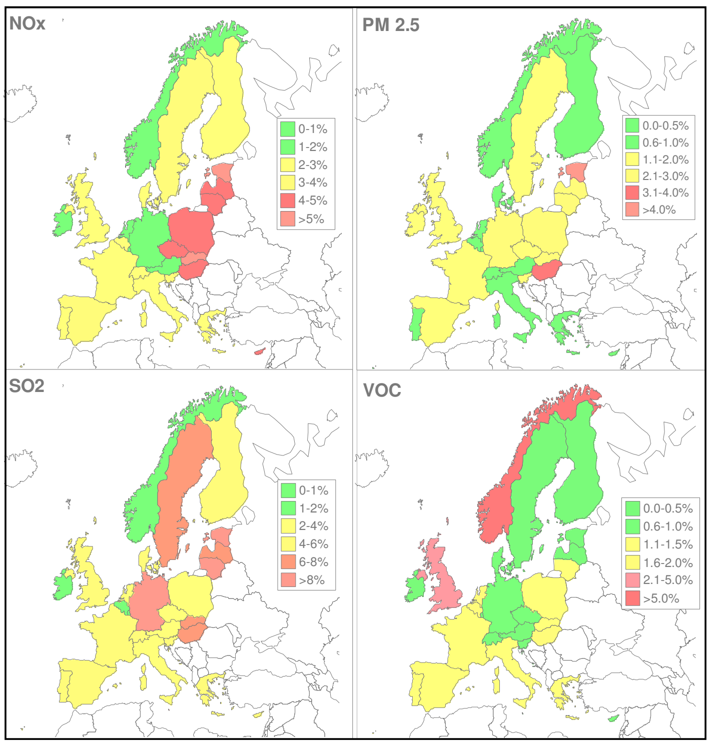
Final Report
for the

“Assessment of the air emissions impact of emerging technologies”

Study Contract n° 21350-2003-10 F1ED SEV DE



French-German Institute for Environmental Research (DFIU/IFARE)

University of Karlsruhe, Germany

Umweltbundesamt GmbH (UBA), Federal Environment Agency

Austria

Title:	Assessment of the air emissions impact of emerging technologies
Customer:	Institute for Prospective Technological Studies (JRC-IPTS), Seville
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Authors:

French-German Institute for Environmental Research (DFIU/IFARE)
University of Karlsruhe
Hertzstrasse 16
76187 Karlsruhe
Germany
Phone: +49-(0)721 608-4582
Fax: +49-(0)721 75 89 09
Email: bernd.calaminus@wiwi.uni-karlsruhe.de

Umweltbundesamt GmbH (UBA), Federal Environment Agency Austria
Spittelauer Laende 5
1090 Vienna
Austria

DFIU/IFARE: Otto Rentz, Bernd Calaminus, Raphaèle Deprost, Michael Hiete
UBA Austria: Ilse Schindler, Thomas Krutzler

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Foreword

At the end of 2003, the Institute for Prospective Technological Studies (IPTS) at the Joint Research Centre (JRC) of the European Commission in Seville in association with DG Environment has launched an eight months service contract "Assessment of Air Emissions Impact of Emerging Technologies" within the framework of the Clean Air for Europe (CAFE) program.
The study focused on emerging technologies and applications within the industrial sector that could have a relevant impact on air emissions (NO_x, SO_x, VOC, PM, CO_2 but also CO, NH_3, N_2O, POPs, Heavy Metals) in EU-25 plus Norway and Switzerland until 2030.

Following the Invitation To Tender [291] both process-integrated and end-of-pipe technologies as well as new products and optimisation of existing technologies were considered. These included e.g. optimisation or new areas of application of existing technologies (e.g. increased efficiency or SCR for gas turbines), new technologies (e.g. stationary fuel cells) or new products (e.g. new paint formulations with reduced VOC contents) (see part 1.2 for definitions used and delimitation to the BREF terminology).
The aim of the project was to give non-commital recommendations which emerging technologies should be considered for future integration in IAM, e.g. RAINS model, and to provide necessary information as far as available. The decision which technologies and data will be integrated lies with the IAM modelers, e.g. IIASA. The outcomes of the project may also serve as non-reviewed source of information used in the revision process of BREF documents. The project also aimed at identifying major drivers and barriers for the diffusion of emerging technologies which had been identified as promising in order to give recommendations on how their diffusion might be supported. Several objectives of the project – as described in the invitation to tender – were the identification of main pollutant-sector combinations, the identification of promising emerging technologies and applications, their techno-economic characterisation (e.g. applicability, emission reduction potential, costs) as well as the development of scenarios to assess their impact on air emissions in the EU until 2030 (potential of reduction of air emissions).
At an early stage of the project, industrial associations and other experts from EU, Japan, Canada and the USA were informed about the project and invited to provide information and data on emerging technologies and applications in their domain of competence.
To ensure the direct involvement of experts from industry and other institutions a workshop with 11 half-day sessions for different industrial sectors was held in Brussels where some of the collected information was presented, discussed, assessed and supplemented. Main problems especially related to emerging technologies are among others uncertainty and confidentiality preventing an objective and enduring assessment. Time dedicated to each sector being rather limited, it is obvious that comprehensive in-depth analyses, discussions and assessments of technologies were hardly possible.
The study was performed by a consortium of the French-German Institute for Environmental Research (DFIU) in Karlsruhe and the Federal Environmental Agency (UBA) of Austria in Vienna with the subcontractors CITEPA in Paris and ITA in Vienna. The time frame for the study was Dec. 2003 – Aug. 2004. However, the deadline of the project was extended in agreement with IPTS to give experts more time to gather information after the workshop.

1. Background and objective of the study

1.1. Framework of the study

The protection of human health and of the environment from air pollution via the development of long term policies are the objectives of the Gothenburg Protocol at UNECE level and the “Clean Air for Europe” (CAFE) program of the European Union. Multinational strategies for the reduction of air emissions are strongly based on emission scenarios from Integrated Assessment Modelling (IAM). The RAINS[1] model developed by IIASA is used for both the CAFE program and the UNECE protocols in order to find an optimal trade-off between expenditures for emission reduction measures and achievement of air quality objectives.

In the framework of the CAFE program and as contribution to the Development of the Thematic Strategy the Institute for Prospective Technological Studies (IPTS at the JRC Seville) in association with DG Environment has launched a study “Assessment of the Air Emissions Impact of Emerging Technologies”. The main aim of the project was to provide information on which emerging technologies in the industrial sector could have a major impact on air emissions in EU-25 plus Norway and Switzerland until 2030 in order to give recommendations which technologies should be considered by IIASA to be integrated into the RAINS model. The project also aimed at providing techno-economic data on these technologies to enable their integration into the RAINS model. It needs to be pointed out that the decision which technologies will be integrated and with which data is at IAM modelers, e.g. IIASA, alone. The project outcomes should also serve as a non-reviewed source of information for the revision of BREF documents by the corresponding experts. Finally, the project also aimed at identifying drivers and barriers of the application of these technologies in order to promote their diffusion.
SO_x, NO_x, NMVOC, PM (TSP, PM10, PM2.5) and CO_2 are in the focus of the CAFE program and hence also in the focus of this project. Abatement of NH_3, CH_4, CO, heavy metals and POPs like PAHs, PCDFs and PCDDs will be addressed as far as they are related to the priority pollutants.
The study is performed by a consortium of the French-German Institute for Environmental Research (DFIU) in Karlsruhe and the Federal Environmental Agency (UBA) of Austria in Vienna with the subcontractors CITEPA in Paris carrying out analyses of VOC emitting processes and ITA in Vienna who was responsible for the workshop concept based on its experience within the IPTS ESTO project. The time frame for the study is 8 months (Dec. 2003 – Aug. 2004).

1.2. “Emerging technologies” – a definition

In the project the term “emerging technologies” was used as in the Invitation To Tender [291] and as discussed in meetings with IPTS and the Commission on 18 Dec. 2003 and 9 March 2004. In the Invitation To Tender [291], the following information useful for characterising the “emerging technologies” is given:

- “currently at demonstration or pilot plant scale”
- technologies in Annex I of the Invitation To Tender [291] as “Categories of technologies to be considered”:
    - “Advanced flue gas desulfurization technologies with improved efficiencies and/or reduced costs”
    - “Primary/secondary measures for emissions from small combustion sources (optimized combustion of solid fuels, use of catalysts for NO_x reduction, particle filters, electronic controlloed combustion, etc.)”
    - “Primary and secondary measures to reduce VOC emissions (e.g. technical and organizatorical measures of the IPPC and solvent directives)”

[1] RAINS (**R**egional **A**ir Pollution **IN**formation and **S**imulation) by International Institute for Applied System Analysis (IIASA) in Laxenburg covers primary and secondary abatement measures for the pollutants SO_2, NO_x, NMVOC, NH_3 and PM.

- "Technologies achieving simultaneous control of multiple pollutants (recent decrease in costs, enlarged applicability to more sources, etc.)"
- "Control of emissions of small industrial combustion sources (<10 MW thermal), cost-efficient application of measures originally developed for larger units"
- "Control of diffuse PM and VOC emissions from industrial processes (technical and organizatorical measures, e.g., metal industry, refineries, material handling, etc.)"
- "Desulfurization of solid fuels (new methods for fuel preparation, etc.)"
- "Desulfurization of heavy fuel oil (cost efficient measures in refineries beyond current practice)"
- "Reduction of greenhouse gas emissions in the energy sector and their side effects on conventional air pollutants (increased fuel efficiency, stationary fuel cells, demand side management, etc.)"
- "Improved fuel efficiency for cement production (improved recipes, improved heat recovery, etc.)"
- "Extended application of SCR and SNCR technologies (including gas turbines, cement production, high dust applications, etc.)"
- "Optimized production processes in the iron- and steel industry (e.g., EOS sinter plants with PM control, etc.)"
- "Integrated gasification combined cycle power plants"
- "New catalytic materials (increased efficiency and durability, reduced costs, etc.)"
- "Low NO_x burners (increased efficiency, reduced costs, low temperature burners, etc.)"
- "Fuel additives (e.g. for reduced NO_x emissions)"
- "New arc furnace technologies"
- "Emissions characteristics related to new products likely to appear on the market over the next 20 years, e.g. new paint or ink formulation, etc."
- "Emissions and cost characteristics of options for storage and handling of industrial and products and waste (including impact on greenhouse gases emissions)"

In the meetings with IPTS and the Commission on 18 Dec. 2002 and 9 March 2004 it was further concluded that:

- ""**Emerging technologies**": will be in general considered as techniques which are currently in the stage of the pilot plant scale or the demonstration plant scale. But as in the case of Al-industry, ongoing intensive and promising research work (here: inert anodes) should be taken into account."
- "It has to be avoided to consider **BATs** – even if not yet applied in practice to a significant extent – as "emerging technologies"..."
- "It was agreed to distinguish between and to consider both **emerging technologies** (e.g. N_2O control in nitric acid plants) and **emerging applications** (e.g. combined cycle natural gas power plants)."

Based on this information, in this project "emerging" is understood as currently in the pilot or demonstration plant scale, i.e. not commercial yet and the development is advanced that far that most serious technical problems have been solved – or it can be expected that they will be solved in the future, e.g. due to onging intensive and promising research – and that the expected costs of the technology are such that they are thought to become competitive in the future (e.g. learning curve effect) or that they are balanced by other positive effects. In this context, however, it should be added that "emerging" refers to currently available information and expectations and does not exclude that the technology might never have a significant market share or even become commercial for various reasons:

- technology-related:
  - underestimation of known technical problems
  - detection of new technical problems
  - unwanted by-products
  - safety reasons
- related to competition with other technologies (e.g. existing technologies, existing technologies after optimisation or new technologies) producing a similar product:
  - higher fixed or variable costs, or both
  - less good performance: reliability, product quality, by-products, maximum capacity, flexibility etc.
  - higher risks, e.g. safety, ecnomic, technical

    - less experience in conjunction with conservative attitude
    - difficulties in integration into existing system, e.g. lack of infrastructure
- market-related:
    - change in demanded product quality or products
    - no need for new installations
    - lack of acceptance by the public (in spite of techno-economic advantages)
    - changing boundary conditions, e.g. energy prices
    - uncertainty about future boundary conditions

A statement received after the workshop highlights from Mr. Rivron this:

"An emerging technology in a pilot or a demonstration plant scale might never further develop if its technical performance is unsatisfactory, its costs are too high or if other important factors are unfavourable.

- *Even though an emerging technology is commercially available its market share could remain low for various reasons: technical evolution, costs, insufficient demand, return on investment, economic risks of a market in liberalisation, uncertain future conditions and competition.*
- *A technology even though already in commercial scale might still be emerging if technical improvements are possible. For this reason, primary DeNO$_x$ and GCC (gas combined cycle) can be still considered as emerging technologies."*[2]

Within this project "emerging technologies" (in the wider sense = i.w.s.) are subdivided in "**emerging technologies**" (in the narrower sense = i.n.s.), "**emerging applications**" and "**emerging products**" where "emerging technologies" i.n.s. refer to new technologies or techniques[3], "emerging applications" to technologies or techniques already existing in one field of application but new in another, e.g. due to vertical or horizontal diffusion (e.g. wind farms offshore), and "emerging products" as new products."Promising" within this project refers to emerging technologies i.w.s. for which – based on the current information available – a significant market share can be expected in the future.
"Relevant" within this project refers to emerging technologies i.w.s. for which – based on the current information available – a significant reduction of air emissions (NO_x, SO_x, VOC, PM, CO_2 but also CO, NH_3, N_2O, POPs, Heavy Metals) from the industrial sector can be expected in EU-25 plus Norway and Switzerland as a whole or in countries thereof in the time frame 2005 to 2030.
"Industrial sector" within this project includes all industrial activities including households but excludes agriculture and transport as well as mining (cf. Invitation to Tender [291], Minutes of meeting on 18 December 2003 [292]).

It should be clearly stated that the definition of emerging technologies i.w.s. and i.n.s. (inferable from the Invitation To Tender [291] as well as the minutes of the project meetings [292, 293], see above) differs from that of "Emerging Techniques" in the BREF documents and thus any mingling of the two terminologies should be avoided. This includes of course also the terms "commercial" and "BAT". Within this project, the term "emerging" is (mainly) used for technologies currently in pilot and demonstration plant scale. In this context, "promising" does not necessarily mean that a technology will be applied in commercial scale in future.

In the "IPPC BREF OUTLINE and GUIDE" from May 2004 the term "Emerging Techniques" is used and the following description is given "This chapter will identify any novel pollution prevention and control techniques that are reported to be under development and may provide future cost or environmental benefits. Information will include the potential efficiency of the technique, a preliminary cost estimate, and an indication of the time scale before the techniques might be commercially "available". This section can also include techniques to address environmental issues that have only recently gained interest in relation to the sector at hand. Established techniques in other sectors that are emerging in practice within the sector concerned will not be included in this chapter."

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[2] Note: The sense of "emerging" here differs from that used in the project.

[3] Agazzi, E. (1998): From Technique to Technology: The Role of Modern Science. Phil & Tech 4:2 Winter 1998.

1.3. Work packages

The project comprises five work packages (Invitation To Tender [291]):

WP 1: “Analysis of emissions from selected sectors”

WP 2: “Identification and description of promising emerging technologies that could gain relevant market shares in the coming years for each sector”

WP 3: “Scenarios development (till 2030)”

WP 4: “Workshop”

WP 5: “Concluding Analysis”

2. Work package 1: Analysis of emissions from selected sectors

2.1. Introduction

Invitation to Tender [291]: "Description of the situtation concerning the selected pollutants within the industrial sector. This analysis should include a description of the current situation and estimations of emissions for the future. The approach could be pollutant by pollutant and will have to be based on the same information sources as those used in the devlopment of RAINS (notably the emission inventories under the NEC Directive), and for EU-15 the European Pollutant Emission Register, which will be available in February 2004."

The main scope of WP 1 is to identify relevant sector/pollutant combinations. The analysis has to consider country specifics. In addition future structural changes in industry and industrial activities with an impact on the air emission situation are to be taken into account as well as legislative projects which have not yet entered into force but which soon will.

The scope of this work package makes the following demands on the emission data to be analysed:

- coverage of the pollutants SO_2, NO_x, NMVOC, PM (TSP, PM_{10}, $PM_{2.5}$) and CO_2 as well as NH_3, CH_4, CO, heavy metals[4] and POPs like PAHs, PCDFs and PCDDs.
- differentiation of industrial sector (the more detailed the better)
- country-by-country
- geographical coverage EU-25 plus Norway and Switzerland
- past, actual and future emission data to take the evolution of the sector emissions into account
- high data quality (reliable, consistent over time, comparable between countries, complete (cf. Jol (2000), preferably approved by national authorities)

Table 2.1: Environmental issues of selected pollutants (after Jol, 2000[5])

Pollutant	Acidifying	Eutrophying	Greenhouse gas	Toxic (at ambient concentrations)	Tropospheric ozone forming
Sulfur dioxide (SO_2)	☹				
Nitrogen oxides (NO, NO_2 as NOx)	☹	☹			☹
Non-methane volatile organic compounds (NMVOC)				☹[6]	☹
Particulate matter (PM)				☹	
Carbon dioxide (CO_2)			☹		
Carbon monoxide (CO)				☹	
Nitrous oxide (N_2O)			☹		
Methane (CH_4)			☹		
Ammonia (NH_3)	☹	☹			
Heavy metals				☹	
Persistent organic pollutants (POPs), e.g. dioxins, furans, PAH				☹	

[4] e.g. As, Cd, Cr, Cu, Hg, Ni, Pb, Zn and their compounds

[5] Jol, A. (2000): Overview on international data collection on air emissions. Meeting of the Working Group „Statistics of the Environment", Joint Eurostat/EFTA Group, Sub-Group „Integrated Emissions Statistics", Meeting of 14-15 Feb. 2000, Bech Building.

[6] only some compounds

2.2. Overview of Emission Inventories

To determine relevant combinations between pollutants and industrial sectors an analysis of sector emission data is necessary. A number of emission inventories exists in EU-25 plus Norway and Switzerland that differ with respect to geographical coverage, covered pollutants, source specifications and reported time frame. In the following a short overview of selected emission inventories is given and the inventories are assessed in terms of their suitability for the objectives of work package 1.

2.2.1. EPER (European Pollutant Emission Register)

Base: Integrated Pollution Prevention and Control (IPPC) Council Directive 96/61/EC and Commission Decision of 17 July 2000 (200/479/EC)

Pollutants: SOx, NOx, NMVOC, CO_2, PM_{10} and CH_4, CO, N_2O, NH_3, heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn and their compounds), halocarbons (Dichloroethane-1,2 (DCE), Dichloromethane (DCM), Hexachlorobenzene (HCB), Hexachlorocyclohexane (HCH), PCDDs (dioxins) & PCDFs (furans), Pentachlorophenol (PCP), Tetrachloroethylene (PER), Tetrachloromethane (TCM), Trichlorobenzenes (TCB), Trichloroethane-1,1,1 (TCE), Trichloroethylene (TRI), Trichloromethane), Benzene, PAH (Polycyclic Aromatic Hydrocarbons), Chlorine and inorganic compounds, Fluorine and inorganic compounds

Geographical coverage: EU-15 plus Norway and Hungary

Source specifications: NOSE-P and NACE

Time schedule: 2001, 2004, from 2008 onwards annually (planned)

Methodologies: EPER-Methodology[7]

Data source: http://www.eper.cec.eu.int/eper/

Disadvantages in the context of WP 1:

- only one reporting year yet
- almost only EU-15
- only emissions above threshold value are reported (no small scale sources like diffuse or mobile sources) which results in the fact that only a part of the total emissions are covered in EPER, e.g. in EU-15 compared to UNFCCC and CLRTAP/NEC (Figure 2-1) (Brand et al. (2004): EPER Review Report)
  - 42% of CO_2 emissions
  - 15% of CH_4 emissions
  - 26% of NOx emissions
  - 70% of SOx emissions
  - 6% of NMVOC emissions
  - 13% of N_2O emissions
- first reporting in 2004 may be erroneous due to lack of experience
- no activity data given for installations which inhibits calculation of specific emissions and comparison between installations
- problems with facilities with several polluting processes
- in general main economic and not main polluting activity determines source specification
- only PM_{10} out of PM

EPER is for several reasons of limited importance for WP 1. Geographically EPER covers only EU-15 plus Norway and Hungary. Small scale sources and hence a high portion of overall emissions are not accounted for. Since no activity data for the installations are indicated it is neither possible to calculate specific emission factors nor is it possible to obtain information on sector activity data or on the structure of the industrial sectors in the countries which would be useful for WP 3. In addition inconsistent and missing data reduces the value of EPER for this project: e.g. a combined heat and power plant in a university hospital in Germany is classified as "health and social work", a major refinery in the north of Germany as "manufacture of other non-metallic mineral products" and a major refinery in the south of Germany as "wholesale of solid, liquid and gaseous fuels and related products". Similar problems can be expected for other countries, too. For NH_3 it is striking that there are no emitters in France due to animal breeding whereas in Germany there are more than 600 (Figure 2-2). One

[7] http://www.eper.cec.eu.int/eper/documents/eper_en.pdf

possible explanation could be a different size structure of animal breeding installations in France compared to Germany. This hypothesis is supported by the fact that a high number of emitters in Germany are situated in the eastern part of Germany (cf. Annex B1) where huge animal breeding installations are a relict of former GDR times. However, it remains striking that in France there is not a single agricultural installation with NH_3 emissions in EPER.
It is also striking the UK has the highest number of intallations in EPER (Figure 2-3) which might be a result of the longer tradition in the preparation of emission registers there.

More maps and figures on EPER can be found in the Annex.

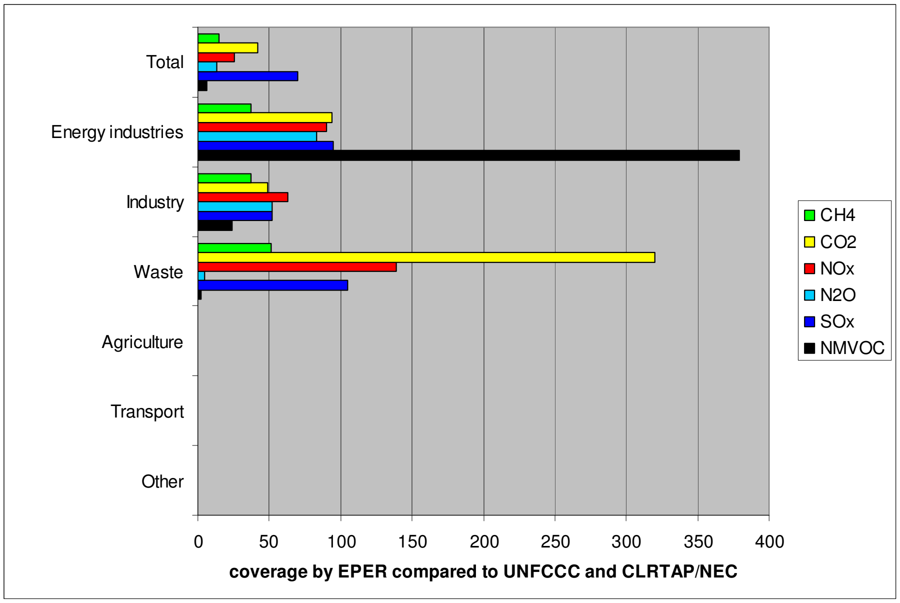

Figure 2-1: Coverage by EPER compared to UNFCCC and CLRTAP/NEC (EU-15) (data source: [294]). More maps and figures on EPER can be found in the Annex.

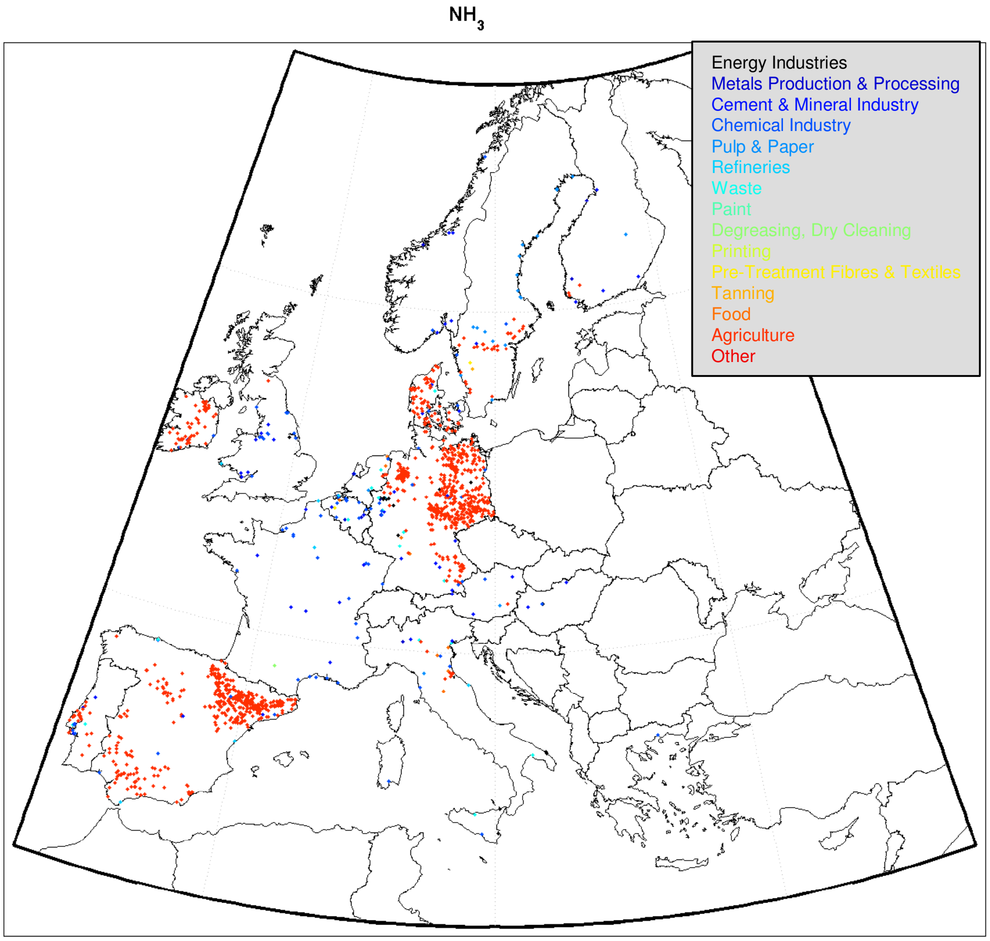

Figure 2-2: Geographical and sector distribution of installations in EPER for NH_3. More maps and figures on EPER can be found in the Annex.

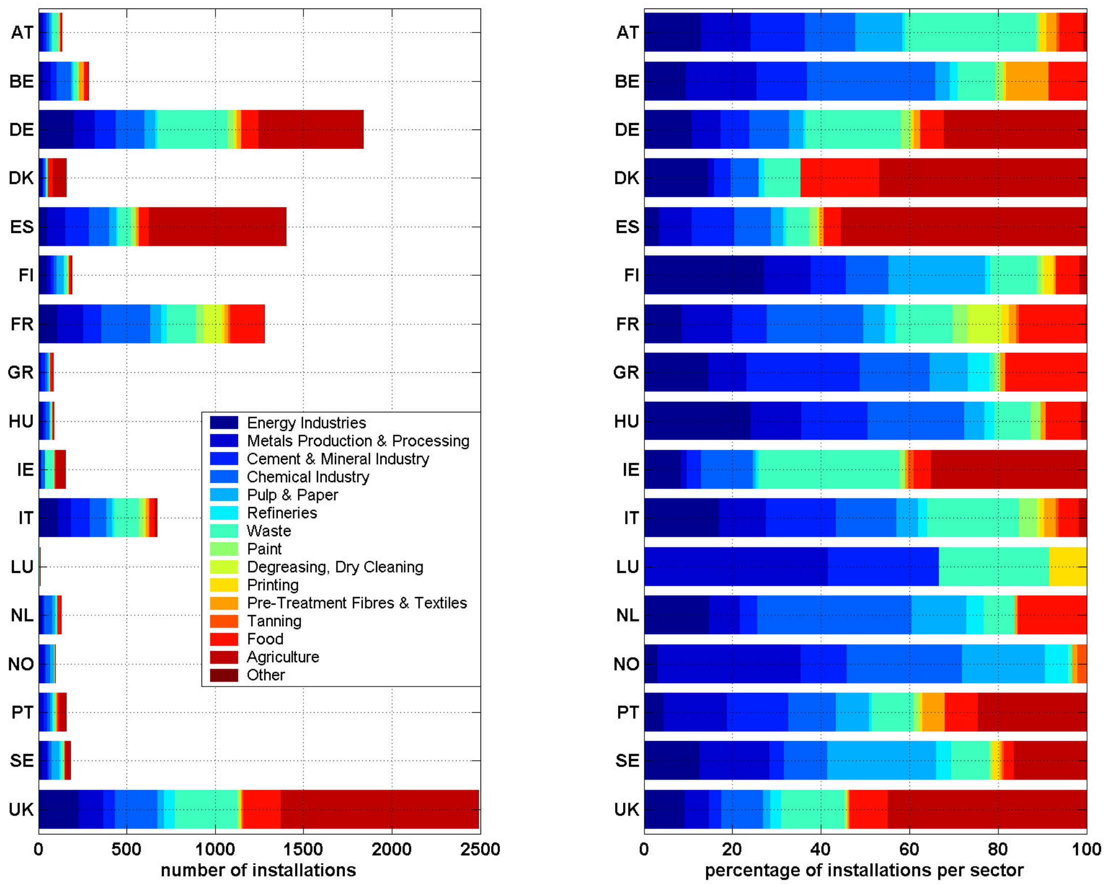

Figure 2-3: Number of installations per pollutant and percentage of installations per pollutant in EPER (country-by-country presentation). More maps and figures on EPER can be found in the Annex.

2.2.2. EMEP[8]/CORINAIR[9]

Base: Long Range Transboundary Air Pollution (LRTAP) Convention, Framework Climate Change Convention (FCCC)
Pollutants (CORINAIR 1990): SO_2, NOx, NMVOC, CO_2 and NH_3, CO, CH_4, N_2O
Geographical coverage: EU-25 (without Malta, Cyprus), Norway, Switzerland, Albania, Bulgaria, Croatia, Romania, Russia
Source specifications: SNAP
Time schedule: 1985 (CORINE), 1990, 1994[10]
Methodologies: EMEP/CORINAIR[11]
Data source: Richardson (1999)[12]; for 1994: http://www.aeat.com/netcen/corinair/94/index.html (only EU-15)
Disadvantages in the context of WP 1:

[8] Co-operative Program for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe

[9] The Core Inventory of Air Emissions in Europe

[10] http://www.aeat.com/netcen/corinair/94/index.html

[11] http://reports.eea.eu.int/EMEPCORINAIR3/en

[12] Richardson, S. (1999) (ed.): Atmospheric emission inventory guidebook, 2nd ed. Vol. 1. UN/ECE, European Environment Agency Technical Report No. 30.

- last update for all countries in 1990
- not all pollutants of WP 1 covered

2.2.3. UNECE/EMEP[13]

Base: EMEP program under the Convention on Long Range Transboundary Air Pollution (LRTAP)
Pollutants: SOx, NOx, NMVOC and heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn), POPs (dioxins, HCB, HCH, PAH, PCB), PM (TSP, $PM_{2.5}$, PM_{10})
Geographical coverage: EU-25 plus Norway and Switzerland, and other countries
Source specifications: NFR01, NFR02, SNAP97
Time schedule: officially reported emission data for 1980-2001 and projections for 2000, 2005, 2010, 2015 and 2020; emission data estimated by EMEP (more complete and consistent) for 1970, 1975, 1980, 1985, 1990-2001
Data source: http://webdab.emep.int/
Disadvantages in the context of WP 1:

- greenhouse gases not covered, e.g. CO_2
- officially reported data is incomplete, e.g. data for some countries is missing
- emission data estimated by EMEP is available only at a less detailed SNAP level

2.2.4. NEC

Base: Directive on National Emission Ceilings (NEC) (2001/81EG) of 21st October 2001
Pollutants: SO_2, NOx, NMVOC, NH_3, partly also CO, TSP
Geographical coverage: EU-15 (not received from the Commission: Finland, France, Spain)
Source specifications: NFR
Time schedule: yearly 1990-2002, however for some countries only 2001 and 2002, projections for 2010 (not obtained)
Methodologies: EMEP/CORINAIR
Data source: reports of the Members States to the Commission
Disadvantages in the context of WP 1:

- only EU-15
- important emitters in EU-15 not received from the Commission: France, Spain
- only few air pollutants

2.2.5. UNFCCC

Base: United Nations Framework Convention on Climate Change (UNFCCC), Kyoto Protocol
Pollutants: SO_2, NOx, NMVOC, CO_2 and CH_4, N_2O, CO
Geographical coverage: EU-25 plus Norway and Switzerland (not: Lithuania, Malta, Cyprus, not 2001: Slovenia) and other countries
Source specifications: source categories of the Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (1996)[14]
Time schedule: 1990-2001 (most countries, cf. http://ghg.unfccc.int/)
Methodologies: UNFCCC reporting guidelines (FCCC/CP/1999/7) and revised UNFCCC reporting guidelines (FCCC/CP/2002/8)
Data source: http://ghg.unfccc.int/ and http://unfccc.int/program/mis/ghg/submis2003.html
Disadvantages in the context of WP 1:

- not all pollutants, e.g. PM

[13] Co-operative Program for Monitoring and Evaluation of the Long-Range Transmission of Air pollutants in Europe (www.emep.int)

[14] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm

2.2.6. CEPMEIP[15]

Base: EMEP program under the Convention on Long Range Transboundary Air Pollution (LRTAP)
Pollutants: TSP, PM_{10}, $PM_{2.5}$
Geographical coverage: EU-25 plus Norway and Switzerland
Source specifications: SNAP levels 1 and 2
Time schedule: 1995
Methodologies: to be verified
Data source: http://www.air.sk/tno/cepmeip/emissions.php
Disadvantages in the context of WP 1:

- only PM
- only 1995

2.2.7. RAINS[16]

Base: Integrated Assessment Modelling in the context of the UNECE Gothenburg Protocol under the Convention on Long Range Transboundary Air Pollution (LRTAP) and in the context of the Directive on National Emission Ceilings (NEC) (2001/81EG) of 21st October 2001
pollutants: SO_2, NO_x, NH_3, NMVOC, PM (TSP, PM_{10}, $PM_{2.5}$)
Geographical coverage: EU-25 plus Norway and Switzerland
Source specifications: RAINS specific (detailed)
Time schedule: 1990-2030 (modelled data)
Methodologies: modelled data
Data source: http://www.iiasa.ac.at/web-apps/tap/RainsWeb/
Disadvantages in the context of WP 1:

- modelled data (however, review process based on bilateral consultations)
- not all pollutants, e.g. CO_2

2.2.8. Assessment of emission inventories with respect to WP 1

The short overview given shows that there is no emission inventory that alone fulfils all requirements for WP 1. Hence, a combination of inventories has to be used to cover all pollutants and countries that are within the scope of WP 1. The most suitable inventories for WP 1 are RAINS data for SO_2, NO_x, PM (TSP, PM_{10}, $PM_{2.5}$), NMVOC and NH_3, UNFCCC data for CO_2, CH_4 and N_2O, CORINAIR90 data for CO, and the “European Atmospheric Emission Inventory of Heavy Metals and Persistent Organic Pollutants” for heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) and POPs (dioxins, HCB, HCH, PAH, PCB). It should be noted that most emission inventories present emission data in a way that is not user-friendly for import into other applications for further analysis.

[15] Co-ordinated European Program on Particulate Matter Emission Inventories, Projections and Guidance (http://www.air.sk/tno/cepmeip/)

[16] Regional Air Pollution INformation and Simulation

2.3. Determination of important pollutant-industrial sector combinations

The identification of main emitting sectors per pollutant is hampered by the fact that none of the emission inventories is ideal. The most appropriate inventories seem to be RAINS data, UNFCCC, CORINAIR90, and the "European Atmospheric Emission Inventory of Heavy Metals and Persistent Organic Pollutants" that cover most of the pollutants with an adequate sector resolution and in the case of RAINS data also with projections.
The determination of important pollutant-industrial sector combinations is done pollutant per pollutant.

2.3.1. NO_x

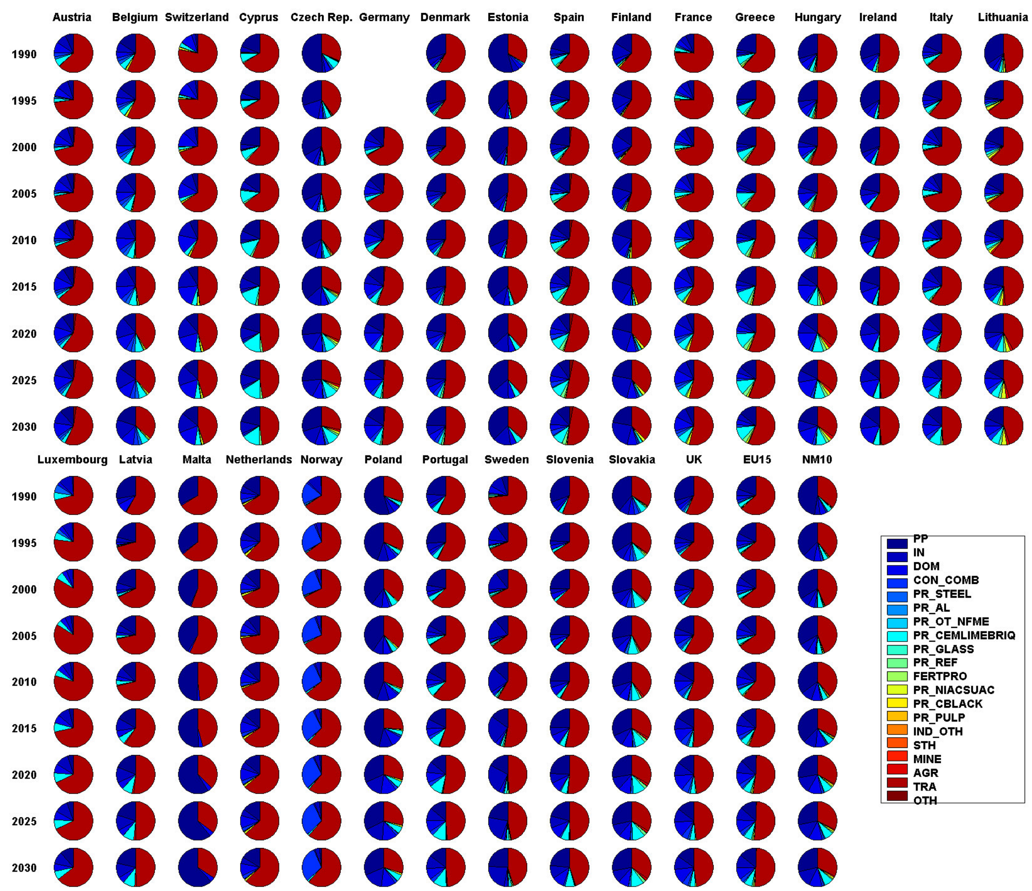

Figure 2-4: Evolution of sectoral NOx emissions in EU-25 plus Norway and Switzerland (RAINS BL_CLE_Apr04 scenario)

The analysis of sectoral NO_x emissions (modelled RAINS data, RAINS BL_CLE_Apr04 scenario, after bilateral consultations) shows that – except for e.g. Norway where the Power Plant sector (PP) plays only a minor role for NO_x emissions (due to hydropower) and e.g. for some of the New Member States like Poland where the share of the transport sector (TRA) is smaller – the overall picture is quite uniform.
The transport sector is the main NO_x emitter in most EU-25 countries. However, in most countries the share of the transport sector will decrease in future but will remain the highest. The second most important sector is the Power Plant sector (PP) followed by Industrial and Domestic Combustion (IN and DOM respectively). Other important sources for NO_x are Production of Cement, Lime and Bricks (PR_CEMLIMEBRIQ) and Nitric Acid Production (PR_NIACSUAC[17]).

[17] production of nitric acid and sulphuric acid

2.3.2. SO_x

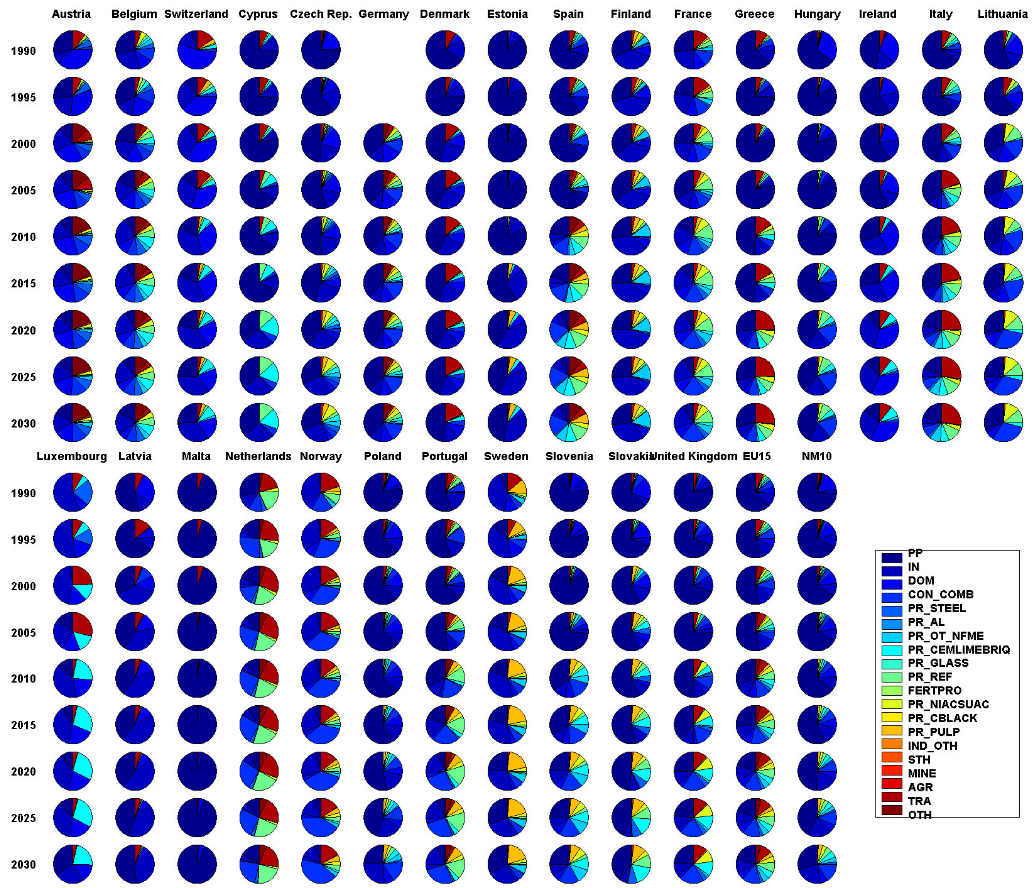

Figure 2-5: Evolution of sectoral SO_2 emissions in EU-25 plus Norway and Switzerland (RAINS BL_CLE_Apr04 scenario)

Compared to NO_x, for SO_2 (modelled RAINS data, BL_CLE_Apr04 scenario, after bilateral consultations) the picture is less uniform between the countries and with more sectors being and becoming relevant. Again, combustion in Power Plants (PP), Industry (IN), Household (DOM) and Fuel Production and Conversion (CON_COM) is a major source for SO_2. The transport sector (TRA) is important in some countries only, e.g. the Netherlands and Norway, but will become more important in future, e.g. Italy. Other important sources for SO_2, at least in some countries, are the Production of Cement, Lime and Bricks (PR_CEMLIMEBRIQ) (e.g. in Luxembourg), Refineries (PR_REF) (e.g. in the Netherlands but also in France, Spain and Portugal) and the Production of Sulphuric Acid (PR_NIACSUAC) (e.g. in Lithuania) as well as the Production of Pulp and Paper (PR_PULP) (e.g. in Sweden). The sector shares differ significantly between the New Member States where combustion is the major source and EU-15 where in addition industrial processes and transport play a major role.

2.3.3. PM

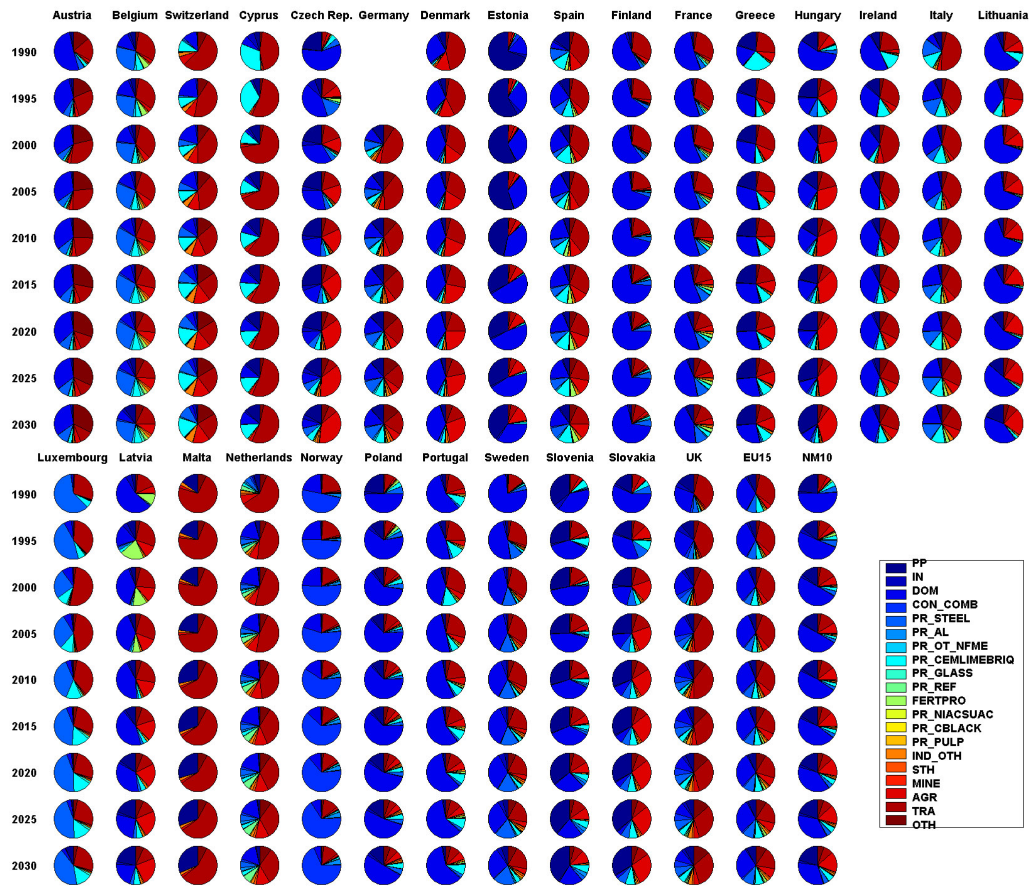

Figure 2-6: Evolution of sectoral $PM_{2.5}$ emissions in EU-25 plus Norway and Switzerland (RAINS BL_CLE_Apr04 scenario)

On behalf of PM,
Figure 2-6 shows sectoral $PM_{2.5}$ emissions (modelled RAINS data, BL_CLE_Apr04 scenario, after bilateral consultations). Again, the number of important sources will increase in future. The shares of the sectors differ significantly from country to country. In many countries, the major emitter for $PM_{2.5}$ is Domestic Combustion (DOM) with Power Plants (PP), Transport (TRA), Production of Cement, Lime and Bricks (PR_CEMLIMEBRIQ), Production of Steel (PR_STEEL) and Agriculture as other important sources. In some countries other sources are also of importance: e.g. in Latvia Fertiliser Production (FERTPRO) and in the Netherlands Refineries (PR_REF). The sectoral $PM_{2.5}$ emissions in EU-15 and NM-10 differ in some ways: e.g. the importance of Transport (TRA) and Production of Steel (PR_STEEL) in EU-15 is higher than in NM-10 while the importance of Domestic Combustion (DOM), Power Plants (PP) and Agriculture (AGR) is lower. It should be noted that this analysis does not take into account that toxicity of PM differs strongly between the emission sources.

