html

Calvert, S. (1977) Scrubbing. In: Stern AC, *Air Pollution,* Third Edition, Volume IV, Engineering Control of Air Pollution, pp. 257-291. Academic Press, New York, San Francisco, London

Central Bureau of Statistics (1983) *Fleet Emission Factors, Road Traffic*. Centraal Bureau voor de Statistiek/Statistics Netherlands, Voorburg.

Corbett, W.E., Beskid, C.S. (2000) Stationary source attainment issues, strategies, and costs. Texas Clean Air Conference, October 12, 2000, Austin, TX. http://www.utexas.edu/research/ceer/texaqs/visitors/billcorbett_files/frame.htm

Durand, M., Scott, B.J. (2004) Geothermal ground gas emissions and indoor air pollution in Rotorua, New Zealand. *Science of the Total Environment* 345: 69-80

EBO (2007) Wet scrubber. Online Article. *Encyclopædia Britannica Online*. http://www.britannica.com/eb/art-19729

EC (1999) Council Directive 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air. *Official Journal L* 163 , 29/06/1999 P. 0041 - 0060: http://europa.eu.int/eur-lex/lex/LexUriServ/LexUriServ.do?uri=CELEX:31999L0030:EN:HTML

EC (2000) Directive 2000/69/EC of the European Parliament and of the Council of 16 November 2000 relating to limit values for benzene and carbon monoxide in ambient air. *Official Journal of the European Communities L* 313, 12 - 21: http://europa.eu.int/eur-lex/lex/LexUriServ/LexUriServ.do?uri=CELEX:32000L0069:EN:HTML

EC (2001) Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on National Emission Ceilings for Certain Atmospheric Pollutants. *Official Journal of the European Communities* L309, 22-30: http://europa.eu.int/eur-lex/pri/en/oj/dat/2001/l_309/l_30920011127en00220030.pdf

EC (2002) Directive 2002/3/EC of the European Parliament and of the Council of 12 February 2002 relating to ozone in ambient air. *Official Journal of the European Communities* L67,14-30: http://eur-lex.europa.eu/LexUriServ/site/en/oj/2002/l_067/l_06720020309en00140030.pdf

EC (2004) Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel, and polycyclic aromatic hydrocarbons in ambient air. *Official Journal of the European Union* L23, 3-16: http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/oj/2005/l_023/l_02320050126en00030016.pdf

EC (2006) REGULATION (EC) No 166/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 January 2006 concerning the establishment of a European Pollutant Release and Transfer Register and amending Council Directives 91/689/EEC and 96/61/EC. *Official Journal of the European Communities* L33/1-17: http://www.eper.cec.eu.int/eper/documents/E-PRTR%20Regulation.pdf

EEA (2000a) COPERT III *Computer programme to calculate emissions from road transport. User manual* (Version 2.1), prepared by C Kouridis, L Ntziachristos and Z Samaras. Technical Report No. 50, European Environment Agency, Copenhagen. http://reports.eea.europa.eu/Technical_report_No_50/en

EEA (2000b) COPERT III *Computer programme to calculate emissions from road transport - Methodology and emission factors.* Technical Report No. 49, European Environment Agency, Copenhagen. http://reports.eea.europa.eu/Technical_report_No_49/en/index_html

EEA(2007) EMEP/CORINAIR *Emissions inventory Guidebook – 2007*. Technical Report No. 16, European Environment Agency, Copenhagen. http://reports.eea.europa.eu/EMEPCORINAIR5/en/page002.html

Encyclopaedia Britannica, Inc., (2002) *Britannica Book of the Year: Nations of the World*, London, 2002. Used to identify point and area sources in Appendix 3.8.1

ENS (2006) Nigerian Court Gives Shell One Year to Stop Gas Flaring. *Environment News Service*, http://www.ens-newswire.com/ens/apr2006/2006-04-11-01.asp

Environmental Management Centre, (2005) *Simple Interactive Model for Better Air Quality (SIM-AIR version 1.1),* Mumbai, India. Developed for the World Bank, Clean Air Asia Initiative. http://www.cleanairnet.org/cai/1403/articles-59386_manual.pdf