2.3.4. VOC

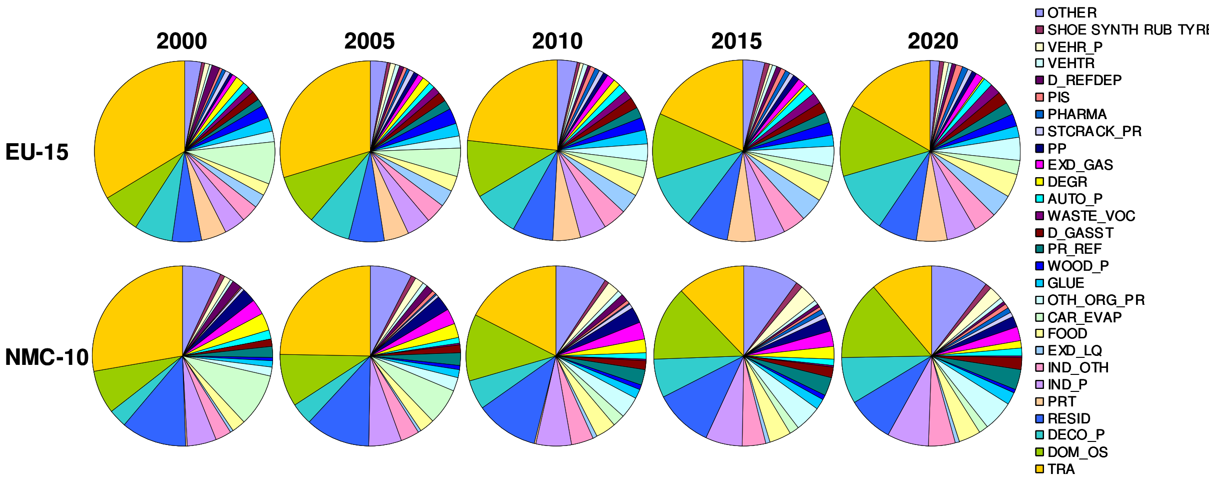

Figure 2-7: Evolution of sectoral VOC emissions in EU-15 and New Member Countries (NMC-10) (RAINS BL_CLE_Apr04 scenario)

For VOC, the emitter structure is completely different.
Figure 2-7 (modelled RAINS data, BL_CLE_Apr04 scenario, after bilateral consultations) shows that transport is the most important emitting sector which accounts for 30% of the VOC emissions in EU-15 in 2000 and 16% in 2020. The next most important sectors in both EU-15 and the New Member Countries (NMC-10) are Domestic Use of Solvents (Other than Paint) (DOM_OS), Decorative Paints (DECO_P), Combustion in Residential and Commercial Sector (RESID), which is more important in NMC-10 than in EU-15, and Industrial Paint Applications (IND_P). These five sectors together account for more than 50% of VOC emissions. With a share of around 5% printing is only of importance in EU-15. Evaporative Emissions from Cars (CAR_EVAP) is the second to third most important sector in 2000 but will be less important in future. Other sectors with significant emissions are: Other Industrial Sources (IND_OTH), Extraction, Processing and Distribution of Liquid Fuels (EXD_LQ), that plays only a minor role in NMC-10, Food and Drink Industry (FOOD) and Organic Chemical Industry – Downstream Units (OTH_ORG_PR). In NMC-10, in addition Petroleum Refineries (PR_REF), Degreasing (DEGR), Extraction, Processing and Distribution of Gaseous Fuels (EXD_GAS), Power Plants (PP) and Vehicle Refinishing (VEHR_P) are of a certain importance. In NMC-10, around 50% of OTHER emissions come from Agricultural Waste Burning (not shown).

2.3.5. CO_2

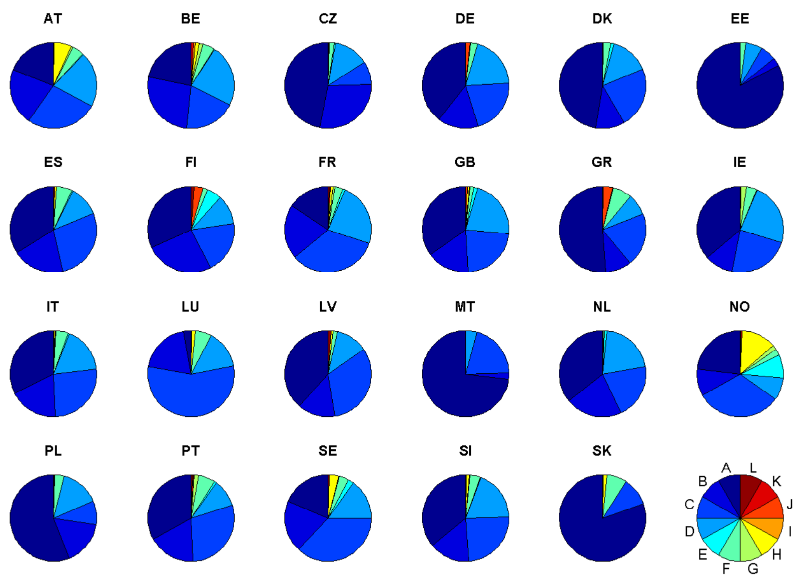

Figure 2-8: Sectoral CO_2 emissions in EU-25 countries and Norway (A = Energy Industries, B = Energy Production in Manufacturing Industries and Construction, C = Transport, D = Other Energy Use, E = Fugitive Emissions from Fuels, F = Production of Mineral Products, G = Chemical Industry, H = Metal Production, I = Other Industrial Production, J = Agriculture, Forestry and Land-Use Changes, K = Waste, L = Other) (UNFCCC data for 2000; EEA_UNFCCC_EN_V4_xlsEEA9075l)

The major source for CO_2 emissions is Energy Production, especially in Energy Industries (A) (not so important in Austria, Belgium (nuclear power), France (nuclear power), Luxembourg, Norway (hydropower) and Sweden), but also in Manufacturing Industries and Construction (B) and Transport whereas Production of Mineral Products (e.g. cement) plays a not so important but nevertheless not negligible role (Figure 2-8). In Norway, Austria and Sweden Metal Production (H) is another non neglibible source and in Finland and Greece as well as in Germany Agriculture, Forestry and Land-Use Changes (J).

2.3.6. CO

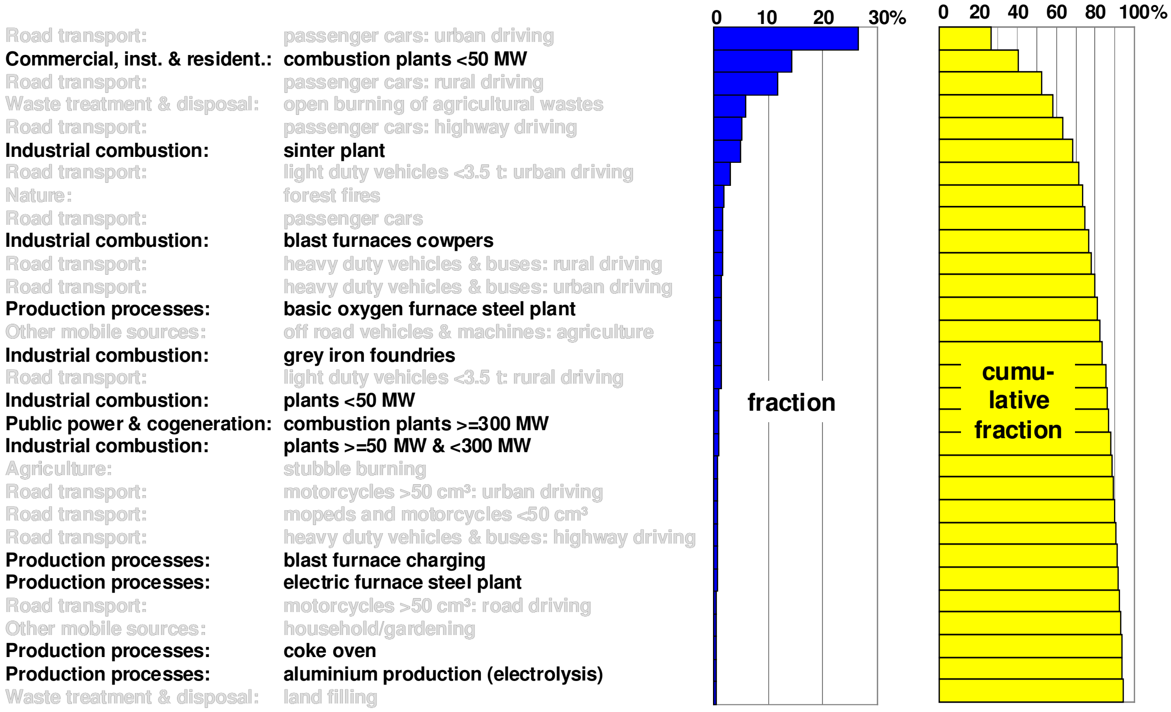

Figure 2-9: Sectoral CO emissions in Europe28 (CORINAIR90)

The major sources for CO within the scope of this project in Europe28 in 1990 (CORINAIR90) were sSmall Scale Combustion (<50 MW) but also Sinter Plants. Shares of other processes of ferrous metal production and processing like Blast Furnaces Copwers, Basic Oxygen Steel Plants, Grey Iron Foundries, Blast Furnace Charging and Coke Ovens are rather small as well as combustion in bigger installations.

2.3.7. NH_3

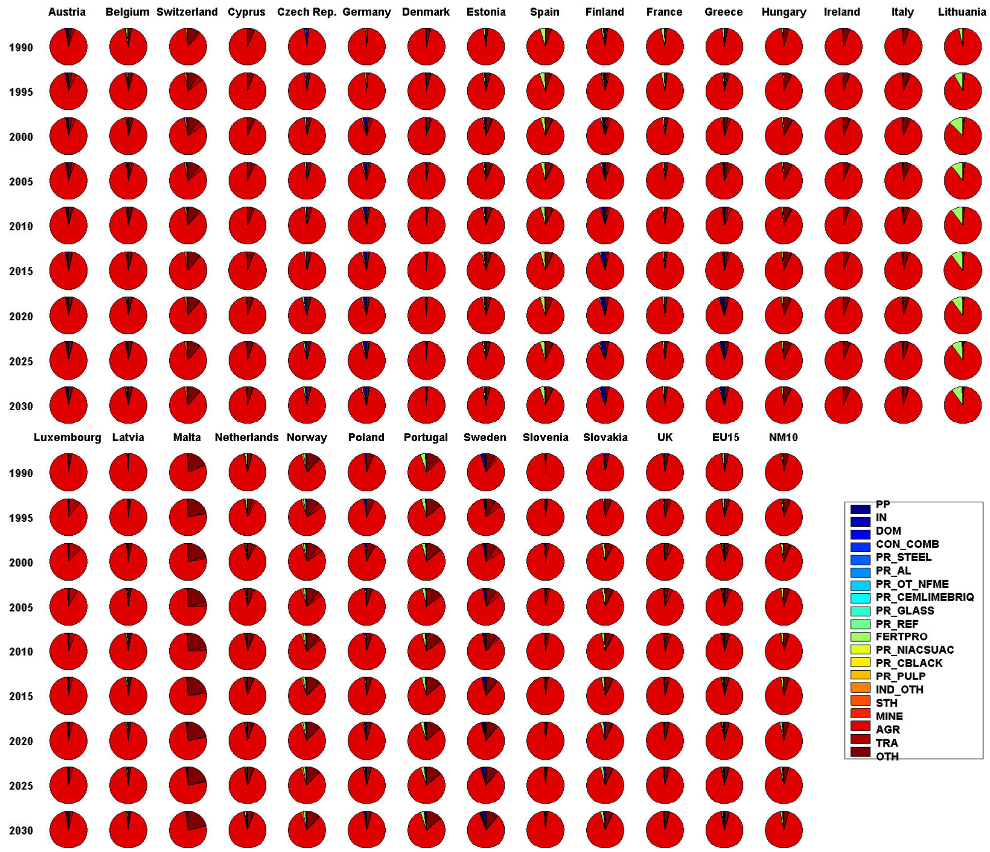

Figure 2-10: Evolution of sectoral NH_3 emissions in EU-25 plus Norway and Switzerland (RAINS BL_CLE_Apr04 scenario

Figure 2-10 shows that more than 75% and often 90% of NH_3 emissions (modelled RAINS data, BL_CLE_Apr04 scenario, after bilateral consultations) result from Agriculture (AGR). The remaining emissions stem mostly from "Other sources" (OTH) and Fertilser Production (FERTPRO). So, in all countries considered only a minor share of NH_3 emissions result from activities that are within the scope of this project.

2.3.8. N_2O

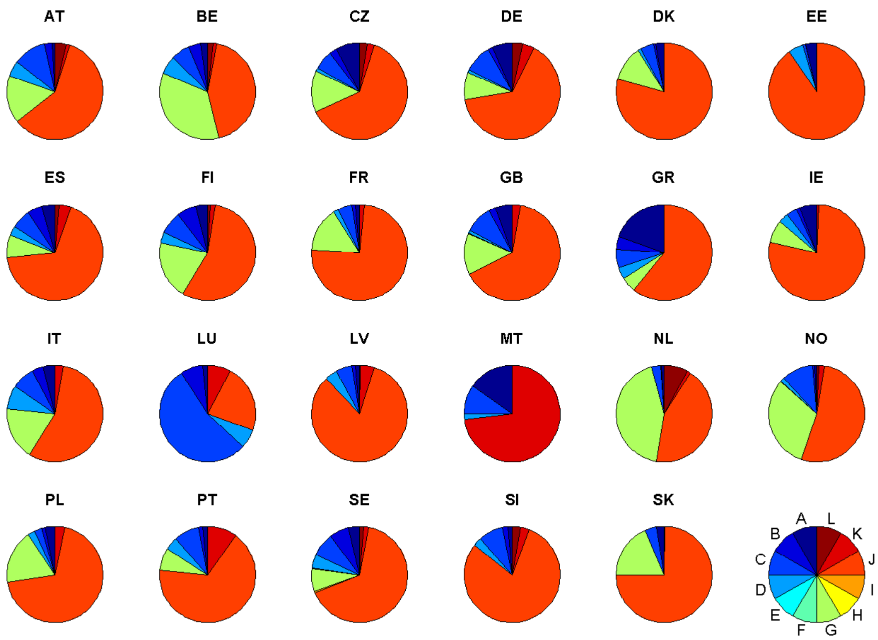

Figure 2-11: Sectoral N_2O emissions in EU-25 countries and Norway (A = Energy Industries, B = Energy in Manufacturing Industries and Construction, C = Transport, D = Other Energy Use, E = Fugitive Emissions from Fuels, F = Production of Mineral Products, G = Chemical Industry, H = Metal Production, I = Other Industrial Production, J = Agriculture, Forestry and Land-Use Changes, K = Waste, L = Other) (UNFCCC data for 2000; EEA_UNFCCC_EN_V4_xlsEEA9075l)

The dominating source for N_2O emissions is Agriculture, Forestry and Land-Use Changes (J) (Figure 2-11, UNFCCC data for 2000) that is responsible for 50-90% of N_2O emissions – except for Malta where Waste (K) and Luxembourg where Transport (C) is the major source. The second most important source is Chemical Industry (G), especially in the Netherlands, Belgium and Norway. Emissions from energy production in Energy Industries (A) (e.g. in Greece and Malta but also in the Czech Republic and Germany) and Transport (C) are also not negligible. To conclude, the only major source for N_2O within the scope of the project is the Chemical Industry.

2.3.9. CH_4

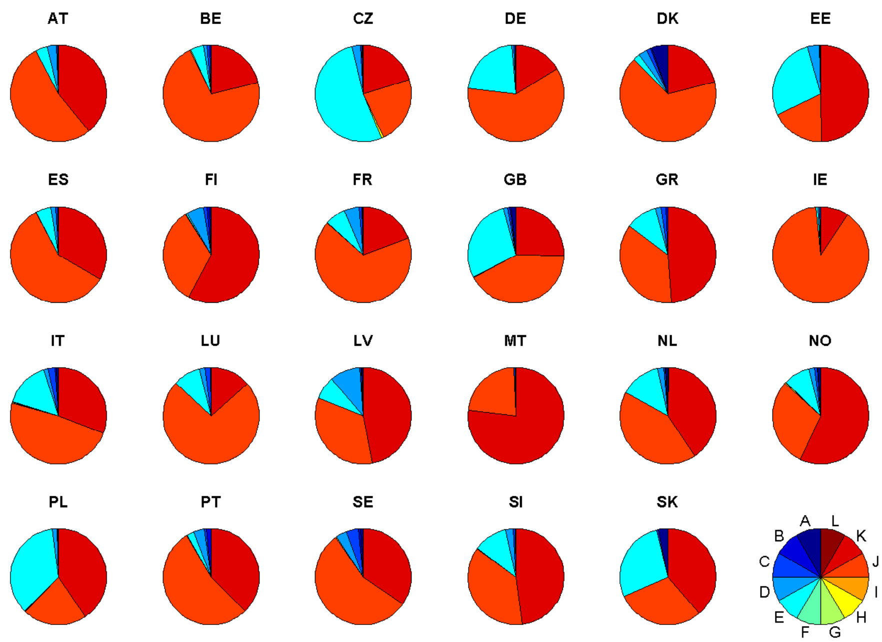

Figure 2-12: Sectoral CH_4 emissions in EU-25 countries and Norway (A = Energy Industries, B = Energy in Manufacturing Industries and Construction, C = Transport, D = Other Energy Use, E = Fugitive Emissions from Fuels, F = Production of Mineral Products, G = Chemical Industry, H = Metal Production, I = Other Industrial Production, J = Agriculture, Forestry and Land-Use Changes, K = Waste, L = Other)(UNFCCC data for 2000; EEA_UNFCCC_EN_V4_xlsEEA9075I)

Figure 2-12 shows that the main sources for CH_4 emission according to UNFCCC data for 2000 are Agriculture, Forestry and Land-Use Changes (J) and Waste (K) (especially dumps) and in some countries also Fugitive Emissions from Fuels (E) (from natural gas production, processing and distribution), especially in the Czech Republic, Great Britain, Poland, Slovakia and Estonia. Other sources only play a minor role. To conclude, most of CH_4 emissions stem from sectors that are not within the scope of this project.

2.3.10. POPs

PAH	
Stationary combustion:	**42.9%**
Solvent use:	
- wood preservation	**30.5%**
Non-ferrous metal industry:	
- Al industry	**6.4%**
Iron & steel industry	
- coke production	**3.1%**
	82.9%

Dioxins/furans	
Stationary combustion:	**38.1%**
Waste incineration:	**23.5%**
Iron & steel industry:	
- sinter plants	**14.6%**
Non-ferrous metal industry:	
- Cu industry	**13.3%**
	89.5%

Table 2-1: Major sources for PAH and dioxins/furans in Europe in 1990 (data source: "The European Atmospheric Emission Inventory of Heavy Metals and Persistent Organic Pollutants for 1990")

It has to be noted that emission data presented in Table 2-1 dates from 1990 and that there was a strong effort to reduce emissions of dioxins and furans, especially in waste incinceration but also in stationary combustion since then. The same is true for emissions of PAH, e.g. from wood preservation. This might have led to completely different structure of emission sources. Thus the use of the data to determine current or even future sector pollutant combinations is questionable but inevitable due to a lack of alternative data.

The main sources for PAH in Europe in 1990 were stationary combustion and solvent use for wood preservation and to a minor degree Al-industry and coke production that together accounted for more than 80% of the emissions (Table 2-1, data source: "The European Atmospheric Emission Inventory of Heavy Metals and Persistent Organic Pollutants for 1990).
For dioxins/furans the main source was stationary combustion followed by waste incineration, sinter plants and Cu industry that were together responsible for almost 90% of the emissions in 1990.

2.3.11. Heavy Metals

		As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Stationary combustion:		74.9	46.1	49.8	28.8	49.5	75.0	7.8	45.6
Iron & steel industry:									
	coke production		1.3	1.3		1.0			
	blast furnace	2.7		1.7	2.7			1.9	8.6
	sinter plants	1.0	3.2	2.9	2.3	1.5	1.2	2.8	
	open hearth furnace		4.1	2.8	2.5			1.8	2.7
	basic oxygen furnace			1.3				0.4	1.9
	electric arc furnace	1.1	6.7	27.6	1.3	1.8		2.2	15.6
Non-ferrous metal industry:									
	Cu industry	12.0	4.2		6.6	1.0		0.5	2.0
	Ni industry			2.3					
	Pb industry	1.0	1.4					1.1	1.1
	Zn industry		8.6					0.3	8.5
Organic chemical industry:									
	Cement industry			1.2		15.3			
	Glass industry	1.8	1.3					0.9	
Waste treatment & disposal:	**Waste incineration**					10.8		1.0	
Road transport:			12.4		15.8		6.1	68.6	
Other mobile sources & machinery:	**Other transport combustion**				28.8		13.9		
		94.5	89.4	91.0	88.8	80.8	96.2	89.2	86.0

Table 2-2: Major sources for heavy metals in Europe in 1990 (data source: "The European Atmospheric Emission Inventory of Heavy Metals and Persistent Organic Pollutants for 1990)

Again, it has to be noted that emission data presented in Table 2-2 dates from 1990 and that there was a certain effort to reduce emissions of heavy metals since then. This might have led to completely different structure of emission sources. For Pb this is most certainly the case, since the introduction of unleaded gasoline has led to a significant reduction of Pb emissions from transport. The use of the data to determine current or even future sector pollutant combinations is thus questionable but inevitable due to a lack of alternative data.

There are only few sources for heavy metal emissions that are together account for around 90% of the emissions in 1990. The major sources for heavy metals emissions in 1990, however, differed from metal to metal (Table 2-2, data source: "The European Atmospheric Emission Inventory of Heavy Metals and Persistent Organic Pollutants for 1990):

- As: stationary combustion and to a smaller degree Cu industry
- Cd: stationary combustion and to a smaller degree transport, Zn and iron & steel industry (especially electric arc furnaces)
- Cu: transport, stationary combustion and to a smaller degree Cu industry and iron & steel industry
- Hg: stationary combustion and to a smaller degree cement industry and waste incineration
- Ni: stationary combustion and transport
- Pb: transport and to a smaller degree stationary combustion and iron & steel industry
- Zn: stationary combustion and to a smaller degree iron & steel industry (especially electric arc furnaces) and Zn industry

2.4. Discussion and Conclusion

The analysis performed in part 2.3 showed that there are strong differences in the emitter structure between the pollutants and partly also between countries of EU-25 plus Norway and Switzerland. In addition, according to the modelled RAINS data, the emitter structure evolves and will become more complex in future, probably as a result of more efficient emission control in power plants than in other sectors. This evolution hinders also the determination of sector-pollutant combinations since some of the emission inventories are quite old, e.g. the inventories used for heavy metals and POPs as well as that for dioxins/furans are almost 15 years old.

For NH_3, CH_4 and N_2O only a minor part of the emissions stem from activities or sectors that are within the scope of this project, e.g. production of fertilisers, adipic acid and ammonia for N_2O emissions. Hence the impact of emerging technologies in industry on the emissions of these pollutants is expected to be rather low. This is – to a lower degree – also correct for NO_x since emissions from transport are responsible for around 30-50% of NO_x emissions.

Except for VOC, one of the most important emitters is combustion for heating and power generation. Small scale combustion (<50 MW) is especially important for emissions of PM and CO but also of considerable importance for VOC whereas most of NO_x and especially SO_2 emissions originate from power plants. This might be explained by the fuel used and the combustion process: In small scale combustion wood and fuel oil are often used as fuel and control of combustion conditions is rather poor which results in high VOC and PM emissions. On the other hand, in power plants nearly optimal combustion conditions and end-of-pipe technologies lead to lower VOC and PM emissions but the more frequent use of coal and oils with higher sulphur content leads to higher SO_2 emissions. For NO_x emissions, both power plants and small scale combustion are of high importance (Figure 2-13).

Besides combustion in power plants, households and industry (in the RAINS model all combustion processes in *industry* are aggregated to "IN" and hence cannot be analysed in more detail), major (process) emission sources within the scope of this project are cement production (e.g. NO_x, SO_2, PM, CO_2, heavy metals (Hg)), iron and steel production (e.g. PM, CO, POPs, dioxins/furans and heavy metals), non-ferrous metals production (e.g. POPs, dioxins/furans and heavy metals), refineries (e.g. SO_2, PM), chemical industry (e.g. NO_x, SO_2, PM, N_2O), waste incineration (e.g. dioxins/furans, heavy metals (Hg)), pulp and paper production (e.g. SO_2) and paint applications, the domestic use of solvents, degreasing, printing and refineries (for VOC).

For the objective of this project, the assessment of the impact of emerging technologies i.w.s. on air emissions in EU-25 plus Norway and Switzerland until 2030, the sector shares of emissions of a pollutant is of course of high importance. However, taking the principles of cost-efficiency-analysis into account it is appropriate to analyse also emerging technologies i.w.s. in sectors that do not belong to the group of the most important emitters. If an emerging technology i.w.s. in such a sector can reduce the emissions significantly and at low costs it may have a stronger impact on air emissions than a not so effective or expensive technology in a more important sector. In this context the remaining emissions reduction potential as well as cost curves, i.e. achieved emission reduction against costs, are of high importance.

Based on the analyses performed and this reflection the following sectors were chosen for analysis:

- Power and district heating plants
- Industrial combustion
- Waste incineration
- Small scale combustion
- Iron ore treatment
- Coke plants
- Iron and steel production
- Ferrous metals processing
- Non-ferrous metals industry
- Foundries
- Pulp and paper

- Glass production
- Cement and lime production
- Refineries
- Coating
- CO_2 sequestration (separation, storage)

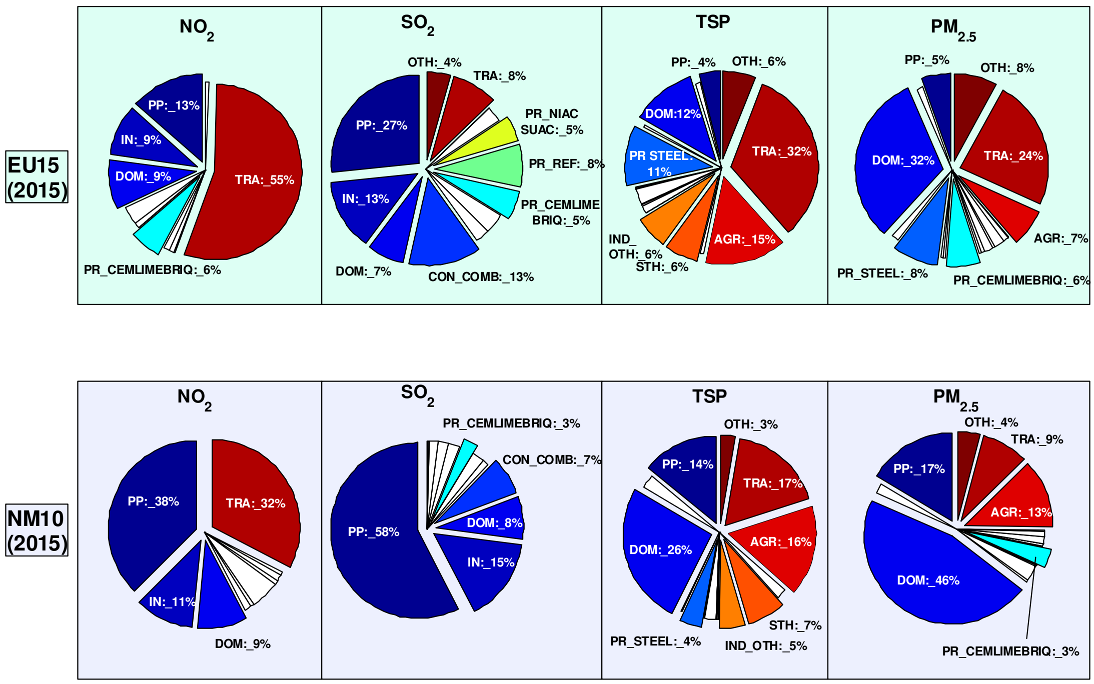

Figure 2-13: Sectoral emissions of NO_2, SO_2, PM_{TSP} and $PM_{2.5}$ in EU-15 and the New Member States (NM-10) in 2015 (RAINS BL_CLE_Apr04 scenario

3. Work package 2: Identification and description of promising emerging technologies that could gain relevant market shares in the coming years for each sector

3.1. Introduction

3.1.1. Objectives

Invitation to Tender [291]: "This task implies the development of a survey of emerging technologies that could gain significant market shares in the coming years within the different industrial sectors. ... This survey will consider both emerging process integrated technologies and end-of-pipe technologies not only in Europe, the study should also consider emerging technologies in other regions (Canada, USA, Japan). ... The survey should include a brief techno-economic description of each technology. This description should include:

- Name of technology
- Stage of development (pilot or demonstration stage)
- Operational performance
- Achievable air pollutants emissions levels/reduction rates.
- Estimated associated costs: fix and running costs, lifetime.
- Applicability (noting constraints to implementation in certain cases)
- Analysis of its possible diffusion within the relevant sector (potential penetration rate), considering the possible obstancles for their development and penetration including technical, economic, cross-media, geographical or political considerations.

"Due to that all these elements have to be provided in a way directly usable in the RAINS model, contacts with IIASA (International Institute for Applied System Analysis) will have to be foreseen. The contractor will have to produce a database on the selected technologies directly usable into the RAINS model."

Thus the main objectives of this work package are:

- to collect information on emerging technologies i.w.s. within the industrial sector and to characterise
  - the technologies technically
  - the technologies economically
  - the reduction of air emissions and cross-media effects
  - side-effects
  - the stage of development
  - the diffusion of the technology within EU-25 plus Norway and Switzerland and if necessary also country-specifics in the diffusion process
  - factors that influence the diffusion of the technology (including country-specifics)

- to assess the emerging technologies and applications with respect to
  - unsolved technical problems
  - their prospects on the market
  - their potential in EU-25 plus Norway and Switzerland for the reduction of air emissions (also based on information from WP 1

- to present the gathered information in a database suitable for RAINS modellers at IIASA

3.1.2. Collection of information on emerging technologies i.w.s.

To collect the necessary information on emerging technologies i.w.s. the following resources have been used:

- reference documents on Best Available Techniques (BAT) (BREF documents) including questionnaires for revision of the BREF documents
- journals, conference proceedings, books
- internet
- research databases, e.g. CORDIS and maESTro II[18]
- experts from
  - industrial associations
  - producers of environmental technology
  - independent research institutes
  - administration

DG Research was directly contacted by IPTS at the beginning of the project and was invited to the project meetings. But there was no response and no representative attended the final meeting [Minutes of meeting on 30 Nov. 2004]. This situation is unsatisfactory if one considers the information available at DG Research that could be interesting within this project. For future work it should be considered to establish personal contacts with DG Research.
The web-based CORDIS database was analysed within this project but the information given is too general (due to legal rights). For further information the name of a contact person is given in the CORDIS database but no contact details like e-mail address, phone number etc. In future work it should be considered to get in touch with the contact persons by mail with a copy of the mail going to the heads of department.

In addition to the sources of information given above and analysed by the consortium, more than 400 experts from EU-25 as well as Japan and Canada have been contacted via questionnaires to gather information on emerging technologies i.w.s. The idea behind this questionnaire was that the producers have an interest to bring their new technologies into the discussion and that independent experts – especially those involved in the BREF process – have an interest to contribute to this project. In contrast to expectations, the backflow of questionnaires was quite low due to various reasons:

- no human resources available to answer due to other, more urgent activities like CO_2 emission trading, revision of BREF documents, etc. (especially experts from industrial associations)
- no human resources availbabe to answer without payment (especially independent experts)
- too short time frame of the project
- confidentiality, especially for industry since emerging technologies are a part of their strategic planning
- worries that cooperation with DG Environment could put off their customers
- overtaxed by information requested
- negative attitutde towards the project (too ambitious, purpose unclear (RAINS model) etc.)

Thus, many experts answered that they could not provide relevant information but that they were nevertheless interested in the project and wanted to be kept informed.
A second, sector-specific questionnaire that contained already names of candidate emerging technologies i.w.s. was sent to selected experts to stimulate them to provide additional information. The purpose of this questionnaire was to lower the barrier to answer, but the backflow was also low. It was also obivous, especially at the workshop, that a lot of experts knew only some of the technologies.

In future, a different strategy should be used that would focus more strongly on personal phone contacts and would try to use first the BREF experts as door-openers. This strategy would also focus on a few technologies only since experts were overloaded by the long list of candidate technologies. In addition, due to overwork the time needed by the experts to answer was underestimated which proved difficult in this 8 months project.

[18] http://www.unep.or.jp/maestro2

3.1.3. Sectoral lists of candidate technologies i.w.s.

Based on the information collected as described in Part 3.1.2 a list of candidate technologies i.w.s. has been prepared per sector (see Part 3.3 to Part 0) containing also technologies considered in the BREF documents as "emerging techniques". The following lists provide brief information on the more interesting candidate emerging technologies i.w.s. (as considered by the experts at the workshop, by the consortium or by other experts). The complete list of technologies i.w.s. including detailed information on all technologies i.w.s. can be found in the annex.

The lists are organised according to 17 sectors as follows:

- Power and district heating plants (coal, biomass, liquid and gaseous fuels, fuel cells, renewables),
- Industrial combustion,
- Waste incineration,
- Small scale combustion,
- Iron ore treatment (sintering, pelletisation),
- Coke plants,
- Iron and steel production,
- Ferrous metal processing,
- Non-ferrous metal production,
- Foundries,
- Pulp and paper,
- Glass production,
- Cement and lime production,
- Chemical industry (ammonia, chlor-alkali etc.),
- Refineries,
- Coating and VOC,
- CO_2 separation and storage

For each technology i.w.s., brief information is given concerning (as far as available):

- a short technical description of the technology with keywords
- processes on which the technology has a positive influence: reduction of air pollutants (PM, NO_x, SO_x, VOC, PCDD/Fs, HM, NH_3, CO_2, CO), increased energy efficiency etc.
- the positive effect e.g. as achievable emission reduction (percentage), emission level (e.g. mg/Nm³), or efficiency improvement (percentage)
- the stage of development (it should be kept in mind that the stage of development is subject to changes and might have already changed)
- the source of information: the number in the three last columns correspond to the numbers in the bibliography (see Bibliography)

The technologies have been assessed with respect to their future prospects by the consortium based on the information available and selected technologies also by the experts present at the workshop that was organised within this project. Of course, taking into account the large number of technologies assessed in a short time, the limited information available, the complex dependencies that determine the future prospects of a technology (technical, economic and ecological aspects, market situation etc.) and the high uncertainty inherent in data on emerging technologies i.w.s. this assessment can only be a first, rough one, that needs permanent update and should be complemented by an in-depth assessment. When reading this report the reader should be aware of these restrictions.

An assessment of emerging technologies i.w.s. should take into account the following criteria:

- technical maturity of technology i.w.s.
- ability to integrate technology i.w.s. into the current system including lifetime of existing installations, possibility of retrofitting, infrastructure, integrated production sites etc.

- market chance of technology
- acceptance by industry and the public
- achievable reduction of specific emissions through technology (especially SO_2, NO_x, CO_2, NMVOC, PM)
- potential to reduce overall air emissions (especially SO_2, NO_x, CO_2, NMVOC, PM) in EU-25 plus Norway and Switzerland in 2005, 2010, ..., 2030
- side- and cross-media effects

3.1.4. Description of the fact sheets on emerging technologies

For some technologies more detailed information could be collected and is presented in fact sheets (in annex). An example for information ideally collected within this project is shown in Table 3-1.

Table 3-1: Example for more detailed information on a technology

Name of technology:		**non-thermal plasma units**
Short description:		non-thermal plasma units enable energy-efficient reduction of low NMVOC concentrations (<1 g/m³) via oxidation using cold plasma
Area of use:		food industry, chemical industry, refineries etc.
Location of plant:		at least three in Germany (odour reduction)
Stage of development:		commercial
Operational performance:		8000 h/a;
Emission factors:		NMVOC, POPs, CO: >99.5% (depending on design)
Costs	**Investments:**	for 80,000 m³/h 400,000 Euro up to 10,000 m³/h 80,000 Euro
	Fix:	0.01 person/a extra demand on manpower
	Variable:	energy costs
	Lifetime:	10 years
Energy consumption:		3 kWh/1000 m³ (very low compared to other techniques) (depending on desired efficiency)
Consumption of other materials:		1000 Euro/a
Quality ranking/uncertainty management:		high (commercial)
Possible sectors:		food industry (odours), chemical industry
Diffusion:		expected to be high, e.g. 20-30% market share in food and chemical industry due to low energy costs
References		pers. comm. Rolf Rafflenbeul www. rdg-life.de

3.1.5. Presentation of data in a database: ECODAT plus

Invitation to Tender [291]: "Due to that all these elements have to be provided in a way directly usable in the RAINS model, contacts with IIASA (International Institute for Applied System Analysis) will have to be foreseen. The contractor will have to produce a database on the selected technologies directly usable into the RAINS model."
Based on the experience gained from the development of ECODAT 1.0 database which was developed in the context of EGTEI and in close cooperation with IIASA, a new, more extended database has been developed within this project.

In order to comply with the requirements set by integrating emerging technologies i.w.s., new features have been added. This extended database, called ECODATplus, will also be further used for EGTEI.

The following list recalls in a brief summary the type of information that can be stored in the initial ECODAT database:

- Reference installations,
- Activity levels,

- Fuel consumptions,
- Fuel characteristics,
- Unabated emission factors,
- Technical options and removal efficiencies,
- Techno-economic parameters of abatement measures,
- Application rates and applicabilities,
- Costs per ton of pollutant abated and per production unit,
- Quality ranking of input parameters

In addition, an aggregation routine has been implemented, in order to allow a comparison of the data stored in the ECODAT format with the data at RAINS level.

For ECODATplus the following modifications/extensions have been included:

- Improved performance, i.e. more efficient database structure that is able to deal with the integration of new technologies/new pollutants
- Edit forms for the user to enter new technologies/reference installations and respective techno-economic parameters
- More user-friendly layout
- Improved representation of comments
- Extended activity time frame until 2030
- Graphical representation of activities
- Calculation of emission inventories for each activity sector according to different emission reduction strategies
- Calculation of sector-specific abatement costs at country level

3.2. Technologies i.w.s. considered as emerging, promising and relevant within the framework of this project

The aim of the project was to give non-commital recommendations which emerging technologies i.w.s (i.e. emerging technologies (i.n.s.), emerging applications and emerging products) should be considered for future integration by IIASA into the RAINS model and to provide necessary information for these technologies (see above). The technologies considered should (cf. parts 1.1 and 1.2, Invitation to Tender [291], Minutes of meeting on 18 December 2003 [292]):

- be emerging, i.e. be in general in demonstration or pilot plant scale
- be promising, i.e. should gain a significant market share according to projections
- be relevant, i.e. should have an impact on air emissions in EU-25 plus Norway and Switzerland in 2005-2030
- be in the industrial sector exluding agriculture and transport as well as mining

"Emerging": This criterion excludes on one hand technologies i.w.s. that are currently still in the laboratory or bench scale and on the other hand technologies i.w.s. that are already commercial (with few exceptions where "ongoing intensive and promising research work should be taken into account", cf. part 1.2)

"Promising" This criterion excludes all technologies i.w.s. for which a low chance on market can be assumed until 2030 due to various reasons like unsolved technical problems, high costs, low acceptance, high risks etc.

"Relevant" This criterion excludes all technologies i.w.s. whose impact on air emissions (NO_x, SO_x, VOC, PM, CO_2 but also CO, NH_3, N_2O, POPs, Heavy Metals) in EU-25 from 2005-2030 is too small and hence irrelvant.

As for the criterion of relevance it can be assumed that a technology in a sector that contributes less than 1% to overall air emissions in EU-25 plus Norway and Switzerland can at best reduce the emissions of a given pollutant by 1% if its application rate is 100% and if it reduces emissions to zero. Under realistic conditions the expectable emission reduction of this technology will be significantly lower. Thus the technology can be regarded as

irrelevant for air emission reduction. An analysis of modelled RAINS emission data (scenario BL_CLE_Apr04 (Aug04) for EU-25 plus Norway and Switzerland in 2020) shows that the number of sectors within the scope of the project that contribute more than one percent to overall emissions of a given pollutant in RAINS is quite limited (Table 3-2).

Table 3-2: Projected shares of air emissions for EU-25 plus Norway and Switzerland in 2020: BL_CLE_Apr04 (Aug04)-Scenario (only sectors within scope of the project) (cf. http://www.iiasa.ac.at/web-apps/tap/RainsWeb for abbreviations)

	>20%	10-20%	5-10%	3-5%	1-3%
NH_3					FERTPRO: 1.3%
NOx		PP 14.4%, DOM 10.1%, IN 10.8%	PR_CEM 6%	CON_COMB: 3.5%	PR_REF 1.2%, PR_NIAC 1.1%, PR_SINT 1%
PM_{10}	DOM 30.1%	PP 14.3%	PR_CEM 5.4%, PR_BAOX 5.2%		PR_EARC 2.0%, PR_FERT 1.9%, PR_COKE 1.4%, IN 1.0%
$PM_{2.5}$	DOM 34.0%	PP 10.6%	PR_BAOX 6.7%, PR_CEM 6.2%		PR_EARC 2.6%, PR_FERT 2.3%, PR_COKE 1.6%, AL_PRIM 1.1%
TSP	DOM 29.0%	PP 13.9%		PR_CEM 3.6%, PR_BAOX 3.2%	PR_PIGI_F 1.6%, PR_EARC 1.3%, PR_LIME 1.3%, PR_FERT 1.2%, IN 1.0%
SO_2	PP 29.2%	IN 14.9% CON_COMB 13.0%	DOM 6.9%, PR_REF 6.8%	PR_CEM 4.6%, PR_OT_NFME 4.2%, PR_SUAC 4.2%, PR_PULP 3.0%,	PR_SINT 1.7%
VOC		DOM_OS 10.0%	RESID 7.9%, DECO_P 6.5%	EXD 4.4%, IND_P 4.3%, PR_REF 3.8%, PRT 3.6%	OTH_ORG_PR 2.9%, GLUE 1.9%, PHARMA 1.1%, WOOD_P 1.0% Auto_P 1.0%

In the following sections, technologies i.w.s. that have been identified as emerging, promising and relevant within the framework of this project and for which an integration into the RAINS model should be considered are listed pollutant-wise. The percentage value behind the RAINS sectors indicates the contribution to the emissions of this pollutant in EU-25 plus Norway and Switzerland in the year 2020 according to RAINS BL_CLE_Apr04 (Aug04) scenario. A brief description of the technologies can be found in Section 3.3 ff. and detailed fact sheets – as far as available – in the Annex (section 7).

3.2.1. NH_3

For reduction of NH_3 emissions in fertiliser production (FERTPRO (1.3%)) no promising emerging technologies i.w.s. for integration into RAINS were identified.

3.2.2. NO_x

For NO_x emission reduction the following technologies have been identified:

Integrated Gasification Combined Cycle (IGCC) for CON_COMB: IGCC is already integrated into the PRIMES model for both electricity production and CHP in Power Plants (pers. comm. L. Mantzos, 2004). Hence, only an integration into RAINS for **CON_COMB** should be considered. IGCC is currently applied in five refineries and was considered as promising by the experts at the workshop [Minutes of workshop, refinery session, cf. 7.5.1]. It is already applied in few areas, e.g. in SARLUX IGCC power plant, Italy, to gasify residual oil from the refinery processes. A NO_x emission factor of 25 mg/Nm³ can be assumed for IGCC in LCP [LCP BREF, 26], but for IGCC

in a refinery the emission factor might be higher: 60 mg/Nm³ at 15% O_2 volume[19] which is equivalent to 182 mg/Nm³ at 3% O_2 volume. Assuming that 280 Nm³ of flue gas (3% O_2, dry) per GJ will be formed during the combustion[20], an emission factor of 51 t/PJ can be calculated[21]. This is almost half of the implied emission factors for CON_COMB in the RAINS model that are 118, 111, 106, 106, and 107 t NO_x per PJ (2005, 2010, ..., 2030) in EU-25 (BL_CLE_Apr04 (Aug04)). Hence, there is a potential to reduce NO_x emissions in CON_COMB by maximum 50%, i.e. to reduce overall NOx emissions by at most 3.5/2 = 1.75%

Pressurised Fluidised Bed Combustion (PFBC) for PP: PFBC is a clean coal technology for PP with an efficiency of about 45%; due to a maximum temperature below 1400°C almost no thermal NO_x is formed and only about 10% of fuel nitrogen is converted to NO_x[22]. In Karita Thermal Power Station, with 360 MW total output the biggest PFBC plant, NO_x emission limit value is 60 ppm which is equivalent to around 123 mg/Nm³ and 103 t NO_x/PJ[23] compared to e.g. 150 t NO_2/PJ for PP_NEW and 250-280 t NO_2/PJ for PP_EX_OTH for Austria in RAINS. Net efficiencies are estimated to be 47% in 2010 and 55% in 2015-2020[24].

Limestone Injection Multistage Burner (LIMB) for PP: LIMB is primarily for SO_2-emission reduction but in combination with low NOx burners NOx emissions are reduced by 40-50%. The advantage of LIMB compared to other, especially wet flue gas desulfurisation systems, is not its efficiency but its cost effectiveness resulting in a higher application rate.

Ultra Low-NOx Burners for PP and IN: Ultra low NO_x burner systems achieve an emission reduction for coal down to 35-82 t/PJ at low costs[25].

Flame Doctor System for PP and IN: Continuous monitoring of the burner allows for optimal combustion conditions resulting in a reduction of 15% of NOx emissions and 50% of CO emissions[26].

(Gas-fired) heat pumps for DOM: AEA Technology Environment[27] considers heat pumps as a prospective emerging technology. Energy consumption and hence NOx emissions can be reduced up to 30% compared to a conventional gas heating system.

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[19] http://www.fwc.com/publications/tech_papers/powgen/pdfs/PIEMSA.pdf: overall efficiency: 42%

[20] cf. conversion chart for steam-based thermal power plants in "Pollution Prevention and Abatement Handbook, 1998" of Worldbank Group

[21] A value of 50 t NOx/PJ is also cited by Furimsky (1999): Gasification in Petroleum Refinery of 21st Century, Oil & Gas Science and Technology – Rev . IFP, 54 (5), pp. 597-618.

[22] Y. C. Bernero (2002): Comparative Evaluation of Advanced Coal-Based Power Plants, PhD thesis, TU Berlin, 2002, 175 pp.

[23] electrical efficiency 42%; 350 Nm³/GJ

[24] Markewitz P. and S. Vögele (2002): Future capacity demand and modern power plant concepts, Forschungszentrum Jülich, Programmgruppe Systemforschung und Technologische Entwicklung (STE).

[25] Ultra low NOx integrated system for NOx emission control from coal-fired boilers. Alstom Power Inc., Power Plant Laboratories, prepared for U.S. Department of Energy, National Energy Technology Laboratory, PPL REPORT NO. PPL-02-CT-19, 2002.
http://www.netl.doe.gov/coal/E&WR/nox/pubs/40754/Final%20Report%2040754.pdf;
http://www.netl.doe.gov/coal/E&WR/nox/control-tech/ultranox1.html

[26] Fuller et al. (2003): Field Experience with the Flame Doctor™ System. Presentation at EPRI-DOE-EPA-AWMA Combined Power Plant Air Pollutant Control Mega Symposium, Washington DC, May 19-22, 2003.

[27] AEA Technology Environment (2004): Costs and environmental effectiveness of options for reducing air pollution from small-scale combustion installations. Final Report for European Commission DG Environment.

SNCR Plant / Staged Combustion combined with SNCR for PR_CEM: A combination of staged combustion and SNCR can achieve NOx emissions in the order of 100-200 mg/m^3 (10% O_2) (or 0.2-0.4 kg NOx per ton of clinker) and hence comparable to SCR [13; [28]] but at lower costs.

SCR Plant for PR_CEM: SCR can reduce NOx emissions in cement plants down to 100-200 mg/m^3 (10% O_2) (or 0.2-0.4 kg NOx per ton of clinker) [13; [28]; [29]]. Pilot plants have been operating in Solnhofer Portland Zementwerke AG (Germany) and Kirchdorf, Gmunden und Peggau (Austria).

Blended Cement for PR_CEM: In blended cement additives like fly ash etc. partially replace the clinker resulting in a reduction of clinker demand of up to about one third[30] and hence would avoid NOx emissions from the clinker production. Blended Cement was considered at the workshop as an emerging application[31]. However, as there already are existing norms, blended cement is considered to be current practice and will therefore not be addressed here.

Catalytic Reduction of NOx Emissions of Fluid Catalytic Cracking Units for PR_REF: It is estimated that half of NO_x emission of a refinery stem from fluid catalytic cracking (FCC)[32]. In a refinery in Carson city (USA) NO_x emissions are reduced from 40 ppm achieved with NOx reducing additives down to 2 ppm with SCR, i.e. by 95%.

Uhde Process for PR_NIAC: The Uhde process for simultaneous reduction of NO_x and N_2O emissions from nitric acid plants was considered as currently not promising by the experts at the workshop due to high costs but if N_2O is considered in CO_2 emission trading this technology might be promising.

Emission process optimising sintering (EPOSINT) for PR_SINT: EPOSINT is considered by EUROFER as emerging. Via recirculation of the waste gas with the highest content of pollutants, EPOSINT can reduce specific air emissions in the order of 35-60% (depending on the pollutant).

See chapter 3.2.7 for **Small-scale CHP, Fuel Cells, Solar photovoltaics, Solar water heating and Wind turbines for DOM.**

3.2.3. PM ($PM_{2.5}$, PM_{10}, TSP)

Integrated Gasification Combined Cycle (IGCC) for CON_COMB: Since IGCC is already integrated into the PRIMES model for both electricity production and CHP in Power Plants (pers. comm. L. Mantzos, 2004), only an integration into RAINS for **CON_COMB** should be considered. Five refineries already apply IGCC, e.g. in SARLUX IGCC power plant, Italy, IGCC is fed with residual oil from the refinery processes. The experts at the workshop considered IGCC as promising [Minutes of workshop, refinery session, cf. 7.5.1]. For gasification of

[28] http://aida.ineris.fr/bref/bref_ciment/site/pages/anglais/bref_ciment_1_6.htm;
Böhmer, S., G. Sammer and I. Schindler (2001): Evaluierung der EU BAT Dokumente: Zement- und Kalkherstellung, Papier- und Zellstoffherstellung, Eisen- und Stahlherstellung, report of Umweltbundesamt Austria, BE-180.

[29] http://www.umweltbundesamt.at/fileadmin/site/umweltthemen/industrie/pdfs/Paper_Cement_SCR.pdf Kossina, I. (2001): Reduction of NOx Emissions from Exhaust Gases of Cement Kilns by Selective Catalytic Reduction, Proceedings of NOx Conference, Paris March 2001

[30] Worrell, E. and C. Galitsky (2004): Energy Efficiency Improvement Opportunities for Cement Making, An ENERGY STAR Guide for Energy and Plant Managers. Ernest Orlando Lawrence Berkeley National Laboratory, University of California. LBNL-54036.

[31] Minutes of Workshop within the EU-Project “Assessment of the Air Emissions Impact of Emerging Technologies” on June 28th to 29th 2004 in Brussels: “Session 09: Cement Manufacturing”

[32] Davey, S. W. (2000): Environmental Fluid Catalytic Cracking Technology Presented at the European Refining Technology Conference (and references cited therein). http://www.gracedavison.com/custpubs/overview.htm

petroleum coke an emission factor of 8.8 t PM/PJ can be assumed[33]. No information is available on the size distribution of the particles.

Pressurised Fluidised Bed Combustion (PFBC) for PP: For PFBC a particulate matter emission factor of ca. 8 t PM/PJ can be assumed[34]. Efficiency is about 45%[22]. No information is available on the size distribution of the particles.

High Efficient Centrifugal Gas Deduster with Closed Helical Channel for IN and DOM: The centrifugal gas deduster is much more efficient than high-efficiency cyclones and achieve a removal efficiency of more than 99% above 0.5 µm and hence even more than electric precipitators and fabric filters[35]. Low investments and low operating costs could make this technology interesting for smaller combustion devices, e.g. in the domestic sector.

Blended Cement for PR_CEM: In blended cement clinker is partially replaced by fly ash etc. Even though considered as an emerging application at the workshop[31], blended cement is current practice and therefore will not be addressed here.

Foaming Techniques at Pig Iron Pretreatment for PR_BAOX: In foaming techniques foam is used to absorb particulate matter arising from hot metal processing.

New Concepts for Electric Arc Furnaces for PR_EARC: New concepts like Consteel, COMELT and CONTIARC for EAF with a continuous melting of scrap allow for a reduction of energy consumption of 25% compared to conventional EAF[36] [37]. Other main advantages are that an almost complete collection of waste gas is possible and that waste gas volume is considerably reduced leading to reduced costs of waste gas cleaning[38].

PROven Single Chamber Pressure Control System for PR_COKE: PROven allows for a separate pressure adjustment in each single chamber and hence optimum pressure level.

No promising emerging technologies i.w.s. for integration into RAINS were identified for the RAINS sectors PR_FERT, AL_PRIM, PR_PIGI_F and PR_LIME.

See chapter 3.2.7 for **Small-scale CHP, Fuel Cells, Solar photovoltaics, Solar water heating and Wind turbines for DOM.**

3.2.4. SO_2

Integrated Gasification Combined Cycle (IGCC) for CON_COMB: IGCC is already integrated into the PRIMES model for both electricity production and CHP in Power Plants (pers. comm. L. Mantzos, 2004). Thus, only an integration into RAINS for **CON_COMB** should be considered. IGCC is applied in five refineries, e.g. in SARLUX (Italy) IGCC power plant fed with residual oil. The experts at the workshop considered IGCC as promising

[33] Furimsky (1999): Gasification in Petroleum Refinery of 21st Century, Oil & Gas Science and Technology – Rev . IFP, 54 (5), pp. 597-618

[34] cf. Berry, E. J. (1998): Power Generation and the Environment – a UK Perspective. Vol. 1, 275 pp., AEA Technology. http://externe.jrc.es/uk.pdf

[35] Kubica, R. (2004): "A high-efficient centrifugal gas deduster with closed helical channel", Questionnaire for EU-Project "Assessment of the Air Emissions Impact of Emerging Technologies".

[36] Gielen, D. J. and A. W. N. van Dril (1998): The basic metal industry and its energy use. Prospects for the Dutch energy intensive industry. ECN-C—97-019.

[37] Riboud, P. V. and J.-P. Birat: Technological development of iron and steel in European countries. 8.pp. http://abmbrasil.locaweb.com.br/cim/download/jean-birat.pdf

[38] Ball, M. and Becker, C (2004): New furnace concepts for EAF. Fact sheets "Assessment of Emerging Technologies". DFIU/IFARE.

[Minutes of workshop, refinery session, cf. 7.5.1]. For gasification of petroleum coke an emission factor of 76 t SO_2/PJ can be assumed[39].

Pressurised Fluidised Bed Combustion (PFBC) for PP: For PFBC a SO_2 emission factor of approx. 126 t SO_2/PJ can be assumed[40]. Efficiency is about 45%[22].

Limestone Injection Multistage Burner (Coal) for PP: Injection of crushed limestone into the boiler reduces SO_2 emissions by 60% for $ 392-791/ton of SO_2 removed[41].

Blended Cement for PR_CEM: A partial replacement of clinker in blended cement e.g. by fly ash reduces environmental impact related to clinker production. However, even though blended cement was considered as an emerging application at the workshop[31], the production and use of blended cement is current practice and therefore will not be addressed here.

Gasification of Black Liquor (e.g. Chemrec) for PR_PULP: Gasification of black liquor was considered as interesting by some of the experts at the workshop held within this project[42] and is more energy efficient than a recovery boiler and allows for a reduction of SO_2 emission to very low levels down to zero (depending on design). As a first guess an emission factor of 76 t SO_2/PJ can be assumed, similar to that for IGCC of petroleum coke[43].

Emission process optimising sintering (EPOSINT) for PR_SINT: EUROFER considers EPOSINT to be an “emerging technology”. Recirculation of the waste gas with the highest content of pollutants, reduces specific air emissions in the order of 35-60% (depending on the pollutant).

No promising emerging technologies i.w.s. for integration into RAINS were identified for PR_OT_NFME and PR_SUAC.

See chapter 3.2.7 for **Small-scale CHP, Fuel Cells, Solar photovoltaics, Solar water heating and Wind turbines for DOM.**

3.2.5. VOC

Smart LDAR for EXD and PR_REF: Smart LDAR offers a cost-efficient possibility to detect VOC leakages quickly. Experts at the workshop held within this project considered Smart LDAR as a promising technology[44]. Measurements of fugitive VOC-emissions at Swedish oil refineries with a laser-based Differential Absorption Lidar (DIAL) technique installed on a truck proved to be very effective[45]. With Smart LDAR, detection of VOC emissions is more effective since it is hand-held allowing to focus on selected areas of the plant and allows to perform measurements regularly at lower costs. The reduction of VOC emissions depends on many factors but at the moment it may be assumed that they can be reduced to one tenth for PR_REF and to one third for EXD.

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[39] Furimsky (1999): Gasification in Petroleum Refinery of 21st Century, Oil & Gas Science and Technology – Rev . IFP, 54 (5), pp. 597-618

[40] cf. Berry, E. J. (1998): Power Generation and the Environment – a UK Perspective. Vol. 1, 275 pp., AEA Technology. http://externe.jrc.es/uk.pdf

[41] http://www.netl.doe.gov/cctc/factsheets/limb/limbdemo.html

[42] Minutes of Workshop on June, 28th-29th 2004 in Brussels within EU-Project: “Assessment of the Air Emissions Impact of Emerging Technologies“ (2004): Session 03: Pulp & Paper.

[43] Furimsky (1999): Gasification in Petroleum Refinery of 21st Century, Oil & Gas Science and Technology – Rev . IFP, 54 (5), pp. 597-618

[44] Minutes of Workshop on June, 28th-29th 2004 in Brussels within EU-Project: “Assessment of the Air Emissions Impact of Emerging Technologies“ (2004): Session 11: Refineries.

[45] Frisch, M. (2003): Fugitive VOC-emissions measured at oil refineries in the Province of Västra Götaland in South West Sweden. Länsstyrelsen Västra Götaland, County Adiministration Report 2003:56, 29 pp.

Primerless Paint System for Automotive Applications for Auto_P: This system is considered as promising by some of the experts at the workshop held within this project. It makes the primer in automotive coating unnecessary and thereby reduces VOC emissions, e.g. by 50% for industries with no VOC emission reduction technologies installed and by 5% if low emission systems are in operation[46]. In addition energy consumption is reduced by ca. 30%.

Radiation Curing Technology for IND_P, GLUE and Auto_P: Radiation curing makes use of ultraviolet light or electron beams to cure coatings, inks, adhesives etc. and thereby reduces VOC emissions. Radiation curing is already applied but from our point of view can be still considered as emerging due to ongoing improvements.

Class-A-Coating in automatic mass production with dry deposition and air circulation for Auto_P: Wheras air recirculation is a well known technique, the innovative part is the combination of air recirculation and an improved filter system for particles[46]. Having cleaned the exhaust air from particles in the filter system, the air can be recirculated leading to increased VOC concentrations and allowing for a more cost-effective combustion of the exhaust air enriched in VOC. The impact on VOC emissions, however, is rather low if exhaust air is combusted anyway.

No promising emerging technologies i.w.s. for integration into RAINS were identified within this project for DOM_OS, DECO_P, OTH_ORG_PR, PHARMA and WOOD_P.

See chapter 3.2.7 for **Small-scale CHP, Fuel Cells, Solar photovoltaics, Solar water heating and Wind turbines for RESID.**

3.2.6. CO_2

No further promising emerging technologies i.w.s. for integration into RAINS have been identified since via PRIMES renewables (Run of river plants, Wind on shore, Wind off shore, Tidal plants, Geothermal plants, Solar photovoltaic, Advanced Solar photovoltaic, Solar thermal) are already integrated into RAINS. Energy efficiency (steady improvements) and CO_2 sequestration is considered as not promising until 2030 due to high costs and partially technical reasons. CO_2 sequestration depends highly on politics.

3.2.7. Technologies already covered by PRIMES and/or RAINS

For NOx, PM, SO_2, VOC:

Small-scale CHP for DOM: AEA Technology Environment[47] considers small-scale CHP as a prospective emerging technology. “Current” and “next generation” “small” “combined cycle gas turbines” are already included in PRIMES (pers. comm. L. Mantzos, 2004) and hence will not be addressed here.

Fuel cells for DOM: AEA Technology Environment[27] considers fuel cells as a prospective emerging technology. Fuel cells are already included as “Fuel Cells of 1st Generation for Power generation (high temperature)” and “Fuel Cells of 2nd Generation for Power generation (high temperature)” in PRIMES (pers. comm. L. Mantzos, 2004) and hence will not be addressed here.

Solar photovoltaics for DOM: AEA Technology Environment[27] considers solar photvoltaics as a prospective emerging technology. However, solar photvoltaics are already included in PRIMES as “solar photovoltaic” and “advanced solar photovoltaic” (pers. comm. L. Mantzos, 2004) and in RAINS via REN (renewables: solar, wind, small hydro) and hence will not be addressed here.

[46] Minutes of Workshop on June, 28th-29th 2004 in Brussels within EU-Project: “Assessment of the Air Emissions Impact of Emerging Technologies“ (2004): Session 07: Coating/VOC.

[47] AEA Technology Environment (2004): Costs and environmental effectiveness of options for reducing air pollution from small-scale combustion installations. Final Report for European Commission DG Environment.

Solar water heating for DOM: AEA Technology Environment[27] considers solar water heating as a prospective emerging technology. However, PRIMES includes already "solar thermal" (pers. comm. L. Mantzos, 2004). Thus, solar water heating will not be addressed here.

Wind turbines for DOM: AEA Technology Environment[27] considers wind turbines as a prospective emerging technology. However, PRIMES includes already "wind on shore" and "wind off shore" in three size categories each (pers. comm. L. Mantzos, 2004) and RAINS wind energy via REN. Thus, wind turbines will not be addressed here.

3.3. Power and district heating plants

3.3.1. Presentation of the power and district heating plants sector

In 1997, there were about 1200 companies generating electrical and thermal energy throughout the EU, and approximately 590 industrial companies operating industrial combustion plants and producing electrical and thermal energy to cover their own demand. Also in 1997, about 90% of the electric power generation in the EU was carried out by plants owned by large electricity generating companies, with only about 10% being accounted for by industrial combustion plants. Table 3-3 shows the subdivision of electric power generation plants into different types.

Table 3-3: Installed electrical capacity in EU-15 Member States [58, EURELECTRIC / VGB, 2001]

Type of power plant		GW
Fossil fuel – fired power plants	Steam	249.679
	Gas turbines	25.310
	Combined Cycles	25.776
	Internal Combustion	5.873
Nuclear power plants		124.151
Hydro power plants	Total installed capacity	116.189
	Pumped storage	29.686
Geothermal		0.539
Wind		3.024

Large combustion plants are classified as base-load, middle-load, peak-load plants, or as spinning reserve power plants, i.e. plants which are operated only to assure grid stability or as emergency units. Table 3-4 shows the fuels used for power generation:

Table 3-4: Electric power gross generation in EU-15 Members States in 1997 [58, EURELECTRIC / VGB, 2001]

Type of fuel		Total gross electric power generation (GWh)	% of total
Fossil fuel-fired power plants	Hard coal	471797	19.5
	Lignite and peat	183140	7.6
	Biomass	27283	1.1
	Petroleum products	185755	7.7
	Natural gas	332331	13.7
	Derived gases	27793	1.1
	Other fuels	7707	0.3
Nuclear		859894	35.5
Hydro		316116	13.0
Geothermal		3957	0.2
Wind		6909	0.3
Total gross generation		2422682	

In spite of an above average increase the amount of electrical power generated from regenerative energy sources (including hydropower and biomass) with 14.6% is quite small.

The ongoing process of deregulation and opening-up of electricity markets is a worldwide phenomenon. The degree of actual market opening varies throughout the EU, from full market opening in the United Kingdom, Germany, Finland and Sweden to partial market opening in others countries such as France and Italy [26].

3.3.2. Candidate technologies i.w.s. for power and district heating plants

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

3.3.2.1. Coal

Coal gasification:

Technology 1: Integrated Gasification Combined Cycle (IGCC)

Short description: Carbon based raw material reacts with steam and oxygen at high temperature and pressure to produce hydrogen, CO_2, CH_4 and CO_2. The high temperature vitrifies inorganic materials into a course material or slag. The syngas is then cleaned, and used to run primary and secondary gas and steam turbines, similar to a natural gas combined cycle.
Positive environmental impact(s): Energy, NO_x, NH_3, PM, CO_2, HM, Hg, SO_x
Emission reduction or emission factor: SO_2 25 mg/Nm³, efficiency 45%, NO_x 25 mg/Nm³
Stage of development: Under development
Bibliography: [26], [82], [79], [88], [89], [93], [94], [158], [228], [48], [49]

Technology 2: Pressurised Gasification in IGCC

Short description: Pressurised gasification in an IGCC.
Positive environmental impact(s): CO_2
Stage of development: Demonstration plant
Bibliography: [26], [113]

Coal combustion:

Technology 1: Pressurised Fluidised Bed Combustion (PFBC)

Positive environmental impact(s): NO_x, SO_x
Stage of development: Commercial
Bibliography: [82], [173], [48]

Technology 2: Pressurised Pulverised Coal Combustion

Positive environmental impact(s): Efficiency, SO_x, NO_x, PM, CO_2
Stage of development: Research
Bibliography: [52], [173]

Technology 3: Supercritical Steam Process for PC Boilers

Short description: A type of Advanced Pulverised Fuel Combustion system. Uses specially developed high strength alloy steels which enable the use of higher steam parameters. New materials for supercritical steam processes are e.g. super heat resistant steel, Ni-based super alloys.
Positive environmental impact(s): Efficiency, SO_x, NO_x, PM, CO_2
Emission reduction or emission factor: Efficiency ≥ 45%
Stage of development: More than 500 units worldwide
Bibliography: [82], [89], [92], [85], [93], [87], [84], [91], [90], [131], [130]

Technology 4: Ultra-Supercritical Steam Process for PC Boilers (700 °C)

Positive environmental impact(s): Efficiency, SO_x, NO_x, PM, CO_2
Emission reduction or emission factor: Efficiency ≥ 50%
Stage of development: Research

[48] Comments by Mr Rivron with EDF (Electricité de France) on the Large Combustion Plants sector, received on 02 July 2004

[49] Minutes of the Session "Large Combustion Plants" of the Workshop on Emerging Technologies, 28-29 June 2004, Brussels

Bibliography: [82], [87], [173], [93], [91], [50]

Technology 5: Circulating Fluidised Bed (CFB)

Short description: Uses jets of air to support combustion, effectively mix feedstock with SO_2 absorbents, and entrain the mixture.
Positive environmental impact(s): NO_x, SO_2
Emission reduction or emission factor: NO_x 371mg/m³, SO_x 347 mg/m³, CO 150 mg/m³, PM 50 mg/m³
Stage of development: Commercial
Bibliography: [94], [92]

Technology 6: Circulating Fluidised Bed with supercritical steam parameters

Positive environmental impact(s): NO_x, SO_2
Emission reduction or emission factor: Higher electric efficiency, less specific emissions
Stage of development: Next generation of CFB
Bibliography: [94], [91], [92], [84], [173], [50]

Technology 7: Combined Cycle Power Stations with Pressurised Pulverised Coal Firing System

Short description: Coal fired gas/steam turbine process.
Positive environmental impact(s): Efficiency
Bibliography: [102], [89]

Technology 8: Ultra Clean Coal

Short description: Sequential leaching with aqueous HF followed by aqueous HNO_3 leaching.
Positive environmental impact(s): PM, SO_x
Stage of development: Research
Bibliography: [63]

Technology 9: Coal Desulphurisation with Potassium Hydroxide and Acid.

Short description: Leaching coal with potassium hydroxide and acid. This technology is applied in India.
Positive environmental impact(s): PM, S
Emission reduction or emission factor: 50% max at 150°C
Bibliography: [62]

Technology 10: High efficiency low NO_x burners

Short description: NOx formation in the combustion process is reduced by reducing the amount of nitrogen in contact with oxygen at high flame temperatures. Available options are oxy-fuel combustion (e.g. in glass, metals industry), improved mixing of combustion air and fuel to maintain a stable temperature profile of the flame, and near stoichometric conditions (reducing the amount of nitrogen in the flame) through staged combustion, as well as flue gas recirculation (FGR) (Berntsson et al. 1997).
Positive environmental impact(s): NOx, efficiency
Stage of development: commercial (depending on efficiency)
Bibliography: [32]

Abatement measures:

Technology 1: Flowpac

Short description: Wet FGD for desulphurisation of flue gas using a bubbling technology instead of circulation pumps.
Positive environmental impact(s): SO_x, energy savings
Emission reduction or emission factor: 0.5-1% energy savings
Stage of development: Demonstration plants, commercial
Bibliography: [127], [183], [50]

Technology 2: Low cost Waste Water Treatment (WWT) for adipic acid from Limestone Wet FGD

Short description: with additives like adipic acid the specific electricity consumption per t of SO_2 removed of wet FGDs can be reduced. However, by now this technique is limited due to expensive waste water treatment..

[50] Comments by Harmut Krüger with VGB Power Tech e.V. on the list of candidate technologies for the Large Combustion Plants sector, received on 20 July 2004.

Positive environmental impact(s): Efficiency, less process costs
Stage of development: Economic evaluation
Bibliography: [50]

Technology 3: Limestone Injection Multistage Burner (LIMB)

Short description: Initially, limestone was injected through staged Low-NO_x burners. Studies have shown that moderate levels of SO_2 emission control were possible by injecting sorbent within certain windows within a boiler's time-temperature profile.
Positive environmental impact(s): NO_x, SO_2
Emission reduction or emission factor: NO_x 40-50%, SO_x 65-70%
Stage of development: Demonstrated, limited combustion temperature, no by-products
Bibliography: [101], [94], [50]

Technology 4: Limestone Injection Dry Scrubbing (LIDS)

Short description: Process in which limestone is first injected into the furnace, and the resulting excess CaO is used as the reagent for dry scrubbing.
Positive environmental impact(s): SO_2
Emission reduction or emission factor: SO_x 70%
Stage of development: Under development
Bibliography: [101], [100], [50]

Technology 5: Duct Sorbent Injection - Coolside

Short description: Process that couples flue gas humidification with hydrated lime $Ca(OH)_2$ injection into the duct downstream of the air heater.
Positive environmental impact(s): SO_2
Emission reduction or emission factor: SO_2 70%
Stage of development: Demonstrated on small scale
Bibliography: [101], [50]

Technology 6: SO_x-NO_x-Rox-Box (SNRB)

Short description: Process that combines hydrated lime and ammonia injection upstream of hot catalytic baghouse (Box) where the solid products calcium sulfite and sulphate and particulate (Rox) are removed, and the NO_x is reduced to nitrogen and water.
Positive environmental impact(s): SO_x, NO_x, NMVOC, PM
Emission reduction or emission factor: SO_2 80-90%, NO_x >90%, HF 84%, HCl 95%
Stage of development: Tests, no by-products
Bibliography: [101], [94], [50]

Technology 7: Advanced PM_1 Agglomeration ESP

Short description: ESP agglomerates very small particulates (typical size below 0.3 µm) to large particulates. Advanced agglomeration supports agglomeration up to PM_1, to increase overall PM_1/$PM_{2.5}$ reduction.
Positive environmental impact(s): ESP Optimisation
Emission reduction or emission factor: Dust, Heavy metals
Stage of development: Research
Bibliography: [50]

Technology 8: Simultaneous Control of SO_x, NO_x and Hg

Short description: The system is a gas phased oxidation process.
Positive environmental impact(s): NO_x, SO_x, HM, Hg
Emission reduction or emission factor: SO_x >99%, NO_x 98%
Stage of development: Laboratory
Bibliography: [26]

3.3.2.2. Liquid and gaseous fuels

Technology 1: Combined Cycle Gas Turbine (CCGT) and Steam Cooling

Short description: Combination of gas turbine, gas generator, steam turbine, condenser. The gas turbine uses steam cooling instead of air cooling.
Positive environmental impact(s): Efficiency
Emission reduction or emission factor: Up to 60%

Stage of development: Commercial
Bibliography: [156], [26], [131], [93], [131], [130], [93], [51]

Technology 2: Microturbines

Short description: A microturbine is a compact turbine generator that delivers electricity close to the point where it is needed.
Positive environmental impact(s): Efficiency
Emission reduction or emission factor: Simple cycle 30%, CHP 80%
Stage of development: Commercial demonstration stage
Bibliography: [32]

Technology 3: Recuperative Cycle in Gas Turbine (recuperate the exhaust gas heat)

Short description: Intercooled Recuperated Gas Turbine, Recuperative Cheng Cycle, Recuperative Humidified Air Turbine (HAT) Cycle, Recuperative TOPHAT Process, Recuperative Cascade Humidified Advanced Turbine (CHAT) Cycle.
Positive environmental impact(s): Heat, efficiency
Bibliography: [26]

Technology 4: Advanced Reciprocating Engines

Short description: Reciprocating engines (e.g., diesel engines) are used to generate electricity. These internal combustion engines convert fuel to shaft power, which then spins a generator.
Positive environmental impact(s): Energy
Emission reduction or emission factor: 49% primary energy savings
Stage of development: Commercial
Bibliography: [32]

Technology 5: Advanced CHP Turbines

Short description: Combined heat and power systems generate electricity (and/or mechanical energy) and thermal energy in a single, integrated system.
Positive environmental impact(s): Efficiency
Bibliography: [32]

Technology 6: Zero Emissions Power Generation

Short description: involves replacing conventional steam boilers and exhaust gas cleaning systems with "gas generator" technology adapted from rocket engines
Positive environmental impact(s): Emissions
Emission reduction or emission factor:
Stage of development: Pilot scale
Bibliography: [230]

3.3.2.3. Renewables

Note: Renewables here refers to the use of renewables for power production and heating.

Technology 1: Wind Power Plants and Offshore Wind Power Generation

Short description: Wind power plants and offshore wind power generation include wind turbines (their optimisation, the growth in size up to 5 MW, the improvement of their efficiency up to 50%) and farms offshore instead of on land (the efficiency offshore should be 40% higher than onshore).
Positive environmental impact(s): All pollutants especially CO_2
Stage of development: Commercial
Bibliography: [116], [89], [154], [164], [52], [53]

[51] Comments by Leslie James on Gas Combined Cycles, Steam Cooling and Flowpac received on 07 July 2004. Sources of information: ABB Alstom Power publicity material, personal interviews with the company, and EIPPCB interview and assessment.

[52] "EREC: Renewable Energy Scenario to 2040" provided by Oliver Schäfer (EREC) during the workshop on Emerging Technologies, session "Renewables and Fuel Cells", Brussels, 28-29 June 2004

[53] Minutes of the Workshop on Emerging Technologies, Session "Renewables and Fuel Cells", Brussels, 28-29 June 2004

Technology 2: Geothermal Heat and Power Plants

Short description: Use of deep seated geothermal reservoirs for power, heat and cold supply: one or two production wells and one injection well (doublet/triplet system) provide heat for heating and cooling purposes as well as for electricity generation.
Positive environmental impact(s): All pollutants especially CO_2
Emission reduction or emission factor: for power ~ 80 t $_{CO2\ equivalent}$ /GWh $_{el.}$, for CHP: ~ 20 t $_{CO2\ equivalent}$ /GWh $_{el.}$
Stage of development: Demonstration plant
Bibliography: [117]

Technology 3: Photovoltaics

Short description: New Technologies for cell making including less raw materials, new production processes, new materials.
Stage of development: Breakthrough expected in 2010
Bibliography: [252], [54]

Technology 4: Solar Thermo-Dynamic Plant

Short description: Production of High Temperature Heat by parabolic mirrors.
Positive environmental impact(s): PM, SO_x, NO_x,, CO_2
Stage of development: Pilot plant
Bibliography: [226]

Technology 5: Micro-Hydraulics

Short description: Generating energy through putting stocked water through turbines in micro-dams. For decentralised exploitation purposes, this technology could be expensive.

Bibliography: [89]

Technology 6: Stirling Motor

Short description: A Stirling motor can be directly heated from a solar collector or work as a motor in a Block-Type Thermal Power Plant (BTTP), which produces both heat and electricity at the same time. It runs clean, quiet and maintenance-free, and it reaches very high efficiency at an electric output of just 1 kilowatt.
Bibliography: [275]

Technology 7: Rankine Cycle

Short description: Rankine cycle is a heat engine with a vapour power cycle; its efficiency is not as high as Carnot cycle but the cycle has less practical difficulties and is more economic.
Bibliography: [274]

Technology 8: Biomass

Short description: Use of Biomass (regenerated lands, agroforestry, urban and community forestry, fermentable fraction of municipal solid waste or landfill deposit, sewage sludge, animal manure, etc.) to produce energy (heat, electricity, CHP….)
Positive environmental impact(s): CO_2
Stage of development: ranging from research (gasification, pyrolysis) to commercial (Wood energy…)
Bibliography: [273]

Technology 9: Pre-dryer of Peat and Biomass with low T, mechanical Thermal or in Fluidised Bed

Short description: The lignite is heated up and squeezed in order to separate the water, or is dried in a fluidised bed apparatus with internal use of the waste heat
Positive environmental impact(s): Heat
Emission reduction or emission factor: Higher electric efficiency, less specific emissions
Stage of development: Under development (Mechanical Thermal), developed (Fluidised Bed)
Bibliography: [26], [50]

[54] Comments by Eric Plantive (European Institute for Energy Research) concerning new technologies like CIS in photovoltaic, received on 02 July 2004

3.3.2.4. Fuel cells

Technology 1: High Temperature Fuel Cells

Short description: O^{2-} ions permeate the fuel cell membrane, oxidising the fuel (e.g. CH_4). There is no mixture between combustion air, fuel gas and flue gas. The flue gas is enriched in CO_2.
Positive environmental impact(s): Efficiency, CO_2
Emission reduction or emission factor: 52-57% efficiency
Bibliography: [125]

Technology 2: Solid Oxide Fuel Cell (SOFC)

Short description: Hydrogen, CO and hydrocarbons such as methane can be used as fuels. The direct oxidation of both CO and H_2 are well established. Reforming of CH_4 to H_2 appears to predominate in current SOFCs.
Positive environmental impact(s): Efficiency
Emission reduction or emission factor: 52-55%
Stage of development: Pilot plants
Bibliography: [93], [135], [89], [32]

Technology 3: Molten Carbonate Fuel Cell (MCFC)

Short description: Methane is internally steam reformed to a mixture of H_2, H_2O and CO. The CO is removed via the water-gas shift reaction $CO + H_2O \leftrightarrow CO_2 + H_2$ and H_2 is used at the anode to produce an electron current.
Positive environmental impact(s): Efficiency
Emission reduction or emission factor: 53-57%
Stage of development: Pilot plants
Bibliography: [93], [32], [89]

Technology 4: Fuel Cell + Microturbine: Hybrid Systems

Short description: A hybrid system of fuel cells and microturbines can increase the energy efficiency by utilising waste heat.
Positive environmental impact(s): Efficiency
Emission reduction or emission factor: 70%
Stage of development: Pilot plants
Bibliography: [93], [32]

Technology 5: MCFC Power Plant

Short description: MCFC uses natural gas as well as biogas, sewage gas and methane to produce electricity.
Positive environmental impact(s): Heat, Power
Emission reduction or emission factor: >90%
Bibliography: [237], [32]

Technology 6: FLOX steam reformer

Short description: Applies the well-known steam reforming process in small-scale or micro-scale technology for decentralised hydrogen production and PEM fuel cell systems.
Positive environmental impact(s): Emissions
Stage of development: Commercial
Bibliography: [180]

Technology 7: Fuel Cells for Stationary Applications

Short description: A fuel cell generates direct current electricity and heat by combining fuel and oxygen in an electrochemical reaction: the process is not dependant on the limits of the Carnot efficiency.
Positive environmental impact(s): Efficiency
Stage of development: Pilot plants
Bibliography: [26], [89], [32], [82]

Technology 8: Coal Compatible Fuel Cell, Hydrogasification and Reforming

Short description: An emission free carbon technology. Coal gasification and hydrogen production are driven by the CaO to $CaCO_3$ reaction. Then the produced H_2 is converted to electricity by an SOFC.
Positive environmental impact(s): CO_2, SO_x, NO_x, Hg, PM
Stage of development: power plant concept not yet being piloted
Bibliography: [114], [126], [93], [184]

3.3.3. List of candidate technologies i.w.s. analysed for the power and district heating plant sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

3.3.3.1. Clean coal

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Integrated Gasification Combined Cycle (IGCC)	Energy, SO_2, NO_x, NH_3, PM, CO_2, HM, Hg, SO_x	X	X	X	X	+
Pressurised Gasification in IGCC	CO_2	X				0
Controlling Nitrogen Injection in gas turbine in IGCC	NO_x, efficiency			X		0
Sulfur-Free Emission Start-Up Process for a Gasification Reactor	SO_2			X		0
Pressurised Fluidised Bed Combustion (PFBC)	NO_x, SO_x	X	X		X	+
Pressurised Pulverised Coal Combustion	Efficiency, SOx, NO_x, PM, CO_2	X	X		X	+
Supercritical Steam Process for PC Boilers	Efficiency, SOx, NO_x, PM, CO_2	X			X	+
(Ultra)-Supercritical Steam Process for PC Boilers (700 °C)	Efficiency, SOx, NO_x, PM, CO_2	X	X	X	X	+
Circulating Fluidised Bed (CFB)	NO_x, SO_2			X		+
Circulating Fluidised Bed / Once-Through Unit (OTU)	NO_x, SO_2			X		0
Once-Through Unit / Siemens-Benson vertical technology.	NO_x, SO_2			X		0
Circulating Fluidised Bed with supercritical steam parameters	NO_x, SO_2	X	X	X		+
Combined Cycle Power Stations with Pressurised Pulverised Coal Firing System	Efficiency	X		X		0
(Atmospheric) Fluidised Bed Combustion (FBC)	NO_x, SO_x	X		X		+
Ultra Clean Coal	PM, SO_x			X		+
Coal Desulphurisation with Potassium Hydroxide and Acid.	PM, SO_x			X		0
Flowpac	SO_x, power	X	X	X	X	+
Low cost Waste Water Treatment (WWT) for adipic acid from Limestone Wet FGD	Efficiency, less process costs			X		-
Limestone Injection Multistage Burner (LIMB)	NO_x, SO_2			X	X	+
Limestone Injection Dry Scrubbing (LIDS)	SO_2			X	X	+
Duct Sorbent Injection - Coolside	SO_2			X	X	+
SOx-NOx-Rox-Box (SNRB)	SO_x, NO_x, NMVOC, PM			X	X	+
Advanced PM1 Agglomeration ESP	PM			X		+
Simultaneous Control of SO_x, NO_x and Hg	NO_x, SO_x, HM, e.g. Hg	X				0
Hg Sorbent using a Zeolite Material with Proprietary Agent	Hg	X				0
Solid sorbents	Hg	X				0
Oxidizing Agents or mechanism	Hg	X				0
Real time measurement of mercury species and total mercury	Hg	X				0
Enhanced Wet and Dry FGD System	Hg			X		0
FGD Using Recycled Sodium Bicarbonate	SO_x, NO_x			X		0
Low cost catalytic sorbents for NO_x reduction	NO_x			X		0
High Efficiency Low NO_x burners	efficiency			X	X	0

3.3.3.2. Liquid and gaseous fuels

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Combined Cycle Gas Turbine (GCCT) and Steam Cooling	Efficiency			X	X	+
Microturbines	Efficiency			X	X	0
Recuperative Cycle in Gas Turbine (recuperate the exhaust gas heat)	Heat, efficiency	X			X	0
Advanced Reciprocating Engines	Energy			X	X	0
Advanced CHP Turbines	Efficiency			X	X	0
Zero Emissions Power Generation	Emissions		X		X	+

3.3.3.3. Renewables

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Wind power plants and offshore wind power generation	All, CO_2		X	X	X	+
Liquid CO_2 storage for electricity peak demand from variable wind power	CO_2 reapplication			X		0
Geothermal Heat and Power Plants	CO_2		X		X	+
Pelamis Wave Energy Converter	Renewable		X		X	0
Photovoltaics	Renewable		X		X	+
Solar Thermo-Dynamic Plant	PM, SO_x, NO_x,, CO_2		X		X	+
Micro-Hydraulics	All			X		+
Gasification of Straw	CO_2	X		X		0
NO_x Reduction in Catalytic Combustion of Gasified Biomass	NO_x			X		0
Pre-dryer of Peat and Biomass with low T, Mechanical Thermal, in Fluidised Bed	Heat			X		0
Stirling Motor	CO_2			X		+
Rankine Cycle	CO_2			X		+
Biomass	CO_2			X	X	+

3.3.3.4. Fuel cells

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
High Temperature Fuel Cells	Efficiency, CO_2		X		X	0
Solid Oxide Fuel Cell (SOFC)	Efficiency	X		X	X	0
Molten Carbonate Fuel Cell (MCFC)	Efficiency			X	X	0
Fuel Cell / Microturbine = Hybrid Systems	Efficiency			X	X	0
MCFC - Power Plant	Heat Power		X	X	X	+
FLOX Steam Reformer	Emissions		X		X	+
Fuel Cells for Stationary Applications	Efficiency		X		X	+
Coal Compatible Fuel Cell, Hydro-gasification and Reforming	CO_2, SO_X, NO_X, Hg, PM	X	X	X	X	0
H_2 Formation	CO_2			X		0
CO_2 Separation	CO_2			X		0
Low-crossover 'rechargeable' PEM fuel cells using cyclo-hexane	CO_2			X		0

3.4. Industrial combustion

3.4.1. Presentation of the industrial combustion sector

In 1997, there were approximately 590 industrial companies operating industrial combustion plants and producing electrical and thermal energy to cover their own demand. About 90% of the electric power generation in EU-15 of 2423 TWh gross was carried out by plants owned by large electric utilities, with only about 10% being accounted for by industrial combustion plants [26].

Boilers range in use from small fired tube boilers to large utility boilers associated with power plant facilities. A boiler will run only as well as the burner performs. The purpose of the burner is to mix fuel with combustion air and to inject the mixture into the combustion chamber. Burners are designed to maximise combustion efficiency while minimising the release of emissions.

3.4.2. Candidate technologies i.w.s. analysed for industrial combustion

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

Technology 1: Low-NO_x Burners

Short description: Low-NO_x burners limit the amount of air available in the initial stages of combustion when fuel-bound nitrogen is volatilised. They lengthen the flame to avoid hot spots, they are integrated with overfire air to ensure complete combustion in a cooler zone.
Positive environmental impact(s): Emissions
Emission reduction or emission factor: Emissions 40%
Stage of development: Available
Bibliography: [82], [94], [86], [81], [100], [113], [32], [77]

Technology 2: Ultra Low-NO_x Burners

Short description: The complete mixing of the fuel and the combustion air (and the flue gases) takes place in the furnace, which has the effect that there is no anchoring of the flame to the burner.
Positive environmental impact(s): NO_x
Emission reduction or emission factor: NO_x 100-200 mg/m³
Bibliography: [5]

3.4.3. List of candidate technologies i.w.s. analysed for the industrial combustion sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Low-NO_x Burners	Emissions			X		+
Regenerative Burners	CO_2, NO_x			X		0
Oxy-fuel Burners	NO_x	X		X		0
Flameless Combustion (a Low-NO_x technology)	CO_2, NO_x			X		0
Flameless Burner = Diffused Flame	NO_x	X				0
Ultra Low-NO_x Burners	NO_x	X				+
Water Injection	NO_x	X				0
Catalytic Combustion	NO_x	X		X		0
Oxy-fuel Combustion of Natural Gas	CO_2, NO_x, Efficiency			X		0
Reburning systems	NO_x	X				0
Oscillating Combustion	NO_x	X	X			-
Fuzzy-Logic for the Controlling of the Air-Knives (Artificial Neural Network ANN)	Energy	X	X			0
Infrared Cameras for Combustion Monitoring and Control (Waste Incineration)	PM, CO, NO_x, PCDDs/Fs	X				0
Flame Doctor System	NO_x, CO			X		0
Online Analysers	Energy			X		0
Oxygen Enhanced Low-NO_x Technology for CF Boilers	NO_x			X		0
Ultra Low-NO_x Integrated System TFS2000	NO_x			X		0
Oxygen enhanced combustion	NO_x	X				0
LOFIR + SOFA	NO_x			X		0
Multistage Slagging Combustor (TRW)	NO_x, CO			X		0

3.5. Waste incineration

3.5.1. Presentation of the waste incineration sector

The objective of waste incineration (WI) is to treat wastes to reduce its volume and hazard, whilst capturing (and thus concentrating) or destroying potentially harmful substances that may be released during incineration. Incineration processes can also provide a means to enable recovery of the energy, mineral and/or chemical content of certain fractions of the waste.

In EU-15 an annual quantity of approximately 200 million tons of waste may be considered suitable for thermal waste treatment, whereas the total installed capacity of thermal waste treatment plants is in the order of 50 million tons [265] and the share of municipal waste incinerated ranges from 0-69%.

Table 3-5: Municipal Solid Waste (MSW) production and total number of MSW Incineration installations (MSWI) in Europe in 2003 [1, UBA, 2001], [64, TWGComments, 2003]

Country	MSW production in 10^6 tons (year of data source)		Total number of MSWI
Austria	1.32	1999	3
Belgium	4.85	1997	17
Denmark	2.77	1996	32
Finland	0.98	1997	1
France	48.5	2000	210*
Germany	45	2000	59
Greece	3.20	1993	0
Ireland	1.80	1998	0
Italy	25.40	1995	32
Luxembourg	0.30	1995	1
Portugal	3.48	1999	3
Spain	17	1997	9
Sweden	3.80	1999**	30
Netherlands	7.95	1997	11
United Kingdom	27.20	1999	17
Bulgaria	3.199	1998	0 (1998)
Czech Republic	4.199	1999	3 (1999)
Estonia	0.569	1999	0 (1999)
Hungary	5	1998	1 (1998)
Latria	0.597	1998	0 (1998)
Lithuania	1.211	1999	0 (1999)
Poland	12.317	1999	4 (1999)
Romania	7.631	1999	0 (1999)
Slovakia	3.721	1999	2 (1999)
Slovenia	1.024	1995	0 (1995)
Norway			11
* On 6 Jan 2003 123 MSW incinerators were operating with a combined capacity of 2000t/h ** Swedish Waste Management 2000 (RVF)			

3.5.2. Candidate technologies i.w.s. analysed for waste incineration

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

Technology 1: Pyrolysis

Short description: Thermal decomposition of organic materials at temperatures in excess of 200°C and in total absence of air/oxygen.
Bibliography: [29]

Technology 2: Combination of Pyrolysis and incineration

Stage of development: Demonstration plant
Bibliography: [30], [55]

[55] Comments by Harmut Krüger, VGB Power Tech e.V., on the list of candidate technologies for the Large Combustion Plants sector, received on 20 July 2004.

Technology 3: Smoulder-Burn Process

Short description: Involves pyrolysis in a drum-type kiln with subsequent high temperature incineration of pyrolysis gas and coke.
Bibliography: [30]

Technology 4: PyroMelt Process with Kubota Surface Melting Furnace (KSMF)

Short description: Involves pyrolysis in a drum-type kiln, followed by condensation of the gaseous tar and oils, high temperature incineration of pyrolysis gas, oil and coke.
Stage of development: Not yet commercial
Bibliography: [30], [56]

Technology 5: Duotherm-Process

Short description: Involves pyrolysis on a grate with directly connected high-temperature incineration.
Stage of development: Shut down
Bibliography: [30], [56]

Technology 6: Co-Combustion of MBM (Meat and Bone Meal) with Natural Gas

Emission reduction or emission factor: SO_2 60 mg/m³, HCl 40 mg/m³
Bibliography: [103]

Technology 7: Gasification

Short description: Thermal degradation of organic compounds at high temperatures (900-1400°C) in a low oxygen atmosphere, to produce syngas and an inert (possibly vitrified) solid residue.
Stage of development: 2 demonstrating plants that were shut down
Bibliography: [29], [55]

Technology 8: Co-Firing of Coal and Waste

Short description: Continuous streams of homogeneous wastes with not too low net calorific values reduce fuel consumption. With biomass wastes CO_2 neutral fuels are available to reduce CO_2 emissions; it is said that ash and gypsum by-products are not be impacted. Expanded lifetime for existing LCPs, and decreased costs for new LCPs.
Stage of development: Commercial but with problems
Bibliography: [113], [82], [153], [55], [56]

Technology 9: Pre-dryer of Sewage Sludge with low T, Mechanical Thermal

Short description: The Sewage Sludge (or other waste with high humidity) is heated up and squeezed in order to separate the water.
Positive environmental impact(s): Heat (secondary fuel)
Stage of development: commercial, to be optimised
Bibliography: [55]

Technology 10: Pre-dryer of Sewage Sludge with low T, in Fluidised Bed

Short description: Drying the Sewage Sludge (or other waste with high humidity) in a fluidised bed apparatus with internal utilisation of the waste heat.
Positive environmental impact(s): Heat (secondary fuel)
Stage of development: proposal
Bibliography: [55]

Technology 11: High Efficient Centrifugal Gas Deduster with Closed Helical Channel

Short description: Compact construction of single module with the possibility of extension into multi-element unit.
Positive environmental impact(s): PM
Emission reduction or emission factor: 100% for particles of about 1 µm in diameter
Bibliography: [179]

Technology 12: Microbiological removal of sulphur, nitrogen oxides and heavy metals from flue gases

Short description: The application of micro-organisms in removal of nitrogen oxides from the gas streams.
Positive environmental impact(s): SO_x, NO_x, N_2O, HM

[56] Minutes of the Workshop on Emerging Technologies, Session "Large Combustion Plants and Waste Incineration", Brussels, 28-29 June 2004

Emission reduction or emission factor: SO_x 70%, NO_x 80%, N_2O 99%, HM 60%
Stage of development: bench / laboratory scale
Bibliography: [257], [56]

Technology 13: Reheating of turbine steam

Short description: The reheating of turbine steam after its first passage through the turbine increases the efficiency of electricity production.
Positive environmental impact(s): efficiency
Emission reduction or emission factor: efficiency + 2 to 3%.
Stage of development: Never been used for municipal waste incineration
Bibliography: [265]

Technology 14: Addition of inhibitors to the waste

Short description: Inhibiting the reactions or reducing the presence of dusts in the temperature range 450–200 °C. Efficiency is limited and secondary reactions require consideration.
Positive environmental impact(s): PCDDs/Fs
Bibliography: [265]

Technology 15: Employment of hot gas dedusters

Short description: Inhibiting the reactions or reducing the presence of dusts in the temperature range 450–200 °C. Dedusting using ceramic filters or cyclones at temperatures of approximately 800 °C and dedusting at temperatures above 450°C e.g. with hot gas electrostatic filters.
Positive environmental impact(s): PCDDs/Fs
Stage of development: Little experience from pilot tests
Bibliography: [265]

Technology 16: Effective cleaning of flue-gas vents, boiler, heating plates

Short description: Inhibiting the reactions or reducing the presence of dusts in the temperature range 450–200 °C. Reduction of deposits of airborne dust on the flue-gas path by effective cleaning of flue-gas vents, boiler, heating plates is a well proven maintenance related issue.
Positive environmental impact(s): PCDDs/Fs
Bibliography: [265]

Technology 17: Oil scrubber

Short description: For the reduction of polyhalogenated aromatics and polyaromatic hydrocarbons (PAHs) in the flue-gases from incineration plants. The oil/emulsion containing absorbed dioxins and furans are exchanged and disposed of as soon as they reach a limit value of 0.1 mg/kg.
Positive environmental impact(s): PCDDs/Fs
Bibliography: [265]

Technology 18: PECK combination process for MSW treatment

Short description: Thermal treatment, fly ash treatment, bottom ash treatment.
Positive environmental impact(s): PCDDs/Fs, HM, NO_x
Stage of development: 1 plant
Bibliography: [265]

Technology 19: Electrox

Short description: Pulsed corona plasma treatment of industrial off-gases. The pollutants are oxidised. NO_x and SO_x form acids which are scrubbed. Organic materials are oxidised to carbon dioxide and water.
Positive environmental impact(s): NO_x, SO_x
Emission reduction or emission factor:
Stage of development: Pilot plant
Bibliography: [190]

Technology 20: Plasma Discharge Technology/ Plasma Gasification

Short description: Plasma discharges uses high temperatures in an oxygen-poor environment to decompose waste. Products include a combustible gas and a solid vitrified material. The heat source is a plasma discharge torch.
Bibliography: [29], [30]

Technology 21: Microwave Plasma

Short description: Feeds microwave energy into a specially designed coaxial cavity to generate a thermal plasma under atmospheric pressure.
Emission reduction or emission factor: CO 4.3 mg/Nm³, PCDDs/Fs 0.0011 ng ITEQ/Nm³, PM 10.6 mg/Nm³
Stage of development: Market
Bibliography: [30]

Technology 22: Depolymerisation

Short description: Use of high-energy microwaves in a nitrogen atmosphere to decompose waste. The waste absorbs microwave energy, the internal energy increases and the waste depolymerises.
Bibliography: [29]

Technology 23: Von Roll Process

Short description: This is the combination of the Pyrotex filter and the catalyst technology for the treatment of NO_x and PCDDs/Fs.
Positive environmental impact(s): PM, NO_x, PCDDs/Fs, HM, Acids
Emission reduction or emission factor: NO_x <70 mg/Nm³
Bibliography: [18]

Technology 24: Integrated Flue gas treatment System

Short description: This system is composed of a quenching chamber with slaked lime, a filtering reactor, and a catalytic NO_x removal unit.
Positive environmental impact(s): PM, HCl, SO_x, NO_x, PCDDs/Fs, HM, Hg
Emission reduction or emission factor: PCDDs/sF <0.5 ng TEQ/Nm³, NO_x <0.002 g/Nm³, fly ash 3-19 ppm, Hg 70%, SO_x <10 ppm, HCl 8-20 ppm
Bibliography: [72]

Technology 25: Advanced Flue Gas Treatment System

Short description: Reaction tower where slaked lime slurry is added, then slaked lime powder, bag house filter, catalytic denitrification tower or activated coke packed tower.
Positive environmental impact(s): PM, NO_x, SO_x, HCl, PCDDs/Fs, HM
Emission reduction or emission factor: PCDDs/Fs <0.1 ng TEQ/Nm³, NO_x <50 ppm, PM <10 mg/Nm³, Pb <0.1, Cd <0.01, Hg <0.02
Bibliography: [72]

Technology 26: Use of steam as a spraying agent in post combustion chamber burners instead of air

Bibliography: [265]

3.5.3. List of candidate technologies i.w.s. analysed for the waste incineration sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Pyrolysis	Energy			X		+
Pyrolysis-incineration	Energy	X		X		+
Smoulder-Burn-Process	Energy	X				0
PyroMelt-Process with Kubota-Surface-Melting-Furnace KSMF	Energy	X		X		0
Duotherm-Process	Energy			X		-
Co-Combustion of MBM (Meat and Bone Meal) with Natural Gas	Energy			X	X	0
Gasification	Energy			X		-
Co-Firing of Coal and Waste	Energy	X		X		-
Pre-dryer of Sewage Sludge with low T, Mechanical Thermal	Heat			X		+
Pre-dryer of Sewage Sludge with low T, in Fluidised Bed	Heat			X		+
High Efficient Centrifugal Gas Deduster with Closed Helical Channel	PM		X		X	+
Microbiological removal of SO_x, NO_x and HM from flue gases	SOx, NOx, N_2O, HM			X	X	+
Application involving the reheating of turbine steam	efficiency	X				-
Addition of inhibitors to the waste	PCDDs/Fs	X				-
Employment of hot gas dedusters	PCDDs/Fs	X				-
Effective cleaning of flue-gas vents, boiler, heating plates	PCDDs/Fs	X				+
Oil scrubber	PCDDs/Fs	X				0
PECK combination process for MSW treatment	PCDDs/Fs, HM, NO_x	X				0
Electrox	NO_x, SO_x		X		X	+
Plasma Discharge Technology/ Plasma Gasification		X			X	0
Microwave Plasma		X				+
Depolymerisation		X				0
Von Roll Process	PM, NO_x, PCDDs/Fs, HM			X		0
Integrated Flue gas treatment System	PM, HCl, SO_x, NO_x, PCDDs/Fs, HM, Hg			X		0
Advanced Flue Gas Treatment System	PM, NO_x, SO_x, HCl, PCDDs/Fs, HM			X		0
Use of steam as a spraying agent in post combustion chamber burners instead of air		X				0

3.6. Small scale combustion

3.6.1. Presentation of the small scale combustion sector

In this project, the small scale combustion sector covers domestic, residential, commercial and small industrial installations with a rated thermal input of less than 50 MW using liquid, gaseous and solid fuels including biomass.