FEEE (2007) *Converting truth tables into Boolean expressions.* Fundamentals of Electrical Engineering and Electronics. http://www.vias.org/feee/boolean_10.html

Friedrich, A. (2002) *Replacement of air quality measurements with model calculations.* Presentation at the Better Air Quality in Asian and Pacific Rim Cities, Hong Kong, 16-18 December, 2002. http://www.cse.polyu.edu.hk/~activi/BAQ2002/BAQ2002_files/Proceedings/Subworkshop2/sw2b-5Friedrich.pdf

GAPF (2007) *The Global Atmospheric Pollution Forum Air Pollutant Emissions Inventory Manual.* Global Atmospheric Pollution Forum, Stockholm Environment Institute, University of York, York. Website: http://www.sei.se/editable/pages/sections/atmospheric/Forum_emissions_manual_v1.3.doc; http://www.gapforum.org/; and http://www.sei.se/index.php?section=atmospheric&page=projdesc&projdescpage=99928

GEIA (2007) *Global Emissions Inventory Activity*, GEIA Center, Boulder, CO. www.geiacenter.org

Geron C, Pierce T (2002) *Biogenic trace gas emissions in the United States.* National Risk Management Research Laboratory, National Exposure Research Laboratory, United States Environmental Protection Agency, Research Triangle Park, NC. http://www.epa.gov/asmdnerl/pdf/Geronposter2002.pdf

GLOBEIS (2003) *The Global Biosphere Emissions and Interactions System*. National Center for Atmospheric Research, Boulder, CO. http://www.globeis.com/

Gottschlich CF (1977) Combustion. In: Stern AC, *Air Pollution*, Third Edition, Volume IV, Engineering Control of Air Pollution, pp. 365-376. Academic Press, New York, San Francisco, London

Guenther A (2000) *IGAC-GEIA natural VOC emissions.* Paper presented at the Aspen IGAC-GEIA Meeting, Boulder, CO, 28 April - 3 May, 2000. IGAC Newsletter 22. http://www.igac.noaa.gov/newsletter/22/organic.php

Hall, S.J., Matson, Roth, P.M. (1996) $NO_x$ emissions from soil: Implications for air quality modelling in agricultural regions. *Annual Review of Energy and the Environment* 21:311-346

HBEFA (2004a) *Handbook of Emission Factors for Road Transport.* Federal Environmental Agency, Berlin; Swiss Agency for the Environment, Forests and Landscape, Berne, INFRAS, Zürich. http://www.hbefa.net/

HBEFA (2004b) *About HBEFA 2.1* (Handbook Emission Factors for Road Transport). Federal Environmental Agency, Berlin; Swiss Agency for the Environment, Forests and Landscape, Berne; Federal Ministry of Agriculture, Forestry, Environment and Water Management, and Austrian Ministry of Transport, Innovation and Technology, Vienna. http://www.hbefa.net/Tools/EN/MainSite.asp

HSE (2002) *Assessment of the Dangerous Toxic Load (DTL) for Specified Level of Toxicity (SLOT) and Significant Likelihood of Death (SLOD).* Hazardous Installations Directorate. Health & Safety Executive. Internet address: http://www.hse.gov.uk/hid/haztox.htm

IF (2007) *Direct flame incinerators.* Industrial Furnace, Ahmedabat, India. http://www.furnacesuppliers.com/direct-flame-incinerators.html

IIASA (1999) *Regional Air pollution Information and Simulation* – Asia. International Institute for Applied Systems Analysis, Laxenburg, Austria. http://www.iiasa.ac.at/~heyes/docs/rains.asia.html

IIASA (2004) *RAINS-WEB Basic Information.* International Institute for Applied Systems Analysis, Laxenburg, Austria. http://www.iiasa.ac.at/web-apps/tap/RainsWeb/RainsServlet1

ISO 9096:2003 Stationary source emissions -- Manual determination of mass concentration of particulate matter. International Organization for Standardization, Geneva

ISO 10396:2007 Stationary source emissions -- Sampling for the automated determination of gas emission concentrations for permanently-installed monitoring systems. International Organization for Standardization, Geneva

ISO 11942:1996 Gas turbines -- Exhaust gas emission -- Part 2: Automated emission monitoring. International Organization for Standardization, Geneva

ISSRC (2005) *International vehicle emissions model*. International Sustainable Systems Research Center, La Habra, CA: http://www.issrc.org/

Kato, N. and Akimoto, H. 1992 Anthropogenic Emissions of SO2 and NOX in Asia: Emission Inventories. *Atmospheric Environment,* 26A, 2997-3017

Kitzler, B., Zechmeister-Boltenstern, S., Holtemann, C., Skiba, U., Butterbach-Kahl, K. (2005) Control over $N_2O$, $NO_x$ and $CO_2$ fluxes in a calcareous mountain forest soil *Biogeosciences Discussions* 2:1423-1455

Lacour, S. (2003) Cours de pollution atmosphérique - Inventaires d'émissions. Ecole Nationale des Ponts et Chaussées, Centre d'Enseignement et de Recherche sur l'Environnement Atmosphérique. Champs sur Marne. http://cerea.enpc.fr/fich/doc_ENPC_transport.pdf

LADCO (2001) White Paper: *Development of biogenic emission estimates for air quality modelling.* Lake Michigan Air Directors Consortium, Rosemont, IL.http://www.ladco.org/tech/photo/biog/whitepaper-biog.pdf

Leifer, I., Boles, J.R., and Luyendyk, B.P. (2007) *Measurement of Oil and Gas Emissions from a Marine Seep.* University of California Energy Institute. Development & Technology. Paper EDT-009r. http://repositories.cdlib.org/ucei/devtech/EDT-009r

Marse, T.J., Tsoflias, S.L. (2001) *Geogenic inputs to the Gulf of Mexico airshed.* Minerals Management Service, EPA Region IX, New Orleans, LO. http://www.epa.gov/ttn/chief/conference/ei10/intemissions/marsepres.pdf

Ministry of Industry (2004a) Emission Standard of the Power Plant. *Government Gazette* 121, special Part 113, 7 October 2004. http://www.jetro.go.jp/thailand/e/data/moinoti36.pdf

Ministry of Industry (2004b) Emission Standard of a Cement Plant. *Government Gazette* 121, Special Part 70, 25 June 2004. http://www.jetro.go.jp/thailand/e/data/moinoti32666222.pdf

Morawska, L., Jamriska, M., Bofinger, N.D. (1997) Size characteristics and aging of the environmental tobacco smoke. *The Science of the Total Environment* 196: 43-55

Morawska, L., Bofinger, N.D., Kosic, L., Nwankwoala, A. (1998) Submicron and supermicron particles from diesel vehicle emissions. *Environmental Science and Technology* 32: 2033-2042.

NAC/AEGL (2001b) *Proposed AEGL Values. National Advisory Committee for Acute Exposure Guideline Levels (AEGLs) for Hazardous Substances.* [Federal Register: May 2, 2001, Volume 66, Number 85, Page 21940-21964. http://www.epa.gov/fedrgstr/EPA-TOX/2001/May/Day-02/t11001.htm

NAC/AEGL (2002) *Proposed AEGL Values. National Advisory Committee for Acute Exposure Guideline Levels (AEGLs) for Hazardous Substances.* Federal Register: February 15, 2002, Volume 67, Number 32, Page 7164-7176. http://www.epa.gov/EPA-TOX/2002/February/Day-15/t3774.htm

NRC (1993) *Guidelines for Developing Community Emergency Exposure Levels for Hazardous Substances.* National Research Council. Washington DC. National Academic Press

NARSTO (2006) *Improving Emissions inventories for Effective Air Quality Management Across North America:* A NARSTO Assessment. Pasco, WA. http://www.narsto.org/section.src?SID=8

OECD (1996) *Pollutant Release and Transfer Registers (PRTRs): A Tool for Environmental Policy and Sustainable Development - Guidance Manual for Governments.* Organisation for Economic Co-operation and Development, Paris. http://www.olis.oecd.org/olis/1996doc.nsf/LinkTo/ocde-gd(96)32