3.6.2. Candidate technologies i.w.s. analysed for small scale combustion

The following list contains brief information on candidate technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

Technology 1: Absorption Gas Heat Pump

Short description: New area of application of an existing technology, with 50% of energy gained.
Positive environmental impact(s): Gas, energy
Emission reduction or emission factor: 30% energy saved
Stage of development: Pilot, demonstration
Bibliography: [133], [134]

Technology 2: Solar Assisted District Heating

Short description: Use of solar-thermal energy in district heating systems with seasonal heat storage. There is less sun available in winter so that this technology cannot replace a conventional heating system completely. The costs are twice as high compared to standard heating systems.
Positive environmental impact(s): Energy
Emission reduction or emission factor: Solar fraction of 50%
Stage of development: Pilot plants
Bibliography: [232]

Technology 3: Trigeneration

Positive environmental impact(s): Heat, Emissions
Bibliography: [12]

Technology 4: Wood Pellets and Wood Chips

Positive environmental impact(s): Heat, Emissions

3.6.3. List of candidate technologies i.w.s. analysed for the small scale combustion sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop (“+” positive assessment, “-“ negative assessment, “0” no assessment).

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Absorption Gas Heat Pump	Gas, Energy	X	X		X	0
Solar Assisted District Heating	Energy		X		X	-
Cyclone-type separator with swirling baffle and bottom take off of clean gas	PM		X		X	0
High efficiency Rigidised Co-Polyimide cartridge filter	PM		X		X	0
Trigeneration	Heat, Emissions			X		0
Stirling- refrigerating machine for industrial use				X		0
Wood Pellets and Wood Chips	Heat, Emissions			X		0

3.7. Iron ore treatment

3.7.1. Presentation of the iron ore treatment sector

Sintering and pelletisation are complementary process routes for the preparation of iron oxide raw materials for primary iron and steel making and are strongly influenced by local conditions such as the availability and type of raw materials.

In EU-15 there is only one integrated steel works that includes a pelletisation plant (in the Netherlands). Sweden has four stand-alone pelletisation plants. Pellet production in the five EU plants mentioned above was 15.1 Mt in 1996. In 1995 total pellet consumption in the EU-15 was about 35 Mt whereas sinter consumption was three times higher.

3.7.1.1. Sinter plants

Sinter is produced at the steel works side for various reasons: it allows solid wastes to be recycled; coke breeze is available at steel works for use as a fuel; sinter is prone to degradation during transport and handling.

Gaseous emissions from the sinter plant dominate overall emissions from an integrated steelworks. The gas contains PM (HM, mainly Fe compounds but also other HM, especially Pb compounds), alkali-chlorides, SO_x, NO_x, HCl, HF, hydrocarbons, CO and also significant trace amounts of PAH and aromatic organo-halogen compounds such as PCDDs/Fs and PCB.

3.7.1.2. Pelletising plants

Pellets of 9-16 mm in diameter are formed from fine ore and additives of <0.05 mm using very high temperatures. This is mainly carried on at the site of the mine or its shipping port.

The pelletisation plant is a source of PM emissions (from grinding, induration strand, screening and handling), NOx emissions (from induration and drying), SO_2, HCl and HF (from induration) and gaseous emissions (from the induration strand).

3.7.2. Candidate technologies i.w.s. analysed for iron ore treatment

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

According to the experts at the workshop [57], "the iron and steel sector in Europe is characterised by continuous improvements and not radical changes or new processes. Much progress is made in the Steel Industry by improving process performance by incremental steps rather than by switching to new technologies. The improvement can be very significant in the long run. On the other hand, when a process has come close to its physical limits (thermodynamics), this "continuous" improvement reaches its limits. An interesting analyses could consist in ascertaining which technologies have room left for improvement, how much, and which have no room left." and "The list of candidate technologies presented before the workshop contains all kind of promising technologies, from commercial ones to some that were at laboratory-scale only. The list is not exhaustive. It

[57] Minutes of the Workshop on Emerging Technologies, Session "Ferrous Metals", 28-29 June 2004, Brussels

should be recognised in any publication that the work done is only a partial contribution to a wider study that ought to be done" [58].

3.7.2.1. Sinter plants

Technology 1: Lignite Coke Powder Injection + Catalytic Oxidation

Short description: Injection of lignite coke powder as an adsorbent, then existing ESP, and finally oxidative catalyst. It was reported during the workshop that catalytic oxidation has failed and that adsorbent injection is now applied at industrial scale in certain sinter plants.
Positive environmental impact(s): PCDDs/Fs
Emission reduction or emission factor: PCDDs/Fs 0.2 to 0.5 ng/Nm^3. Catalytic oxidation in the sinter plant may be a good technology for reduction of PCDDs/Fs but it is obsolete for other pollutants.
Stage of development: Tests
Bibliography: [1], [59]

Technology 2: MEA (amines) as Inhibitor of PCDDs/Fs

Short description: Addition of MEA (Mono-ethanolamine) to fly ash with a reaction time of 2-4 h. It was reported during the workshop that injection of amines in windboxes has failed (low abatement, negative impact on dust emissions).
Positive environmental impact(s): PCDDs/Fs
Emission reduction or emission factor: PCDDs/Fs 90%
Stage of development: Pilot Plant
Bibliography: [34], [176], [181], [59]

Technology 3: Energy Optimised Sintering (EOS) Process

Short description: The EOS-System (Lurgi process/Ijmuiden, NL) re-circulates a part of the whole waste gas of the sinter plant (PI measure No. 7, Chapter 4, I&S BREF). The SWGR-System (Nippon Steel, Yawata Works JP) re-circulates the part of the waste gas with the largest heat content, for heat recovery (PI measure No. 8, Chapter 4, I&S BREF). The LEEP-System (Low Emissions Energy Process/HKM, D) uses a gas hood over the whole sinter strand. Due to the additional heat input at the end of the sinter strand, more heat is emitted at the cooler. For instance, the Energy Optimised Sintering (EOS) which is among the candidate BAT (BREF Iron and Steel Production [1]), may give rise to a decreasing productivity of the sinter plant which may lead to adapting operating conditions at blast furnace level.
Positive environmental impact(s): PM, NO_x, PCDDs/Fs, SO_x, CO, Heat
Emission reduction or emission factor: Emissions reduction of 50%
Stage of development: EOS was only applied in one plant for specific production conditions. EOS cannot be an emerging technology because it is already commercially used in the Netherlands [Minutes of Workshop]. For EOS "emerging application" or "increased application" would be more appropriate terms. An alternative process (LEEP) was applied in another site with negative impact on productivity (-5%). These processes are very controversially discussed. They have impacts on quality, productivity, NO_x abatement, solid fuel savings. The penetration rates should be rather low, the processes are not mature [Minutes of Workshop].
Bibliography: [2], [23], [144], [59], [59]

Technology 4: Emission process optimizing sintering (EPOSINT)

Short description: The EPOSINT-System (Voestalpine Stahl/Linz, A) re-circulates the part of the waste gas with the largest content of pollutants, such as SO_2, HM, NO_x, PM, PCDDs/Fs and achieves the maximum of specific reduction of emissions.
Positive environmental impact(s): SO_2, HM, NO_x, PM, PCDDs/Fs
Emission reduction or emission factor: Depending on the kind of pollutant, 35-60%
Stage of development: "EPOSINT" is in the state of a pilot plant; there will be commercial plants at the beginning of 2005.
Bibliography: [59]

[58] Comments by Jean Pierre Birat with EUROFER/ARCELOR on the Ferrous Metals sector for the Emerging Technologies project, received on 01 July 2004

[59] Comments by Jean-Pierre Debruxelles with EUROFER on the Ferrous Metals sector, received on 15 September 2004

Technology 5: Main Exhaust Gas Waste Heat Recovery

Short description: The temperature of the main exhaust gas leaving the later stages of strand may be as high as 500°C, and can be recuperated if separated from the cooler gas leaving the earlier stages of the strand.
Positive environmental impact(s): Heat
Stage of development: 1 Plant in 1998
Bibliography: [2], [23], [144]

Technology 6: High Temperature Metallic Filter

Short description: Metallic filter screens of relatively large mesh size. A cake of collected dust acts as a filtration medium.
Positive environmental impact(s): PM
Stage of development: Pilot Plant
Bibliography: [35], [176]

3.7.2.2. Pelletising plants

Technologies for NO_x reduction:

Technology 1: Water Injection into the Induration Strand Burners

Short description: reduces peak flame temperatures
Stage of development: considered as possible “Emerging Technique” in the Iron and Steel Production BREF [1] (cf. section 1.2 for BREF definition of “Emerging Technique”)
Bibliography: [1], [23]

Technology 2: Exhaust Gases as Combustion Air

Short description: aims to reduce availability of oxygen in the burners and hence NO_x formation
Stage of development: considered as possible “Emerging Technique” in the Iron and Steel Production BREF [1]
Bibliography: [1], [23]

Technology 3: Indirect Water Injection in the Cooling Section

Short description: the generated steam might reduce NO_x formation in the burners
Stage of development: considered as possible “Emerging Technique” in the Iron and Steel Production BREF [1] (cf. section 1.2 for BREF definition of “Emerging Technique”)
Bibliography: [1], [23]

Technology 4: SCR

Short description: process of adding ammonia to flue gas which passes through catalyst layers. NO_x is decomposed into nitrogen and steam
Positive environmental impact(s): NO_x
Emission reduction or emission factor: NO_x >90%
Stage of development: considered as possible “Emerging Technique” in the Iron and Steel Production BREF [1] (cf. section 1.2 for BREF definition of “Emerging Technique”)
Bibliography: [1], [72], [98]

Technologies for SO_x reduction:

Technology 1: AIRFINE Scrubbing Process (Wet DeSO$_x$)

Short description: Includes an ESP for the removal of coarse dust, a system for waste gas cooling and moisture saturation, a fine scrubber system for fine dust separation and simultaneous gas cleaning, and a water treatment facility for by-products separation and recovery.
Positive environmental impact(s): SO_2, PM, HM, PCDDs/Fs, PAH, HCl, HF
Emission reduction or emission factor: PM <50 mg/Nm³, PCDDs/Fs 0.4 ng I-TEQ/Nm³, HCl and HF 80-95%, HM >90%
Stage of development: Commercial
Bibliography: [1], [23], [144]

Technology 2: Regenerated Activated Carbon (Dry DeSO$_x$)

Short description: Adsorption of SO_2 on activated carbon. In the case where activated carbon is regenerated, a high quality activated carbon is used and sulphuric acid (H_2SO_4) is yielded as a by-product. The bed is regenerated either with water or thermally.

Positive environmental impact(s): SO_2, HCl, HF, Hg, (NO_x)
Emission reduction or emission factor: SO_x >95%
Stage of development: considered as possible "Emerging Technique" in the Iron and Steel Production BREF [1]
Bibliography: [1]

3.7.3. List of candidate technologies i.w.s. analysed for the iron ore treatment sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

3.7.3.1. Sinter plant

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Lignite Coke Powder Injection + Catalytic Oxidation	PCDDs/Fs	X			X	+/-
MEA (amines) as Inhibitor of PCDD/Fs	PCDDs/Fs	X	X	X	X	+/-
Energy Optimised Sintering (EOS) Process	PM, NO_x, PCDDs/Fs SO_x, CO, Heat	X		X		+/-
Emission process optimising sintering (EPOSINT)	SO_2, HM, NO_x, PM, PCDDs/Fs			X		+
Main Exhaust Gas Waste Heat Recovery	Heat	X		X		0
Injection of $NaHCO_3$ in Sinter Flue Gas	SO_2			X		0
High Temperature Metallic Filter	PM			X		0
Granulating Coke Breeze	NO_x			X		0

3.7.3.2. Pelletisation plants

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Water Injection into Induration Strand Burners	NO_x	X		X		+
Exhaust Gas as Combustion Air	NO_x	X		X		+
Water Injection into Cooling Section	NO_x	X		X		+
Nagoya Works	SO_x, NO_x	X				0
NKK-Corac process	SO_x, NO_x	X				0
SCR	NO_x	X		X		+
Shell DeNO$_x$	NO_x	X				0
Degussa H_2O_2	NO_x	X				0
Regenerated Activated Carbon	SO_2, HCl, HF, Hg, (NO_x)	X				+
Wet DeSO$_x$	SO_2	X				0
AIRFINE Scrubbing Process (Wet DeSO$_x$)	SO_2, PM, HM, PCDDs/Fs, PAH, HCl, HF	X		X		0
Semi-Dry DeSO$_x$	SO_2	X				0
Dry Alkali Injection	SO_2	X				0
DeSO$_x$ with Scrubbing Liquid	SO_2	X		X		0

3.8. Coke plants

3.8.1. Presentation of the coke plants sector

Coal pyrolysis means the heating of coal in an oxygen free atmosphere to produce gases, liquids and a solid residue (char or coke). Coal pyrolysis at high temperature is called carbonisation. This produces blast furnace and foundry cokes. Coke is the primary reducing agent in blast furnaces.

The partial substitution of coke in the blast furnace by oil and, more recently, pulverised coal has played a major role in reducing fuel costs. Apart from the fuel savings achieved, coal injection has a positive environmental effect because less coke is consumed and so emissions from coke oven plants are avoided. However, coke can only partly be substituted by coal.

Furthermore, several new iron-making techniques that use coal instead of coke as a fuel/reducing agent are being developed with Corex being already in commercial operation. It is expected that within the coming 25-50 years these new techniques will take over the role of the blast furnaces. This would make the metallurgical coke oven plant superfluous.

Nevertheless, developments to decrease emissions from existing coke oven plants are still going on. New plant concepts with lower emissions and/or higher energy efficiency are operated or are under development [1].

3.8.2. Candidate technologies i.w.s. analysed for coke plants

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

According to the experts at the workshop [60], the iron and steel sector in Europe is characterised by continuous improvements (cf. section 3.7.2).

Technology 1: Coke Oven Improvement: Coke dry quenching (CDQ), Recovery of sensible heat

Short description: Technologies for saving energy consumption in the coke making process. Dry quenching raises the cost for the coke by about 7.80 €/t.
Positive environmental impact(s): Energy
Emission reduction or emission factor: Energy savings are from 1.4 $GJ/t_{dry\ coke}$ to 1.7 $GJ/t_{dry\ coke}$. But the process is very debatable in relation to its environmental (dis)advantages (dust emissions) and its negative impact on coke quality and reduction of blast furnace performance.
Stage of development: CDQ is a mature technology, for example in Japan, taking into account the costs for energy in this country. In Europe, its usage remains economically not feasible.
Bibliography: [290], [61], [62]

Technology 2: CSQ Coke Stabilizing Quenching

Short description: Wet Quenching System. In comparison with the Dry Quenching System the CSQ-System is much cheaper: about 100 Mio € for the Schwelgern plant.
Positive environmental impact(s): Energy
Bibliography: [2], [140], [148]

[60] Minutes of the Workshop on Emerging Technologies, Session "Ferrous Metals", 28-29 June 2004, Brussels

[61] Comments by Jean Pierre Debruxelles with EUROFER on the Ferrous Metals sector, received on 15 September 2004

[62] Minutes of the Workshop on Emerging Technologies, Session "Ferrous Metals", 28-29 June 2004, Brussels

Technology 3: PROven (Pressure Regulated Oven)

Short description: Single Chamber Pressure Control System. This is the highest standard of emission control system.
Positive environmental impact(s): Energy
Bibliography: [2], [140], [148]

Technology 4: Non Recovery Coke Ovens

Short description: All of the by-product gas is burnt within the process.
Positive environmental impact(s): Heat, energy
Bibliography: [129]

Technology 5: Wet Desulphurisation of Coke Oven Gas

Short description: Scrubbing with a caustic soda solution to increase the removal efficiency of the absorption processes.
Positive environmental impact(s): SO_x
Emission reduction or emission factor: SO_x 0.1 mg/Nm³
Bibliography: [1]

Technology 6: Measurement of the Coke Oven Wall Temperature

Short description: Is of great importance for the evaluation of the coke oven heating.
Positive environmental impact(s): Energy
Bibliography: [2]

Technology 7: Coke Making at Lower Temperature

Short description: Coke produced at 800°C instead of 1100°C, by completing the heating of the coke while it descends into the blast furnace.
Positive environmental impact(s): Fuel
Stage of development: Tested on small scale
Bibliography: [17]

3.8.3. Candidate technologies i.w.s. analysed for the coke plants sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant. The assessment refers to expert judgement at the workshop (“+” positive assessment, “-“ negative assessment, “0” no assessment).

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Single Chamber System / Jumbo Coke Oven	Heat	X		X	X	-
PROven Single Chamber Pressure Control System	Energy			X	X	+
Coke Oven Improvement: Coke dry quenching (CDQ), Recovery of sensible heat	Energy			X	X	+/-
CSQ Wet Quenching System	Energy			X		+
Non Recovery Coke Ovens	Heat, energy			X		0
Wet Desulphurisation of Coke Oven Gas	SO_x	X				0
Measurement of the Coke Oven Wall Temperature	Energy			X		0
Coke Making at Lower Temperature	Fuel			X		0

3.9. Iron and steel production

3.9.1. Presentation of the iron and steel production sector

Since the oil crisis in 1974-75 iron and steel production has been virtually stagnant worldwide, with Europe being particularly affected. In 1999, the production of crude steel in EU-15 was 155.3 million tons or 19.7% of world production [EUROFER and IISI].

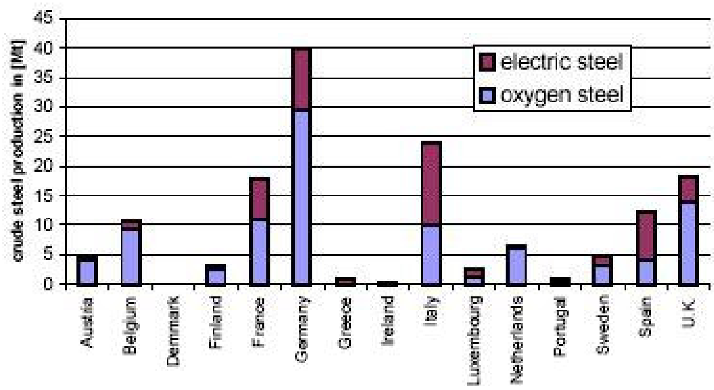

Figure 3-1: Oxygen and electric arc furnace steel production in the EU-15 in 1996 - [Stat. Stahl, 1997]

Production of oxygen steel has remained fairly steady from 1985 to 1995, whereas electric arc furnace steel production gradually increased. The share of the latter total steel production reached 34.4% in 1995. Nevertheless, the blast furnace - basic oxygen furnace route is predicted to remain the dominant means of steel production, at least until 2015 [Luengen, 1995]. Furthermore, there was a decline in the number of electric arc furnaces and oxygen converters after 1990, whilst the capacities of both remaining and new installations increased. Integrated steelworks in EU-15 are concentrated along the coal belt in Central Europe. The introduction of new technologies and working practices implied an increase in productivity of 64% between 1985 and 1994.

The iron and steel industry is undergoing intensive structural changes. This is characterised by the development of new concepts in steelworking (e.g. mini-electric steel mills, new concepts for electric arc furnaces, new casting technologies and direct or smelting reduction technologies).
Air pollution remains an important issue. In integrated steelworks, sinter plants dominate the overall emissions for most atmospheric pollutants, followed by coke-oven plants. The contribution of the iron and steel industry to the overall air emissions in EU-15 is significant for PM, heavy metals and PCDDs/Fs. The energy consumption is considerable: the specific energy consumption for 1 t liquid steel, produced via the coke oven/sinter plant/blast furnace route is about 19.3 GJ. The specific energy consumption for the production of electric arc furnaces steel is about 5.4 GJ/$t_{\text{Liquid Steel}}$ [1] (not taking into account the efficiency of electricity production)

3.9.2. Candidate technologies i.w.s. analysed for the iron and steel production

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

3.9.2.1. Blast furnaces

Technology 1: Higher Blast Temperature with Plasma Blast Superheating

Short description: An oxy-coal technique that will be reconsidered in the framework of the ULCOS program. Coal injection tends to decrease the efficiency of combustion. A higher blast temperature is obtained using electrically powered plasma blast super heating.
Positive environmental impact(s): Coke
Stage of development: Pilot plants
Bibliography: [1], [23], [63],[64]

Technology 2: Oxygen addition to the blast

Short description: An oxy-coal technique that will be reconsidered in the framework of the ULCOS program. Coal injection tends to decrease the efficiency of combustion, and here oxygen is added to the blast to avoid this disadvantage.
Positive environmental impact(s): Coke
Stage of development: Pilot plants
Bibliography: [1], [23], [63], [64]

Technology 3: Pulverised Coal Injection

Short description: This partial substitution of coke in the blast furnace by pulverised coal is a common industrial procedure. However the CO_2 emissions are higher compared to liquid or gas fuel injection.
Positive environmental impact(s): Coke, emissions
Emission reduction or emission factor: 30% less coke use
Stage of development: commercial
Bibliography: [1], [35], [63], [64]

Technology 4: Auxiliary Reducing Agents

Short description: Injection of auxiliary reducing agents (coal, natural gas, heavy fuel oil, coal breeze, plastics, biomass, etc.) into the tuyères of a blast furnace. The injection of alternative reducing agents is only a question of cost and/or revenues. There are legislative barriers in certain countries for injection of residues such as plastics.
Positive environmental impact(s): Coke
Bibliography: [1], [35], [63], [64]

Technology 5: Zero Waste Process

Short description: This process converts all relevant steel works residues into valuable by-products. This could be of interest for stainless steel making, however technical and economical evaluations still have to be completed.
Positive environmental impact(s): CO_2
Stage of development: Some test campaigns (5t slag per campaign) are carried out in an adapted vessel in Vitkovice (Czech Rep.).
Bibliography: [115], [63], [64]

Technology 6: Slag Heat Recovery

Short description: The slag Temperature is approximately 1450°C, and there are 250-300 kg_{slag} per $t_{pig\ iron}$. However this principle could be technically and economically very problematic.
Positive environmental impact(s): Heat
Emission reduction or emission factor: 0.35 $GJ/t_{pig\ iron}$
Stage of development: Tests
Bibliography: [1], [23], [63]

3.9.2.2. Basic Oxygen Furnace

Technology 1: Use of Inert gas Above the Hot Metal (CO_2, N_2)

Short description: Reducing the O_2 concentration above the hot metal during pig iron pre-treatment reduces the generation of oxides and PM.

[63] Minutes of the Workshop on Emerging Technologies, Session "Ferrous Metals", 28-29 June 2004, Brussels

[64] Comments by Jean Pierre Debruxelles with EUROFER on the Ferrous Metals sector, received on 15 September 2004

Positive environmental impact(s): PM
Stage of development: Tests in certain plants.
Bibliography: [1], [23], [63], [64]

Technology 2: Near Net-shape and Horizontal Casting

Short description: This type of casting allows to connect directly with the downstream hot rolling process.
Positive environmental impact(s): Energy
Stage of development: Commercial
Bibliography: [1], [32]

Technology 3: Processing of Zn-Rich Dusts

Short description: Extraction of the non-ferrous metals from the dust.
Positive environmental impact(s): Material
Stage of development: Commercial
Bibliography: [1], [23]

Technology 4: New Reagents in Desulphurisation Process

Positive environmental impact(s): PM, SO_x
Stage of development: Under Development
Bibliography: [1]

Technology 5: Foaming Techniques at Pig Iron Pretreatment

Short description: The foam absorbs the particulate matter arising from the hot metal processing.
Positive environmental impact(s): PM
Stage of development: Available
Bibliography: [1], [23]

3.9.2.3. Electric Arc Furnaces, Direct Reduction, Smelting reduction

Technology 1: New Concepts for Electric Arc Furnaces

Short description: The major energy input is electricity. Some concepts are the Comelt EAF, the Conarc EAF, the Contiarc EAF, Hytemp technology, and the Finger Shaft Furnace.
Positive environmental impact(s): Coke
Stage of development: Commercial
Bibliography: [2], [17], [3], [76], [23], [32]

Technology 2: Direct Reduction

Short description: Involves the reduction of iron ore in the solid state to metallic sponge iron without melting,. Process temperatures are less than 1000 °C. Some examples of technologies are Midrex, Hyl, Fior, Fastmet, Iron carbide, Circored, Inmetco, Finmet, AREX, SL/RN, CIRCOFER, PRIMUS, Danarex.
Positive environmental impact(s): CO_2
Bibliography: [3], [23], [1], [2], [129], [147]

Technology 3: Smelting Reduction

Short description: Iron oxide is reduced in the liquid state in pig iron or liquid steel or metal by carbon or carbon monoxide. Hismelt, DIOS, AISI-DOE, CCF, Romelt, Jupiter, CIP.
Bibliography: [1], [3], [129], [32]

Technology 4: Electrolysis, Molten Oxide Electrolysis

Short description: Electrolysis of iron ore. One electrolysis process: iron oxide is electrolytically decomposed to produce liquid iron at the cathode and oxygen gas at the anode. For this process there is one pilot plant. This technology will be studied in the framework of the ULCOS program.
Positive environmental impact(s): CO_2
Stage of development: Under development
Bibliography: [1], [2], [3], [138] [64]

3.9.3. List of candidate technologies i.w.s. analysed for the iron and steel production sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

3.9.3.1. Blast furnaces

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Higher Blast Temperature with Plasma Blast Superheating	Coke	X				+
Oxygen addition to the blast	Coke	X			X	+
Pulverised Coal Injection	Coke, emissions	X		X	X	+
Auxiliary Reducing Agents	Coke	X		X	X	+
Zero Waste Process	CO_2	X			X	-
Slag Heat Recovery	Heat	X				-
Recycling Top Gas of Blast Furnace	CO_2	X		X		0
Synthetic Cold Blast SCB Process				X		0
Steel Sheet in Refractory Wall of Hot Stove with Internal Combustion Chamber	CO	X				0
Second Dedusting	PM			X		0

3.9.3.2. Basic Oxygen Furnace

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Use of Inert gas Above the Hot Metal (CO_2, N_2)	PM	X				+
Near Net-shape and Horizontal Casting	Energy	X		X		+
Gas and Heat Recovery at BOF						0
Processing of Zn-Rich Dusts	Material	X				+
New Reagents in Desulphurisation Process	PM, SO_x	X				+
Foaming Techniques at Pig Iron Pretreatment	PM	X				+
Blast furnace coupled with combined cycle CC	Efficiency			X		0

3.9.3.3. Electric Arc Furnaces

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
New Concepts for Electric Arc Furnaces	Coke			X	X	+
Comelt EAF	Energy	X		X		0
Conarc EAF	PM, Energy	X		X		0
Contiarc EAF		X		X		0
Scrap Sorting	PCB	X		X		0
Twin Electrodes DC				X		0
EAF Dust in WAELZ Process	Zn, Pb			X		0
Hytemp (Hot Charge of DRI)	Heat	X				0
Iron Carbide Melting in the EAF	Electricity	X				0
Energy Optimised Furnace	Electricity	X				0
Finger Shaft Furnace				X		0

3.9.3.4. Direct Reduction

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Direct Reduction	CO_2	X	X	X	X	+
Using Hydrogen as Reducing Agent	PM, CO_2, VOC, HM			X		0
Midrex Process	PM, CO_2, VOC, HM	X		X		0
HyL I, HyL II Process	PM, CO_2, VOC, HM	X				0
HyL III Process	PM, CO_2, VOC, HM	X		X		0
Fior	PM, CO_2, VOC, HM	X		X		0
Fastmet	PM, CO_2, VOC, HM	X				0
Iron Carbide	PM, CO_2, VOC, HM	X		X		0
Circored	PM, CO_2, VOC, HM	X		X		0
Inmetco	PM, CO_2, VOC, HM	X				0
Finmet	PM, CO_2, VOC, HM	X				0
AREX Process				X		0
Using Biomass and Charcoal	PM, CO_2, VOC, HM	X		X		0
SL/RN Process		X				0
Iron Dynamics	Coal			X		0
PRIMUS	Coal			X		0
Danarex Direct Reduction Process				x		0
CIRCOFER		X		X		0

3.9.3.5. Smelting reduction

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Smelting Reduction		X	X		X	+
COREX (see also FINEX)	Coke, PM, VOC, CN, HM	X				0
FINEX				X		0
HIsmelt	Energy, Coke, PM, VOC, HM	X		X		0
DIOS Process (Direct Iron Ore Smelting)	Energy, Coke, PM, VOC, HM	X		X		0
AISI-DOE (American Iron And Steel Institute, US Department Of Energy)	Energy, Coke, PM, VOC, HM	X		X		0
Cyclone Converter Furnace CCF	Energy, Coke, PM, VOC, HM	X		X		0
ROMELT	Energy, Coke, PM, VOC, HM	X		X		0
Redsmelt NST Process (New Smelting Technology)	PM, Zn			X		0
Kawasaki XR Process				X		0
Jupiter	Energy			X		0
High Intensity Smelting				X		0
INRED, ELRED, Plasmamelt				X		0
Centrifuge Iron Making Process (CIP)				X		0
Foster Gas In-Process Recycling				X		0

3.9.3.6. Electrolysis

Name of the technology	Positive environmental impact	BREF	Questionnaire	Other	Fact sheet	Assessment
Electrolysis, Molten Oxide Electrolysis	CO_2	X			X	+
Electrification of By-Products		X				0

3.10. Ferrous metals processing

3.10.1. Presentation of the ferrous metals processing sector

Sub-sectors of the Ferrous Metals Processing sector are: Hot and Cold Forming, Continuous Coating, Batch Galvanizing etc.

Hot and cold forming comprises different manufacturing methods, such as hot rolling, cold rolling and drawing of steel. A great variety of semi-finished and finished products are manufactured: hot and cold rolled flats, hot rolled long products, drawn long products, tubes and wires.

In the hot dip coating process, steel sheet or wire is continuously passed through molten metal. Main environmental issues are acidic air emissions and energy consumption of furnaces, Zinc-containing residues, oil- and chrome-containing waste waters.

Hot dip galvanizing is a corrosion protection process in which iron and steel fabrications are protected from corrosion by coating them with zinc. The size, amount and nature of the inputs can differ significantly. The items to be coated in batch galvanizing plants are e.g. steel fabrications, construction parts and structural components. Galvanized steel is used in construction, transport, agriculture, power transmission and where good corrosion protection and long life are essential.

The sector operates with short lead times and short order books to give enhanced service to customers. Distribution issues are important, and so plants are located close to market concentrations. Consequently, the industry consists of a relatively large number of plants (about 600 all over Europe), servicing regional markets in order to minimise distribution costs and increase economic efficiency [5].

3.10.2. Candidate technologies i.w.s. analysed for ferrous metals processing

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

3.10.2.1. Modern casting and rolling

Technology 1: Thin Slab Casting (TSC)

Short description: The casting mold is adapted to cast slabs with thicknesses of 40-50 mm for the compact strip production, 30-60mm for the inline strip production and 70-90 mm for the Conroll process. TCS facilities combine the caster and the rolling mill in one plant.
Positive environmental impact(s): Energy
Emission reduction or emission factor: Primary energy savings of 0.93-1.2 GJ/t
Stage of development: Several plants, technology improvement
Bibliography: [1], [129], [3], [17], [32], [40], [139], [5]

Technology 2: Spray Casting

Short description: Involves atomisation of the liquid metal and deposition of the formed droplets on a substrate.
Emission reduction or emission factor: Primary energy savings of 2.07-2.23 GJ/t
Stage of development: Pilot plant
Bibliography: [17]

Technology 3: Thin Slab Casting with Liquid Core Reaction (TSC with LCR)

Short description: Slabs with thicknesses of less than 25 mm can be cast by compressing the cast steel shortly after it leaves the mold, i.e. while the edges are already solid and the core is still liquid.
Emission reduction or emission factor: Primary energy savings of 1.52-1.59 GJ/t
Stage of development: Under demonstration
Bibliography: [17], [32], [139]

Technology 4: Powder Metallurgy

Short description: Shaping directly from a ferrous or non-ferrous powder by pressing it into a mold of the desired shape and subsequently heating (not smelting) it in a furnace to bond the fibers together.
Stage of development: Commercial
Bibliography: [17]

3.10.2.2. Hot rolling mill

Technology 1: Thin Strip Casting

Short description: Pouring molten steel between two rotating cylinders, which does not require a casting mold. Thin strip casting competes with hot and cold rolling mills.
Positive environmental impact(s): Energy
Emission reduction or emission factor: Primary energy savings of 2.23-2.46 GJ/t
Stage of development: 1 Pilot plant
Bibliography: [1], [129], [3], [17], [40]

Technology 2: Direct Strip Casting (DSC)

Short description: By direct casting of strip, which can be subsequently cold rolled, the process chain from liquid steel to the final product can be shortened.
Stage of development: Pilot plants
Bibliography: [5], [146]

Technology 3: Shell $DeNO_x$ Process

Short description: SCR with catalyst operation at lower temperatures of 120°C.
Positive environmental impact(s): NO_x
Bibliography: [5]

Technology 4: $DeNO_x$ Processes

Short description: Several technologies are included here: Regenerative Active Coal Process, Degussa H_2O_2 Process, Bio $DeNO_x$ Process
Positive environmental impact(s): NO_x
Bibliography: [5]

Technology 5: Endless Rolling

Short description: The transfer bars are welded together before they enter the finishing train in order to form an endless strip and divided to desired specific coil weight after the finishing mill.
Positive environmental impact(s): Energy
Stage of development: Pilot plant
Bibliography: [5]

Technology 6: Bio $DeNO_x$ Process

Bibliography: [5], [174]

3.10.2.3. Coating

Technology 1: Plasmait-PA (Plasma Annealing) and Plasmait -PC (Plasma Cleaning) Machines

Short description: Uses advanced magnetically coupled glow discharge plasma for annealing, cleaning and surface smoothing of steel, stainless steel and other materials.
Positive environmental impact(s): NO_x, CO, CO_2, Energy
Stage of development: One pilot plant
Bibliography: [254]

3.10.2.4. Batch Galvanizing

Technology 1: Low Fume Flux

Short description: Used for batch galvanizing instead of traditional 'double' or 'triple' salt flux.
Positive environmental impact(s): Emissions
Emission reduction or emission factor: PM emissions 5-10 mg/m³
Bibliography: [231], [65]

Technology 2: Drop Out Box (Fume Reduction At Source)

Short description: Substitution of the fabric filter.
Stage of development: Under development
Bibliography: [5]

Technology 3: Wiping System DAK (Dynamic Air Knife)

Short description: Achieves a high coating performance with reduced zinc consumption: a real time adjustment of zinc coating.
Stage of development: 12 facilities operating
Bibliography: [2]

3.10.3. List of candidate technologies i.w.s. analysed for the ferrous metals processing sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

3.10.3.1. Modern casting and rolling

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Thin Slab Casting (TSC)	Energy	X		X	X	+
Spray Casting				X		+
Thin Slab Casting with Liquid Core Reaction (TSC with LCR)				X		+
Powder Metallurgy				X		+
Recycling of Mill Scale				X		0
Compact Strip Production, Twin Roller				X		0

3.10.3.2. Hot rolling mill

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Thin Strip Casting	Energy	X		X	X	+
Direct Strip Casting (DSC)		X		X		+
Shell DeNO$_x$ Process	NO$_x$	X				0
DeNO$_x$	NO$_x$	X				0
Rotor Descaling	Energy	X				0
Endless Rolling	Energy	X				+
Directly Connected Rolling		X				+
By Product Recycling without Deoiling		X				0

[65] Minutes of the Workshop on Emerging Technologies, Session "Ferrous Metals", 28-29 June 2004, Brussels

Thermocon Process		X				0
Thermal Deoiling Process		X				0
DCR Process (Dispersion of Oil by Chemical Reaction)		X				0
TRF Process (Turbular Rotor Filter)		X				0
HP Process (High Pressure Method)		X				0
Temperature Measurement of Galvaneal Steel	Energy	X				0
Bio DeNOx Process		X		X		0

3.10.3.3. Cold rolling mill, Wire plants, Coating, Batch Galvanizing

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Pickling: Hydro-abrasive Predescaling (Ishi Clean)		X				0
Pickling: Predescaling by Ferromagnetic Abrasive		X				0
Acid Regeneration Process with Bipolar Membrane		X				0
Acid Regeneration Process with Electrodialysis		X				0
Plasmait-PA (Plasma Annealing) and Plasmait -PC (Plasma Cleaning)	NO_x, CO, CO_2, Energy		X		X	+
Passivation with Cr-free Products				X		0
Low Fume Flux	Emissions		X		X	+
Drop Out Box (Fume Reduction At Source)		X				+
Wiping System DAK (Dynamic Air Knife)				X		+
Thermaprep Process for Hot-Dip Batch Galvanizing	Energy	X				0

3.11. Non-ferrous metals industry

3.11.1. Presentation of the non-ferrous metals industry sector

Many high technology developments, particularly in the computing, electronic, telecommunications and transport industries are dependent upon non-ferrous metals and their alloys. In EU, at least 42 non-ferrrous metals are produced [6]. This sectors covers sintering and roasting as well as like rolling, drawing and pressing of non-ferrous metals but excludes foundry processes.
Metals are inherently recyclable and can be recycled time after time without losing any of their properties. Thus the recycling performance of the industry is unmatched by any other industry.

3.11.1.1. Copper and its Alloys

In 1997, there were ten major refineries, more than 100 Semis manufacuturing companies, some 20 companies producing electrical wire-rods and about 80 companies in the other copper semis manufacturing industry in EU-15. The EU copper industry has developed technologies to be able to process a wide range of copper scrap, including complex, low grade residues. Almost 100% of new or process copper scrap is recycled and according to some studies 95% of old copper scrap collected is also recycled. Altogether, secondary raw materials account for about 45% of the use of copper and it's alloys in Europe. The quality of secondary raw materials varies greatly and many sources of these materials are not suitable for direct use by the Semis manufacturers. Additional treatment or abatement systems may be needed.

Table 3-6: EU-15 and EAA Production of copper and its alloys in thousand tons in 1997

Country	Mine production	Primary cathode(Anode)	Secondary cathode (anode)	Semis Production
Austria	-	-	77	58
Belgium	-	203 (35)	183 (126)	392
Finland	9	116 (171)	-	120
France	-	6	29	684
Germany	-	296	378	1406
Greece	-	-	-	81
Italy	-	6	80	990
Portugal	108	-	-	-
Spain	37	229 (+61)	63 (+28)	268
Sweden	87	95	34	206
UK		9	58	483
Norway	7 *	33	-	-
Switzerland	-	-	-	70
Notes: * Current ore production will cease in 2000.				

The main environmental issues associated with the production of secondary copper are also related to the off-gases from the various furnaces in use. These gases are cleaned in fabric filters and thus the emissions of dust and metal compounds such as Pb can be reduced. There is also the potential for the formation of PCDFs due to the presence of small amounts of chlorine in the secondary raw materials. Hence, the destruction of dioxins is an issue that is being pursued. Fugitive or uncaptured emissions are also an issue that is becoming increasingly important for both primary and secondary production.

3.11.1.2. Aluminium

In 1997, total production of un-wrought Al amounted to 3.9 million tons of which about 43% (1.7 million tons) is accounted for by the processing of recycled scrap, which has been constantly increasing. In 1998, 22 primary aluminium smelters were operating in EU-15, and another 8 in the EEA. The number of companies involved in secondary aluminium production is much larger. There are about 200 companies whose annual production of secondary aluminium is more than 1000 tons per year [tm 116, Alfed 1998].
The main air emissions are poly-fluorinated hydrocarbons and fluorides from primary aluminium production during electrolysis as well as dust and dioxins from secondary aluminium production. Primary aluminium production is

very energy demanding, whereas the production and refining of secondary aluminium consumes less than 5% of the energy needed to produce primary aluminium.

Country	Bauxite production	Alumina production	Primary aluminium	Secondary aluminium	Semis production
Austria	-	-	-	98	189
Belgium	-	-	-	-	353
Denmark	-	-	-	14	18
Finland	-	-	-	33	35
France	-	600	399	233	741
Germany	-	750	572	433	1797
Greece	2211	640	133	10	213
Ireland	-	1250	-	-	-
Italy	-	880	188	443	862
Netherlands	-	-	232	150	200
Portugal	-	-	-	3	-
Spain	-	1110	360	154	330
Sweden	-	-	98	26	131
UK	-	120	248	257	507
Iceland	-	-	123	-	-
Norway	-	-	919	59	250
Switzerland	-	-	27	6	131

Table 3-7: European aluminium production in thousand tons in 1997

3.11.1.3. Zinc

Country	Process	Capacitiy [t/a]
Belgium	E	200000
Finland	E	175000
France	E ISF-RT	220000 100000
Germany	E ISF-RT E	96000 100000 130000
Italy	ISF-RT E E	75000 100000 80000
Netherlands	E	210000
Spain	E E	320000 60000
UK	ISF-RT	105000
Norway	E	140000
E = Electrolytic plant ISF = Imperial Smelting Furnace RT = Fire Refining Source: industry statistics		

Table 3-8: Top European producers in terms of annual capacity, 1994

In 1994, 1,749,000 ton of zinc, nearly 33% of the market economy countries' total, were produced in EU-15. Zinc [tm 36, Panorama 1997; tm 120, TU Aachen 1998] has the third highest usage of non-ferrous metals, trailing aluminium and copper. The metal is produced from a range of zinc concentrates by pyrometallurgical or hydrometallurgical processes, mainly the roast-leach-electro-winning processes and by the Imperial Smelting Furnace – distillation process .

Fugitive emissions from roasting and calcinating are very important and need to be considered for all of the process stages. A recovery rate of 80% of recoverable zinc has been reached.

3.11.1.4. Lead

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EU-15 lead production was 1,398,000 tons in 1994. Refined lead is derived from primary material in the form of lead ores and concentrates, and secondary material in form of scrap and residue, that together accounted for 52% of total production. The United Kingdom, Germany, France and Italy were the major producers. Within EU-15 there were 7 primary smelters/refiners whose production capacity ranges in size from 40,000 to 245,000 tons per year. The secondary industry is characterised by a large number of smaller refineries, of which many are independent. The battery industry are responsible for up to 70% of the demand and is fairly stable but other uses are in decline.

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Country	Lead blast furnace *	Direct smelting *	Secondary rotary furnaces	Total Lead Refining
Austria	-	-	32000	32000
Belgium	115000	-	20000	175000
France	110000	-	162000	299000
Germany	35000	220000	130000	507000
Greece	-	-	12000	12000
Italy	-	90000	125000	235000
Netherlands	-	-	20000	20000
Spain	14000	-	62000	76000
Sweden	50000	65000	-	155000
UK	-	40000 (200 000 t/a refining capacity)	107000	307000
* Primary and / or secondary raw materials				

Table 3-9: Annual capacities for EU-15 Lead processing [t/a]

The main environmental issues associated with the production of secondary lead are also related to the off-gases from the various furnaces in use. The off-gases are cleaned in fabric filters to reduce the emissions of dust and metal compounds. There is also the potential for the formation of dioxins.

3.11.2. Promising emerging technologies for the non-ferrous metals industry

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

3.11.2.1. Primary Lead and Zinc Production

Technology 1: Clean Lead

Short description: This process is based on a hydrometallurgical technology. It comprises battery paste desulphurisation and leaching to get a lead liquor as well as a sellable gypsum product.
Positive environmental impact(s): Emissions, SO_2
Stage of development: Demonstration Plant
Bibliography: [235], [66]

Technology 2: ZincEx Process

Short description: This is a hydrometallurgical technology able to treat primary and secondary zinc bearing materials.
Positive environmental impact(s): Emissions
Stage of development: Commercially available
Bibliography: [233], [66]

Technology 3: Modified ZincEx Process (MZP)

Short description: This is a hydrometallurgical technology able to treat primary and secondary zinc bearing materials. The process uses a leaching, solvent extraction and zinc production unit to yield electrolytic lead (SHG quality) or a pure salt.
Positive environmental impact(s): Emissions
Emission reduction or emission factor: No emissions except CO_2
Stage of development: Commercially available
Bibliography: [234]

Technology 4: Placid and Placid Intermediate (PLINT) Processes

Short description: Hydrometallurgical technologies that intend to complement and improve existing smelting technologies for lead acid batteries recycling.
Positive environmental impact(s): Emissions
Emission reduction or emission factor: 90% emissions reduction
Stage of development: Pilot Plant
Bibliography: [236]

[66] Minutes of the Workshop on Emerging Technologies, Session "Non-Ferrous Metals", 28-29 June 2004, Brussels

Technology 5: Ezinex Process

Short description: Ammonia/ammonium chloride based leaching followed by cementation and electrolysis.
Positive environmental impact(s): PM
Stage of development: 1 Plant
Bibliography: [6], [159]

Technology 6: Advanced Forming

Short description: Near net shape or thin strip casting integrates the casting and hot rolling of aluminium into one process step, thereby reducing the need to reheat the aluminium ingot before rolling it.
Positive environmental impact(s): Energy
Emission reduction or emission factor: - 12% primary energy used
Stage of development: Near commercial
Bibliography: [32]

Technology 7: Processing of Jarosite and Sewage Sludge in Autoclave

Short description: The cellulose in the sewage sludge is the source of energy and the product is a molten material.
Stage of development: Reported
Bibliography: [6]

Technology 8: Smelting of Jarosite and Goethite

Stage of development: Demonstrated
Bibliography: [6]

Technology 9: Graveliet

Short description: In a low energy process, iron slag is treated with goethite resulting in stones that may be used in concrete.
Positive environmental impact(s): Energy
Stage of development: The process is considered available and fit for scale up. A pilot plant for the Umicore's Graveliet process was run for several months on a continuous and semi-continuous basis, with a capacity of 2 t graveliet/h (compared to approximately 40 t graveliet/h for a full scale plant). The weight ratio graveliet/goethite is approximately 3 to 1. The regime is 5 days / week. Costs for the Opex are approx. 5 MEuro/year = 60 Euro/t goethite, 50% of costs for purchase of slags and transport, 50% for other operational costs (labour, energy, maintenance, ...). Costs for Capex are approx. 25 MEuro. The Flemish authorities (environmental department "OVAM") delivered a certificate for the use of graveliet in bonded concrete applications.
Bibliography: [6], [66]

Technology 10: Ausmelt, Outokumpu Processes

Short description: Zinc and other volatile metals are fumed off and recovered. The slag produced could be suitable for construction processes.
Stage of development: Demonstrated in one plant
Bibliography: [6] , [66]

Technology 11: Outokumpu Flash Smelting Furnace

Short description: Production of lead by direct smelting.
Emission reduction or emission factor: Demonstration
Bibliography: [6]

Technology 12: Waelz Kiln, SDHL Process

Short description: Production of lead by direct smelting.
Stage of development: Reported
Bibliography: [6], [175]

Technology 13: Jarofix

Short description: In the Jarofix process, jarosite precipitates made during the leaching of zinc ferrites, which are not stable, are mixed with preset ratios of Portland cement, lime, and water. The reaction generates a chemically and physically stable material, reducing the long-term liability associated with iron residue disposal while offering concomitant processing advantages. Supporting mineralogical studies of aged Jarofix products indicate that jarosite reacts with the alkaline constituents of the cement to form various stable phases that incorporate zinc and other soluble metals. The persistence of alkaline phases in the Jarofix product helps to ensure its long-term

environmental stability. This stabilisation/solidification process was successfully implemented into existing operations in 1998.
Positive environmental impact(s): Waste
Stage of development: Integrated in many operations
Bibliography: [6], [264] , [66]

Technology 14: Concentrate From Newer Mines

Short description: These fine ground concentrates are often characterised by low iron, elevated silica, high manganese levels as well as of elements such as germanium, which may cause concern.
Stage of development: New technology
Bibliography: [6]

Technology 15: Leaching Process Based on Chloride

Stage of development: Demonstration stage
Bibliography: [6]

3.11.2.2. Primary Copper

Technology 1: Bath Smelting Techniques

Short description: According to the experts there are 5-6 bath smelting technologies available.
Stage of development: Under development
Bibliography: [6] , [66]

Technology 2: ISA Smelt

Short description: Technology for reduction / oxidation. The ISA Smelter technology was developed at the end of the 1980s. ISA Smelters have a bigger off-gas volume than Flash smelters.
Stage of development: Emerging, five plants in operation world-wide for Cu, Pb and Zn
Bibliography: [6] , [66]

Technology 3: Hydro-Metallurgical Process

Short description: Suitable for mixed oxidic / sulphidic ores that contain low concentrations of precious metals.
Stage of development: Emerging
Bibliography: [6]

Technology 4: Leach/Solvent extraction/ Electro win L:SX:EW

Short description: Concentrate and dust treatment based on leaching.
Positive environmental impact(s): PM
Stage of development: Emerging
Bibliography: [6]

Technology 5: Modern Fabric or Bag Filters

Short description: According to experts this technology is commercially available.
Stage of development: Emerging for copper production
Bibliography: [6] , [66]

3.11.2.3. Primary Aluminium Production

Technology 1: Improved Electrodes (Inert Anodes, Wettable Cathodes = Drain Cells)

Short description: A new carbon free anode (ceramic), which would make it possible to construct a completely new electrolytic cell, and producing O_2 at the cathode instead of CO_2.
Positive environmental impact(s): CO, PAH, CF
Stage of development: Pilot plant
Bibliography: [6], [14], [32], [150]

Technology 2: New Decoating Kilns for Aluminium Scrap

Short description: Decoating of metals using indirect-fired, controlled atmosphere kilns.
Positive environmental impact(s): Energy
Emission reduction or emission factor: -41%

Stage of development: Demonstrations
Bibliography: [32], [150]

Technology 3: Vertical Floatation Melter VFM

Short description: Simultaneous decoating and melting of aluminium scrap.
Positive environmental impact(s): Energy, NO_x, SO_x, CO, and VOC
Stage of development: Pilot scale
Bibliography: [150]

Technology 4: Electric Arc Furnace

Short description: For salt free melting of drosses.
Bibliography: [6], [14]

Technology 5: Use of Regenerative Thermal Oxidiser (Afterburner) for Anode Bake Ovens

Short description: This is a continuous operation, which is a new area of application of an existing technology. There is an increase of the energy consumption.
Positive environmental impact(s): POPs
Emission reduction or emission factor: 90% reduction of POPs
Stage of development: Used in 3 plants and can be retrofitted.
Bibliography: [263] , [66]

Technology 6: Alloy Separation

Short description: Technologies for separation of aluminium scrap into different types of alloy have been tested using laser and eddy current technology.
Emission reduction or emission factor: Electricity -1,600 Wh/t
Stage of development: Tested
Bibliography: [6], [14]

Technology 7: Rotary Flux or Gas Injection for Refining

Stage of development: Pilot plants
Bibliography: [6], [14]

Technology 8: Reuse of Filter Dust

Short description: The dust is collected in a fabric filter and can be included with the salt charged to the furnace.
Stage of development: Pilot plants
Bibliography: [6]

Technology 9: Recover Iron from Red Mud

Stage of development: Under development
Bibliography: [6], [14]

Technology 10: Use of Recycled Iron in Construction

Stage of development: Research
Bibliography: [6], [14]

3.11.3. List of candidate technologies i.w.s. analysed for the non-ferrous metals industry sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

3.11.3.1. Primary Lead and ZincProduction

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Clean Lead	Emissions, SO_2		X			+
ZincEx Process	Emissions		X			+
Modified ZincEx Process (MZP)	Emissions		X			+
Placid and Placid Intermediate (PLINT) Processes	Emissions		X			+
Ezinex Process	PM					+
Advanced Forming	Energy			X		+
Processing of Jarosite and Sewage Sludge in Autoclave		X				0
Smelting of Jarosite and Goethite		X				0
Graveliet	Energy	X		X		+
Ausmelt, Outokumpu Processes		X		X		+
Outokumpu Flash Smelting Furnace		X				+
Waelz Kiln, SDHL Process		X		X		0
Jarofix	Waste	X		X		+
Concentrate From Newer Mines		X				0
Leaching Process Based on Chloride		X				0
Injection of Fines in Tuyères of BF	Energy	X				0
Control Parameter Temperature	Zn, Pb	X				0
Furnace Control Systems		X				0
BSN Process		X				0

3.11.3.2. Primary Copper

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Bath Smelting Techniques		X		X		+
ISA Smelt		X		X		+
Hydro-Metallurgical Process		X				+
Leach/Solvent extraction/ Electro win L:SX:EW	PM	X				0
Modern Fabric or Bag Filters		X		X		+
Sealed Charging Cars or Skips	Fugitive, fume	X				0
Intelligent Damper Controls	Fugitive, fume	X				0

3.11.3.3. Primary Aluminium Production

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment

Improved Electrodes (Inert Anodes, Wettable Cathodes = Drain Cells)	CO, PAH, CF	X				0
Efficient Cell Retrofit Design	Energy			X		0
New Decoating Kilns for Aluminium Scrap	Energy			X		0
Vertical Floatation Melter VFM	Energy, NO_x, SO_x, CO, VOC	X				0
Electric Arc Furnace		X		X		0
Use of Regenerative Thermal Oxidiser (Afterburner) for Anode Bake Ovens	POPs		X	X		+
Alloy Separation		X		X		0
Rotary Flux or Gas Injection for Refining		X		X		0
Catalytic Filter Bag	PCDDs/Fs	X		X		+
Processing of Salt Slag		X		X		0
Salt Recovery with Electro-Dialysis		X		X		0
Continuous Monitoring of HF	HF	X		X		0
Reuse of Filter Dust		X				0
Recover Iron from Red Mud		X		X		0
Use of Recycled Iron in Construction		X		X		0

3.11.3.4. Sulphur Removal

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Combination of Single Contact Sulphuric and Modified Tower Acid Plant	SO_2	X				0
Biological Flue Gas De-Sulphurisation Process	SO_2	X				0

3.12. Foundries

3.12.1. Presentation of the foundries sector

Foundries melt ferrous and non-ferrous metals and alloys and reshape them into products at or near their finished shape through the pouring and solidification of the molten metal or alloy into a mould. The organisation within the sector is based on the type of metal input, with the main distinction being made between ferrous and non-ferrous foundries [266].

Table 3-10: Ferrous (iron, steel and malleable iron) castings, and non-ferrous metal castings in Europe in 2002 (in thousand tons) [168, CAEF, 2002], [202, TWG, 2002] (n.d. = no data)

Country	Ferrous (iron, steel and malleable iron) castings		Non-ferrous metal castings	
	Productionin thousand tons	Number of foundries	Production in thousand tons	Number of foundries
Austria	181.2	41	116.2	61
Belgium	143.7	21	26.7	10
Czech Republic	381.6	143	59.6	63
Denmark	87.3	12	4.6	8
Estonia	1.1	1	0	0
Finland	112.5	19	9.7	25
France	2128.6	159	390.3	283
Germany	3749.7	273	845.8	400
Great Britain	886.3*	179*	n.d.	n.d.
Hungary	67.9	n.d.	68.3	n.d.
Ireland	n.d.	n.d.	n.d.	-
Italy	1460.9	281	979.7	n.d.
Netherlands	123.7	n.d.	n.d.	n.d.
Norway	67.3	11	26.7	13
Poland	598.0	190	76.3	280
Portugal	96.7	61	25.6	54
Slovakia	n.d.	n.d.	n.d.	n.d.
Slovenia	n.d.	n.d.	n.d.	n.d.
Spain	992.9	98	149.9	57
Sweden	234.6	50	52.9	84
Switzerland	81.8**	20	21.1	48
* Without steel casting ** Without steel and malleable iron castings				

3.12.2. Candidate technologies i.w.s. analysed for foundries

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

Technology 1: FAR Furnace

Short description: In order to reduce the consumption of (high quality) coke, technologies have been developed to allow the use of high calorific value solid waste and lower grade coke as a fuel.
Positive environmental impact(s): less coke use
Stage of development: Pilot scale
Bibliography: [4]

Technology 2: Low Cost Coke

Short description: The use of low cost coke increases the CO concentration in waste gas, which allows its combustion in a 950°C hot chamber.
Positive environmental impact(s): CO, PM, Heat
Emission reduction or emission factor: PM 9-20 mg/Nm³

Bibliography: [12]

Technology 3: Recycling Filter Dust

Short description: Metal-bearing dust will be agglomerated either using a binder (most preferably cement) or by mixing it with chips from machining, when the foundry has a machining shop.
Positive environmental impact(s): Dust
Stage of development: Under development
Bibliography: [4]

Technology 4 Separate Spraying of Release Agent and Water in Aluminium Die-Casting

Short description: Water and release agent are applied separately. A row of nozzles is added to the spray head for the separate application of release agent.
Stage of development: Tests
Bibliography: [4]

Technology 5 Inorganic Binder Material for Core-Making

Short description: In order to reduce the consumption of organic binding material (responsible for emissions and odour in foundries), different compositions of inorganic binding materials have been developed.
Positive environmental impact(s): Emissions
Stage of development: Applied
Bibliography: [4] [67]

3.12.3. List of candidate technologies i.w.s. analysed for the foundries sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop (“+” positive assessment, “-“ negative assessment, “0” no assessment).

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
FAR Furnace	Coke	x			X	+
Low Cost Coke	CO, PM, Heat			X		+
Recycling Filter Dust	Dust	X			X	+
Amine Recovery from the Core-making Waste Gas by Gas Permeation	Amines	X			X	+
Separate Spraying of Release Agent and Water in Aluminium Die-Casting		X				+
Internal Cleaning of Pipings	Energy			X		+
Inorganic Binder Material for Core-Making	Emissions	X			X	+
Low-Emission PUR-Cold-Box-Binder	PCDDs/Fs			X		0
Biofilter	Dusts, VOC			X		0

[67] U. Anders: „Ökologisch und ökonomisch optimierter Trennstoffeinsatz beim Aluminiumdruckguss“, in „Integrierter Umweltschutz in Gießereien“. Verein Deutscher Gießereifachleute, 2003.

3.13. Pulp and Paper

3.13.1. Presentation of the pulp and paper sector

The term paper covers paper and paperboard of all grammages. In Europe[68] there are 900 companies producing some 95 million tons of paper and board and 41 million tons of pulp (29% of the world production). Main paper producers are Germany (20.2%), Finland (14.2%), Sweden (12.4%), France (11.7%), Italy (9.6%) and UK (8.5%) and main pulp producers are Finland and Sweden (Figure 3-2) [20].
The total number of paper mills in Western Europe is 1064 of which 679 are located in Italy, Germany, France and Spain [20]. In the last 25 years the number of paper machines in Europe has been reduced by about 60% while the total capacity has almost doubled. There are only 66 paper mills with a capacity of more than 250,000 t/a but still 342 mills with a capacity below 10,000 t/a. Pulp production is integrated in about 30% of the paper mills [20]. Western European pulp mills have an average size of 180,000 t/a [20].
53% of the used paper and board are recycled[69] corresponding to 45% of total fibres used for papermaking [20].

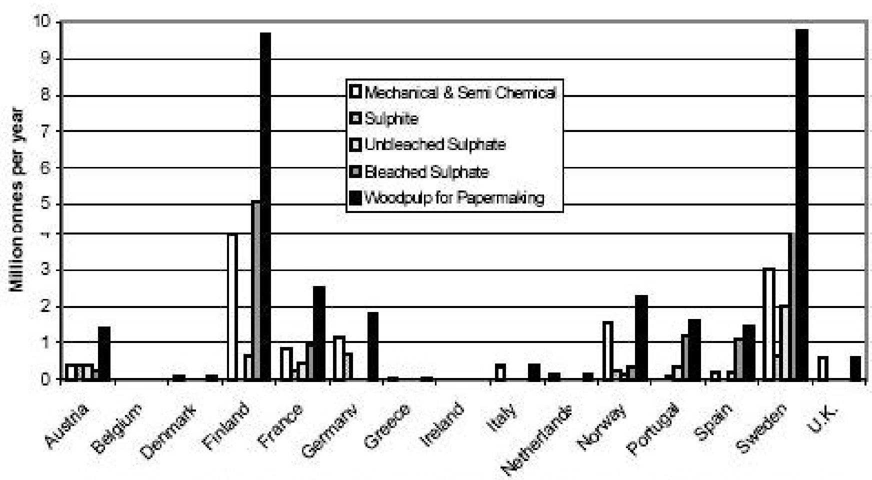

Figure 3-2: Overview of the distribution of industry for pulp production in Europe [CEPI 1997, Annual Statistics 1996]

3.13.2. Candidate technologies i.w.s. analysed for the pulp and paper sector

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

After the workshop, the consortium received the following statement by CEPI: The exercise done in the project cannot be considered as a full assessment of emerging technologies for air pollution abatement measures in the pulp and paper industry[70] but must be seen as a first step towards this target.

[68] EU-15 plus Czech Rep., Hungary, Norway, Poland, Slovakia and Switzerland

[69] http://www.esc.eu.int/ccmi/audition_events/reach20102004/paper_Pantsar-Kallio.ppt

3.13.2.1. Kraft (sulphate) pulping process

Technology 1: Gasification of Back Liquor

Short description: The gasification is an alternative to direct combustion of black liquor. There are two types of gasification: the low and the high temperature gasification.
Positive environmental impact(s): Energy, emissions, PM, NO_x
Stage of development: Pilot Plants
Bibliography: [20], [32], [177], [71]

Technology 2: Integrated Gasification with Combined Cycle Technology IGCC

Short description: Technology for pulp mills for the generation of a surplus of electrical energy. After gasification, combustion in gas turbines designed to accommodate the lower energy content of the black liquor gas.
Positive environmental impact(s): Energy, Emissions, PM, NO_x
Emission reduction or emission factor: Prim. Energy -23%
Stage of development: Pilot Plants
Bibliography: [20], [32], [177], [71]

Technology 3: Chemrec Process

Short description: A gasification technology.
Positive environmental impact(s): Energy, Emissions
Stage of development: Pilot Plants
Bibliography: [20], [177], [71]

Technology 4: SCR on recovery boiler

Short description: New area of application of an existing technology.
Positive environmental impact(s): NO_x
Emission reduction or emission factor: 70-90% NO_x reduction
Stage of development: Demonstration Pilot Plants
Bibliography: [182], [72], [73]

Technology 5: Direct Electrolytic Causticizing

Short description: An electrolysis cell is used to remove carbonate from the green liquor (usually the green liquor is re-causticized to convert sodium carbonate Na_2CO_3 back to NaOH and a precipitate of $CaCO_3$ that is removed).
Positive environmental impact(s): Emissions, PM
Stage of development: Pre-commercial
Bibliography: [32], [177], [74]

Technology 6: ASAM, FORMACELL, MILOX Processes, Organosolv Pulping

Short description: These processes are based on organic solvents.
Stage of development: Under development
Bibliography: [20], [177]

[70] Comments by Inneke Claes with CEPI - Confederation of European Paper Industries – on the Pulp and Paper Fact Sheets “Assessment of Emerging Technologies” and on the Workshop “Emerging Technologies” received on 26 July 2004

[71] Comments by Lennart Delin with ÅF-Celpap AB for CEPI - Confederation of European Paper Industries – on the Pulp and Paper Fact Sheet “Gasification of Black Liquor” received on 26 July 2004

[72] Comments by Ann-Mari Carlsson with ÅF-Celpap AB for CEPI - Confederation of European Paper Industries – on the Pulp and Paper Fact Sheet “SCR on Recovery Boilers at Kraft Pulp Mills”, received on 26 July 2004

[73] Minutes of the Workshop on Emerging Technologies, Session “Pulp and Paper”, 28-29 June 2004, Brussels

[74] Comments by Mattias Redeborn and Malin Nilsson with ÅF-Celpap AB for CEPI – Confederation of European Paper Industries – on the Pulp and Paper Fact Sheet “SCR on Recovery Boilers at Kraft Pulp Mills”, received on 26 July 2004

Technology 7: NO_xOUT Process

Short description: Makes use of the principle of Selective Non Catalytic Reduction (SNCR) to cut down NO_x emissions.
Positive environmental impact(s): NO_x
Emission reduction or emission factor: NO_x 55 mg/Nm³, 50%, 50-80 mg NO_x/MJ
Stage of development: 1 Plant
Bibliography: [20], [177]

3.13.2.2. Sulphite pulping process

Technology 1: Organosolv Pulping

Short description: Based on organic solvents.
Stage of development: Under development
Bibliography: [20], [177]

3.13.2.3. Recovered paper

Technology 1: Recovery of Boiler Ash and CO_2 for use in Paper

Short description: Uses both ash and carbon dioxide to produce a type of recycled mineral filler precipitated calcium carbonate (RMF PCC) for use in paper.
Positive environmental impact(s): CO_2
Stage of development: Tests
Bibliography: [20], [177]

3.13.2.4. Paper making

Technology 1: Impulse Drying Technology

Short description: The wet paper web is exposed to an intense impulse of heat energy under pressure between a hot rotating roll (300-900°C) and a static concave conventional shoe press.
Positive environmental impact(s): Energy
Emission reduction or emission factor: Primary energy -13%
Stage of development: Under development, US commercial
Bibliography: [20], [32], [75]

Technology 2: Condensing Belt Drying Condebelt

Short description: The paper is dried in a drying chamber by contact with a continuous hot steel band, heated either by steam or hot gas, rather than being run through the steam-heated cylinders. There are high investments that question whether this technology can be economically feasible.
Positive environmental impact(s): Energy
Emission reduction or emission factor: Primary energy -15%
Stage of development: 2 Plants
Bibliography: [20], [32], [75], [73]

Technology 3: Total Site Integration Tool

Short description: An intelligent process solution should try to combine the whole energy / water / fibers / chemicals system to create a better integration of the mill.
Positive environmental impact(s): Energy, emissions
Stage of development: Under development
Bibliography: [20]

3.13.3. List of candidate technologies i.w.s. analysed for the the pulp and paper sector

[75] MAASKOLA Ilkka, ÅF-Celpap AB for the CEPI - Confederation of European Paper Industries, Comments on the Pulp and Paper Fact Sheet "SCR on Recovery Boilers at Kraft Pulp Mills", received the 26 July 2004

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

According to CEPI, the Fact Sheets presented in the Pulp and Paper session at the workshop are taken from two literature sources: the Reference Document on Best Available Techniques in the Pulp and Paper Industry [20] and the report "Emerging Energy-Efficient Industrial Technologies" [32]. These sources reflect the situation in the Pulp and Paper Industry around 1999-2000. Emerging technologies five years ago may have developed further or may have been abandoned, and there may be new emerging technologies developed. The second document is a study with a North American perspective. Energy efficient technologies in the pulp and paper industry have been developed further in European countries in the recent years [76].

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Gasification of Back Liquor	Energy, Emissions, PM, NO_x	X		X	X	+
Integrated Gasification with Combined Cycle Technology IGCC	Energy, Emissions, PM, NO_x	X		X	X	+
Chemrec Process	Energy, Emissions	X		X	X	0
SCR on recovery boiler	NO_x		X		X	+
Direct Electrolytic Causticizing	Emissions, PM			X	X	+
ASAM, FORMACELL, MILOX Processes, Organosolv Pulping		X		X		0
NO_xOUT Process	NO_x	X		X		0
Increasing System Closure	Energy	X		X		0
Bifunctional Iron-Chelate Process	H_2S			X		0
Organosolv Pulping		X		X		0
LO-Cat	H_2S			X		0
Sulfint/Sulferex	H_2S			X		0
RTS Process (Retention, Temperature, Speed)	Energy	X		X		-
Thermopulp Process	Energy	X		X		-
Recovery of Boiler Ash and CO_2 for use in Paper	CO_2	X		x		0
Impulse Drying Technology	Energy	X		X	X	+
Condensing Belt Drying Condebelt	Energy	X		X	X	-
Heat Recovery Technologies for Paper	Energy (Heat), Emissions			X	X	0
Dry Sheet Forming	Energy			X	X	-
High Consistency Forming (SymFlo HC)	Energy			X	X	0
Total Site Integration Tool	Energy, Emissions	X				0

[76] Comments by Inneke Claes with CEPI – Confederation of European Paper Industries – on Pulp and Paper Fact Sheets "Assessment of Emerging Technologies" and on the Workshop "Emerging Technologies", received on 26 July 2004

3.14. Glass production

3.14.1. Presentation of the glass production sector

Table 3-11: Approximate sector based breakdown of Glass Industry production in the EU-15 in 1996

Sector	% of Total EU-15 Production (1996)
Container Glass	60
Flat Glass	22
Continuous Filament Glass Fibre	1.8
Domestic Glass	3.6
Special Glass	5.8
Mineral Wool	6.8
Ceramic Fibre	-
Glass Frit and Enamel Frit	-

60% of total glass production can be allocated to the container glass sector, making it the largest of the EU Glass Industry. Although some machine-made tableware may also be produced in this sector, it largely is made up by glass packaging, i.e. bottles and jars [8]. Western Europe is the biggest producer of container glass, followed by the USA and Japan. [8].
There are few major companies (with the notable exception of Saint-Gobain) operating in more than two of the eight sectors specified in Table 3-11, e.g. the Owens Corning Corporation specialises in glass fibre technology, continuous filament glass fibre and glass wool, PPG is a large international producer of flat glass and continuous filament glass fibre, and the Pilkington Group specialises mainly in flat glass activities. [8]

Table 3-12: Distribution of container glass installations in Member States

Member State		Germany	France	Italy	U.K.	Spain	Portugal	Netherland	Austria	Belgium	Greece	Finland	Denmark	Ireland	Sweden	Luxembourg	Total
Container Glass	**Number of furnaces**	70	54	54	32	23	17	13	9	9	5	2	3	2	2	-	295
	% of EU-15 production	26	20	17	11	10	-	-	-	-	-	-	-	-	-	-	17,316,000 t (in 1997)
Flat glass	**Number of float tanks**	9	6	6	3	4	1	1	-	6	-	1	-	-	1	2	40
	% of EU-15 production	20	15	15	10	10	-	-	-	15	-	-	-	-	-	-	6,893,000 t (in 1997)
Continuous filament glass fiber	**Number of furnaces**	10	4	3	4	2	-	2	-	7	-	3	-	-	-	-	26 (475,000 t) (in 1997)
Domestic glass	**Number of installations**	35	15	14	16		17	1	6	2	1	>4	1	>4	15		>131
	% of EU-15 production	9.8	44.5	17.5	10.7		2.4		1.3		1.3						1,045,694 t (in 1997)

Air emissions and energy consumption are the major environmental issues of the glass industry. In 1997 total energy consumption was approximately 265 PJ. 9000 tons of dust, 103,500 tons of NO_x, 91,500 tons of SO_2 and 22 million tons of CO_2 (including power generation) were emitted in the same year. [8]

Large furnaces with lifetimes of up to twelve years are continuously operating in many sectors of the Glass Industry, representing a large capital commitment. A "natural" cycle of investment is induced by the continuous operation of the furnace and its periodic rebuilding. Thus major changes of melting technology are most economically implemented if coinciding with furnace rebuilds. For the integration of complex secondary abatement measures it is important that they fit correctly in size and implement any necessary gas conditioning. Nonetheless many improvements to the operation of the furnace, including the installation of secondary techniques, are possible during the operating campaign.[8]

3.14.2. Candidate technologies i.w.s. analysed for the glass production sector

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

During the Workshop the experts present noted that there is no need for an extension of this project since no emerging technologies are available or at least are currently publicly known, which might be a problem of confidentiality. The situation was different 10-15 years ago when 3R, SNCR, Preheating, Low NO_x, Flex melter, Oxyfuel were emerging [cf. [77]].

Technology 1: ALGLASS SUN

Short description: ALGLASS SUN (Separate Ultra low NO_x) burner is the latest technology developed by AIR LIQUIDE to control the heat transfer to the load while obtaining ultra low NO_x levels.
Positive environmental impact(s): NO_x
Emission reduction or emission factor: NO_x 100 ppm
Stage of development: Demonstration plant
Bibliography: [187], [77]

Technology 2: FENIX System

Short description: This system is an optimisation of the combustion conditions in the furnace thanks to burner modifications and knowledge of the factors that affect the NO_x formation. It is developed by Saint-Gobain.
Positive environmental impact(s): Energy, NO_x
Emission reduction or emission factor: Energy savings 6%, NO_x 580 mg/m³
Stage of development: Commercial tests, not emerging
Bibliography: [8], [77]

Technology 3: Reburning

Short description: Reburning is a combustion modification technology removing NO_x from combustion products by using fuel as a reducing agent. It can be used to control emissions from virtually any continuous emission source, and is not fuel specific although natural gas is generally used.
Positive environmental impact(s): NO_x
Emission reduction or emission factor: NO_x 50-65% abatement
Stage of development: Developing
Bibliography: [8], [77]

Technology 4: Plasma Melter

Short description: Makes use of the electrical conductivity of molten glass. The energy source is constituted of three electric arc torches fed with high purity argon gas.
Positive environmental impact(s): PM, NO_x, SO_x
Stage of development: Pilot Scale
Bibliography: [8], [10], [77],[78]

Technology 5: Segmentation of the Fusion Process / Seg Melter

Short description: Separation of the stages of the glass fusion process into distinct process devices.
Bibliography: [10], [8], [32], [238], [77]

Technology 6: High Luminosity Oxy-Gas Burners

Short description: For this technology, energy and costs for oxygen production are technical and economical barriers[77].
Positive environmental impact(s): NO_x
Bibliography: [150], [77]

[77] Minutes of the Workshop on Emerging Technologies, Session "Glass", 28-29 June 2004, Brussels

[78] Comments by Guy TACKELS on the minutes of the session "Glass" of the Workshop received on 14 September 2004.

Technology 7: Vortec CMS process

Short description: Process for conversion of spent potliners (waste from aluminium production) to useful glass fiber products. CMS technology (a similar process) is used in fiber glass industry to separate glass from organic material. This is not a technology to melt glass but to re-melt glass containing organic material.
Positive environmental impact(s): Energy
Bibliography: [251], [77]

Technology 8: New Glass Composition

Short description: New glass composition without boron or added fluorine. It started in the late 1990s and is an integrated process that changes the melting and can be run with oxy firing. It was developed for continuous filament glass by Owens Corning ("Advantex") in order to reach emissions values without installing any end-of-pipe techniques.
Positive environmental impact(s): PM, F, energy savings
Stage of development: 1 plant, not emerging
Bibliography: [8], [77], [79]

Technology 9: (Sorg) Flex Melter

Short description: This is a Low NO_x Burner system (furnaces that integrate features intended to permit lower flame temperatures). In this case there is a combination of electricity and natural gas.
Positive environmental impact(s): NO_x
Bibliography: [8], [2]

Technology 10: Thermophotovoltaic Electric Power Generation Using Exhaust Heat

Positive environmental impact(s): Energy
Bibliography: [150]

Technology 11: Advanced Glass Melter (AGM)

Short description: Batch materials are injected into the reaction zone of the flame in a natural-gas fired combuster. Development of the GRI Advanced Glass Melter (AGM) began in the mid-1980s. The primary benefits cited for the development of the AGM were its smaller furnace footprint (initial capital cost), lower overall NO_x emissions, improved energy efficiency, reduced operating costs and greater production flexibility.
Positive environmental impact(s): Energy, NO_x
Stage of development: Under development. A 13 ton/d AGM demonstration unit produced 5 ton/d of commercial-quality glass-fiber insulation, but technical issues of glass quality, refractory wear, exhaust carryover and operating conditions resulted in shutdown of the project. The economic potential for the AGM melter was not quantified or realised, because the project was suspended due to technical challenges and the lack of funding to pursue solutions to these technical problems.
Bibliography: [8], [10], [261], [77]

Technology 12: New Selenium Raw Material

Short description: New selenium raw material with lower volatility and improved decolorising efficiency.
Positive environmental impact(s): HM, PM
Emission reduction or emission factor: PM 70-100 mg/m³
Stage of development: Under development
Bibliography: [8]

Technology 13: Flue Gas Recirculation

Short description: Waste gas from the furnace could be re-injected into the flame to reduce the O_2 content and therefore the temperature and the NO_x formation efficiency.
Positive environmental impact(s): NO_x; In Germany, the potential of heat gain via gas recycling is rather small.
Stage of development: Pilot plant.
Bibliography: [8], [77]

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[79] Comments by Fabrice Rivet on the minutes of the session "Glass" of the Workshop received on 14 September 2004.

3.14.3. List of candidate technologies i.w.s. analysed for the glass production sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop (“+” positive assessment, “-“ negative assessment, “0” no assessment).

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Cullet and Batch Preheating	SO_x, NO_x	X		X	X	-
Oxy-fuel Melting = Oxy-Combustion	NO_x, Energy	X		X	X	-
ALGLASS SUN	NO_x		X		X	+
3R Process	NO_x	X		X	X	-
FENIX System	Energy, NO_x	X			X	-
(Sorg) LoNOx Melter	NO_x	X		X	X	-
Reburning	NO_x	X			X	+
Plasma Melter	PM, NO_x, SO_x	X		X	X	+
P-10 System	Energy			X	X	-
Brichard Submerged Melter	Energy, NO_x			X	X	+/-
Segmentation of the Fusion Process / Seg Melter		X		X	X	+
High Luminosity Oxy-Gas Burners	NO_x	X		X	X	-
Vortec CMS process	Energy	X		X	X	0
New Glass Composition	PM, F, Energy savings are	X		X		-
Foaming Process				X		-
Vacuum Process	Emissions			X		-
Refining in a thin layer of Molten Glass				X		0
Subatmospheric Refining SAR	Emissions			X		0
(Sorg) Flex Melter	NO_x	X		X		0
Thermophotovoltaic Electric Power Generation Using Exhaust Heat	Energy	X				0
RAMAR and FARE Systems				X		-
Advanced Glass Melter (AGM)	Energy, NO_x	X		X		+
New Selenium Raw Material	HM, PM	X				0
Integration of Frit Processes	PM	X				0
Flue Gas Recirculation	NO_x	X		x		-
Synthetic air	NO_x	X		X		-
Controlling Sulphate Addition and Redox State	SO_2	X				0
New High-Strength Fibers	Energy	X				0

3.15. Cement and lime production

3.15.1. Presentation of the cement and lime production sector

3.15.1.1. Cement

Cement is a finely ground, non-metallic, inorganic powder which forms a paste that sets and hardens when mixed with water. In 1995 cement production in the EU-15 totalled 172 Mt [13].
There was a total of 437 kilns in the countries of the EU-15 (not all in operation). In recent years the typical kiln size has become around 3000 tons per day, and although kilns of widely different sizes and ages exist, very few kilns have a capacity of less than 500 tons per day [13].
Euopean cement production is made up of 78% from dry process kilns, 16% from semi-dry and semi-wet process kilns and the remaining 6% coming from wet process kilns. The nature of the available raw materials is the main criterion for the selection of the manufacturing process. [13]
NOx, SO_2 and PM are major environmental issues for cement plants, while CO, CO_2, VOCs, PCDDs and PCDFs, heavy metals and noise are of less importance but nevertheless have to be dealt with.
Between 30% and 40% of production costs (excluding capital costs) are needed for energy consumption, making cement a very energy intensive industry branch. Traditionally, the primary fuel used is coal. While a wide range of other fuels is also in use (including petroleum coke, natural gas and oil). In recent years the use of waste as fuel has become an ever more important issue. [13]. Cement is also a capital intensive industry, since the investment for a new plant roughly equals 3 years' turnover.

3.15.1.2. Lime

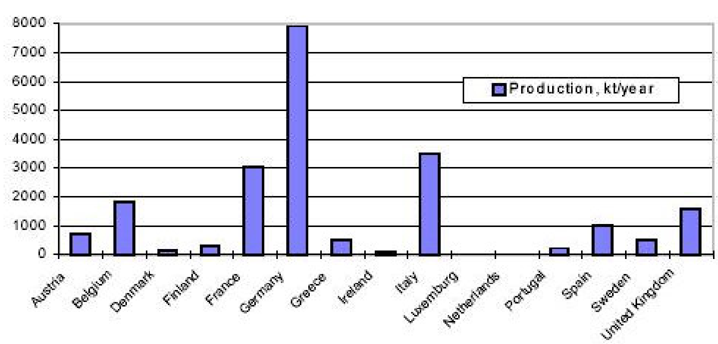

Figure 3-3: Sales-relevant lime production in EU-15 countries in 1995 [EC Mineral Yearbook, 1997], EuLA

A production low around 1990 was caused by the reduction of the specific lime consumption per ton of steel from 100 kg to 40 kg. However, since 1994 production increases again, as lime became more important in the use for environmental protection.[13]. Up to 50% of total production costs are accounted for by energy consumption, making the lime industry highly energy intensive. The use of natural gas has increased substantially in recent years, but still all kinds of fuel are used [13]. Major environmental issues for lime plants are emissions of CO, CO_2, NO_x, SO_2 and PM [13].
There are approximately 240 lime-producing installations and a total of about 450 kilns (excluding captive lime) in EU-15 (Table 3-13).

Table 3-13: Number of non-captive lime plants operational, non-captive lime kilns in EU-15 in 1995[80]

	Lime Plants	Lime kilns					
		Rotary	Annular shaft	Regenerative shaft	Other shaft	Other kilns	Total
Austria	7	0	2	6	3	1	12
Belgium	6	8	5	14	0	2	29
Denmark	2	2	0	0	0	0	2
Finland	4	5	0	0	0	0	5
France	19	4	21	20	18	1	64
Germany	67	7	31	12	74	12	136
Greece	44	1	2	1	39	1	44
Ireland	4	1	0	1	3	0	5
Italy	32	0	5	25	30	0	60
Luxembourg	0	0	0	0	0	0	0
Netherlands	0	0	0	0	0	0	0
Portugal	12	0	0	2	1	9	12
Spain	26	4	1	21	16	0	42
Sweden	6	5	0	3	2	0	10
UK	9	8	0	7	10	1	26
Total	238	45	67	114	196	27	449

3.15.2. Candidate technologies i.w.s. analysed for the cement and lime production

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

3.15.2.1. Cement

Technology 1: Secondary fuels, Co-incineration of waste

Stage of development: Increased application
Bibliography: [81], [82]

Technology 2: Wet Process: Conversion to State of the Art Dry Process

Short description: Dry process technology that includes multi-stage preheater and pre-calciner kiln.
Positive environmental impact(s): Energy, CO_2
Emission reduction or emission factor: Energy -2.8 GJ/t
Bibliography: [19], [82]

Technology 3: More Efficient Pre-Calciner Kiln

Positive environmental impact(s): NO_x, SO_x
Bibliography: [19]

Technology 4: Fluidised Bed Manufacturing (cement kiln)

Short description: The system consists of a suspension preheater, a spouted bed granulating kiln, a fluidised bed sintering kiln, a fluidised bed quenching cooler and a packed bed cooler.
Positive environmental impact(s): NO_x, CO_2, Energy
Emission reduction or emission factor: Heat gain of 10-12%, CO_2 reduction of 10-12%, NO_x 380 mg/m³
Stage of development: 2 pilot plants, no development since 8 years. This technology would allow only low production rates. It was not considered as promising by the group of experts during the Workshop.
Bibliography: [13], [23], [25], [82]

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[80] [EuLA], [Aspelund], [Bournis, Symeonidis], [Gomes], [Junker], [Slavin], [Göller], [Jørgensen] cited in http://aida.ineris.fr/bref/bref_ciment/site/pages/anglais/bref_chaux_2_1.htm

[81] Comments by Willem van Loo with CEMBUREAU – The European Cement Association – on the Cement and Lime sector for the Emerging Technologies project received on 30 June 2004

[82] Minutes of the Workshop on Emerging Technologies, Session "Cement and lime production", 28-29 June 2004, Brussels

Technology 5: Gyrotherm Technology

Short description: Improves gas flame quality.
Positive environmental impact(s): Energy, CO, NO_x, Fuel
Emission reduction or emission factor: Fuel -4%
Stage of development: 2 Pilot plants
Bibliography: [19], [32]

Technology 6: Staged Combustion combined with SNCR

Short description: Could be comparable to SCR in performance.
Positive environmental impact(s): NO_x
Emission reduction or emission factor: NO_x 100-200 mg/m³
Bibliography: [23], [19], [13], [25]

Technology 7: SCR Plant

Short description: Process of adding NH_3 to flue gas which passes through catalyst layers, by which NO_x is decomposed into N_2 and H_2O, e.g. Solnhofener Portland Zementwerke AG.
Positive environmental impact(s): NO_x, NH_3, SO_2
Stage of development: emerging application
Bibliography: [16], [72], [69], [82]

Technology 8: SNCR Plant

Short description: SNCR for clean gas concentrations of 500-800 mg NO_x/ Nm^3 is an available technique for which about 20 applications are reported. SNCR for clean gas concentrations of 200-500 mg/Nm^3 is considered to be an emerging technology.
Stage of development: emerging application. In Sweden one cement plant is reported to achieve 200 mg NO_x/ Nm^3 in combination with a wet scrubber.
Bibliography: [82]

Technology 9: Blended Cement

Short description: Intergrinding of clinker with one or more additives (fly ash, blast furnace slags, volcanic ash etc.).
Positive environmental impact(s): CO_2, Energy
Emission reduction or emission factor: Energy -1.41 GJ/t cement
Stage of development: Commercial, increased application
Bibliography: [19], [23], [82]

3.15.2.2. Lime

Technology 1: Fluidised Bed Calcination

Short description: Calcination of fine-grained limestone in a fluidised bed.
Positive environmental impact(s): NO_x, SO_2
Stage of development: Small scale tests
Bibliography: [13]

Technology 2: Flash Calciner/Suspension Preheater

Short description: Technology of feeding fine-grained limestone via a suspension preheater into a flash calciner.
Stage of development: Small scale tests
Bibliography: [13]

Technology 3: Fine Limestone

Short description: Feedstones that either contain high levels of fine-grained limestone or easily break up on heating.
Positive environmental impact(s): Significant reductions in SO_2 emissions
Stage of development: Considered as already commercial
Bibliography: [13], [82]

Technology 4: Lime Injection in Combustion Air

Short description: Injecting fine-grained quick- or hydrated lime into the air fed into the firing hood of the kiln.
Positive environmental impact(s): SO_2

Stage of development: Considered as already commercial
Bibliography: [13], [82]

Technology 5: CO Peak Management

Short description: Technology for cement kilns fitted with electrostatic precipitators. It may be applicable in some circumstances to rotary lime kilns equipped with electrostatic precipitators.
Positive environmental impact(s): CO
Stage of development: This is a current practice in the cement sector, but it may be a new application for lime kilns.
Bibliography: [13], [82]

3.15.3. List of candidate technologies i.w.s. analysed for the cement and lime production sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

3.15.3.1. Cement production

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
High Efficiency Roller Mills, or Ball Mills Combined with High Pressure Roller Presses, or Horizontal Roller Mills	Energy, CO_2			X		0
Co-incineration of Waste				X	X	+
Wet Process: Conversion to State of the Art Dry Process	Energy, CO_2					0
More Efficient Pre-Calciner Kiln	NO_x, SO_x			X		0
Fluidised Bed Manufacturing (Kiln)	NO_x, CO_2, Energy	X		X	X	-
Gyrotherm Technology	Energy, CO, NO_x, Fuel			X		0
Staged Combustion combined with SNCR	NO_x	X		X		+
Non Mechanical Grinding	Energy			X		-
Roller Presses, or Roller Mills, or Roller Presses for Pre-Grinding in Combination with Ball Mills	Energy, CO_2			X		0
SCR Plant	NOx, NH_3, SO_2			X	X	+
SNCR Plant				X	X	+
Hybridfilter	Dust			X		0
Blended Cement	CO_2, Energy			X	X	+

3.15.3.2. Lime production

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Fluidised Bed Limestone Calcination	NO_x, SO_2				X	+
Flash Calciner / Suspension Preheater						0
Fine Limestone	SO_2	X		X		-
Lime Injection in Combustion Air	SO_2	X		X		-
Injection of Absorbent in Exhaust Gas	SO_2	X		X		0
CO Peak Management	CO	X		X		+
Ceramic Filters	Dust	X		X		-

3.16. Chemical industry

3.16.1. Presentation of the chemical industry sector

3.16.1.1. Chlor-Alkali Industry

Due to the ever rising demand for plastics (e.g. PVC and polyurethanes) the chlorine production has multiplied since the 1940s [27]. After a short period of decline Western European production has stabilised at approximately 9 million t/a. The 9.2 million tons in 1999 placed Europe second to the USA in front of Japan [27]. 95% of world chlorine production are obtained by the chlor-alkali process [Ullmann's, 2003]. There are no facilities in Denmark nor Luxembourg and only a small amount of chlorine is produced in Ireland (6000 t/a). 93 process units in 79 plants were distributed over the other Western European countries in 2000 [27]. Compared to the situation in the USA, European facilities have to cope with higher costs for raw matierials and energy and use smaller plants in size. An important second product of the process in almost equal amounts is caustic soda.

Chlorine production 1999 (thousands of tons)	
Germany	3607
France	1504
UK	747
Italy	706
Belgium	706
Spain	653
Netherlands	619
Fin/Sweden/Austria	319
Norway/Switzerland	262
Portugal/Greece	98
Total	9219

Table 3-14: Chlorine production in western European countries in 1999 - [Euro Chlor cited in 27]

3.16.1.2. Organic Chemical Industry

Figure 3-4: Structure of Industrial Organic Chemistry [CITEPA, 1997 #47 cited in 240]

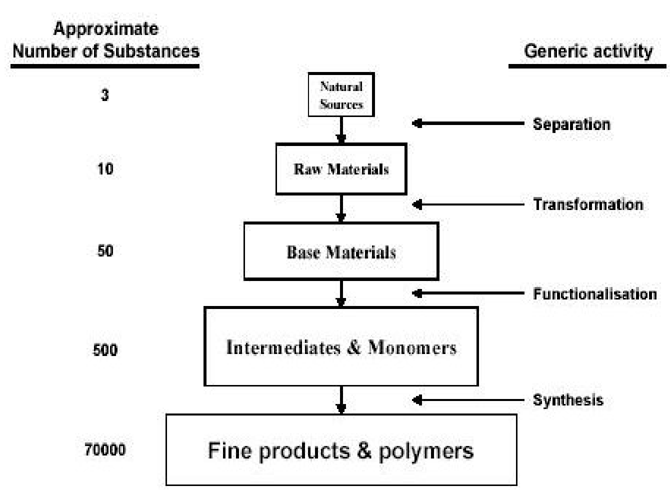


Figure 3-4 gives an overview of the organic chemical industry. Although the distinction between the tiers is sometimes subtle the tree impressively discribes the huge diversity coming from few sources [240]. In the BAT-process the sector is divided into Organic Fine Chemicals (OFC), e.g. dyes, fragrants, pharmaceutical and biocides, and Large Volume Organic Chemicals (LVOC). The boundary to refineries is rather empirical. Chemical installations are mostly highly integrated units that combine diverse plants. The main difference between OFC and LVOC (apart from production amount) is the dedication of facilities to single substances in the latter case, while multi-purpose units are mainly used by OFC plants. About one third of world production is accounted for by the EU, making it the market-leader. The turnover of organic chemicals is approximately four times the turnover of inorganic chemicals [CEFIC, 1999 #17; 241].

Product		Production capacity (kt/a)
Lower olefins	**Ethylene**	18700
	Propylene	12100
	1,3-Butadiene	2282
Aromatics	**Benzene**	8056
	Ethylbenzene	4881
	Styrene	4155
	Xylenes (mixed)	2872
	Toluene	2635
	Iso-propyl benzene (cumene)	2315
Oxygenated compounds	**Formaldehyde**	6866
	Methyl tertiary butyl ether (MTBE)	3159
	Methanol	2834
Halogenated compounds	**1,2-Dichlorethane**	10817
	Vinyl chloride (VCM)	6025

Table 3-15: Products and production capacities in European chemical industry (production capacities in excess of 2000 kt/a) [UBA (Germany), 2000 #89] based on Standard Research Institute (SRI) data, Directory of Chemical Products Europe, Vol. II, 1996 cited in 240].

3.16.2. Candidate technologies i.w.s. analysed for the chemical industry

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

3.16.2.1. Waste gas treatment in the chemical industry

Technology 1: Biological SO_2 Removal

Short description: A combination of a waste gas scrubber (absorber) and a biological waste water treatment facility. Technologies offered by Shell which could be interesting for abating SO_2.
Positive environmental impact(s): SO_2, HM
Bibliography: [22]

Technology 2: Gas Gas Separation

Short description: Separation of hydrogen from syngas for fuel cells, turbines, hydrogen separation membranes based on ceramics, etc.
Positive environmental impact(s): Energy
Emission reduction or emission factor: 20% primary energy savings
Stage of development: considered as promising by the group of experts
Bibliography: [93], [184], [32], [83]

[83] Minutes of the Workshop on Emerging Technologies, Session "Chemical Industry", Brussels, 28-29 June 2004.

Technology 3: Electron Beam Flue Gas Treatment

Short description: The technology removes SO_2 and NO_x under the influence of electron beam. Ammonia is the only reagent of this process and the mixture of ammonium salts is generated as the only byproduct.
Positive environmental impact(s): SO_x, NO_x
Emission reduction or emission factor: 95% SO_x removal, 70% NO_x removal
Stage of development: Pilot scale. The Electron Beam technique for waste gas treatment is not promising as energy efficiency will be a key-aspect in any future evaluation [experts' statement at the workshop, cf. Minutes of Workshop [83]].
Bibliography: [242], [84]

Technology 4: Activated Carbon Adsorption

Short description: A polluted gas stream is passed through adsorbers with activated carbon grains in a fix or moving bed, or fibres.
Positive environmental impact(s): VOC
Stage of development: Not an emerging technology. Could be emerging for chemical plants.
Bibliography: [72], [83]

3.16.2.2. Chemical industry

Technology 1: Levulinic Acid for the Manufacture of Chemicals

Short description: Levulinic acid (LA) could be an inexpensive feedstock for producing many industrial chemicals and products. The two chemicals that could significantly increase the market for levulinic acid are methyltetrahydrofuran (MTHF) and delta-amino levulinic acid (DALA).
Positive environmental impact(s): Energy
Emission reduction or emission factor: 9% primary energy savings
Stage of development: Demonstration stage. It should be considered as an emerging product rather than as an emerging technology.
Bibliography: [32], [83]

Technology 2: Liquid Membrane Technologies

Short description: Liquid membranes offer an alternative to liquid-liquid extraction, and use much less energy. This technology can be used to separate both aqueous and organic mixtures. A thick emulsion of water droplets forms a barrier and acts as a membrane.
Positive environmental impact(s): Energy
Emission reduction or emission factor: 53% primary energy savings
Stage of development: Commercial
Bibliography: [32], [83]

Technology 3: New Catalysts

Short description: New catalysts might use less energy, and are environmentally acceptable agents (for example, air or oxygen as an oxidant instead of hydrogen peroxide) and perhaps water as a solvent, resulting in less noxious waste.
Positive environmental impact(s): Energy
Emission reduction or emission factor: 20% primary energy savings
Stage of development: Continuous research. Considered as promising by the experts at the workshop but an evaluation must be made on a more detailled level. The development of new catalysts is a very unspecific "technology".
Bibliography: [32], [83]

Technology 4: Autothermal Reforming (or Combined Reforming)

Short description: Ammonia synthesis starts with the reduction of syngas from natural gas. Reforming takes place in two stages, the primary and the secondary reformer. The inputs for the reforming process are NG (mainly CH_4), water (steam) and air.
Positive environmental impact(s): Energy
Emission reduction or emission factor: 20% primary energy savings

[84] Comments by Brigitte Zietlow with German Federal Environmental Agency Berlin on the chemical Industry sector, received on 08 July 2004.