Oglesby Jr., S., Nichols, G.B. (1977) Electrostatic precipitation. In: Stern AC, Air Pollution, Third Edition, Volume IV, Engineering Control of Air Pollution, pp. 189-256. Academic Press, New York, San Francisco, London

Olivier, J. (2000) *Emissions inventories of natural sources.* Paper presented at the Aspen IGAC-GEIA Meeting, Boulder, C.O., 28 April - 3 May, 2000. IGAC Newsletter 22. http://www.igac.noaa.gov/newsletter/22/natural.php

OSHA (1987) *Dust Control Handbook for Mineral Processing,* Chapter 4: Collecting and disposing of dust. Bureau of Mines, U.S. Department of the Interior. Occupational Safety & Health Administration, Washington, DC http://www.osha.gov/SLTC/silicacrystalline/dust/chapter_4.html

OSHA (2007) *Regulations (Standards 29 CFR) Results.* U.S. Department of Labor, Occupational Safety & Health Administration, Washington, DC. http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

Pichard, A. (2001) *Accidental release of a chemical substance into the atmosphere – Methodology for establishing thresholds for lethal or irreversible effects for the purposes of controlling urban development.* Institut National de l'Environnement Industriel et des Risques (INERIS), Direction des Risques Chroniques, Unité d'Expertise Toxicologique des Substances Chimiques. http://www.ineris.fr/recherches/download/methodologie_gb.pdf

Pierce, T.E. (1999) *Importance of lightning NO for regional air quality modelling.* Atmospheric Modelling Dividion, National Exposure Research Laboratory, United States Environmental Protection Agency, Air Pollution Training Institute, Research Triangle Park, NC. http://www.epa.gov/asmdnerl/pdf/pierce-lightning.pdf

Roymech (2006) *Thermodynamic condensers.* Roy Beardmore. http://www.roymech.co.uk/Related/Thermos/Thermos_Condensors.html

Schwela, D., Morawska, L., Kotzias, D. (2002) *Guidelines for Concentration and Exposure-Response Measurement of Fine and Ultra Fine Particulate Matter for Use in Epidemiological Studies.* EU 2038 EN, European Commission Joint Research Centre, Ispra, Italy, World Health Organization, Geneva

Shin Pung (1999-2004) *Multicyclone*. Shin Pung Company, Seoul. http://www.shinpungfan.com/product5-1.php

Spaite, P.W., Burckle, J.O. (1977) Selection, Evaluation, and Application of Control Devices. In: Stern AC, Air Pollution, Third Edition, Volume IV, *Engineering Control of Air Pollution,* pp. 43-95. Academic Press, New York, San Francisco, London

TF (2007) *Polyester/PP Monofilament Fabric*. Tianyuan Filtercloth Co, Ltd., shanghai. Website: http://www.tradekey.com/product_view/id/413391.htm

Thelocke, J., Winiwarter, and the NatAir TeAM (2006) *PM emissions from natural events in Europe – the NatAir view.* Universität Stuttgart, Institut für Energiewirtschaft und rationelle Energieanwendung. http://ies.jrc.cec.eu.int/uploads/media/Theloke_NATAIR.pdf

TPC (2005) Gas flaring in Africa. Thomko Petro Chemical ,Gary, Indiana. http://thomko.squarespace.com/display/ShowJournal?moduleId=209208&categoryId=35419

UBA (2002) German Federal Environmental Agency, Berlin, TÜV Automotive GmbH, Herzogenrath, IVU GmbH, Sexau, .http://www.umweltdaten.de/verkehr/downloads/citair-dok.pdf

UBA (Ed.) (2004) Handbuch Emissionsfaktoren des Straßenverkehrs (Handbook emission factors for road traffic), Version 2.1/April 2004. Documentation compiled by INFRAS AG Bern/Switzerland in collaboration with IFEU, Heidelberg. Federal Environmental Agency, Berlin