Stage of development: Not commercial. This technology is considered to be available as there have been already shut-downs. Retrofitting is too expensive so that this technology is used for new plants only.
Bibliography: [32], [83]

3.16.2.3. Nitric acid plants

Technology 1: UHDE Process

Short description: A combined N_2O and NO_x abatement reactor which is installed between the final tail gas heater and the tail gas turbine and operates at tail gas temperatures of about 400-480°C. The reactor consists of two catalyst layers (Fe zeolites) and an intermediate injection of NH_3.
Positive environmental impact(s): N_2O, NO_x
Emission reduction or emission factor: 30 ppm
Stage of development: Test plant. The UHDE-Process for N_2O reduction in nitric acid production is applied in a full-scale nitric acid plant in Austria. According to an expert's feedback received after the workshop the UHDE Process "should be considered BAT" (cf. Workshop Minutes [83]).
Bibliography: 128, [84]

3.16.2.4. Chlor alkali production

Technology 1: Oxygen Depolarised Cathodes in Modified Membrane Cells

Short description: Integration of the fuel cell process into the membrane electrolysis cell. One of the main disadvantages is that hydrogen is no more produced. A plant per plant study is necessary to define the applicability of the technology, taking into account both the energetic value of hydrogen and its use (hydrogen quality produced by electrolysis is very good).
Positive environmental impact(s): Energy
Emission reduction or emission factor: Energy: -500/600 kWh/t Cl_2
Stage of development: 2 Pilot plants
Bibliography: 27, [83]

Technology 2: Membrane for Direct Production of 50% Caustic Soda

Short description: Has an additional protective layer on the cathode side of the traditional bi-functional membrane forming an intermediate room between the carboxylic and the protective layer.
Positive environmental impact(s): Energy
Stage of development: Prototype. Up to now this technology is not industrially developed for both technical and economical reasons.
Bibliography: 27, [84]

Technology 3: Built-in Precathode Diaphragm

Short description: A composite assembly comprising: the standard mild steel cathode screen, the precathode itself, and the microporous asbestos or asbestos-free diaphragm.
Positive environmental impact(s): Energy
Emission reduction or emission factor: Energy: -175 kWh/t Cl_2
The impact on air emissions of this technology is rather low since this technology is applicable for less than 5% of global chlorine production capacity.
Stage of development: Pilot plants
Bibliography: 27,[84]

3.16.3. List of candidate technologies iw.s. analysed for the chemical industry sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Biological SO_2 Removal	SO_2, HM	X				+
Low Temperature NO_x Oxidation	NO_x, SO_x, HCl	X				0
Gas Gas Separation	Energy	X		X	X	+
Electron Beam Flue Gas Treatment	SO_x, NO_x		X	X	X	+/-
Activated Carbon Adsorption	VOC			X		+
Heat Recovery Technology for Harsh Environments in Chemical Manufacturing	Energy			X	X	0
Levulinic Acid for the Manufacture of Chemicals	Energy			X	X	+
Liquid Membrane Technologies	Energy			X	X	0
New Catalysts	Energy			X	X	+
Membrane contactor application for absorption in ionic liquid	CO_2, POPs, NMVOC			X	X	+
Autothermal Reforming (or Combined Reforming)	Energy			X	X	-
Clean Fractionation	Energy			x	X	-
UHDE Process (Nitric acid plants)	N_2O, NO_x			X	X	+
Extended Oxidation Reactor (Nitric acid plants)	N_2O			X		-
Oxygen Depolarised Cathodes in Modified Membrane Cells (Chlor alkali production)	Energy	X		X	X	0
Membrane for Direct Production of 50% Caustic Soda (Chlor alkali production)	Energy	X		X	X	0
Built-in Precathode Diaphragm (Chlor alkali production)	Energy	X		X	X	0

3.17. Refineries

3.17.1. Presentation of the refineries sector

Refineries convert crude oil and natural gas into a wide spectrum of products, e.g. fuel for vehicles and raw materials for a number of industrial branches (chemistry, building). The oil refining capacity in EU-15 plus Switzerland and Norway was around 700 million tons per year in 1999 with Italy and Germany having the greatest capacity (Table 3-16).

Table 3-16: Charge capacity for mineral oil refining in Mio. m³/a in western European countries. Source Data from [Radler, 1998 reviewed by the TWG, cited in 21]

Country	Number of refineries	Crude	Vacuum distillation	Coking	Thermal operations	Catalytic cracking	Catalytic reforming	Catalytic hydrocracking	Catalytic hydrorefining	Catalytic hydrotreating
Austria	1	12.2	3.8		1.0	1.6	1.3	3.0	2.9	2.3
Belgium	5	41.7	15.8		3.7	6.5	6.0		13.4	16.2
Denmark	2	7.8	1.3		3.1		1.2		0.6	2.5
Finland	2	11.6	5.5		2.0	2.6	2.5	1.2	6.0	3.4
France	15	113.0	44.6		9.0	21.4	15.4	0.9	11.2	46.9
Germany	17	130.3	50.3	7.0	12.1	19.5	22.9	7.0	43.3	54.0
Greece	4	22.9	7.9		2.8	4.2	3.3	1.6	5.0	10.1
Ireland	1	3.9					0.6		0.8	0.6
Italy	17	141.9	44.6	2.6	24.2	17.4	16.4	11.4	20.3	42.6
Netherlands	6	69.0	25.0	2.1	7.0	6.1	10.0	6.2	5.0	32.5
Norway	2	15.0		1.5	1.8	3.1	2.2		2.0	6.2
Portugal	2	17.7	4.5		1.4	1.8	2.9	0.5	1.8	8.4
Spain	10	77.3	25.0	1.7	8.6	11.1	12.0	0.9	4.9	26.3
Sweden	5	24.8	7.8		3.6	1.7	4.1	2.8	4.1	11.0
Switzerland	2	7.7	1.4		1.2		1.6	0.4	1.6	4.3
UK	13	107.6	46.9	3.9	5.5	26.1	21.4	3.2	15.0	50.2
EU-15 plus	104	804.3	284.4	18.9	86.7	123.2	123.8	39.1	137.9	317.5

Tabelle 3-17: Production capacity for mineral oil refining in Mio. m³/a in western European countries. Source Data from [Radler, 1998 reviewed by the TWG, cited in 21]

Country	Alkylation	Polymerisation Dimerisation	Aromatics	Isomerisation	Base oil production	Etherification	Hydrogen (MNm³/d)	Coke (t/d)	Sulphur (t/d)	Bitumen
Austria				0.6		0.1			180	0.1
Belgium	0.8			0.1		0.3	4.4		1184	1.5
Denmark				0.3						0.5
Finland	0.2	0.02				0.2	0.6		156	0.7
France	1.1	0.35	0.3	4.0	2.3	0.2	1.3	701	850	2.6
Germany	1.4	0.14	3.8	3.4	1.5	0.9	35.5	3570	1982	5.2
Greece	0.1	0.51		1.2	0.2	0.1	0.5		186	0.3
Ireland									2	
Italy	2.1	0.18	1.3	5.2	1.6	0.3	6.5	2000	1410	1.3
Netherlands	0.7		1.5	0.8	0.7	0.2	4.1		823	0.8
Norway		0.67		0.2				610	24	
Portugal	0.3		1.0						180	
Spain	0.9		1.9	0.8	0.5	0.6	3.0	1250	703	2.8
Sweden		0.20		1.6	0.1		1.3		312	1.7
Switzerland				0.6						0.3
UK	5.4	0.97	0.9	5.6	1.4	0.2	2.7	2300	601	3.5
EU-15 plus	13.1	3.04	10.7	24.6	8.3	3.2	59.9	10431	8604	21.0

3.17.2. Candidate technologies i.w.s. analysed for the refineries sector

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

Some technologies of the list were sorted out during the Workshop on Emerging Technologies since little relevance were attributed to them or high risks were associated to their commercialisation. "IGCC", "De-NO_x additives for FCC" and "Smart LDAR" were identified as promising technologies [85], [86].

3.17.2.1. Catalytic cracking

Technology 1: IGCC in Refineries

Short description: IGCC is the cleanest, most efficient way of producing electricity from coal, petroleum residues and other low- or negative-value feedstock. It was identified as a promising technology during the Workshop.
Positive environmental impact(s): Efficiency, Energy
Emission reduction or emission factor: Efficiency of electrical power generation 40-42%
Stage of development: In use
Bibliography: [23], [86]

Technology 2: Fouling Minimisation

Short description: Fouling requires the combustion of additional fuel. Several methods of investigation have been underway to attempt to reduce fouling.
Positive environmental impact(s): Energy
Emission reduction or emission factor: 15% primary energy savings
Stage of development: Bench scale trials
Bibliography: [32]

3.17.2.2. Base oil production

Technology 1: Application of membrane for solvent recovery

Short description: Membrane for solvent recovery in the solvent extraction/dewaxing processes.
Less than 20% of refineries produce base oil and use membranes.
Positive environmental impact(s): Energy
Stage of development: New technology
Bibliography: [21], [86]

Technology 2: Vortex Inertial Staged Air (VISTA) Burner

Short description: Uses two combustion stages: a first stage to convert natural gas to H_2 and CO, and a second stage with low temperature and low oxygen concentration.
Positive environmental impact(s): NO_x
Bibliography: [150]

3.17.2.3. Waste gases

Technology 1: Catalytic Reduction of NO_x Emissions of Fluid Catalytic Cracking Units

Short description: Based on the understanding of NO_x formation in the FCCU regenerator, two novel additives to catalytically reduce NO_x formation were developed: DENOX® and XNOx®. The objective was to provide a simple, cost effective alternative to capital intensive hardware such as Selective Catalytic Reduction (SCR). The NO_x removal additives were identified as promising technologies during the workshop[86].

[85] Peter Meulepas: Report by T. J. Dougan and J. R. Riley (2002): Reducing FCCU NOx Emissions Catalytically.

[86] Minutes of the Workshop on Emerging Technologies, Session "Refineries", Brussels, 28-29 June 2004

Positive environmental impact(s): NO_x
Emission reduction or emission factor: In the range of 50% reduction
Stage of development: Commercial
Bibliography: [260], [86]

Technology 2: Carbon Filters for Dioxines Reduction

Short description: According to the experts present at the workshop this technology has only little relevance for refineries.
Positive environmental impact(s): PCDDs/Fs
Bibliography: [2], [86]

Technology 3: Smart LDAR (Leakage detection and repair)

Short description: This technology was identified as promising during the workshop. LDAR is a detector that is able to detect VOC emissions by real video imaging of the process under surveillance. The VOC reducing measures (e.g. change of valves and other equipment) have to be taken afterwards. If the system shows a good performance, leakage detection will become more efficient and a reduction of fugitive VOC emissions is possible. The possible advantages are a cheap and standardised detection method for fugitive VOC emission sources in refineries and in the chemical industry. The system will be successful if it is able to detect leakages in a more cost effective way than current methods. Today only a small percentage of possible sources is controlled.
Pollutant: A reduction of fugitive VOC emissions is possible if once detected
Stage of development: The system is developed at pilot plant scale. Information about it was distributed by CONCAWE in 1999. The workshop participants had no information when the system could be commercially available. If the system would be cheap and well performing its application rate may reach 100% in a few years
Bibliography: [21], [86]

3.17.3. List of candidate technologies i.w.s. analysed for the refineries sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop (“+” positive assessment, “-“ negative assessment, “0” no assessment).

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
IGCC in Refineries	Efficiency, Energy			X	X	+
Fouling Minimisation	Energy			X	X	0
Biodesulphurisation of Gasoline	Energy			X	X	-
Application of Membrane for Solvent Recovery	Energy	X		X		0
Vortex Inertial Staged Air (VISTA) Burner	NO_x	X				0
Catalytic Reduction of NO_x Emissions of Fluid Catalytic Cracking Units	NO_x			X	X	+
DeNOx Additives in Catcracker Regenerators	NO_x	X		X		0
Carbon Filters for Dioxines Reduction	PCDDs/Fs			X		-
Hot Ceramic Filters	PM	X				0
Cansolv's Amine Scrubbing	SO_2	X		X		-
Methane Pyrolysis	CO_2	X		X		-
Smart LDAR	Fugitive VOCs	X		X		+
SO_2 Capture and Conversion into Liquid Sulphur	SO_2	X				0
Ceramic Filters and Rotating Particulate Separator	PM	X				0
CO_2 Abatement Techniques	Energy, CO_2	X		X		0
Wet Scrubbing Using Caustic Soda	SO_2, NO_x, CO_2	X		X		-
New Solid Catalyst for the Alkylation Process	HF	X		X		-
Process Heavier Feedstocks	Efficiency	X				0
Catalyst Separation with Magnet		X				0

3.18. Coating sector

3.18.1. Presentation of the coating sector

Among others the appliance industry uses epoxies, epoxy/acrylics, acrylics and polyester enamels as main coating types. For liquid coatings either water or organic solvents are possible as paint solids carrier [87]. From an environmental perspective, one of the major drawbacks of coating is the release of VOCs into the atmosphere from the coating materials, plus the generation of solid waste in the form of material that misses the target. As coatings are the main source of VOC emissions, improvement in coating formulation (content of VOC, coating thickness) and application efficiency (transfer efficiency) are the main target areas for emission reduction[88]. Spray application has the lowest transfer efficiency (20%) while direct methods (brush, roller, dip or flow) have transfer efficiencies of over 90%. Apart from increasing waste, low transfer efficiencies also induce more hazards to workers and environment[89].

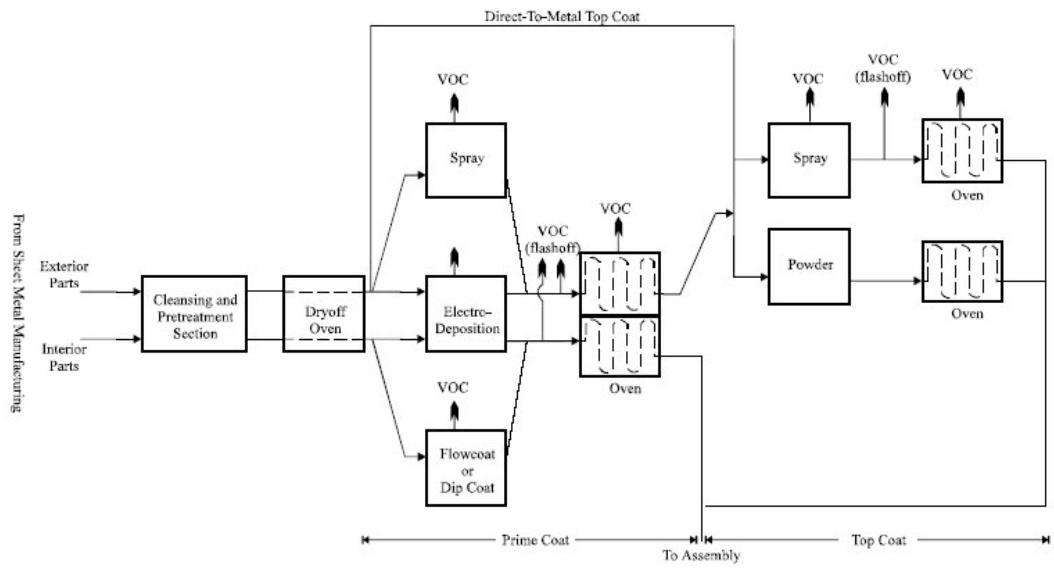


Figure 3-5: Typical coating application methods in the large scale industry[90]

3.18.2. Candidate technologies i.w.s. analysed for the coating sector

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

[87] http://www.epa.gov/ttn/chief/eiip/techreport/volume02/ii07_july2001.pdf

[88] http://www.epa.gov/ttn/chief/ap42/ch04/final/c4s02_2l.pdf

[89] http://www.p2pays.org/ref/01/00636.pdf

[90] http://www.epa.gov/ttn/chief/ap42/ch04/final/c4s02_2l.pdf

Currently there are no radical innovations in the sector (concerning end-of-pipe technologies). Theoretical issues are often well researched (a lot of new paints or solvents are still under development). New application fields and improvements should be regarded as emerging technologies, too [91].

Technology 1: Non Thermal Plasma Units

Short description: Excited species (free radicals and ions) that oxidise, reduce or decompose molecules of pollutants.
Technologies like plasma or photo oxidation etc. are assumed to be cheaper.
Positive environmental impact(s): NMVOC, CO, POPs
Emission reduction or emission factor: NMVOC Dryers >99.5%, CO 100%
Stage of development: Commercial
Bibliography: [118], [91]

Technology 2: Primerless Paint System for Automotive Applications

Short description: A new product, a two-component waterborne basecoat with slightly increased film-thickness makes a primer surfacer superfluous. Here, VOC emissions are reduced by 50% for industries that have no technologies for VOC emission reduction implemented yet and by 5% for industries with low emission systems already working. Energy consumption is reduced by 30% because one step (primer deposition) is removed of the process.
Positive environmental impact(s): SO_x, NO_x, CO_2
Emission reduction or emission factor: NMVOC Emissions -30%
Stage of development: Commercial, few plants operating
Bibliography: [171], [91]

Technology 3: Radiation Curing Technology

Short description: Radiation curing of coatings is a new area of application of an existing technology. New is the application on non-flat substrates.
Positive environmental impact(s): Process length (Energy)
Stage of development: Demonstration plant
Bibliography: [172]

Technology 4: Dense Fluid Degreasing

Short description: Extend carbon dioxide applications to replace VOC and hazardous compounds (organic solvents) on degreasing and surface treatment
Positive environmental impact(s): VOC
Stage of development: Commercial
Bibliography: [189]

Technology 5: Web Air Unit

Short description: The basic idea behind Web Air is to regenerate the adsorber via electromagnetic induction heating.
Positive environmental impact(s): VOC
Emission reduction or emission factor: Up to 100% reduction
Bibliography: [191]

Technology 6: Electron Beam Flue Gas Treatment for VOC Removal

Short description: The electron beam (EB) flue gas purification technology has been already applied for SO_2 and NO_x removal.
Positive environmental impact(s): SO_x, NO_x, NMVOC, POPs
Emission reduction or emission factor: SO_x 90%, NO_x 80%, NMVOC 70%, POPs 70%
Stage of development: Bench scale
Bibliography: [246]

Technology 7: Class-A-Coating in automatic mass production with dry deposition and air circulation

Short description: Dry deposition and recirculation of exhaust air in coating applications enables a low cost combustion of VOC in exhaust air.
Positive environmental impact(s): VOC

[91] Minutes of the workshop on Emerging Technologies, Session "coating and VOC", Brussels, 28-29 June 2004

Stage of development: Demonstration plant
Bibliography: [245]

Technology 8: Water-Borne Coating with Solvent <4%

Short description: By using new developed chemicals, the solvent content of painting systems can be decreased, with the same short cycle time and without lowering the quality.
Positive environmental impact(s): VOC
Stage of development: Commercial
Bibliography: [7], [123], [124]

Technology 9: CoatingOff: Eddy current based decoating

Short description: Use of eddy currents to decoat electrical conductive objects.
Positive environmental impact(s): VOC, Energy
Stage of development: Commercial
Bibliography: [256]

Technology 10: Vacuum Vapour Deposition

Short description: This coating method is a physical process to deposit evaporated metal on base metal in a vacuum (<50 Pa).
Stage of development: 1 pilot plant
Bibliography: [5]

Technology 11: CO_2 cleaning machine (CO_2 dry cleaning process)

Short description: This machine dissolves dirt, fats and oils on all materials currently dry-cleaned. Consists of the following main components: washing chamber, storage tank, distilling unit, compressor, refrigeration unit and (depending on the machine design) a pump and a filter.
Positive environmental impact(s): VOC
Emission reduction or emission factor: No VOC emissions
Stage of development: Commercial in the U.S.A.
Bibliography: [259]

3.18.3. List of candidate technologies i.w.s. analysed for the coating sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Non Thermal Plasma Units	NMVOC, CO, POPs			X	X	+/-
Primerless Paint System for Automotive Applications	CO_2, SO_x, NO_x		X	X	X	+
Radiation Curing Technology	VOC		X		X	+
Dense Fluid Degreasing	VOC		X		X	0
Web Air Unit	VOC			X	X	0
Electron Beam Flue Gas Treatment for VOC Removal	SO_x, NO_x, NMVOC, POPs		X		X	+
Class-A-Coating in automatic mass production with dry deposition and air circulation	VOC			X	X	+
Water-Borne Coating with Solvent <4%	VOC		X	X	X	+
CoatingOff: Eddy current based decoating	VOC, Energy		X		X	+
CO_2 cleaning machine (CO_2 dry cleaning process)	VOC		X		X	+
Vacuum Vapour Deposition		X				0
New Drying Technologies for Water Based Coating Systems	VOC		X	X		0
Ultra Low Layer Thickness for Powder Coating	VOC		X	X		0
High Solid Varnish, Very High Solid Varnish	VOC		X	X		0
Powder coating, powder coating for temperature sensitive substrates	VOC		X	X		0
Chemically enhanced chemical Scrubbing	VOC			X		0
UV Coating with 100% Solids Content	VOC		X			0

Powder-Slurry Coating	VOC		X			0
Nano-structured polymers	VOC		X			0
Photo-catalytic coating with nano-titanium dioxide	VOC		X			0
Biological Waste Air Treatment	VOC			X		0
Roll Coaters	Effluents	X				0
Passivation with Cr-Free Products		X				0
Air-knives with Variable Profile		X				0
Removing the Pot Roll (Catenary, Air-cushion)		X				0
Core Less Pot		X				0
Micro Water Spray at the Cooling Tower		X				0
Ultrasound Cleaning		X				0
Electrolytic and Ultrasound Cleaning (Scale Removal)		X				0
Aqueous Foams for Suppressing VOC Emissions	VOC			X		0

3.19. CO_2

3.19.1. Presentation of the "CO_2" sector

Fossil fuel combustion is a major of anthropogenic CO_2 emissions. A single power plant may emit several million tons of CO_2 per year. Other important industrial CO_2 emission sources are refineries, cement works and iron and steel production. The contribution by transport and domestic buildings has to be kept in mind, but was not part of the scope of this project. A substantial reduction of emissions without major changes to processes would be the capturing and storing of CO_2.
Currently, capturing activities are starting in the chemical and the oil and gas industries. While several plants have installed facilities for capturing CO_2 from the flue gas, the yield is still small. When deposited, it has to be made sure that the gas will stay in the deposits for hundreds of years. Options for storage are beneath the earth's surface (unminable coal beds) or in the oceans.

3.19.2. Candidate technologies i.w.s. analysed for the "CO_2" sector

The following list contains brief information on *candidate* technologies i.w.s. for which information has been collected within this project; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive.

Technology 1: Increase of Efficiency in Existing Power Plants

Short description: Existing LCPs have to be evaluated for higher overall process efficiency, i.e. steam turbine, condenser, heat exchanger, flue gas cleaning, cooling techniques
Positive environmental impact(s): Efficiency
Emission reduction or emission factor: less specific CO_2, PM, NO_x, SO_2 emissions
Stage of development: Commercial to research

Technology 2: O_2 / CO_2 Combustion

Short description: Burning the fuel in an atmosphere of oxygen and recycled flue gas instead of in air. Oxy-Combustion, High Temperature Fuel Cells, Sorbent Energy Transfer System, etc.
Positive environmental impact(s): SO_x, NO_x, CO_2, PM reapplication
Emission reduction or emission factor: SO_x >99%, NO_x >66%, CO_2 >99.5%, PM >91%
Bibliography: [46], [105], [125]

Technology 3: Oxy-Fuel Combustion

Short description: An O_2/CO_2 Combustion technology. Pure oxygen instead of air: flue gas consists of CO_2 and H_2O. CO_2 is partly recycled and mixed with O_2 for temperature control.
Positive environmental impact(s): CO_2
Emission reduction or emission factor: ~100%
Bibliography: [125]

Technology 4: Chemical Looping Combustion (Sorbent Energy Transfer System)

Short description: An O_2/CO_2 Combustion technology. Oxygen transfer from the combustion air to fuel via circulating particles of metal/metal oxide.
Stage of development: New Technology
Bibliography: [125]

Technology 5: IGCC with CO_2-Sequestration - Shift Converter

Short description: Increase CO_2 concentration and partial pressure. Gasification / reforming of fossil fuels plus CO shift (reaction with steam in a catalytic reactor) to give more CO_2 and hydrogen plus sequestration of enriched CO_2. Hydrogen is used as fuel in a gas turbine combined cycle.
Positive environmental impact(s): CO_2
Emission reduction or emission factor: 90%
Stage of development: New Technology
Bibliography: [125]

Technology 6: Hydrogen by Decarbonising Fossil Fuels

Short description: Centralised installations generate H_2 from fossil fuels (natural gas / coal), hydrogen is fed in the NG-system, thus enabling small decentralised consumer to participate at the CO_2-capture and storage process.
Positive environmental impact(s): CO_2
Bibliography: [125]

3.19.2.1. CO_2 separation

Technology 1: Pressure Swing Adsorption

Short description: Gas mixture flows through a bed of adsorbent at elevated pressure, regeneration is done by reducing pressure. One expert of the workshop doubted that this technology could be promising.
Positive environmental impact(s): CO_2 capturing
Bibliography: [125]

Technology 2: Amine Scrubbing

Short description: When flue gas is scubbed in an amine-water solution, CO_2 reacts with the amine.
. After leaving the scrubber, the amine is heated to release high purity CO_2. The CO_2-free amine is then reused.
Positive environmental impact(s): CO_2 capturing
Emission reduction or emission factor: CO_2 80-90%; CO_2 98% with mono-ethanolamine (MEA); product purity 99%
Stage of development: Numerous Industrial Installations
Bibliography: [125], [21]

Technology 3: Direct Air Capture Technology for CO_2

Short description: Direct capture of CO_2 from the atmosphere through chemical sorbents. Capture and emissions of CO_2 are decoupled.
Positive environmental impact(s): CO_2 capturing
Stage of development: Bench / Laboratory
Bibliography: [119]

Technology 4: Cryogenic Distillation

Short description: Cooling high concentrated (>90%) CO_2 gases to a very low temperature so that the CO_2 condenses.
Positive environmental impact(s): CO_2
Emission reduction or emission factor: CO_2 80%
Stage of development: Commercially Available
Bibliography: [125]

Technology 5: Carbon Absorbents

Positive environmental impact(s): CO_2
Stage of development: Commercially Available
Bibliography: [125]

Technology 6: Sodium Absorbents

Short description: Sodium carbonate aqueous solution used as a sorbent, vacuum stripping plus vapour recompression for solvent regeneration. Low costs and minimal degradation of solvent.
Positive environmental impact(s): CO_2
Bibliography: [125]

Technology 7: Temperature Swing Adsorption

Short description: Gas mixture flows through a bed of adsorbent, regeneration is done by raising the temperature of the adsorbent.
Positive environmental impact(s): CO_2
Bibliography: [125]

Technology 8: Electrical Swing Adsorption

Short description: Carbon fiber composite molecular sieve (a carbon-bonded activated carbon fiber) is used as CO_2 adsorbent. The adsorbed gas is released by the passage of an electric current.
Positive environmental impact(s): CO_2

Bibliography: [125]

Technology 9: Polymer Membranes

Short description: Membranes (cellulose acetate, polysulfone, poyimide) separate gas molecules by size, with a CO_2/N_2-selectivity of 20-40.
Positive environmental impact(s): CO_2
Bibliography: [125]

Technology 10: Ceramic Membranes, Hydrides, Lithium Silicate

Positive environmental impact(s): CO_2
Bibliography: [125]

Technology 11: CO_2 Hydrate Separation

Short description: CO_2 saturated water is mixed with shifted synthesis gas at temperatures near 0°C and 6-20 bar: CO_2 hydrate forms.
Emission reduction or emission factor: 86% efficiency
Stage of development: New Technology
Bibliography: [125]

Technology 12: Membrane / Amine Process

Short description: Microporous hollow fiber membranes are used to separate the liquid solvent from the flue gas and as a contacting medium. High gas/liquid contact area, less foaming and minimum solvent degradation.
Positive environmental impact(s): CO_2
Bibliography: [125]

3.19.2.2. CO_2 storage

Technology 1: Enhanced Coal Bed Methane (ECBM)

Short description: Enhanced Coal Bed Methane (ECBM) production using CO_2 and nitrogen mixtures.
Positive environmental impact(s): CO_2 reapplication
Stage of development: field test
Bibliography: [125], [157]

Technology 2: Deep Saline Aquifer

Short description: CO_2 is pumped into an aquifer. In some formations CO_2 reacts with minerals to form carbonates.
Positive environmental impact(s): CO_2 sequestration
Stage of development: commercial
Bibliography: [125], [157]

Technology 3: Enhanced Oil Recovery: CO_2-EOR

Short description: Depleted Oil Reservoir. Porous rocks covered by impermeable cap rock.
Positive environmental impact(s): CO_2 sequestration
Stage of development: available
Bibliography: [125], [157]

Technology 4: Enhanced Gas Recovery: CO_2-EGR

Short description: Depleted Gas Reservoir. Porous rocks covered by impermeable cap rock.
Positive environmental impact(s): CO_2 sequestration
Stage of development: theoretical concept
Bibliography: [125], [157]

Technology 5: Mineral Sequestration

Short description: Sequesters CO_2 in the form of thermodynamically stable solid mineral carbonates. The source of the appropriate metal ions would be magnesium or calcium silicate rocks.
Positive environmental impact(s): CO_2 sequestration
Stage of development: Bench / Laboratory
Bibliography: [120]

Technology 6: Sequestration of CO_2

Positive environmental impact(s): CO_2
Bibliography: [82]

Technology 7: Coal Compatible Fuel Cell, Hydrogasification and Reforming

Short description: Emission Free Carbon Technology. Coal gasification and hydrogen production driven by the CaO to CaO_3 reaction. Then the produced H_2 is converted to electricity by a solid oxide fuel cell.
Positive environmental impact(s): CO_2, SO_x, NO_x, Hg, PM
Stage of development: power plant concept not yet being piloted
Bibliography: [114], [126], [93], [184]

Technology 8: Intermediate storage

Short description: Same safety considerations as for natural gas, ethene and LPG.
Positive environmental impact(s): CO_2
Stage of development: Experience for other products
Bibliography: [125]

Technology 9: Unminable Coal Bed

Short description: CO_2 can be injected into suitable coal seams where it will be adsorbed onto the coal, locking it up permanently provided the coal is never mined.
Positive environmental impact(s): CO_2
Bibliography: [125]

Technology 10: Deep Ocean Storage

Short description: Pumping of CO_2 in the deep ocean.
Positive environmental impact(s): CO_2, negative side effect on ocean ecosystem possible
Bibliography: [125]

3.19.3. List of candidate technologies i.w.s. analysed for the CO_2 reduction/sequestration sector

The following tables summarise the information on all candidate technologies i.w.s. analysed; the candidate technologies i.w.s. are not necessarily emerging, promising or relevant nor is the list exhaustive. The assessment refers to expert judgement at the workshop ("+" positive assessment, "-" negative assessment, "0" no assessment).

3.19.3.1. CO_2 reduction

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Increase of Efficiency in Existing Power Plants	Efficiency			X		+
O_2/CO_2 Combustion (reapplication)	SO_x, NO_x, CO_2, PM,		X	X	X	0
Oxy-Fuel Combustion	CO_2		X			0
Chemical Looping Combustion (Sorbent Energy Transfer System)	CO_2		X			0
IGCC with CO_2-Sequestration - Shift Converter	CO_2		X			0
Hydrogen by Decarbonising Fossil Fuels	CO_2		X			0

3.19.3.2. CO_2 separation

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Pressure Swing Adsorption	CO_2 (only capturing)		X			-
Amine Scrubbing	CO_2 (only capturing	X	X		X	+

Direct Air Capture Technology for CO_2	CO_2 (only capturing		X		X	+
Cryogenic Distillation	CO_2		X			+
Carbon Absorbents	CO_2		X			+
Sodium Absorbents	CO_2		X			+
Temperature Swing Adsorption	CO_2		X			0
Electrical Swing Adsorption	CO_2		X			0
Polymer Membranes	CO_2		X			0
Ceramic Membranes, Hydrides, Lithium Silicate	CO_2		X			0
CO_2 Hydrate Separation	CO_2		X			0
Membrane / Amine Process	CO_2		X			0

3.19.3.3. CO_2 storage

Name of the technology	Positive environmental impact (examples)	BREF	Questionnaire	Other	Fact sheet	Assessment
Enhanced Coal Bed Methane (ECBM)	CO_2 reapplication		X		X	0
Deep Saline Aquifer	CO_2 sequestration		X		X	0
Enhanced Oil Recovery: CO_2-EOR	CO_2 reapplication		X		X	0
Enhanced Gas Recovery: CO_2-EGR	CO_2 reapplication		X		X	0
Mineral Sequestration	CO_2 sequestration		X		X	+
Sequestration of CO_2	CO_2			X		0
Coal Compatible Fuel Cell, Hydrogasification and Reforming	CO_2, SO_X, NO_X, Hg, PM	X	X	X		0
Intermediate storage	CO_2		X			0
Unminable Coal Bed	CO_2		X			0
Deep Ocean	CO_2		X			0

3.20. Conclusion

There are several emerging technologies in each of the chosen sectors. It should be noted, that a technology that is BAT may still be improved in a gradual manner. These research activities are not covered by this project. The definition of emerging per se makes a substantial description difficult, because the technologies are not commercially proven and applied in such a manner that secure data were available. Often it is not in the interest of the developing company to publish their research activities because by successfully applying a new technology an advantage on the market is obtained which basically translates into money. Hence getting reliable data and especially data about costs is difficult and often almost impossible. Another problem with emerging technologies is that their chances on the market are difficult to foresee even by experts in the field (as turned out during the workshop) since there are not only technical and economic reasons for a success or a failure of a technology. In addition, it is not foreseeable which of the existing problems can be solved and which remain problematic; new problems may arise during real-life application of the emerging technology. Nonetheless, based on the available information the consortium identified a number of technologies that have the highest potential to make an impact on future air emissions. This impact will be quantified in the following chapter. It has to be noted, however, that the assumptions were made by the consortium by request of the Commission, as the Commission considers the consortium to be the experts in the field. The assumptions are made with current knowledge. When considering identified removal potential, it has to be kept in mind, that the costs for this additional reduction of emissions are not known.

4. Work Package 3: Development of emissions scenarios

4.1. Introduction

4.1.1. Scope of this work package

The main objective of this work package was to estimate the emissions for the years up to 2030, and by calculating the achieved additional reduction compared to a baseline scenario without emerging technologies determining the impact of emerging technologies on air emissions.

The scenarios to be calculated were discussed during the kick-off meeting.

a) A Business as Usual (BAU) scenario including relevant current and upcoming legislation: this is the baseline scenario as developed by IIASA using RAINS and PRIMES model

b) The “Emerging Technologies” scenario will additionally incorporate new technologies.

Legislation in the pipe that will have an impact on emissions is: IPPC-Directive (BREFs and reviews thereof), LCP-Directive, Directive on Waste Incineration, VOC-Directive, NEC-Directive, ET-Directive and Fuel Content Directive. Most of the legislation in the pipe with respect to air emissions reduction will have been fully implemented by 2010 in the industry – at least in EU-15 (e.g. LCP, IPPC).

The scenarios are based on the penetration of emerging technologies according to expert judgement. Corresponding emission control costs were not calculated because – according to the experts present at the workshop – the estimation of costs for emerging technologies is very uncertain and depends on many factors that are not foreseeable.

4.1.2. RAINS structure

Power and district heating plants sector:

Centralised power and district heating plants are sub-divided into existing plants with wet bottom boilers (PP_EX_WB), other existing plants (PP_EX_OTH), and new plants (PP_NEW). The total energy consumption in this sector is (PP_TOTAL). Electricity and heat losses as well as the own use are reported in the conversion sector.

Fuel conversion sector:

The fuel conversion sector includes refineries, coke and briquettes production plants, coal gasification plants etc, The conversion sector in RAINS includes processes of fuel production and conversion other than conversion to electricity and district heating (these are included in the centralised power plant and district heating sector respectively). The fuel consumption in the conversion sector is divided into combustion (CON_COMB) and losses (CON_LOSS). Energy use reported in the conversion sector (CON) includes energy that is combusted in that sector, not energy converted into other energy forms.

Industrial energy use:

Consumption in industry is divided into combustion in industrial boilers for the auto-production of electricity and heat (IN_BO) and other industrial combustion (IN_OCTOT). Further, non-energy use of fuels (NONEN) is also reported. However, for calculations of emissions from other industrial combustion, values from the column (IN_OC) are used. This column is created during the initialisation of model coefficients through subtraction of energy consumption in cement and lime industry from the column (IN_OCTOT).
Due to this structure the energy consumption of industrial sectors cannot be derived from the RAINS model and neither can the emissions thereof.

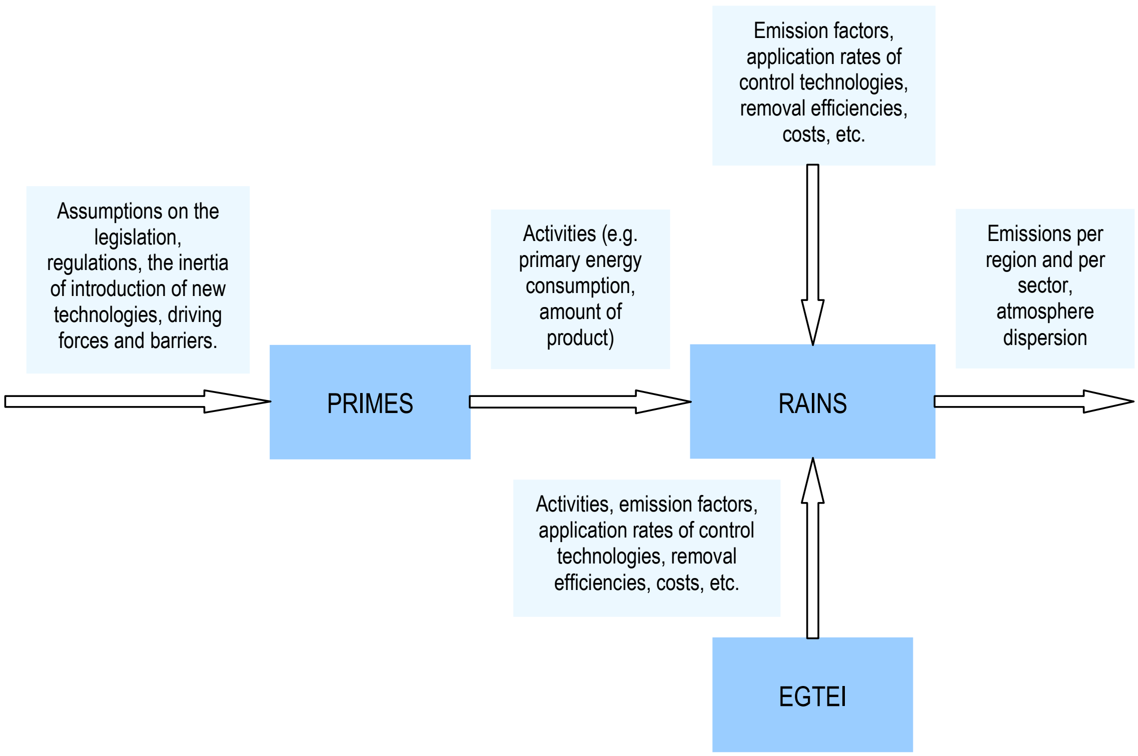
Process emissions:

RAINS also includes the so-called "Process emissions" in the industrial sector, i.e., emissions that cannot be directly linked to energy consumption. Except for cement this means that the emissions from an non-energy -producing industrial sector are divided between combustion (IN) and process emissions (PR).

4.1.3. BAU Scenario in RAINS (based on the PRIMES baseline scenario)

PRIMES is a modelling system that simulates a market equilibrium solution for energy supply and demand in the EU. The model serves to support policy analysis in the field of new technologies and renewable sources.

PRIMES simulates in detail the technology choice in energy demand and energy production. The model explicitly considers the existing stock of equipment, its normal decommissioning and the possibility for premature replacement. At any given point in time, the consumers or producers select the technology of the energy equipment on an economic basis and can be influenced by policy (taxes, subsidies, regulation) market conditions (tariffs etc.) and technology changes (including endogenous learning and progressive maturity on new technologies). Inertia in the penetration of new technologies is taken into account. Energy savings, technology progress in power generation, abatement technologies, renewables and alternative fuels (biomass, methanol, hydrogen) are determined at each country-specific energy system.



The model considers 15 EU countries and 24 energy forms in total: Coal, Lignite and Peat, Crude-oil, Residual Fuel Oil, Diesel Oil, Liquefied Petroleum Gas, Kerosene, Gasoline, Naphtha, Other oil products, Bio-fuels, Natural and derived gas, Thermal Solar (active), Geothermal low and high enthalpy, Steam (industrial and distributed heat), Electricity, Biomass and Waste, Hydrogen, Solar electricity, Wind, Hydro [271].

4.2. Emerging technologies and their consideration in the RAINS model

4.2.1. New power and district heating plants

The “new power and district heating plants” sector is represented by PP_NEW in the RAINS model. All capacities put into operation before the end of 1995 are treated as existing (PP_EX_WB and PP_EX_OTH).

Table 4.1: The power and district heating plants sector in RAINS

Abbreviation	Name of the sector	Activity unit
PP_EX_OTH	Power & district heat plants: Exist. other	PJ
PP_EX_OTH1	Power & district heat plants: Exist. other, grate firing	PJ
PP_EX_OTH2	Power & district heat plants: Exist. other, fluidised bed	PJ
PP_EX_OTH3	Power & district heat plants: Exist. other, pulverised	PJ
PP_EX_WB	Power & district heat plants: Exist. wet bottom	PJ
PP_NEW	Power & district heat plants: New	PJ
PP_NEW1	Power & district heat plants: New, grate firing	PJ
PP_NEW2	Power & district heat plants: New, fluidised bed	PJ
PP_NEW3	Power & district heat plants: New, pulverised	PJ
PP_TOTAL	Power & district heat plants (total)	PJ

4.2.1.1. Electricity and steam generation in the PRIMES baseline scenario

The PRIMES baseline scenario considers 148 different plant types per country for the existing thermal plants; 678 different plant types per country for the new thermal plants; 3 different plant types per country for the existing reservoir plants; 30 different plant types per country for the existing intermittent plants; in addition, chronological load curves, interconnections, network representation; three typical companies per country; cogeneration of power and steam, district heating.

The representation of technologies that are now available or will be available in the future is a major focus of the model, as it is intended to serve as well for strategic analyses on technology assessment. To support such analyses, the model uses a large list of alternative technologies and differentiates their technical-economic characteristics according to the plant size, the fuel types, the cogeneration technologies, the country and the type of producer. A model extension is also designed aiming at representing a non-linear cycle of the penetration of new technologies, for which learning through experience (and other industrial economic features) relates penetration with the technology performance.

The consideration of intermittent energy sources, such as renewables, also requires a representation of chronological curves, as the random availability of the source over time can be approximated. Nevertheless, the correct modelling of intermittent production also requires a representation of geographical characteristics of production and transmission and a modelling of congestion over the electricity networks. Obviously, such features are necessary to adequately represent the market for steam and heat. Such features have not been yet introduced in PRIMES, as the model mainly aims to serve for integrated strategic analyses [271].

4.2.1.2. Technologies of the “new power and district heating plants” sector in RAINS

NO_x

The level of NO_x emissions arising from burning the same fuel varies considerably with the type of the combustion process. There are three categories of options to reduce NO_x emissions from energy sector in RAINS, namely through:

- changes in the energy system leading to lower fuel consumption (energy conservation or fuel substitution)
- combustion modification

- treatment of the flue gases

The primary measures to reduce NO_x emissions from power and district heating plant boilers that fall into the "Combustion Modification " (CM) category are:

- Low-NO_x burners (air-staged LNB, flue gas recirculation LNB and fuel-staged LNB)
- Fuel Injection or Reburning at boiler level
- Oxycombustion
- Fluidised Bed Combustion

The secondary measures to reduce NO_x emissions from boilers of power plants in RAINS are the Selective Catalytic Reduction in high-dust or in tail-gas configuration (SCR). It is not possible to combine primary measures such as CM and SCR for new plants (only for existing plants) in the RAINS model [267].

Table 4.2: Combination of NO_x control technologies and activites for the power plants sector in the RAINS model

Control technologies	Activities in the RAINS model
PBCSCR	BC1, BC2
PHCSCR	HC1, HC2, HC3, OS2
POGSCR	GAS, HF

PM

To reflect the differences in solid fuel quality across countries, PM_{TSP} emission factors are computed using a mass balance approach, taking into account the country-specific information on the ash content of different solid fuels, the heating values, and the fraction of ash retained in the respective boiler type. Emission factors for fine particulate matter are calculated from the TSP estimates using typical size profiles available in literature. For the combustion of other fuels, emission factors from literature have also been used.

Moreover a distinction is made for power plants between three types of boilers, which are characterised by significantly different ash retention and particle size distribution:

- Grate combustion (NEW1): typically smaller installations. Particles from grate combustion are usually relatively large.
- Fluidised bed combustion (NEW2): typically mid-size installations. Particles size differ with technologies like atmospheric fluidised bed, limestone injection, circulating fluidised bed.
- Pulverised fuel combustion (NEW3)

The RAINS model considers a limited number of emission control options reflecting groups of technological solutions with similar control efficiencies. For large boilers in power stations the following options are available in RAINS:

- Cyclones (CYC)
- Wet scrubbers (WSCRB)
- Electrostatic precipitators (one field (ESP1), two fields (ESP2), more than two fields (ESP3P))
- Fabric filters (FF)
- Good maintenance in industrial oil boilers
-

The RAINS model considers size-fraction specific removal efficiencies for these control options [268].

Table 4.3: Combination of PM control technologies and activities for the power plants sector in RAINS

Control technologies		Activities in the RAINS model
CYC, ESP1, ESP2, ESP3P	PP_NEW1, PP_NEW2, PP_NEW3	BC1, BC2, HC1, HC2, HC3
	PP_NEW	OS1, OS2
FF	PP_NEW1, PP_NEW2, PP_NEW3	BC1, BC2, HC1, HC2, HC3
	PP_NEW	HF, MD, OS1, OS2
GHIND	PP_NEW	HF, MD
WSCRB	PP_NEW1	BC1, BC2, HC1, HC2, HC3

SO_x

There is a variety of options to reduce SO_2 emissions from the power plant sector, and the economic assessment in RAINS concentrates on the technical emission control options, which do not imply structural changes of the energy system. Changes in the energy system that lead to lower consumption of sulphur containing fuels are energy conservation or fuel substitution.

The use of low-sulphur fuels or the fuel desulphurisation are documented in RAINS. For low sulphur fuels, a distinction is made between low-sulphur coal (LSCO), coke (LSCK), fuel oil (LSHF) and diesel oil (LSMD1, LSMD2, LSMD3). Any change in emission factors over time (e.g., caused by a changed sulphur content) is interpreted as an emission control measure and reflected via a modified application factor of a control technology with a certain efficiency.

Typical means of sulphur emission reduction by combustion modification (“CM” in RAINS) are the addition of limestone into conventional boilers (LINJ) and the fluidised bed combustion.

To represent flue gas treatments, RAINS has selected the wet flue gas desulphurisation (WFGD) with typical sulphur removal rates between 85 and 95% and advanced high-efficiency processes with emission reductions of up to 99%. Technical approaches to achieve these removal rates can be specially designed wet FGD processes or the Wellman-Lord technology [269].

Table 4.4: Combination of SO_x control technologies and activities for the power plants sector in RAINS

Control technologies	Activities in the RAINS model
LINJ	BC1, BC2, HC1, HC2, HC3, OS2
LSCK	DC
LSCO	HC1, HC2, HC3
LSHF	HF
LSMD1, LSMD2	MD
PWFGD	BC1, BC2, HC1, HC2, HC3, HF, OS2
RFGD	BC1, BC2, HC1, HC2, HC3, HF

VOC

No control of VOC emissions are implemented in the RAINS model for the “New power and district heating plants” sector.

4.2.2. Industrial combustion in boilers

4.2.2.1. Industry in the PRIMES baseline scenario

The industrial model separately contains 9 industrial sectors, namely iron and steel, non-ferrous metals, chemicals, building materials, paper and pulp, food, drink and tobacco, engineering, textiles, and other industries. For each sector different sub-sectors are defined (in total about 30 sub-sectors, including recycling of materials). At the level of each sub-sector a number of different energy uses is represented (in total about 200 types of technologies of energy use are defined) [271].