UBA (2007) German Federal Environmental Agency, Roßlau-Dessau, Germany. http://www.umweltbundesamt.de/verkehr/index-daten.htm#mobilev

UN (2007) ISIC Rev. 4 (draft). United Nations, New York, NY. http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=27&Lg=1

USEPA (1998) *Methods for Exposure-Response Analysis for Acute Inhalation Exposure to Chemicals.* Review Draft. United States Environmental Protection Agency, Washington, DC

USEPA (2004a) *Introduction to emissions inventories.* United States Environmental Protection Agency, Air Pollution Training Institute, Research Triangle Park, NC. http://www.epa.gov/apti/course419a/docs/lesson5.pdf

USEPA (2004b) *Preparation of fine particulate emissions inventories.* United States Environmental Protection Agency, Air Pollution Training Institute, Research Triangle Park, NC. http://www.epa.gov/apti/course419b/studentmanual/studentmanual.pdf

USEPA (2006a) *Air and radiation.* National Ambient Air Quality Standards (NAAQS). United States Environmental Protection Agency, Research Triangle Park, NC. http://www.epa.gov/air/criteria.html

USEPA (2006b) *Biogenic emissions Inventory System (BEIS)* Modelling. Atmospheric Sciences Modelling, NOAA-EPA Partnership, United States Environmental Protection Agency, Research Triangle Park, NC. http://www.epa.gov/asmdnerl/biogen.html

USEPA (2006c) *Best available control technology.* Terminology Reference System, Office of Communications, Education, and Media Relations: Terms of Environment: Glossary, Abbreviations, and Acronyms (Revised December 1997) (Glossary). United States Environmental Protection Agency, Washington DC. http://iaspub.epa.gov/trs/trs_proc_qry.org_info?P_REG_AUTH_ID=8&p_list_option_cd=ORG

USEPA (2007a) *About Air Toxics.* Technology Transfer Network - Air Toxics Web Site, United States Environmental Protection Agency, Research Triangle Park, NC. http://www.epa.gov/ttn/atw/allabout.html

USEPA (2007b) *Clearing House for Inventories and Emission Factors.* Technology Transfer Network, United States Environmental Protection Agency, Research Triangle Park, NC. http://www.epa.gov/ttn/chief

USEPA (2007c) *Biogenic Emissions Characterization.* Atmospheric Protection Website, United States Environmental Protection Agency, Research Triangle Park, NC. http://www.epa.gov/appcdwww/apb/biogenic.htm

USEPA (2007d) *Modelling and inventories*. AP-42: Compilation of Air Pollutant Emission Factors, United States Environmental Protection Agency, Research Triangle Park, NC. http://www.epa.gov/otaq/ap42.htm

WHO (1993) *Assessment of Sources of Air, Water, and Land Pollution: A Guide to Rapid Source Inventory Techniques and their Use in Formulating Environmental Control Strategies.* Part One: Rapid Inventory Techniques in Environmental Pollution. (Economopoulos AP, ed.). WHO/PEP/GETNET 93.1-A. World Health Organization, Geneva. http://whqlibdoc.who.int/hq/1993/WHO_PEP_GETNET_93.1-A.pdf

WHO (1995) Decision Support System for Industrial Pollution Control (DSS IPC). Computer programme to be found on the Air Management Information System, see WHO (1997; 1998). World Health Organization, Geneva

WHO (1996a) *One week training workshop in assessment of sources of air, water, and land pollution – A Tutor's Guide. Part One*: Rapid inventory techniques in environmental pollution (Economopoulos AP, ed.). World Health Organization, Geneva

WHO (1996b) *One week training workshop in assessment of sources of air, water, and land pollution – A Tutor's Guide. Part Two*: Exercise material & evaluation questionnaire. (Economopoulos AP, ed.). World Health Organization, Geneva

WHO (1996c) *Motor Vehicle Air Pollution: A Teacher's Guide: One Week Training Workshop*. WHO/EHG/96.1, World Health Organization, Office of Global and Integrated Environmental Health, Geneva

WHO (1997) Air Management Information System (AMIS). CD ROM Version 1. World Health Organization, Geneva