Table 4.5: The industrial combustion sector in RAINS

Abbreviation	Name of the sector	Activity Unit
IN_BO	Industry: Combustion in boilers	PJ
IN_BO1	Industry: Combustion in boilers, grate firing	PJ
IN_BO2	Industry: Combustion in boilers, fluidised bed	PJ
IN_BO3	Industry: Combustion in boilers, pulverised	PJ

IN_OC	Industry: Other combustion	PJ
IN_OC1	Industry: Other combustion, grate firing	PJ
IN_OC2	Industry: Other combustion, fluidised bed	PJ
IN_OC3	Industry: Other combustion, pulverised	PJ
IN_OCTOT	Industry - Other combustion	PJ

4.2.2.2. Technologies included in RAINS

NO_x

Table 4.6: Combination of NO_x control technologies and activities for industrial combustion in boilers in RAINS

Control technologies	Activities in the RAINS model
IOGCM	ETH, GAS, GSL, HF, LPG, MD, MTH
IOGCSC	GAS, HF
IOGCSN	GAS
ISFCM	BC1, BC2, HC1, HC2, HC3, OS1, OS2
ISFCSC	BC1, BC2, HC1, HC2, HC3, OS2
ISFCSN	BC1, BC2, HC1, HC2, HC3, HF, OS2

PM

Table 4.7: Combination of PM control technologies and activities for industrial combustion in boilers in RAINS

Control technologies	Activities in the RAINS model	
GHIND	IN_BO	HF, MD
IN_CYC, IN_ESP1, IN_ESP2, IN_ESP3P	IN_BO	DC, OS1, OS2
	IN_BO1	BC1, BC2, HC1, HC2, HC3
IN_FF	IN_BO	DC, HF, MD, OS1, OS2
	IN_BO1	BC1, BC2, HC1, HC2, HC3
IN_WSCRB	IN_BO1	BC1, BC2, HC1, HC2, HC3

SO_x

Table 4.8: Combination of SO_x control technologies and activities for industrial combustion in boilers in RAINS

Control technologies	Activities in the RAINS model
IWFGD	BC1, BC2, HC1, HC2, HC3, HF, OS2
LINJ	BC1, BC2, HC1, HC2, HC3, OS2
LSCO	HC1, HC2, HC3
LSHF	HF
LSMD1, LSMD2	MD

4.2.2.3. Technologies that could be added to the RAINS model

The most important emerging technologies found within the project for the industrial combustion sector are Low-NO_x burners and Ultra Low-NO_x burners. These technologies are both already considered in the RAINS model (combustion modification "CM").

4.2.3. Small scale combustion

4.2.3.1. The commercial and residential sectors in the PRIMES baseline scenario

In the PRIMES baseline scenario, five categories of dwellings are distinguished in the residential sector. These are defined according to the main technology used for heating. They include secondary heating as well. At the level of the sub-sectors, the model structure defines the categories of dwellings, which are further subdivided in energy uses. The electric appliances for non heating and cooling are considered as a special sub-sector, which is independent of the type of dwelling. Four energy use types are defined per dwelling type.

In the commercial and agriculture sector 4 sub-sectors are distinguished. At the level of the sub-sectors, the model defines energy services, which are further subdivided in energy uses defined according to the pattern of technology. In total, 7 sub-sectors and more than 30 end-use technology types are defined [271].

4.2.3.2. The small scale combustion sector in RAINS

Table 4.9: The small scale combustion sector in RAINS

Abbreviation	Name of the sector	Activity unit
DOM_FPLACE	Residential-Commercial: Fireplaces	PJ
DOM_MB_A	Residential-Commercial: Medium boilers (<50MW) - automatic	PJ
DOM_MB_M	Residential-Commercial: Medium boilers (<1MW) - manual	PJ
DOM_SHB_A	Residential-Commercial: Single house boilers (<50 kW) - automatic	PJ
DOM_SHB_M	Residential-Commercial: Single house boilers (<50 kW) - manual	PJ
DOM_STOVE	Residential-Commercial: Stoves	PJ
DOM	Combustion in residential-commercial sector (liquid fuels)	PJ

4.2.4. Process emissions in the RAINS model

For **industrial** energy use, the RAINS database distinguishes between energy combustion in industrial boilers for the auto-production of electricity and heat (IN_BO) and fuel combustion in other industrial furnaces (IN_OC). In addition, the available energy statistics and forecasts do not always enable a split of industrial combustion between boilers and furnaces. In such a case, all industrial fuel combustion is reported as IN_OC.

RAINS also includes the so-called ‘**process emissions**’ in the industrial sector, i.e., emissions that cannot be directly linked to energy consumption. Industrial processes included in RAINS are [267]:

- oil refineries (IN_PR_REF),
- coke plants (IN_PR_COKE),
- sinter plants (IN_PR_SINT),
- pig iron - blast furnaces (IN_PR_PIGI),
- non-ferrous metal smelters (IN_PR_NFME),
- sulfuric acid plants (IN_PR_SUAC),
- nitric acid plants (IN_PR_NIAC),
- cement and lime plants (IN_PR_CELI), and
- pulp mills (IN_PR_PULP).

Other production processes distinguished in the CORINAIR inventory are covered by sector IN_OC [267].

4.2.4.1. Example of the NO_x process emissions in RAINS

Industrial activities emitting nitrogen oxides can be divided into combustion processes and processes where emissions cannot be directly linked to energy use. The latter are processes that release nitrogen contained in the raw material (e.g., during production of nitric acid) or processes where the emission factors are intrinsically different compared to the emissions from boilers due to different (much higher) process temperatures (e.g., cement production) [267].

RAINS uses emission factors to estimate emissions from the industrial activities in oil refineries, coke plants, sinter plants, pig iron - blast furnaces, non-ferrous metal smelters, sulphuric acid plants, nitric acid plants, cement and lime plants and pulp mills. In order to accurately calculate the energy- and non-energy related emissions from these processes, RAINS defines the emission factors for these processes as the difference between the actual emissions per ton of production and the hypothetical emissions that would result from fuel use only. However, there is an exception to this rule. It relates to cement and lime production, where total emissions per ton of product are used to calculate the emissions [267].

The available measures for reducing emissions from process sources are strongly related to the main production technology. They are site-specific and depend, inter alia, on the quality of raw materials used, the process temperature and on many other factors [267].

Therefore, it is difficult to develop generally valid technological characteristics of control technologies at the same degree of detail as for fuel-related emissions. Thus, for estimating emission control potentials and costs, the emissions from all processes are combined into one group, to which three stages of control can then be applied. Without defining specific emission control technologies, these three stages are represented by typical removal efficiencies with increasing marginal costs of reduction [267].

4.2.4.2. Iron ore treatment

Table 4.10: The iron ore treatment sector in the RAINS model

Abbreviation	Name of the sector	Activity unit
PR_PELL	Ind. Process: Agglomeration plant - pellets	Mt
PR_SINT	Ind. Process: Agglomeration plant - sinter	Mt
PR_SINT_F	Ind. Process: Agglomeration plant - sinter (fugitive)	Mt

Technologies included in RAINS:

Table 4.11: Combinations of control technologies and activity types for the iron ore treatment sector in RAINS

Sector	Pollutant	Control technology
PR_PELL	-	-
PR_SINT	NOX	PRNOX1, PRNOX2, PRNOX3
	PM	PR_CYC, PR_ESP1, PR_ESP2, PR_ESP3P, PR_FF
	SO2	SO2PR1, SO2PR2, SO2PR3
PR_SINT_F	PM	PRF_GP1, PRF_GP2

4.2.4.3. Coke plants (PR_COKE)

Table 4.12: The coke plants sector in RAINS

Abbreviation	Name of the sector	Activity unit
PR_COKE	Ind. Process: Coke oven	Mt

Technologies included in RAINS:

Table 4.13: Control technologies for the coke plants processes in the RAINS model

Control technologies	Activities in the RAINS model
NOX	PRNOX1, PRNOX2, PRNOX3
PM	PR_CYC, PR_ESP1, PR_ESP2, PR_ESP3P, PR_FF, PR_WSCRB
SO2	SO2PR1, SO2PR2, SO2PR3

4.2.4.4. Iron and steel production (PR_PIGI, PR_BAOX, PR_EARC etc.)

Table 4.14: The iron and steel production sector in the RAINS model

Abbreviation	Name of the sector	Activity unit
PR_PIGI	Ind. Process: Pig iron, blast furnace	Mt
PR_PIGI_F	Ind. Process: Pig iron, blast furnace (fugitive)	Mt
PR_BAOX	Ind. Process: Basic oxygen furnace	Mt
PR_EARC	Ind. Process: Electric arc furnace	Mt
PR_HEARTH	Ind. Process: Open hearth furnace	Mt
PR_HMTRA	Ind. Process: Hot metal transport in iron and steel plant	Mt

4.2.4.5. Non-ferrous metals industry (PR_OT_NFME, PR_ALPRIM, PR_ALSEC)

Table 4.15: The non-ferrous metals industry in the RAINS model

Abbreviation	Name of the RAINS sector	Activity unit

PR_ALPRIM	Ind. Process: Aluminium production - primary	Mt
PR_ALSEC	Ind. Process: Aluminium production - secondary	Mt
PR_OT_NFME	Ind. Process: Other non-ferrous metals prod. - primary and secondary	Mt

For the primary lead, zinc and cadmium production, one interesting emerging technology that could be integrated in RAINS is the Graveliet process that consumes less primary energy. For the primary copper production, bath smelting techniques and the ISA smelt process could be taken into account in the RAINS model, as well as the use of modern fabric or bag filters that reduce PM emissions.

4.2.4.6. Foundries (PR_CAST, PR_CAST_F)

Table 4.16: The foundries sector in the RAINS model

Abbreviation	Name of the RAINS sector	Activity unit
PR_CAST	Ind. Process: Cast iron (grey iron foundries)	Mt
PR_CAST_F	Ind. Process: Cast iron (grey iron foundries) (fugitive)	Mt

4.2.4.7. Pulp and paper manufacturing (PR_PULP)

Table 4.17: The pulp and paper sector in the RAINS model

Abbreviation	Name of the RAINS sector	Activity unit
PR_PULP	Ind. Process: Paper pulp mills	Mt

The control technologies included in RAINS are shown in Table 4.18.

Table 4.18: Control technologies available for the pulp and paper sector in the RAINS model

Pollutant	Control technology
NOX	PRNOX1, PRNOX2, PRNOX3
SO2	SO2PR1, SO2PR2, SO2PR3

4.2.4.8. Glass production (PR_GLASS)

Table 4.19: The glass manufacturing in the RAINS model

Abbreviation	Name of the RAINS sector	Activity unit
PR_GLASS	Ind. Process: Glass production (flat, blown, container glass)	Mt
PR_OTHER	Ind. Process: Production of glass fibre, gypsum, PVC, other	Mt

The control technologies included in RAINS are shown in Table 4.20.

Table 4.20: Control technologies in the glass manufacturing sector in the RAINS model

Pollutant	Control technology
PM	PR_CYC, PR_ESP1, PR_ESP2, PR_ESP3P, PR_FF

4.2.4.9. Chemical industry (PR_NIAC, PR_SUAC)

Table 4.21: Some chemical industry sectors in RAINS

Abbreviation	Name of the RAINS sector	Activity unit
PR_NIAC	Ind. Process: Nitric acid	Mt
PR_SUAC	Ind. Process: Sulphuric acid	Mt

The control technologies included in RAINS are shown in Table 4.22.

Table 4.22: Example: Control options in the sulphuric acid sector of the RAINS model

PR_SUAC	NOX	PRNOX1, PRNOX2, PRNOX3
	SO2	SO2PR1, SO2PR2, SO2PR3

4.2.4.10. Refineries (PR_REF, REF_PROC)

Table 4.23: The refineries sector in RAINS

Abbreviation	Name of the RAINS sector	Activity unit
PR_REF	Ind. Process: Petroleum refineries	Mt
REF_PROC	Refineries - process	Mt crude

4.2.4.11. Coating

Table 4.24: Examples of coating sectors in RAINS

Abbreviation	Name of the RAINS sector	Activity unit
IND_P_CNT	Industrial paint applications - General industry (continuous processes)	kt
IND_P_OT	Industrial paint applications - General industry	kt
IND_P_PL	Industrial paint applications - General industry (plastic parts)	kt

4.2.5. Cement and lime sectors

In RAINS, for cement and lime production total emissions per ton of product are used to calculate emissions. This is because the retention of sulphur in the material during cement and lime production is so high (more than 80%) that the standard approach outlined above would require negative SO_2 process emission factors. To avoid computational difficulties caused by negative emission factors, total emissions (also of NO_x) are included in the process emission factor. In order to avoid double counting, fuel consumption by cement and lime industry is subtracted from industrial fuel use before performing emissions calculations [267].

Table 4.25: The cement and lime production sector in RAINS

Abbreviation	Name of the RAINS sector	Activity unit
PR_CEM	Ind. Process: Cement production	Mt
PR_LIME	Ind. Process: Lime production	Mt

4.2.5.1. Cement (PR_CEM)

Table 4.26: Control technologies for the cement production sector in RAINS

NOX	PRNOX1, PRNOX2, PRNOX3
PM	PR_CYC, PR_ESP1, PR_ESP2, PR_ESP3P, PR_FF, PR_WSCRB
SO2	SO2PR1, SO2PR2, SO2PR3

4.2.5.2. Lime (PR_LIME)

Table 4.27: Control technologies for the lime production sector in RAINS

NOX	PRNOX1, PRNOX2, PRNOX3
PM	PR_CYC, PR_ESP1, PR_ESP2, PR_ESP3P, PR_FF, PR_WSCRB
SO2	SO2PR1, SO2PR2, SO2PR3

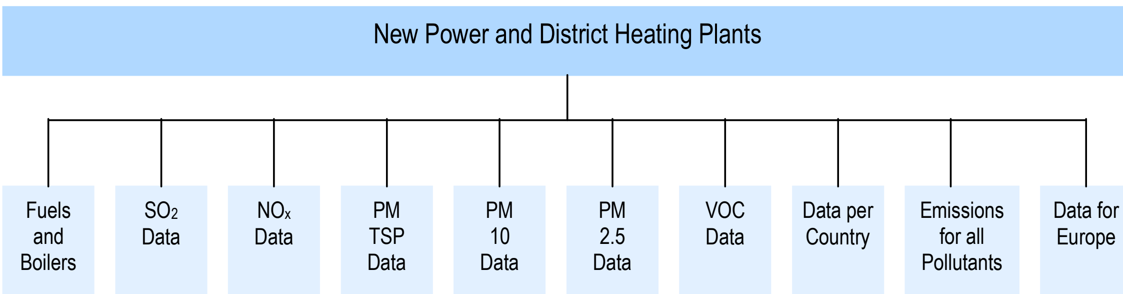
4.3. Tools for the "Emerging technologies" scenarios

The RAINS model calculates present and future sector emissions as a product of activity level (e.g., fuel consumption) and an emission factor. The main purpose of the tool presented here is to use the data already available in the RAINS database and to allow the user to change parameters as well as to add additional technologies (e.g. emerging) or sectors and finally to recalculate the emissions resulting from the new scenario.

Running this tool requires a sound knowledge of the structure and contents of the RAINS database.

4.3.1. Tool for the New Power and District Heating Plants sector

The Excel-VBA tool described here contains 9 worksheets as represented in the following Figure:



The Excel worksheet entitled "Fuels" shows the fuel and boiler types scenarios for each country from 1995 to 2030 in steps of 5 years. The next 6 worksheets contain the pollutant related parameters, e.g. the fuel emission factors, the removal efficiencies of control technologies and finally the control scenarios.

The sheet called "BAU – Emerging" displays the results of the emissions calculations (Emerging Technologies Scenario), the emissions of the RAINS database (BAU Scenario) and a comparison between the two scenarios. The last sheet, entitled "countries", allows the user to view all data for a chosen country.

Du to the fact that most NH_3 emissions result from agriculture, no worksheet has been developed for NH_3.

4.3.1.1. Fuels (sheet "Fuels")

The RAINS data for the emission calculations can be downloaded from the RAINS website. Some data are presented in the form of matrices, whose dimension is (27,9) since 27 countries and 9 years are taken into account. This is the case for the fuel use scenarios (energy consumption in the power plant and district heating sector by fuel type in PJ), as shown in the following figure:

		1990	...	...	...	2025	2030
GAS	*AT*	0	...	...	...	182.57	179.95
GAS	...	...	...	...	...	...	...
GAS	*UK*	0	...	...	...	2357.5	2501.33
*HC*1	*AT*	0	...	...	...	76.27	107.12
*HC*1	...	...	...	...	...	...	...
*HC*1	*UK*	0	...	...	...	481.52	610
...	...	...	...	...	...	...	...

There are 21 fuels, i.e. 21 existing matrices in RAINS that describe the fuel use in Europe in the "New Power and District Heating Plants" sector, plus 4 new technologies that were added as matrices, namely TECH1, TECH2, TECH3, TECH4. These 25 matrices are identical in all emission calculations.

4.3.1.2. NOx (sheet "NO_2")

NO_x emission factors

Some data are country-specific and time independent. This is the case for fuel emission factors (non-abated emissions):

	BC1	BC2	HC1	...	...	TECH3	TECH4
AT	0.1	0.1	0.15	...	...	0	0
...	...	...	...	...	...	...	...
CZ	0.12	0.12	0.15	...	...	0	0
...	...	...	...	...	...	...	...
IE	0.065	0.1	0.15	...	...	0	0
..	...	...	...	...	...	...	...
UK	0.1	0.1	0.15	...	...	0	0

The emission factor associated to a fuel is the same for a country from 1990 to 2030. The simplifications made by the RAINS model were transferred to this tool, e.g. time independent parameters in RAINS are also time independent in the tool.

NO_x removal efficiencies

NO_x emissions are only reduced via end-of-pipe technologies: the removal efficiencies are country and time independent. The data are scalars and not vectors as is the case of SO_2 where SO_2, removal efficiencies can be country-specific, because of the use of low sulphur fuels that differ from country to country.

NO_x control scenarios

Other country-specific and time dependent data are the control scenarios, that determine the percentage of activity in the entire sector to which a given control measure can be applied. For each country, year and fuel, these matrices contain the application rate of each control measure:

			1990	1995	...	2025	2030
BC1	PBCSCR	AT	0	90	...	90	90
BC1	PBCSCR	...	...	...	...	...	...
BC1	PBCSCR	UK	0	25	...	40	40
HC1	PHCSCR	AT	0	90	...	100	100
HC1	PHCSCR	...	...	...	...	...	...
HC1	PHCSCR	UK	0	25	...	70	70
GAS	POGSCR	...	...	...	...	...	...

The code "SO_2HC2PWFGD (2, 3) = 50" means that the application rate of PWFGD in HC2 fuelled-plants in Belgium was 50% in 2000.

Calculation of the NO_x emissions

Emission calculation comprises three steps:

- calculation of the total emissions before abatement
- calculation of the abated emissions

- calculation of the difference between the two results to obtain the emissions after abatement

Calculation of the total NO_x emissions before abatement (and without low sulphur fuels)

$$NO_2TOTkt(i, j) = \sum_{k=1}^{21} (FuelPJ_k(i, j) \times NO_2EfFuelktPJ_k(i) \quad (1)$$

$NO_2TOTkt(i, j)$	Total emissions of NO_2 in kt before abatement in country i in time step j
$FuelPJ_k(i, j)$	Use of fuel k (activity level of sector) in PJ in country i in time step j
$NO_2EfFuelktPJ_k(i)$	NO_2 emission factor in kt/PJ of fuel k in country i

Calculation of the amount of NO_x emissions removed

$$NO_2ABATkt(i, j) = \sum_{k=1}^{21} (FuelPJ_k(i, j) \times NO_2EfFuelktPJ_k(i) \times (\sum_{n=1}^{P_k} NO_2RmFuel_kTech_n \times NO_2SceFuel_kTech_n(i, j))) \quad (2)$$

$NO_2ABATkt(i, j)$	Total abated emissions of NO_2 in kt in country i in time step j
P_k	Number of control technologies applied for fuel k
$NO_2RmFuel_kTech_n$	NO_2 removal efficiency in [%] of technology n applied to fuel k
$NO_2SceFuel_kTech_n(i, j)$	NO_2 application rate (application factor from control scenario) in [%] for technology n applied to fuel k in country i in time step j

NO_x emissions after abatement

$$NO_2EMkt(i, j) = NO_2TOTkt(i, j) - NO_2ABATkt(i, j) \quad (3)$$

$NO_2EMkt(i, j)$	Total emissions of NO_2 in kt after abatement in country i in time step j

4.3.1.3. SO_x (sheet "SO_x")

SO_2 removal efficiencies

Removal efficiencies of SO_2 add-on control technologies are country and time independent. However, the control of SO_2 emissions with process integrated measures such as the use of low sulphur fuels requires different removal efficiencies for each country, since the available fuels are different from country to country. Finally, a matrix represents SO_2 removal efficiencies of control technologies with columns of fixed parameters for add-on technologies and columns of variable parameters for process-integrated measures like low sulphur fuels:

	HC1 LINJ	HC1 LSCO	HC1 ...	HF LSHF	HF PWFGD	HF ...	...
AT	60	40	...	60	95	...	...
BE	60	33	...	83	95	...	...
...	60	...	...	...	95	...	...
SK	60	60	...	77	95	...	...
UK	60	30	...	74	95	...	...

SO_2 emission calculation

The calculation of abated emissions is the same as for NO_2 emissions, except that SO_2 removal efficiencies are country-specific:

$$SO_2ABATkt(i, j) = \sum_{k=1}^{21}(FuelPJ_k(i, j) \times SO_2EfFuelktPJ_k(i)$$
$$\times (\sum_{n=1}^{P_k} SO_2RmFuel_kTech_n(i) \times SO_2SceFuel_kTech_n(i, j))) \quad (4)$$

$SO_2RmFuel_kTech_n(i)$ SO_2 removal efficiency in [%] of technology n applied to fuel k **for country i**

4.3.1.4. PM_{TSP}, PM_{10}, $PM_{2.5}$ (sheets "PM $_{TSP}$", "PM_{10}" and "PM $_{2.5}$")

PM $_{TSP}$, PM_{10} and $PM_{2.5}$

PM is divided into three size classes: PM_{TSP}, PM_{10} and $PM_{2.5}$. The procedure of calculating theses emissions is the same as for SO_2 and NO_x, but of course emission factors and removal efficiencies differ.

The control measures applied concern PM as a whole: there is only one control scenario for PM_{TSP}, PM_{10} and $PM_{2.5}$, but the removal efficiencies of the technologies applied are different for the three size classes.

Emissions for PM_{TSP}, PM_{10} and $PM_{2.5}$ are calculated separately in the tool. PM_{TSP}, PM_{10} and $PM_{2.5}$ emissions are calculated respectively with the data of the worksheets "PM_{TSP}", "PM_{10}" and "$PM_{2.5}$" when the user clicks on the buttons "calculate the PM_{TSP} emissions", "calculate the PM_{10} emissions", and "calculate the $PM_{2.5}$ emissions" respectively. Emissions are displayed in the work sheet "BAU – Emerging".

Boiler types for the PM emissions calculations

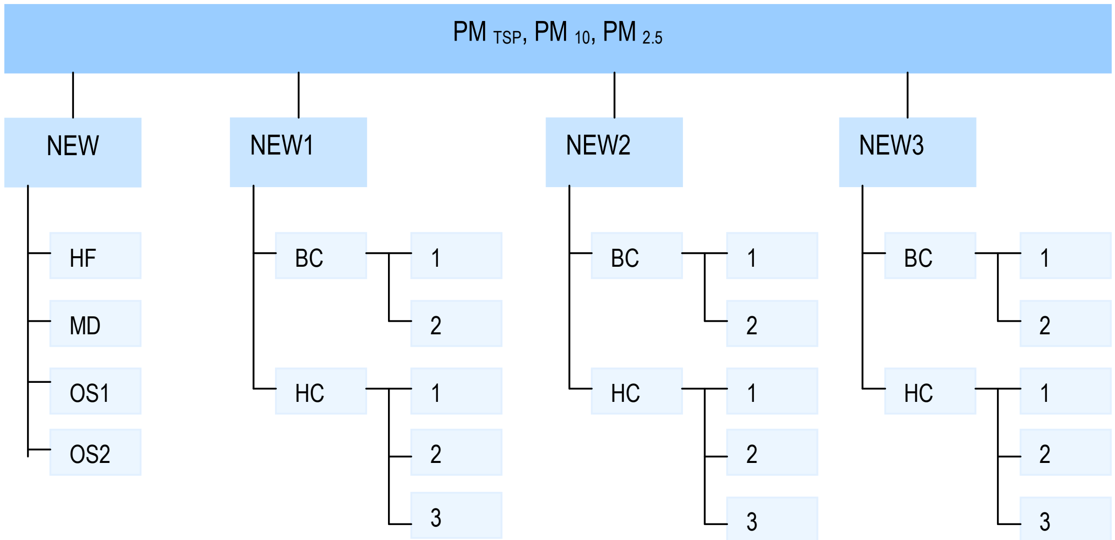
For the emissions resulting from the use of fuels other than hard or brown coal, calculations can be performed using the same method as for SO_2 and NO_2. However, for the use of brown coal and hard coal, one has to distinguish between three cases:

- grate firing (PM_NEW1)
- fluidised bed (PM_NEW2)
- pulverised coal (PM_NEW3)

The use of other fuels than brown and hard coal is calculated under PM_NEW. Emission factors are not only dependent on the fuel and the country but also on the boiler type.

$$\begin{cases} \text{"PM}_{TSP} = \text{PM}_{TSP}\text{\_NEW1} + \text{PM}_{TSP}\text{\_NEW2} + \text{PM}_{TSP}\text{\_NEW3} + \text{PM}_{TSP}\text{\_NEW"} \\ \text{"PM}_{10} = \text{PM}_{10}\text{\_NEW1} + \text{PM}_{10}\text{\_NEW2} + \text{PM}_{10}\text{\_NEW3} + \text{PM}_{10}\text{\_NEW"} \\ \text{"PM}_{2.5} = \text{PM}_{2.5}\text{\_NEW1} + \text{PM}_{2.5}\text{\_NEW2} + \text{PM}_{2.5}\text{\_NEW3} + \text{PM}_{2.5}\text{\_NEW"} \end{cases}$$

Calculation of PM_{TSP}, PM_{10} and $PM_{2.5}$ emissions



4.3.1.5. <u>VOC</u>

There are no add-on technologies available in the RAINS data base. The VOC emissions are the simple product of the quantity of fuel used and the fuel emission factor.

4.3.1.6. <u>Sheet “BAU-Emerging”</u>

NO_x emissions are calculated with the data of the worksheet “NO_x” when the user clicks on the button “calculate the NO_x emissions”, and the principle is exactly the same as for other pollutants. For all pollutants, emissions are displayed in the work sheet “BAU – Emerging” in form of tables.

Once calculated, the calculated emissions are compared with the emissions given in the left part of the table (here the RAINS BAU scenario but the user can enter other data before running the calculations). The results of this comparison are displayed in [%] in the right part of the table. The emissions of the BAU scenario can be reloaded for comparison with the button “initialise” (this button will also put all results back to zero).

If the new scenario leads to a decrease of emissions greater than 5%, the emissions of the new scenario are displayed in cells with a green background colour (positive influence). If the new scenarios lead to an increase of emissions greater than 5%, the colour is red (negative influence).

4.3.1.7. <u>Parameters of a country (Sheet “Countries”)</u>

In the worksheet entitled “countries” the tool gives the possibility to display all data for a selected country, from fuel emissions to emissions of each pollutant,.

In order to change some parameters the user has two possibilities:
- change the data in the fuels and pollutants related parameters worksheets,
- or change the data concerning a country in the worksheet “countries” and click on “accept the new data”.

The worksheets can be initialised one by one, e.g. all data entered by the user are replaced by the parameters of the RAINS BAU scenario, and the results or emissions are put back to zero.

4.3.1.8. <u>Tools for other sectors</u>

Similar tools could be designed for each sector of the RAINS model. However, the use of the model could be very complex for e.g. industrial sectors because of the distinction made between energy (combustion in industrial

boilers, combustion in the industry other than in boilers) and process emissions (no fuel use, NOF) in the RAINS model.

The data used for the “new power and district heating plants” tool were downloaded from the BAU scenario of RAINS, without emission certificates (BL_CLE_Aug04). Updates of the RAINS database are available on the RAINS website since September 2004.

4.3.2. How to add an additional (e.g. emerging) technology to the scenarios

4.3.2.1. Introduction

The impact of diffusion of a new technology on air emissions can be reflected:

- **in the activity rates**: the primary energy use can be reduced because of the use of emerging technologies that have a better efficiency and consume less energy. This aspect has only an influence on the activity rates when these are expressed in primary energy (not when they are e.g. an amount of the product)
- **in the emission factors**: the emission factor associated with an activity (primary energy or amount of product) can be reduced thanks to the use of a technology that produces less emissions by consuming the same quantity of primary energy.
- **in the application rates**: application rates of some technologies that are already integrated in the RAINS could increase more strongly than taken into account in the BAU scenario of the RAINS model
- **in the removal efficiencies**: the removal efficiencies of existing pollution control technologies can be improved in future, and emerging technologies have to be implemented in the model with their own removal efficiencies.

Future application rates of emerging technologies are highly dependent on the general conditions and must be – to calculate reasonable emissions – estimated by experts.

4.3.2.2. Calculation of new emission factors associated with the RAINS activities

The structure of the RAINS model is highly aggregated and aggregation rules must be known in order to use or to change the data in the RAINS model (or in the tool).

One way to introduce new technologies is to calculate new emission factors associated with the different activities. The former emission factor in the RAINS model was:

$$Ef_{i,j,k} = \frac{\sum_{t=0}^{t=m} A_{i,j,k,t} \times Ef_{i,j,k,t}}{\sum_{t=0}^{t=m} A_{i,j,k,t}}$$

$Ef_{i,j,k}$ Emission factor for the activity/sector i in country j for time step k

$A_{i,j,k,t}$ Activity of technology t for sector i in country j for time step k

$Ef_{i,j,k,t}$ Emission factor of technology t for sector i in country j for the step k

m Number of technologies considered in sector i in the PRIMES baseline scenario

In the case of the Emerging Technologies scenario, new emission factors have to be calculated for each sector or sector activity (e.g. HC1, PR_PELL). In order to calculate these new emission factors, new activities have to be calculated for existing technologies of the sector. In general, one would assume that the introduction of emerging technologies would reduce the market shares and hence activities of existing technologies. However, since the detailed activities in RAINS are not published, here the emission factors of existing technologies remain unchanged.

The emission factor of a sector is calculated taking into account the activities and emission factors of the new technologies:

$$Ef'_{i,j,k} = \frac{\sum_{t=0}^{t=m} A'_{i,j,k,t} \times Ef_{i,j,k,t} + \sum_{t=0}^{t=n} A''_{i,j,k,t} \times Ef''_{i,j,k,t}}{\sum_{t=0}^{t=m} A'_{i,j,k,t} + \sum_{t=0}^{t=n} A''_{i,j,k,t}}$$

$A'_{i,j,k,t}$ Activity of existing technology t for sector i in country j for time step k in the Emerging Technologies scenario

$A''_{i,j,k,t}$ Activity of emerging technology t for sector i in country j for time step k in the Emerging Technologies scenario

$Ef''_{i,j,k,t}$ Emission factor of emerging technology t for sector i in country j for time step k in the Emerging Technologies scenario

n Number of emerging technologies considered now in sector i in the Emerging Technologies scenario

4.3.2.3. Integration of new activities in the model

A possibility to add 4 new types of activities was integrated in the tool, their names are TECH1 to TECH4. The user has to enter the following parameters for these technologies:

- quantity in PJ in the worksheet “Fuels” for each country and each year. For example, the user can replace 2X PJ of BC1 by X PJ of TECH1 in Germany in 2010. This means that 2X PJ less BC1 as primary energy is used, and that it is replaced by X PJ of TECH1. TECH1 could be e.g. tidal energy: now this renewable energy source is treated together with other renewables but it could be considered separately in order to improve the transparency of the model.
- SO_2, NO_x, PM_{TSP}, PM_{10}, $PM_{2.5}$ and VOC emission factors of this technology in the corresponding worksheets in kt/PJ or t/PJ.

4.3.3. Power and District Heating Plants

In the power sector, including large combustion plants (LCP), the impact of process integrated as well as end-of-pipe and add-on technologies for SO_2, NO_2, CO_2 and VOC reduction should be analysed. Even though there is no possibility for the user to add end-of pipe technologies in the tool end-of-pipe technologies can be accounted for by changing application rates and removal efficiencies of existing control technologies.

4.3.3.1. Example 1: Introduction of (ultra) supercritical steam boilers in the EMTECH scenario

Data on (ultra) supercritical steam boiler (fact sheets):

The Supercritical Pulverised Coal Firing has nowadays efficiencies of 40-45%. It is commercial, e.g. there is a unit in Esbjerg (Denmark) with 415 MW, 45.3% efficiency, 250 bar, 560°C, that started operation in 1992. The Ultra-Supercritical Pulverised Coal Firing allows to increase efficiencies to 50%. The real commercial break-through of these technologies is expected to be in 10 to 15 years.

Table 4.28: Diffusion of advanced steam cycles in the world till 2030

	2005	2010	2015	2020	2025	2030
chance	medium	medium	high	high	high	high
market share of clean coal technologies in the world-wide energy sector (coal technologies)	-	10%	-	50%	-	100%

Implementation in the tool:

New activities have to be calculated as follows and can be used to develop new emission factors associated with the activities HC1, HC2, HC3, BC1 and BC2.

$$E_{HC1i,j} = HC1_{BAUi,j} \times 0.38$$

$E_{HC1i,j}$ Final energy produced with non emerging technologies (conventional plants) fed with HC1 in the BAU scenario for country j and time step i [PJ]

$HC1_{BAUi,j}$ Activities of non emerging technologies (conventional plants) in the BAU scenario for country j and time step i [PJ]

"0.38" Electrical efficiency of conventional plants (BAU scenario)

$$HC1_{EMi,j} = HC1_{BAUi,j}(1-\alpha_{HC\,i})$$

$HC1_{EMi,j}$ Activity of non emerging technologies (conventional plants) fed with HC1 in the EMTECH scenario for country j and time step i in [PJ]

α_{HC1i} Share of supercritical steam cycles in energy produced with HC1 in time step i in the sector HC1 [%/100]

$$HC1'_{i,j} = \frac{1}{\varepsilon_i}(\alpha_{HC1i} \times E_{HC1i,j})$$
$$HC1'_{i,j} = \frac{0.38}{\varepsilon_i}\alpha_{HC1i} \times HC1_{BAUi,j}$$

$HC1'_{i,j}$ Activity of supercritical steam cycles fed with HC1 in the EMTECH scenario for country j and time step i in [PJ]

ε_i Efficiency of supercritical steam cycles in time step i [-]

The calculations have to be done for HC1, HC2, HC3, BC1 and BC2. In practice these calculations (preparation of the data) can be performed in a separate Excel sheet using the following parameters:

Table 4.29: Parameters for the introduction of advanced steam cycles in the EMTECH scenario

Name	2005	2010	2015	2020	2025	2030
α_{BCi}	0	0.10	0.25	0.50	0.75	0.100
α_{HCi}	0	0.05	0.125	0.25	0.375	0.50
ε_i	0.40	0.45	0.45	0.45	0.50	0.50

If the emission factors of this emerging technology are known, new emission factors for the overall activities HC1, HC2, HC3, BC1 and BC2 can be calculated using the changed activities of existing technologies and the activity of the emerging technology.

4.3.3.2. Example 2: Introduction of IGCCs in the EMTECH scenario

Data on IGCCs (fact sheets):

This technology is considered to be at pilot or demonstration plant scale. Its fields of improvement will be an increased efficiency and a reduction of the emissions of CO_2 and other pollutants. The typical size of IGCC installations is 480 MW. IGCC plants mostly operate at intermediate load (4500 h/a) which means they produce

7.776 PJ/a. At present the efficiency of IGCC is 44-46%, it is project to be 50% in 2005 and 51% in 2010. The break-through of IGCCs is expected for 2005-2010 [228], and the construction period is 5 years (The Royal Academy of Engineering, 2004). The technical lifetime of these installations is about 25 years. Full repowering of existing coal-fired power station is possible [158].

Table 4.30: Diffusion of IGCC technology in Europe till 2030

Hard coal	2005	2010	2015	2020	2025	2030
chance [158]	medium	medium	medium-(high)	medium-(high)	medium-(high)	medium-(high)

Emission factors:

SO_x: 0.043 kg SO_x / GJ
NO_x: 0.030 kg NO_x / GJ
PM_{TSP}: 0.0043 kg PM_{TSP} / GJ

Implementation in the tool:

New activities have to be calculated as follows and have to be entered in the sheet “fuels” of the tool.

$$\mathrm{E}_{HC1i,j} = HC1_{BAUi,j} \times 0.38$$

$\mathrm{E}_{HCi,j}$ Final energy produced with conventional technologies fed with HC1 in time step i in [PJ]

$HC1_{BAUi,j}$ Activities of conventional technologies in the BAU scenario for country j and time step i [PJ]

“0.38“ Electrical efficiency of conventional plants (BAU scenario)

$$HC1_{EMi,j} = HC1_{BAUi,j}(1-\alpha_{HCi})$$

$HC1_{EMi,j}$ Activities of conventional technologies fed with HC1 in the EMTECH scenario for country j and time step i in [PJ]

α_{HCi} Share of final energy from the new technology in time step i [%/100]

$$HCI'_{i,j} = \frac{\alpha_{HCi} \times \mathrm{E}_{HC1i,j}}{\varepsilon_i} = \alpha_{HCi} \times \frac{HC1_{BAUi,j}}{\varepsilon_i} \times 0.38$$

$HCIGCC_{i,j}$ Activity of IGCC fed with HC1 in the EMTECH scenario in [PJ]

ε_i Efficiency of IGCC fed with HC1 in time step i [%/100]

In the practice, these calculations (preparation of the data) can be done for HC2 and HC3, too, and in a separate Excel sheet using the following parameters:

Table 4.31: Parameters for the introduction of advanced steam cycles in the EMTECH scenario

Name	2005	2010	2015	2020	2025	2030
α_i	0	0.05	0.125	0.25	0.375	0.50
ε_i	0.50	0.51	0.51	0.51	0.51	0.51

Emission factors of the emerging technology HCIGCC:

SO_x: 0.043 kt/PJ
NO_x: 0.030 kt/PJ
NMVOC: no data

PM_{TSP}: 0.004 kt/PJ

4.3.4. Other sectors

With minor changes only, the tool offers also the possibility to calculate the impact of emerging technologies on air emissions in other industrial sectors. However, these sectors are highly aggregated in the RAINS model (e.g. industrial combustion processes are not differentiated between processes but between similar combustion conditions, e.g. boilers, grate firing etc.).

4.4. Assessment of the impact of promising and relevant emerging technologies identified within the framework of this project on air emissions

In this chapter the impact of selected technologies on air emissions in EU-25 plus Norway and Switzerland until 2020 is assessed. As in the current RAINS scenarios there are no activity data for the years 2025 and 2030, an impact assessment was not possible for those years. The selection of the technologies is based on experts' judgement at the workshop and own judgement by the consortium. The selection process and the technologies are described in brief in Chapter 3.2. A more detailed description of the technologies can be found in the fact sheets in the Annex.

The assessment is based on estimated emission factors and estimated application rates. It should be kept in mind that the workshop showed that due to the complex interrelations with boundary conditions even experts at the workshop had difficulties in estimating these application rates. Hence calculated emission reduction should be seen as one possibility out of several.

It was assumed that a new technology replaces an "average polluting" technology. Emission factors of integrated technologies that are commonly equipped with end-of-pipe emission reduction techniques, e.g. pressurised fluidised bed combution (PFBC), were further reduced by the end-of-pipe technology.

4.4.1. NOx

Estimates for emission factors and application rates used for the development of the scenario are given in Table 4-1.

Table 4-1: Emission factors and Application rates used in the scenario for NO_x emissions

Technique/Technology	RAINS Sector	Emission factor	Application rate [%]				
			2000	2005	2010	2020	2030
Catalytic Reduction of NOx Emissions of Fluid Catalytic Cracking Units	PR_REF	95% reduction	0	0	0	5	15
Emission process optimising sintering (EPOSINT)	PR_SINT	40% reduction	0	0	0	5	10
Flame Doctor System	PP, IN	15% reduction	0	0	2	5	5
(Gas-fired) heat pumps for DOM	DOM (GAS, LPG)	30% reduction	0	0	2	5	10
Integrated Gasification Combined Cycle (IGCC)	CON_COMB (except for GAS, LPG)	51 t/PJ	0	1	5	7	15
Limestone Injection Multistage Burner (LIMB)	PP_NEW (BC, HC, OS)	30% reduction	0	0	5	10	15
Ultra Low-NOx Burners	IN	60 t/PJ	0	0	2	5	10
Ultra Low-NOx Burners	PP_NEW	60 t/PJ	0	0	5	10	15
Pressurised Fluidised Bed Combustion (PFBC)	PP_NEW (BC, HC, OS)	25 t/PJ	0	0	5	10	15
SCR Plant	PR_CEM	0.3 kg/t	0	0	1	2	5
SNCR Plant / Staged Combustion combined with SNCR	PR_CEM	0.3 kg/t	0	0	2	5	10

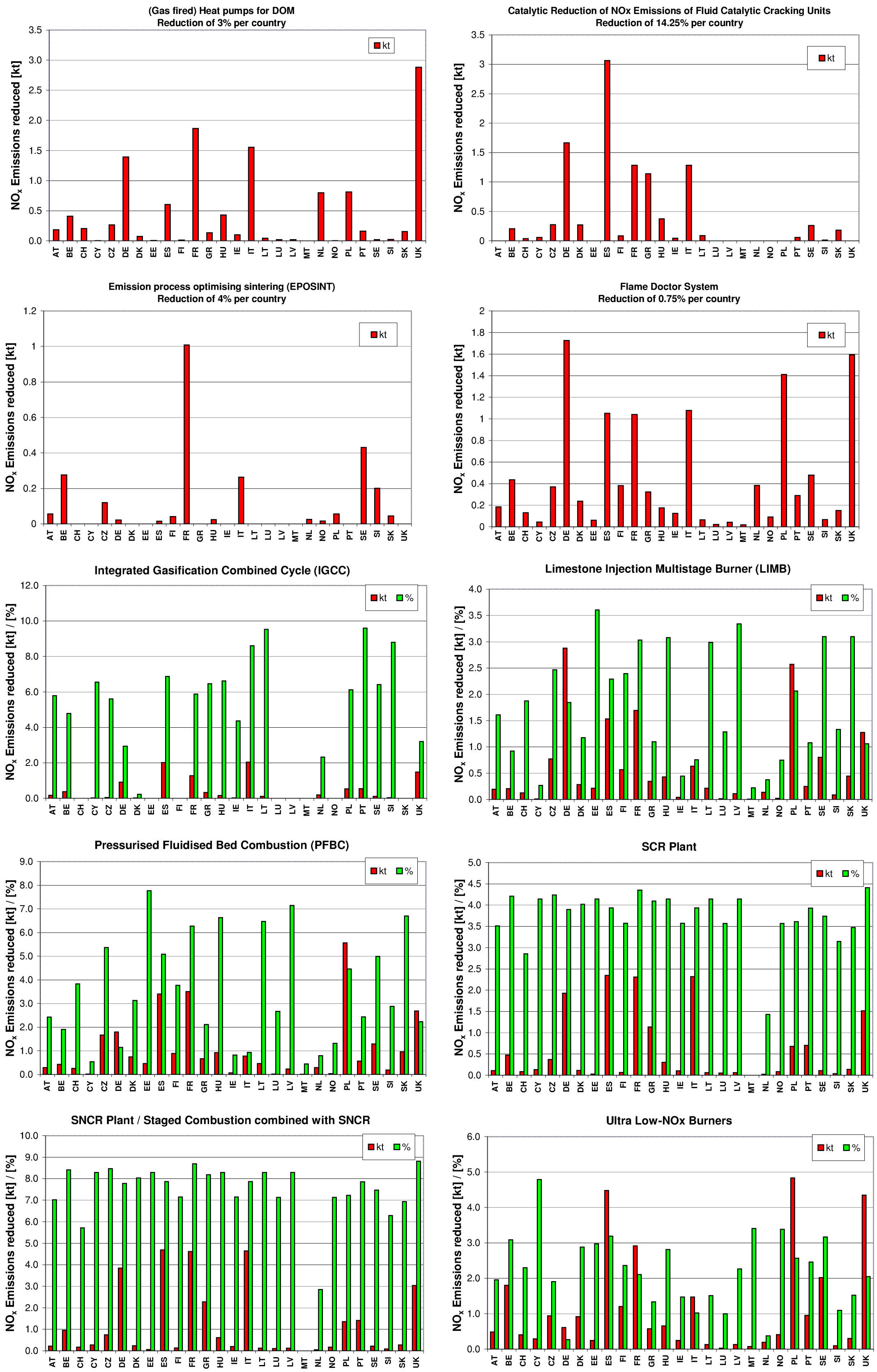


Figure 4-1: Scenario: reduction of NO_x emissions in 2020 (emission reduction of (Gas fired) heat pump refers to emissions in DOM (GAS, LPG) only)

4.4.2. SO_2

Estimates for emission factors and application rates used for the development of the scenario are given in Table 4-2.

Table 4-2: Emission factors and Application rates used in the scenario for SO_2 emissions

Technique/Technology	RAINS Sector	Emission factor	Application rate [%]				
			2000	2005	2010	2020	2030
Gasification of Black Liquor	PR_PULP	76 t/PJ	0	0	2	5	10
Emission process optimising sintering (EPOSINT	PR_SINT	40% reduction	0	0	0	5	10
Integrated Gasification Combined Cycle (IGCC)	CON_COMB except for GAS, LPG)	76 t/PJ	0	1	5	7	15
Limestone Injection Multistage Burner (LIMB)	PP_NEW (BC, HC, OS)	60% reduction	0	0	5	10	15
Pressurised Fluidised Bed Combustion	PP NEW (HC, BC, OS)	126 t/PJ plus 95% end-of-pipe reduction	0	0	5	10	15

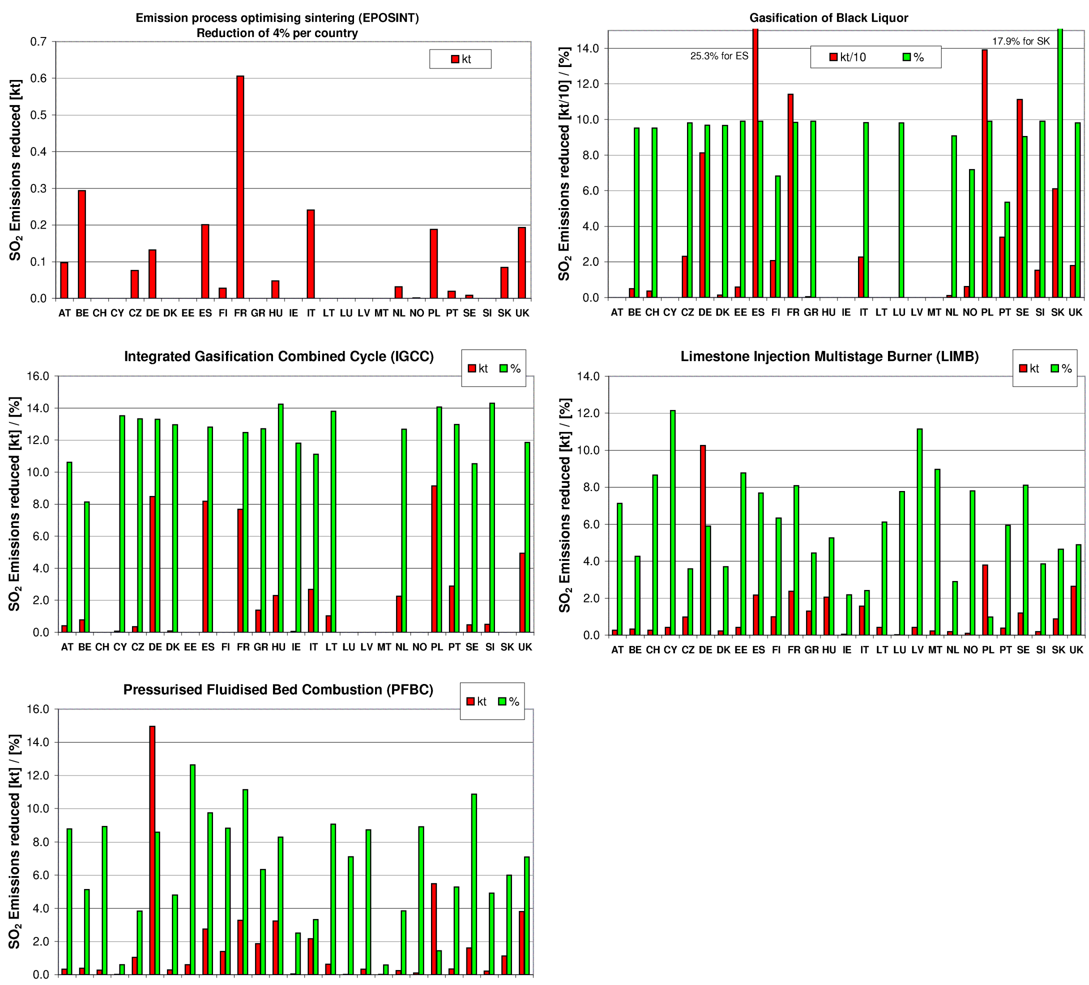


Figure 4-2: Scenario: reduction of SO_2 emissions in 2020

4.4.3. $PM_{2.5}$

Estimates for emission factors and application rates used for the development of the scenario are given in Table 4-3.

Table 4-3: Emission factors and Application rates used in the scenario for $PM_{2.5}$ emissions

Technique/Technology	RAINS Sector	Emission factor	Application rate [%]				
			2000	2005	2010	2020	2030
High Efficient Centrifugal Gas Deduster with Closed Helical Channel	DOM (GSL, HF, SHB)	99% reduction	0	0	1	2	5
High Efficient Centrifugal Gas Deduster with Closed Helical Channel	DOM (MB), IN_BO (except for GAS)	99% reduction	0	0	2	5	10
New Concepts for Electric Arc Furnaces	PR_EARC	20% reduction	0	0	1	2	5
Foaming Techniques at Pig Iron Pretreatment	PR_BAOX	20% reduction	0	0	2	5	10
Integrated Gasification Combined Cycle (IGCC)	CON_COMB (except for GAS, LPG)	8.8 t/PJ	0	1	5	7	15
Pressurised Fluidised Bed Combustion (PFBC)	PP_NEW (BC, HC, OS)	8 t/PJ plus 90% end-of-pipe eduction	0	0	5	10	15
PROven Single Chamber Pressure Control System	PR_COKE	10% reduction	0	0	2	5	10

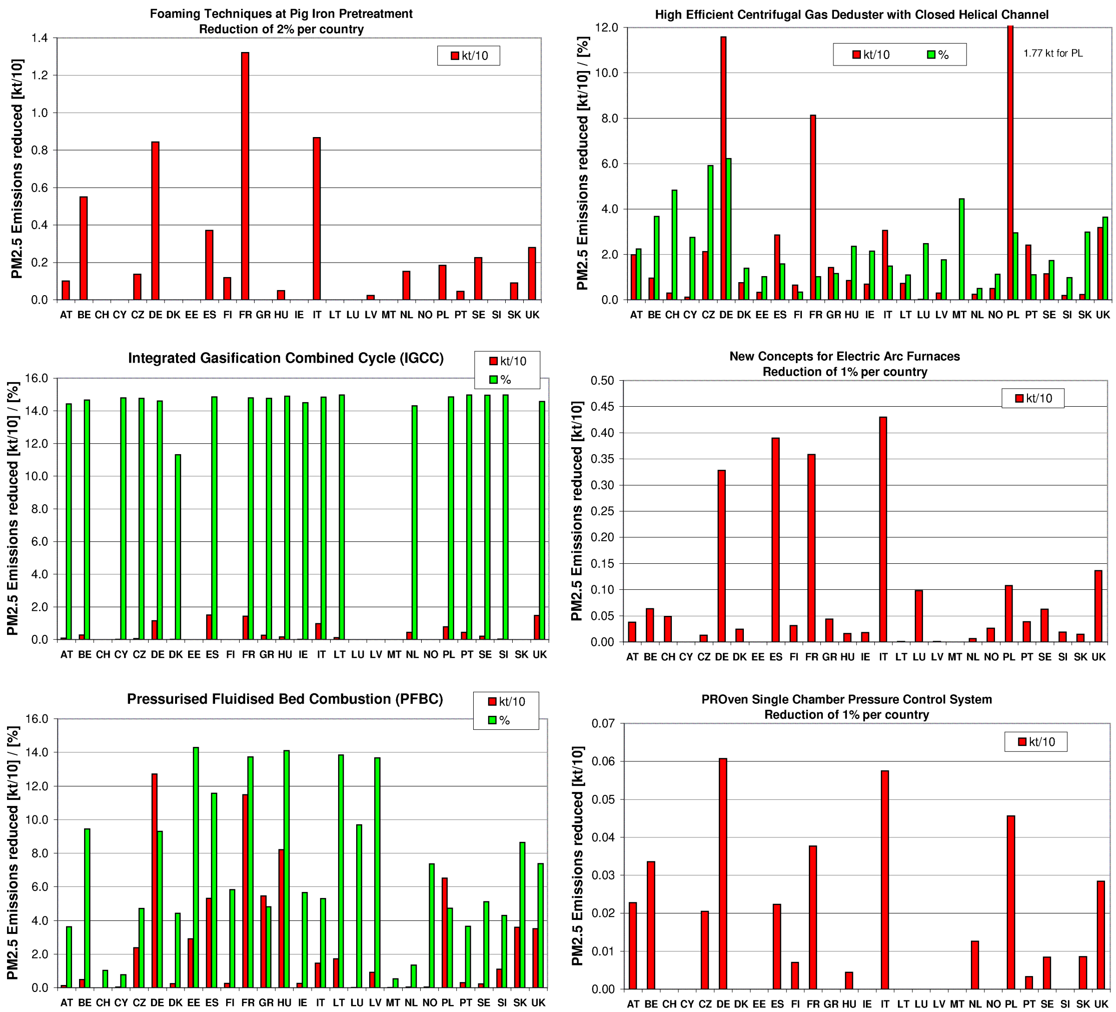


Figure 4-3: Scenario: reduction of $PM_{2.5}$ emissions in 2020

4.4.4. <u>VOC</u>

Estimates for emission factors and application rates used for the development of the scenario are given in Table 4-4.

Table 4-4: Emission factors and Application rates used in the scenario for VOC emissions

Technique/Technology	RAINS Sector	Emission factor	Application rate [%]				
			2000	2005	2010	2020	2030
Class-A-Coating in automatic mass production with dry deposition and air circulation	AUTO_P	10% reduction	0	0	5	5	5
Primerless Paint System for Automotive Applications	AUTO_P	10% reduction	0	0	5	10	15
Radiation Curing Technology	AUTO_P	10% reduction	0	5	7	10	15
Radiation Curing Technology	GLUE_INT-ADH	20% reduction	0	5	7	10	15
Radiation Curing Technology	IND_P_PL_PNT, IND_P_CNT_PNT	30% reduction	0	5	7	10	15
Smart LDAR	EXD	66% reduction	0	0	10	15	20
Smart LDAR	PR_REF	90% reduction	0	0	10	15	20

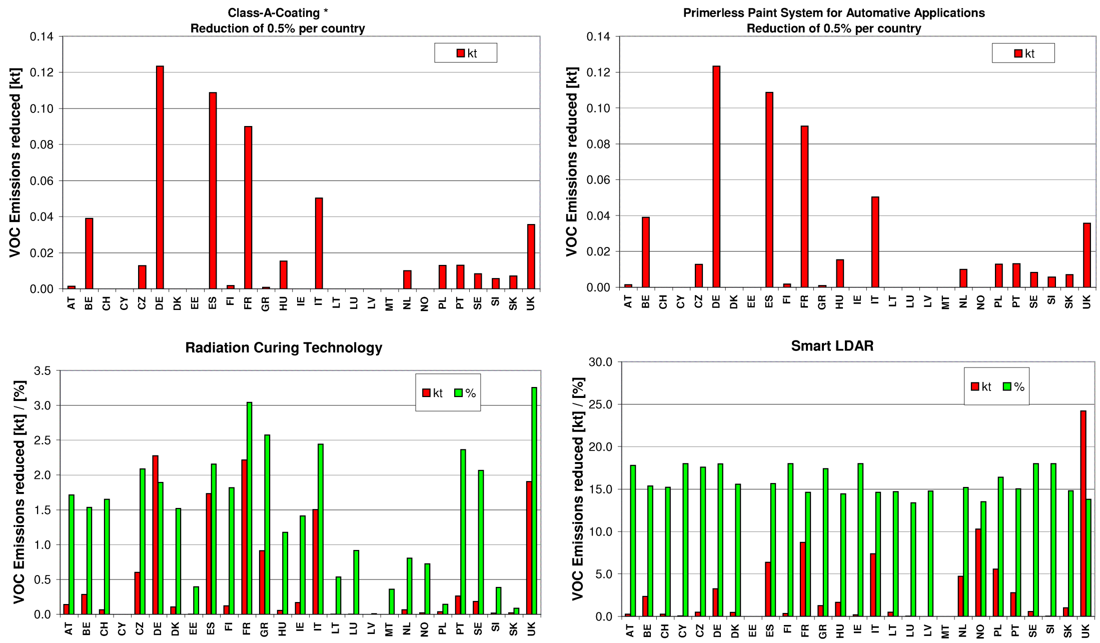


Figure 4-4: Scenario: reduction of VOC emissions in 2020

4.4.5. Overall emission reduction for NO_x, SO_2, $PM_{2.5}$ and VOC in 2020

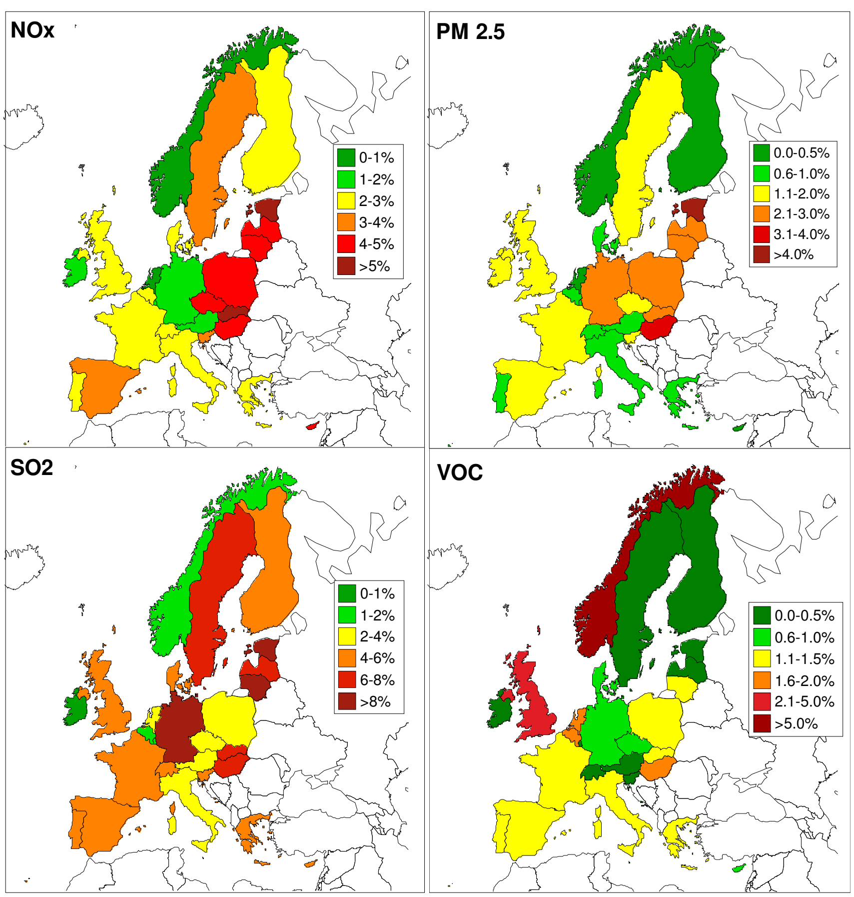


Figure 4-5: Scenario: maps of reduction of NO_x, SO_2, $PM_{2.5}$ and VOC emissions in 2020

At first glance the overall reduction for the single pollutants may seem rather small (Figure 4-5), but it has to be kept in mind that only industrial sectors have been considered in this project. Industrial sectors roughly contribute only around half of total NO_x and $PM_{2.5}$ emissions and around ¾ of total SO_2 and VOC emissions.

NO_x: The picture for NO_x is divided into clear geographical areas. The largest potential for reduction in the scenario is located in the New Member States. Spain and Sweden have a higher potential than the rest of the former EU-15, while the selected emerging technologies will have almost no impact in Norway and the Netherlands.

$PM_{2.5}$: Like for NO_x the reduction potential in the scenario is higher in the New Member States, with the exceptions of the Czech Republic and Germany which can be explained by the use of coal for power production but also domestic heating. It has to be kept in mind that the data acquisition for $PM_{2.5}$ is rather difficult and IIASA has reported significant data gaps when considering this pollutant.

SO_2: According to the scenario, Germany, Estonia and Latvia may draw most benefit from the application of the selected emerging technologies in 2020 concerning the reduction of SO_2 emissions. They are closely followed by Sweden, Hungary, Slovakia and Lithuania, while Poland will have less reduction than most former EU-15 countries and Ireland only a very limited reduction.

VOC: Being hardly involved regarding the other pollutants, in the scenario Norway has the highest potential for VOC emission reduction in 2020. This can be explained by the strong reduction of VOC emissions from EXD by Smart LDAR. On the other hand, Sweden and Finland may be hardly affected by the selected technologies. The second largest reduction potential will be in the UK, for all other countries it is significantly lower.

Table 4-5: Assessment of the potential of selected technologies to reduce air emissions in EU-25 plus Norway and Switzerland in 2020

Technology	RAINS Sector	NOx	PM25	SO2	VOC
		kt reduced in 2020			
(Gas-fired) heat pumps	DOM (GAS, LPG)	12.2			
Catalytic Reduction of NOx Emissions of Fluid Catalytic Cracking Units	PR_REF	10.4			
Emission process optimising sintering (EPOSINT)	PR_SINT	2.6		2.2	
Flame Doctor System	PP, IN	12.0			
Limestone Injection Multistage Burner (LIMB)	PP_NEW (BC, HC, OS)	15.9		34.1	
Pressurised Fluidised Bed Combustion (PFBC)	PP_NEW (BC, HC, OS)	28.3	6.93	46.5	
SCR Plant	PR_CEM	15.3			
SNCR Plant / Staged Combustion combined with SNCR	PR_CEM	30.6			
Ultra Low-NOx Burners	PP_NEW, IN	30.8			
Foaming Techniques at Pig Iron Pretreatment	PR_BAOX		0.54		
High Efficient Centrifugal Gas Deduster with Closed Helical Channel	DOM (GSL, HF, SHB), DOM (MB), IN_BO (except for GAS)		6.25		
Integrated Gasification Combined Cycle (IGCC)	CON_COMB (except for GAS, LPG)	10.3	0.94	53.6	
New Concepts for Electric Arc Furnaces	PR_EARC		0.23		
PROven Single Chamber Pressure Control System	PR_COKE		0.04		
Gasification of Black Liquor	PR_PULP			9.2	
Class-A-Coating in automatic mass production with dry deposition and air circulation	AUTO_P				0.5
Primerless Paint System for Automative Applications	AUTO_P				0.5

Radiation Curing Technology	AUTO_P, GLUE_INT-ADH, IND_P_PL_PNT, IND_P_CNT_PNT				12.7
Smart LDAR	PR_REF, EXD				82.9
TOTAL		**168.2**	**14.92**	**145.7**	**96.7**

Table 4-5 provides an overview of the most promising emerging technologies that have been identified within this project, the relevant sectors in RAINS and the emission reduction for each of the major pollutants in EU-25 plus Norway and Switzerland in 2020. Some technologies are important for several pollutants and others only for a particular one. The impact of each technology on total emissions largely depends on the activity share of the related sector.
Total achievable reduction values roughly equal the total emissions of Hungary for NO_x (190 kt), of Slovenia for $PM_{2.5}$ (14.9 kt) and of Ireland for SO_2 (133 kt) and VOC (93 kt) in 2000. The most promising emerging technologies in terms of impact on air emissions are Pressurised Fluidised Bed Combustion (for NO_x, SO_2 and $PM_{2.5}$), IGCC (refineries) (mostly for SO_2 but also for NO_x and $PM_{2.5}$), Smart LDAR for VOC, Ultra Low_NOx Burners and SNCR (cement plants) for NO_x, Limestone Injection Multistage Burner for SO_2 and NO_x and High Efficient Centrifugal Gas Deduster with Closed Helical Channel for $PM_{2.5}$.

4.5. Conclusion

The aim of work package 3 was to estimate and assess the potential of emission reduction by applying emerging technologies. In the PRIMES and RAINS models a number of candidate emerging technologies like IGCC, CCGT, or fuel cells for power plants and district heating are already integrated. Due to not yet published detailed documentation about the technologies integrated into both models, it is difficult to judge which technologies are already integrated with which data and how the technologies have been aggregated and integrated.
To compare the BAU scenarios of the RAINS model with a scenario that takes emerging technologies into account a Visual Basic software tool was designed in Excel. This tools reproduces the emissions calculations of the RAINS model and allows the user to assess the impact of emerging technologies on air emissions in a transparent way by changing parameters for implemented technologies (e.g. lower emission factors) and/or by adding new technologies.
The scenario for the assessment of the air emisssions impact of selected candidate emerging technologies is based on a number of assumptions, e.g. emission factor, future application rates and that the new technologies can be integrated independently from the already integrated technologies which is probably not the case in real life. In should be addded that in none of the sessions at the workshop any contributions related to application rates were made. There are two main reasons for this: Information on emerging technologies is often confidential and due to unknown future general conditions any estimations are highly uncertain.

According to the scenario developed within this project the selected candidate emerging technologies together offer the possibility to reduce air emissions by 168.2 kt NO_x, 14.9 kt $PM_{2.5}$, 145.7 kt SO_2 and 96.7 kt VOC in 2020 in EU-25 plus Norway and Switzerland. It has to be kept in mind that these are additional reductions beyond the significant reductions made until 2020 by currently applied technologies. Furthermore the impact of some emerging technologies in the energy field could not be assessed, as these technologies are already integrated in the RAINS model via the PRIMES model.

5. Work Package 4: Expert Workshop

5.1. Introduction

In the invitation to tender [291] page 4 reads under Task 4: Workshop: "The contractor will organise an expert workshop to be held in Brussels, in co-ordination with the IPTS in order to consolidate the results of the research. The costs for organising the workshop (invitations and reimbursement of travel expenses and daily allowances for 15 external participants) must be included in the final price of the offer."
Following the prescription, the organisation of an expert workshop was part of the tender of the project. The workshop was held rather near the planned project deadline, since its initial objectives were the following (inter alia consultation with industry and other experts):

- to inform experts about the findings of the project
- to get feedback from experts about these findings
- to get additional information from the experts
- to obtain information about future market penetration and costs of emerging technologies
- to identify drivers, barriers and policy measures for the diffusion of emerging technologies

For a description of the selection process see chapter 5.2.

On the basis of first emission projections coming from the CAFE baseline scenario, a number of priority sectors have been identified and were discussed during the workshop (see the list below).

The workshop was held in Brussels on the 28th and 29th of June 2004. It was organised in 4 units (morning/ afternoon on each day) with 3 parallel sessions each. 80 experts were present on the two days, with 28 experts attending more than one session, resulting in a number of 151 total participants. From the European Commission, IPTS and IIASA 8 people were present and 8 people from the consortium as organisers/ moderators/ reporters.
As can be seen in Table 5.1. the number of participating experts has by far exceeded the number required in the invitation to tender.

Table 5-1: Participants per session at the expert workshop in Brussels.

session	LCP	Ferrous metals	Pulp and Paper	SSC	Non-Ferrous metals	Renewables
number of participants	26	18	7	17	17	7
session	Coating/ VOC	Glass	Cement/ Lime	Chemical Industry	Refineries	Drivers and Barriers
number of participants	14	13	15	12	8	23

Two weeks after the workshop minutes of each session and an evaluation questionnaire were sent to the participating experts. The comments were used for a revision of the minutes. The analysis of the evaluation questionnaire can be found at the end of the minutes of each session.

5.2. Selection and invitation of experts for the workshop

The selection of the experts for the workshop was based on the following criteria and constraints:

- good coverage of all the 11 industrial sectors plus subsecors concerned
- equilibrium of experts from industry (industrial stakeholders) and independent experts from administration, universities, research institutes and NGOs

- approximately 10 to 15 experts per session
- available budget for refunding travel expenses allowing an invitation of around 15 independent experts
- good representation of EU-25 countries

Based on these criteria and experience gained in other projects like EGTEI but also taking into account the activities related to the development and revision of BREFs a first list with candidate experts was presented to IPTS and the Commission at the end of March 2004 for annotation and extension. Two further updates were issued at the end of April 2004 and beginning of June. The Commission and IPTS distributed the information about the workshop from their side, too, resulting in the participation of a few additional experts. Some 50 of the invited experts had unfortunately to call off, mostly due to concurrent dates but also because no allowances could have been paid. As a consequence, for some of the sector sessions, one would have preferred a broader spectrum of experts actively participating in the discussions on emerging technologies and their drivers/barriers.

The invitation and information sent to the experts before the workshop contained the following information:

- agenda of the workshop including a description of the project and the objectives of the workshop
- slides that were presented
- an open list of candidate technologies for each sector
- fact sheets for some candidate technologies as a base for discussion
- an open list of possible barriers, drivers and policy measures that have an impact on the diffusion of emerging technologies
- information on transport and logistics

5.3. Concept of the workshop

As has been proposed in the tender, the consortium has given a subcontract to the Institute of Technology Assessment (ITA, Vienna) for the workshop proposal and moderation. The workshop concept was based on the experience derived from a previous project (ESTO) where it yielded good results.

Two weeks before the workshop lists of candidate technologies for each sector were sent to the participants along with the corresponding fact sheets. An accompanying email explained the purpose of the workshop and what the experts were asked for.

As the lists of candidate technologies are extensive for each sector, it was clear in advance, that it is impossible to thoroughly discuss all technologies. Thus the aim of the concept was to focus on the technologies, where the most knowledge among the experts was available. To identify these, the experts were invited to choose from the list themselves, supposing that they would choose technologies they were familiar with. This idea was also explained to the experts by the moderators at the workshop.

In most sessions three technologies were selected for further discussion. The experts were asked to provide information about the technologies' stage of development in future years, their influence on emissions, penetration rates in future years, costs and about specific drivers and barriers for these technologies.

Finally the plenum was invited to talk about general drivers and barriers of the sector.

5.4. General Results

Of major importance was that the workshop succeeded in informing industrial companies and stakeholders about the ongoing activities of the European Commission concerning Emerging Technologies..

A further achievement was the qualitative assessment of the candidate technologies, providing information about the stage of development (in fact, many technologies were considered to be already commercial). There were also considerable problems with the definition of emerging, as can be deducted from the minutes of the sessions. The term "commercial" strictly is to be applied after one sold item, but is sometimes interpreted as "significant market share". Several technologies were assigned negative future prospects, but some also credited a positive development. It is noteworthy, that the experts have been very cautious about making prognosis of more than 5 years in advance.

Main drivers and barriers were identified for the whole sectors and for some specific technologies. Policies and legislation have a huge impact on all sectors. There were complaints about a lack of funds for (wider) implementation of technologies. The costs of technologies have a decisive influence on their application.

Research is hardly done in an integrative manner (i.e. possible pollutant shift from air to water) and mostly in the fields, where money is available.
Another interesting outcome was that for the impact on air emissions emerging applications are supposed to be more important than emerging technologies.

5.5. Results of the workshops per sector

5.5.1. Session "Large combustion plants and waste incineration"

According to the experts, a realistic estimation of future application rates is not possible due to the high complexity of technology development.
Long innovation cycles, uncertainty about future legislation and prices of raw materials (fuel, catalysts, etc.) were among others identified as barriers that could be overcome by public acceptance and political decisions.

In this sector the highest number of candidate technologies was identified and the largest number of experts was present. "Low NOx burner", "CCGT combined with steam cooling" and "IGCC combined with heat recovery" were selected for a detailed discussion. All three were considered as promising.

5.5.2. Session "Ferrous metals production and processing"

The experts noted that the list of candidate technologies distributed beforehand had the typical flaws of a research project like this: some technologies were missing, others were over-emphasised and a third group was already no longer emerging. None of the listed technologies was considered as emerging in the strict sense. "COREX" and "Low Fume Flux" have been discussed in detail.
It was further stated, that in the steel industry much progress is made by improving process performance by incremental steps rather than by switching to new technologies and that the determination of the future potentials of existing technologies would be an interesting project. EUROFER stated that the work should be recognised as partial contribution to a wider study that ought to be done.
Necessary high investments were identified as a barrier, which could be countered by long-term policies and a steel technology platform within the European research framework. A further barrier is the uncertainty of the technological performance.

5.5.3. Session "Pulp and Paper"

The experts of this sector argued that the time frame of the project was too short, since the information requested is often confidential and that its gathering is cost intensive and time consuming. Therefore the project had to be regarded as a first step in a lengthy process with continuous review of the collected information. Hence, the experts were unable to provide detailed information on future application rates, economic data and emission factors at the workshop.
There are several types of barriers for the development and diffusion of emerging technologies: organisational (small equipment market and monopolies), technical (long life-time of equipment and long development time of technologies) and economic (high investments and related economic risks).
Research platforms could help to promote emerging technologies.

5.5.4. Session "Small scale combustion"

Small scale combustion was not in the main focus of this project, as there is a parallel ongoing project "Cost and Environmental Effectiveness of Reducing Air Pollution for Small-Scale Combustion Installations" by AEA Technology. Mike Woodfield made a short presentation thereof.
As small scale combustion in the sense of the project was defined as ranging from 0 to 50 MW_{th}, a further split into several size ranges would be desirable. Since technologies for large combustion plants are more advanced in environmental terms an analysis of their applicability for small scale combustion (possibility of downscaling) could be promising.

Costs, uncertainties, lack of long term policy and legislation and especially low public awareness on the importance of small scale combustion for air pollution were identified as barriers. A comprehensible document similar to the BREFS but shorter might solve some of the problems.

5.5.5. Session “Non-ferrous metals production and processing”

Experts stated that since there are currently no radical innovations in the sector, new application fields or improvements of commercial technologies (“emerging applications”) should be regarded as emerging technologies, too. A realistic estimation of application rates in future is not possible due to the complex conditions of the technology development.
Most barriers mentioned by experts were policy barriers (e.g. waste legislation and lack of research funds) but also uncertainties about future general conditions were mentioned. On the other hand, health policy, recycling strategies and increased public awareness could help to promote new technologies.

5.5.6. Session “Renewables”

The renewables sector is very inhomogeneous in terms of variety of technologies, potentials, related costs etc. All of the listed technologies can be regarded as emerging (at least in terms of increasing application). Stirling engine, Rankine Cycle and “Solar-thermo-dynamic plant” are suggested to be added to the list. Wind power, photovoltaic and biomass were selected as subjects for further discussions.
Insufficient interregional and international grid connection, transmission capacities as well as grid management are limiting factors for the installation of huge wind farms (problems of intermittence of power).
Whilst for small biomass installations higher specific emissions of POPs and PM are a barrier, large installations bear the disadvantage that adequate fuel supply logistics is often difficult, costly and energy intensive.
Inclusion of external costs in all types of energy supply processes would be a major driver for renewables. In addition market introduction programs promote renewables to become competitive (self-sustaining market share). Increasing energy prices and the substitution of decommissioned nuclear power plants may further increase the share of renewable energy sources.

5.5.7. Session “Chemical industry”

According to the experts that were present at the workshop there are relatively few emerging technologies on the market at the moment; a lot of BAT technologies were applied only recently so that they are in some sense still “emerging”. It will take years to improve them.
It was also stated that sometimes a differentiation between BAT and emerging is not reasonable: if a BAT technology is applied in another field it can become emerging (“emerging application”). Therefore it is important to know exactly for which kind of application an example technology has been used and is considered as BAT.
After a brief discussion of all technologies Gas/Gas Separation (GGS), New Catalysts and Electron Beam Flue Gas Treatment have been selected for a more detailed discussion. The latter was considered by one of the experts as promising while others regarded this technology as not promising at all and potentially dangerous.
Legislation can be both a driver (prescription of limits) and barrier (forbiddance of materials and substances). Additional drivers are increasing energy costs and cost reduction by saving of resources.
Further barriers are handling and disposing of new materials, too short lifetime and costs in general.

5.5.8. Session “Refineries”

IGCC (Integrated Gas Combined Cycle), DeNOx Additives for FCC (Fluidised Bed Catalytic Cracker) and Smart LDAR (detector for fugitive VOC emissions) were selected for a more detailed discussion.
Production of hydrogen and flexibility concerning the use of heavy residues were identified as main drivers for IGCC implementation for which an important application potential exists in European refineries.
Only FCCs operating in full combustion mode can possibly make use of DeNOx additives.

Smart LDAR was identified as a very interesting technology if costs related to its introduction will be reasonable. Materials savings (due to reduced fugitive losses) are also expected to be considerable[92].

5.5.9. Session "Coating"

Currently there are no radical innovations in the sector (concerning end-of- pipe -technologies). It is important to modify and improve available technologies for new applications especially for application in SMEs. It is necessary to consider both the supplier and user side, since VOC emissions are caused by both.

For a more detailed discussion experts have chosen technologies from three different categories: "Non thermal Plasma" (abating, end-of-pipe technology), "Primerless Paint System for Automotive Applications" (coating), "Dense Fluid Degreasing for Dry Cleaning and Metal Degreasing" (cleaning).

Costs and uncertainty risks are the main barriers that could be overcome by research funds and/or additional policy measures (new NEC, special ruling for SME).

5.5.10. Session "Glass"

According to the experts, there are currently no emerging technologies known in the glass sector (problem of confidentiality?). Nevertheless, the candidate technologies in the list were discussed in brief.
Barriers for technologies are long life-time of installations, interacting short term policies and the securing of a very high glass quality. Because of long pay-back times funds for implementation (rather than development) of new technologies might be a driver.

5.5.11. Session "Cement and lime production"

Increased application of blended cement, high efficiency SNCR and secondary fuels have been selected for a more detailed discussion. High investments and operating costs, uncertainties and lack of social acceptance for waste co-incineration were identified as barriers, while legislation like NEC and the Waste Incineration Directive could be a driver.

5.6. Results of the Workshop for drivers and barriers

5.6.1. Drivers

One of the most powerful divers for emerging technologies is to increase the public awareness of certain issues. Public awareness is important for several reasons: e.g. support of or public pressure for political initiatives, higher demand for environmentally friendly products or production including the willingness to pay higher prices for these products as well as change in personal behaviour. Health issues and increasing energy prices could lead to long term political initiatives that guarantee the funds for research platforms or incentives for implementation of new technologies.
An aspect of the energy situation is the question of the future use of nuclear power in the new member states. Will new plants be built when the old ones are shut down?
Legislative measures (e.g. taxes, limit values) could be supportive, but on the other hand do always have the potential of "backfiring". Voluntary agreements are favourable but naturally harder to reach.

5.6.2. Barriers

Even though an emerging technology is commercially available, its market share could remain low for various reasons. The following barriers are most likely to hinder a healthy development of a new technology:

[92] cf.: FRISCH (2003): Fugitive VOC-emissions measured at Oil Refineries in the Province of Västra Götaland in South West Sweden – a success story. Länsstryrelsen Västra Götaland County Administration Report 2003: 56, 29 pp.

Information deficiency

If the experts do not know about cost-effective opportunities, the resource productivity will not be improved. The example of energy efficiency suggests that this is often the case, e.g. consumers, especially those with a low energy demand, often do not know that they could save money by taking measures to improve energy efficiency (no regret or win-win measures). Similar circumstances apply to resource productivity and resource use more generally. Getting the relevant information is often time-consuming and costly.

Limited access to capital

In reality we are not dealing with perfect capital market conditions. That means that capital needed for the installation of a new technology may simply be not available for the company, due to its financial situation. In some cases, only one activity out of several options may be undertaken and the others have to be postponed.

Contractual problems

This mainly concerns the relationship between house owners and tenants, but similar issues arise for businesses that do not own the buildings from which they operate. There may also be some cases, where a technology cannot be implemented due to the lack of a necessary resource, e.g. if there is no natural gas available, waste gas incinerators can only be built autothermal.

Private and social discrepancies

This barrier arises as a result of a discrepancy between private costs/benefits and social costs/benefits. The latter reflect the full impact of activities on a society as a whole and will include, e.g. environmental and social impacts. In contrast, the former reflect only the impact on the individual decision-maker.

Uncertainty

Many investments and particularly innovative developments are subject to long time lags between the up-front costs and long-term benefits or are subject to long lifetimes. Uncertainty about the future general conditions makes an investment with long a payback time risky.

5.7. Problems of the workshop and lessons to be learned

As has been stated in the final meeting, the workshop was the first of its kind and some of the problems encountered were naturally to be expected. The problems were that despite the sent information and clarifying mail beforehand some experts clearly did not study the material sent in advance (for whatever reasons). Some were not familiar with the concept of a workshop and supposedly expected rather a presentation of the results and the role of a listener.

Due to the organisation of the workshop in morning and afternoon sessions, some experts used the opportunity to get information about other sectors, which made them to listeners in these sessions as well.

Concerning Small Scale Combustion there was a misunderstanding about the role of AEA Technology, but in the end it has been managed to steer around the generated problems.

The main problems, however, are, that the data asked for was seldom available, since it mostly can only be obtained by time-consuming and expensive research and that the data is only known by a small group of experts, which means there is rarely room for discussion.

As has been stated frequently by the participants the time-frame of the workshop was too strict. For future workshops there should be more time per sector and probably a focus on technologies to be discussed beforehand.

5.8. Evaluation of the workshop

This subchapter provides a summary of the comments in the evaluation questionnaires that have been distributed after the workshop. The return ratio was rather low (13 answers, not counting some emails with additional information). The comments themselves may be found in the minutes.

Undoubtedly, the experiences of the participants on the two workshop days have been as different as their background. The grades given range from best to worst, sometimes even for one and the same session. The

same is true for grades for the fact sheets sent in advance, while the minutes were generally well received (only one D and two Cs).
There have been several remarks that the time frame of the project was too short, as the gathering of information is very time consuming and difficult, especially for this type of technologies.
There were also several comments concerning the limited number of experts and the choice of experts.
The selection process of the technologies for discussion was not liked by all attendants while the ability to debate and discuss was generally appreciated. However, in a few session it became obvious that some sectors were not familiar with such an open workshop concept.
Some remarks stated that air emissions are only part of the problem.
Concerning technologies it was stated that 20 minutes (the time for discussion for the three selected technologies) are too short, and that discussion is difficult at this early stage of development of a technology and that the available data on costs were insufficient for discussion.

5.9. Conclusion

The main conclusion of the workshop may be that the time frame of both the workshop and the project was very tight and perhaps too tight. Three hours were too short to discuss the list of candidate technologies and to have a look at drivers and barriers specific for a single sector.
Furthermore, despite the documents were sent in advance, not all experts had a clear idea of what they were supposed to do. Some obviously expected a presentation rather than to supply information themselves.
Nevertheless, the two days were in some respects very productive. It was clearly demonstrated that contributions of experts are needed for a lot of reasons:

- for a more exhaustive list of candidate technologies in the sector
- for an assessment of these technologies (are they really still emerging or commercial or stranded developments)
- for hard facts and data concerning emission potential and costs curves

The experts agreed mostly that reliable data, especially on costs and future application rates, are very difficult to obtain due to confidentiality problems and uncertainty about future developments, not only at the level of the technologies but also at the level of the general conditions, e.g. fuel prices, market situation. Furthermore, the research of information is often time consuming and hence expensive, e.g. for industry associations. Confidentiality may pose a problem as well. Even if all information were available there remains the uncertainty of knowledge, and a different point of view between producers and appliers.
There are also some similar, high-priority activities (like the revision of the BREFs) going on, which makes it more difficult for experts to afford the time for this project.

The main **barriers** for the implementation of new technologies are

- uncertainties (legislation, prices, market situation, technical development)
- costs (investment and operational)
- long life time of equipment/ no possibility for retrofitting

The main **drivers** are a stable long-term policy and increasing public awareness.

6. Work Package 5: Concluding analysis

The eight months project “Assessment of Air Emissions Impact of Emerging Technologies” was launched within the framework of the Clean Air for Europe (CAFE) program by the Institute for Prospective Technological Studies (IPTS) in association with DG Environment to assess the impact of emerging technologies in the industrial sector on air emissions (NO_x, SO_x, VOC, PM, CO_2 but also CO, NH_3, N_2O, POPs, Heavy Metals) in EU-25 plus Norway and Switzerland until 2030. Emerging technologies in the wider sense were – in contrast to the definition in the BREFs – defined as technologies beyond best available techniques (BAT) that are currently in demonstration or pilot plant scale (emerging technologies in the narrower sense) and include (as “increased applications”) technologies that might be commercial in some areas but are emerging in a new area of application (e.g. *offshore* wind farms).
The project was carried out by a consortium of the French-German Institute for Environmental Research (DFIU) in Karlsruhe and the Federal Environmental Agency (UBA) of Austria in Vienna with the subcontractors CITEPA in Paris and ITA in Vienna.

Work package 1 aimed at defining important pollutant-sector combinations now and in future. An analysis of the available emission inventories showed that none of the inventories is in all aspects suitable for this task:
The European Pollutant Emission Register (EPER) covers all considered pollutants but does neither contain emission projections nor does it take into account diffuse emissions nor emissions from smaller sources. The geographical coverage is EU-15 plus Norway and Hungary, only. In rare cases there are problems with the appropriate attribution of an economic activity to some emission sources and the inventory seems to be incomplete for at least some pollutants. The EMEP/CORINAIR inventory contains too old data (last update for all countries was 1990) and does not cover all considered pollutants.
UNECE/EMEP does not cover all pollutants, officially reported data is incomplete and estimated data is too highly aggregated for the scope of this project.
The NEC inventory includes only EU-15 with some important countries missing, and only some of the pollutants.
The UNFCC inventory contains only selected pollutants.
The CEPMEIP inventory is for PM only and data is from 1995.
The data modelled by RAINS does not cover all pollutants and for NMVOC only energy and transport related emissions but it has the advantage of offering projections. The per se disadvantage of modelled data is reduced by a review process based on bilateral consultations.

The analysis of the different emission inventories showed that the major source for the emissions of CO_2, SO_2, NOx and PM within the scope of this project is combustion for heat and power generation and here mainly in power plants but also small scale combustion. However, according to the RAINS data, due to effective emission control measures absolute emissions of power plants as well as their share decreases in future so that other industrial sectors become relatively more important emitters. The main emitter for NH_3 and CH_4 and also for N_2O is agriculture which is not within the scope of the project whereas industrial emissions are of only minor importance, especially for NH_3 and CH_4.

The analysis revealed that the following sectors are interesting within the scope of the project: power and district heating plants, industrial combustion, waste incineration, small scale combustion, iron ore treatment, coke plants, iron and steel production, ferrous metals processing, non-ferrous metals production, foundries, pulp and paper manufacturing, glass production, cement and lime production, chemical industry, refineries, coating and CO_2-sequestration (separation and storage).

In **work package 2** different sources of information like BREF, journals and databases as well as contacts to experts from universities, industrial associations and companies were used to establish a list of candidate technologies and applications that could be promising with respect to future industrial air emissions in EU25 and hence should be considered for being integrated into the RAINS model at IIASA. To do so information on technical and environmental performance, stage of development, costs as well as chances of success and future application rates etc. of these candidates was collected and reviewed. The collected information was presented in fact sheets and to facilitate its use, based on the experience gained within the EGTEI project and in accord with IIASA, a database (ECODATplus) was developed.

The consultation process with industry culminated in a two-days workshop (**work package 4**) in Brussels with nearly 100 participants from industry, industrial associations, universities and independent research institutes aimed at presenting, discussing, assessing and completing the collected information on about the candidate technologies in 17 sector-specific sessions and identifying the most promising technologies. Even though only three technologies were meant to be chosen for a more detailed discussion per session, the experts in general stated that data on costs and estimations of future application rates are often confidential and depend on a complex system of general conditions and hence are difficult – if at all – to obtain. In fact, in none of the sessions any contributions related to costs or application rates were made. The industrial associations noted that – even if these data could theoretically be collected – their resources were limited and mostly attributed to top issues like revision of the BREF documents and CO_2 emission trading schemes. In addition the experts criticised the general approach of the project focussing too much on new technologies and neglecting that in many sectors most progress stems from steady improvements and rarely from new developments. So an analysis of the remaining potential for improvements would be fruitful.

A special session at the workshop dedicated to drivers and barriers revealed that main drivers for the diffusion of emerging, clean technologies are a long-term policy strategy combined with the increase of public awareness and in some sectors the establishment of research platforms (e.g. pulp and paper sector), market introduction programs (e.g. renewables) and accessible information (e.g. small scale combustion). On the other hand, uncertainty, e.g. about future, often short-term legislation and general conditions like fuel prices combined with long lifetimes of the installations as well as high operating costs and investments, especially when approaching physical limits, associated with high risks were identified as the main barriers. Also sector-specific barriers were identified e.g. an oligopoly of machine manufacturers in pulp and paper industry.

Work package 3 aimed at estimating and assessing the achievable emission reduction by the application of emerging technologies. In order to compare the BAU scenarios of the RAINS model and a scenario with emerging technologies a Visual Basic based software tool in Excel was designed. It reproduces the emission calculations of the RAINS model and allows the user to add new technologies and to change parameters. It should be noted that the PRIMES model and hence also the RAINS model contains already a number of candidate emerging technologies for heat and power generation, e.g. fuel cells. Due to not yet published detailed documentation about the technologies integrated into both models, it is difficult to judge which technologies are already integrated with which data and how the technologies have been aggregated and integrated.

Despite of high uncertainties related to estimates of future application rates the impact of selected promising candidate emerging technologies on air emissions was assessed. The scenario shows a considerable impact of the selected candidate emerging technologies on air emissions of NO_x, SO_2, $PM_{2.5}$ and VOC in EU-25 plus Norway and Switzerland until 2020. In some countries air emissions are reduced by more than 5%. The impact on air emissions differs from country to country and from pollutant to pollutant. The most promising emerging technologies in terms of impact on air emissions are Pressurised Fluidised Bed Combustion (for NO_x, SO_2 and $PM_{2.5}$), IGCC (mostly for SO_2 but also for NO_x and $PM_{2.5}$), Smart LDAR for VOC, Ultra Low_NO_x Burners and SNCR for NO_x, LIMB for SO_2 and NO_x and High Efficient Centrifugal Gas Deduster with Closed Helical Channel for $PM_{2.5}$.

7. Annex

7.1. Additional Figures for WP1

Maps showing the geographical and sector distribution of installations in EPER
Bar charts showing the sector distribution of emission data in EPER
Bar and pie charts showing the evolution and sector distribution of RAINS emission data (BL_CLE_Apr04)

7.2. Complete lists of candidate technologies i.w.s. analysed

List of candidate technologies i.w.s. analysed for the Power and district heating plants sector
List of candidate technologies i.w.s. analysed for the Industrial combustion sector
List of candidate technologies i.w.s. analysed for the Waste incineration sector
List of candidate technologies i.w.s. analysed for the Small scale combustion sector
List of candidate technologies i.w.s. analysed for the Iron ore treatment sector
List of candidate technologies i.w.s. analysed for the Coke plants sector
List of candidate technologies i.w.s. analysed for the Iron and steel production sector
List of candidate technologies i.w.s. analysed for the Ferrous metals processing sector
List of candidate technologies i.w.s. analysed for the Non-ferrous metals industry sector
List of candidate technologies i.w.s. analysed for the Foundries sector
List of candidate technologies i.w.s. analysed for the Pulp and paper sector
List of candidate technologies i.w.s. analysed for the Glass production sector
List of candidate technologies i.w.s. analysed for the Cement and lime production sector
List of candidate technologies i.w.s. analysed for the Chemical industry sector
List of candidate technologies i.w.s. analysed for the Refineries sector
List of candidate technologies i.w.s. analysed for the Coating sector
List of candidate technologies i.w.s. analysed for the “CO2“ sector (emission reduction/sequestration)

7.3. Fact sheets for technologies i.w.s.

7.3.1. Power and district heating plants

7.3.1.1. Clean coal

1 Integrated Coal Gasification Combined Cycle (IGCC)
2 Pulverised Coal Firing, (ultra) supercritical (PCF - USC), Pressurised Fluidised Bed Combustion (PFBC), Pressurised Pulverised Coal Combustion (PPCC)
3 Flowpac ™
4 Limestone Injection Multistage Burner (LIMB)
5 Limestone Injection Dry Scrubbing (LIDS), Enhanced Limestone Injection Dry Scrubbing (E-LIDS)
6 Duct Sorbent Injection (Coolside)
7 SO_x-NO_x-ROx Box™ (SNRB)
8 Oxygen-Enriched Low-NO_x Technology for CF Boilers
9 High Efficiency Low NO_x Burners
10 Pre-Dryer of Lignite with Low Temperature Heat

7.3.1.2. Liquid and gaseous fuels

1 Combined-Cycle Gas Turbine (CCGT)
2 Microturbines
3 Catalytic combustion
4 Steam cooling
5 Recuperative options for turbine processes
6 Advanced Reciprocating Engines
7 Advanced CHP Turbines CHP at Manufacturing Facilities
8 Zero-emissions power generation based on oxy-combustion with water recycle

7.3.1.3. Renewables

1 Wind power plants
2 Offshore wind turbines
3 Geothermal heat and power plants
4 Pelamis wave energy converter
5 Photovoltaic sysrems (PV)
6 Solar thermo-dynamic plant
7 Solar assisted district heating central solar heating plants with seasonal storage (CSHPSS)
8 Biomass

7.3.1.4. Fuel cells

1 Fuel Cell technologies for stationary applications
2 High temperature fuel cells molten carbonate fuel cell (MCFC) solid oxide fuel cell (SOFC)
3 Fuel cell / microturbine or hybrid technologies
4 MCFC – Power Plant /Hotmodule
5 Emission-free coal and carbon energy technology coal compatible fuel cell hydrogasification and reforming CO2 sequestration
6 FLOX® steam reformer

7.3.2. Industrial combustion

1 Oscillating Combustion for Industrial Gas-Fired Boilers
2 Catalytic Combustion
3 Oxygen-Enriched Low-Nox Technology for CF Boilers

7.3.3. Waste incineration

1 Co-combustion of Meat and Bone Mill (MBM) and Natural Gas
2 Plasma Discharge / Plasma Gasification Microwave Plasma
3 Electrox
4 High-Efficient Centrifugal Gas Deduster with Closed Helical Channel
5 Microbiological removal of sulphur, nitrogen oxides and heavy metals from flue gases

7.3.4. Small scale combustion

1 Gas Heat Pump of the Second Generation
2 Solar Assisted District Heating, Central Solar Heating Plants with Seasonal Storage (CSHPSS)
3 Cyclone-type separator with swirling baffle and bottom take off of clean gas
4 High efficiency Rigidised Co-Polyimide cartridge filter

7.3.5. Iron ore treatment

7.3.12. Glass production

7.3.13. Cement and lime production

7.3.14. Chemical industry

7.3.15. Refineries

1 Biodesulfurisation of Gasoline
2 Integrated gasification combined-cycle, IGCC
3 Fouling Minimisation
4 Catalytic Reduction of NOx Emissions of Fluid Catalytic Cracking Units (FCCUs)

7.3.16. Coating and VOC

1 Non Thermal Plasma Unit
2 Primerless Paint System for Automotive Applications
3 Radiation Curing Technologies for Coatings on Complex Objects
4 Dense Fluid Degreasing/Treatment as supercritical carbon dioxide: Process & Machine
5 VOC Treatment and Recovery with the WEB AIR Unit
6 Electron Beam Flue Gas Treatment for VOCs Removal
7 Class-A-Coating in automatic mass production with dry deposition and air circulation
8 Water borne coating with solvent <4%
9 CoatingOff: Eddy current based decoating
10 CO_2 cleaning machine (CO_2 dry cleaning process)

7.3.17. CO_2

1 Amine Scrubbing for CO_2 Removal
2 O_2/CO_2 Combustion
3 Direct Air Capture Technology for Carbon Dioxide
4 CO_2 Sequestration Enhanced Gas / Oil Recovery (EGR / EOR) Saline Aquifer Storage Enhanced Coal Bed Methane (ECBM)
5 Mineral Sequestration of CO_2

7.4. Emerging Technologies Emissions Scenarios Tool

Emerging Technologies Emissions Scenarios Tool

7.5. Workshop on "Emerging Technologies"

7.5.1. Minutes of the workshop

1 Session "Large combustion plants and waste incineration"
2 Session "Ferrous metals production and processing"
3 Session "Pulp and Paper"
4 Session "Small scale combustion"
5 Session "Non-ferrous metals production and processing"
6 Session "Renewables"
7 Session "Chemical industry"
8 Session "Refineries"
9 Session "Coating"
10 Session "Glass"
11 Session "Cement and lime production"
12 Session "Drivers and barriers"

7.5.2. Feedback received after the Workshop

Please note that comments to the minutes have been integrated directly into the minutes.

Comments by Leslie James (Friends of the Earth) (Large Combustion Plants)
Comments by EDF (Large Combustion Plants, Small Scale Combustion)
Comments on list of candidate technologies (Large Combustion Plants)
Comments by EUROFER (Ferrous Metals)
Comments by EUROFER on list of candidate technologies (Ferrous Metals)
Comments by CEPI (Pulp and Paper)
Comments by Eric Plantive (ElfER) (Renewables)
Comments by CEMBUREAU and other experts for the cement sector are integrated into the minutes
Comment by VGB PowerTech e.V. / EURELECTRIC (Large Combustion Plants, Waste Incineration)

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