WHO (1998) Air Management Information System (AMIS). CD ROM Version 2. World Health Organization, Geneva

# Appendix A: Emission Factors for Generating Power

| Process | Unit (U) | TSP kg/U | $SO_2$ kg/U | $NO_x$ kg/U | CO kg/U | VOC kg/U | | kg/U |
|---|---|---|---|---|---|---|---|---|
| **Electricity Gas and Steam** [1] | | | | | | | | |
| **Gaseous Fuels** | | | | | | | | |
| **Natural Gas** [2] | | | | | | | | |
| Utility Boilers | 1000 $Nm^3$ | 0.048 | 15.6S | 8.8f [3] | 0.64 | 0.028 | | |
| | t | 0.061 | 20S | 11.3f | 0.82 | 0.036 | | |
| Industrial Boilers | 1000 $Nm^3$ | 0.048 | 15.6S | 2.24 | 0.56 | 0.092 | | |
| | t | 0.061 | 20S | 2.87 | 0.72 | 0.118 | | |
| Domestic Furnaces | 1000 $Nm^3$ | 0.048 | 15.6S | 1.6 | 0.32 | 0.127 | | |
| | t | 0.061 | 20S | 2.05 | 0.41 | 0.163 | | |
| Stationary Gas Turbines | 1000 $Nm^3$ | 0.224 | 15.6S | 6.62 | 1.84 | 0.673 | | |
| | t | 0.287 | 20S | 8.91 | 2.36 | 0.863 | | |
| | MWh | 0.138 | 9.6S | 4.08 | 1.14 | 0.415 | | |
| **Liquified Petroleum Gas (LPG)** | | | | | | | | |
| Industrial Boilers | $m^3$ (Liq) | 0.031 | 0.004 | 1.51 | 0.37 | 0.06 | | |
| | t | 0.060 | 0.007 | 2.9 | 0.71 | 0.12 | | |
| Domestic Furnaces | $m^3$ (Liq) | 0.031 | 0.004 | 1.07 | 0.22 | 0.09 | | |
| | t | 0.060 | 0.007 | 2.05 | 0.42 | 0.17 | | |
| **Liquid Fuels** | | | | | | | | |
| **Distillate Fuel Oil** | | | | | | | | |
| Industrial and Commercial Boilers | t | 0.28 | 20S | 2.84 | 0.71 | 0.035 | $SO_3$ | 0.28S |
| Residential Furnaces | t | 0.36 [4] | 20S | 2.60 | 0.71 | 0.354 | $SO_3$ | 0.28S |
| Stationary Gas Turbines | t | 0.710 | 20S | 9.62 | 2.19 | 0.791 | | |
| | MWh | 0.369 | 10.4S | 5.01 | 1.14 | 0.415 | | |
| **Residual Fuel Oil** [5] | | | | | | | | |
| Utility Boilers | | | | | | | | |
| Uncontrolled | t | P | 20S | 8.5 [6] | 0.64 | 0.127 | $SO_3$ | 0.25S |
| ESP - Low Efficiency | t | 0.5P | 20S | 8.5 | 0.64 | 0.09 | $SO_3$ | 0.25S |
| ESP - High Efficiency | t | 0.1P | 20S | 8.5 | 0.64 | 0.09 | $SO_3$ | 0.25S |
| Scrubber | t | 0.45P | 1.5S | 8.5 | 0.64 | 0.09 | | |
| Industrial and Commercial Boilers [7] | t | P | 20S | 7.0 [8] | 0.64 | 0.163 | $SO_3$ | 0.25S |
| **Waste Lub Oil** [9] | | | | | | | | |
| Industrial and Commercial Boilers | t | 8.1A | 20S | 2.7 | 0.67 | 0.13 | Pb | 5.6P |
| Domestic Heaters | t | 8.6A | 20S | 2.7 | 0.67 | 0.13 | Pb | 6.8P |
| **Solid Fuels** | | | | | | | | |
| **Anthracite Coal** [10] | | | | | | | | |
| Pulverised Coal Furnace | | | | | | | | |
| Uncontrolled | t | 5A | 19.5S | 9.0 | 0.3 | 0.055 | | |
| Cyclone | t | 1.25A | 19.5S | 9.0 | 0.3 | 0.055 | | |
| ESP - High Efficiency | t | 0.36A | 19.5S | 9.0 | 0.3 | 0.055 | | |
| Fabric Filter | t | 0.01A | 19.5S | 9.0 | 0.3 | 0.055 | | |
| Travelling Grate Stoker | | | | | | | | |
| Uncontrolled | t | 4.6 | 19.5S | 5.0 | 0.3 | 0.055 | | |
| Cyclone | t | >1.2 | 19.5S | 5.0 | 0.3 | 0.055 | | |
| Hand Fed Units | t | 5.0 | 19.5S | 1.5 | 45.0 | 9.0 | | |
| **Bituminous and Subbituminous Coal** [11] | | | | | | | | |
| Pulverized Coal/Dry Bottom Furnace | | | | | | | | |
| Uncontrolled | t | 5A | 19.5S | 10.5 [12] | 0.3 | 0.055 | | |
| Multiple Cyclones | t | 1.25A | 19.5S | 10.5 | 0.3 | 0.055 | | |
| ESP - High Efficiency | | | | | | | | |
| - Low S Coal + No Cond'ning | t | 0.33A | 19.5S | 10.5 | 0.3 | 0.055 | | |
| - Otherwise | t | >0.01A | 19.5S | 10.5 | 0.3 | 0.055 | | |
| Fabric Filter | t | 0.01A | 19.5S | 10.5 | 0.3 | 0.055 | | |
| Flue Gas Desulphurisation | t | 0.05A | 1.95S | 10.5 | 0.3 | 0.055 | | |

t metric ton; $Nm^3$ normal cubic metre; MWh Megawatt hour

1. (a) "S" is the weight percent of Sulphur in the fuel.

   (b) "A" is the weight percent of Ash in the solid fuel.

   (c) "N" is the weight percent of Nitrogen in the fuel.

2. Typical sulphur content of Natural Gas is 0.000615%.

3. For tangentially fired boilers use 5.6f kg/1000Nm³. The load reduction coefficient "f" is computed from Equation

$$f = 0.3505 - 0.005235\ L + 0.0001173\ L^2,$$

   where L is the mean boiler load, %. A typical mean boiler load is 87%.

4. In the absence of boiler I/M programs, smoke emission factors may be closer to 1.6 kg/t.

5. "P", the uncontrolled TSP emission factor, is function of the sulphur content of fuel oil and is computed from Equation

$$P = 0.4 + 1.32\ S$$

6. Use 5.3 kg/tn for tangentially fired boilers, 13.3 for vertical fired boilers and 8.5 for all other boiler types.

7. (a) In the absence of boiler I/M programs, the average smoke emission factor (EF) can exceed that in the table by about 60%, Econompoulos (1987)

   (b) In cases where very effective boiler I/M programs are implemented, the average smoke emission factor can be lower by up to 45% of that listed in the table, Econompoulos (1991)

8. If the nitrogen content of the fuel is known, the $NO_x$ emission factor $EF(NO_x)$ can be computed more accurately from the empirical formula

$$EF(NO_x) = (3.25 + 59.2\ N^2).$$

9. (a) Typical values of "A" and "S" in lub oils are 0.65% and 0.5%.

   (b) "P" is the weight percent of lead (Pb) in the fuel. The value of P depends on the lead content of the gasoline used. In the U.S.A. the average values of P dropped from 1% in 1970 (catalytic cars and unleaded gasoline were not in use) to 0.11% in 1982-83 (three years after the introduction of catalytic cars and unleaded gasoline) and to 0.04% in 1985-86 (six years after the introduction of catalytic cars and unleaded gasoline).

10. Typical Ash and Sulphur contents are 8.1% and 0.9% for Meta Anthracite, 9.4% and 0.6% for Anthracite, and 12.4% and 2% for Semianthracite respectively (dry basis).

11. (a) In Bituminous coals typical Ash and Sulphur contents are 4.9% and 0.8% for Low Volatility coals, 2.9% and 0.6% for Medium Volatility coals, 6.5% and 1.3% for High Volatility A coals, 5.4% and 1.4% for High Volatility B coals, and 9.1% and 2.6% for High Volatility C coals, respectively (dry basis).

    (b) In Subbituminous coals typical Ash and Sulphur contents are 4.7% and 1% for A type, 2.8% and 0.5% for B type, 13.2% and 0.4% for C type, respectively (dry basis).

12. For tangentially fired boilers use 7.5kg/t.

## Appendix B: Emission Factors[a] for Heavy Duty Vehicles

| Source | Weight [tons] | Driving mode | Unit [U] | TSP | $SO_2$ | $NO_x$ | CO | VOC |
|---|---|---|---|---|---|---|---|---|
| | | | | Factor [kg/U] | Factor[b] [kg/U] | Factor [kg/U] | Factor [kg/U] | Factor [kg/U] |
| **Heavy Duty Diesel Powered Vehicles[c]** | 3.5-16.0 | Urban | 1000 km | 0.9 | 4.29S | 11.8 | 6.0 | 2.6 |
| | | | tons of fuel | 4.3 | 20S | 55.0 | 28.0 | 12.0 |
| | | Suburban | 1000 km | 0.9 | 4.15S | 14.4 | 2.9 | 0.8 |
| | | | tons of fuel | 4.3 | 20S | 70.0 | 14.0 | 4.0 |
| | | Highway | 1000 km | 0.9 | 4.15S | 14.4 | 2.9 | 0.8 |
| | | | tons of fuel | 4.3 | 20S | 70.0 | 14.0 | 4.0 |
| **Heavy Duty Diesel Powered Trucks[d]** | > 16.0 | Urban | 1000 km | 1.6 | 7.26S | 18.2 | 7.3 | 5.8 |
| | | | tons of fuel | 4.3 | 20S | 50.0 | 20.0 | 18.0 |
| | | Suburban | 1000 km | 1.6 | 7.43S | 24.1 | 3.7 | 3.0 |
| | | | tons of fuel | 4.3 | 20S | 65.0 | 10.0 | 8.0 |
| | | Highway | 1000 km | 1.3 | 6.1S | 19.8 | 3.1 | 2.4 |
| | | | tons of fuel | 4.3 | 20S | 65.0 | 10.0 | 8.0 |
| **Heavy duty Diesel Powered Buses[d]** | > 16.0 | Urban | 1000 km | 1.4 | 6.6S | 16.5 | 6.6 | 5.3 |
| | | | tons of fuel | 4.3 | 20S | 50.0 | 20.0 | 16.0 |
| | | Suburban | 1000 km | 1.2 | 5.61S | 18.2 | 2.8 | 2.2 |
| | | | tons of fuel | 4.3 | 20S | 65.0 | 10.0 | 8.0 |
| | | Highway | 1000 km | 0.9 | 6.11S | 13.9 | 2.1 | 1.7 |
| | | | tons of fuel | 4.3 | 20S | 65.0 | 10.0 | 8.0 |

a The emission factors listed are based on a mean ambient temperature of 20°C and on the following assumptions:
For Urban Driving: Average speed = 25 km/h; Average trip length = 8 km; Cold/hot starts: = 75/25
For suburban Driving: Average speed = 60 km/h; Average trip length = 12 km; Cold/hot starts: = 75/25
For highway Driving: Average speed = 100 km/h; Average trip length = 20 km; Cold/hot starts: = 75/25

b S is the percent weight of sulphur in fuel

c Emission factors of the Central Bureau of Statistics, Netherlands (1983) for the TSP (Smoke) emissions from Urban, Suburban and Highway Driving are 5.4, 2.0 and 1.4 kg/1000 km, respectively

d Emission factors of the Central Bureau of Statistics, Netherlands (1983) for the TSP (Smoke) emissions from Urban, Suburban and Highway Driving are 5.1, 1.8 and 1.0 kg/1000 km, respectively

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