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Assessment of International Air Pollution Prevention and Control Technology

Volume 2. Technical Report

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16. ABSTRACT The report gives results of a study that identifies new and innovative air pollution prevention and/or control technologies, of selected industrialized countries, that are not currently used extensively in the U.S. The technologies may be entirely new to the U.S., or they may be technologies currently in limited use in the U.S. that achieve either a higher level of control than existing technologies or the same level of control more cost effectively. The study addressed technologies that prevent or control the emissions of the following pollutants from each of four sources of air pollution: (1) Urban emissions--ozone precursors to include nitrogen oxides (NOx), volatile organic compounds (VOCs), particulate matter (PM), and air toxics; (2) Motor vehicle emissions--NOx, carbon monoxide (CO), and PM; (3) Toxic air emissions--any one of the 189 compounds on the list of hazardous air pollutants (HAPs) in the 1990 CAAA (Title III); and (4) Acid deposition--NOx, sulfur oxides (SOx), and, to a lesser extent, VOCs. The report describes the approach taken to identify potentially useful technologies, gives results of the technology search and evaluation, and describes the selected technologies.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Toxicity	Pollution Control	13B	06T
Nitrogen Oxides	Carbon Monoxide	Stationary Sources	07B	
Sulfur Oxides	Motor Vehicles	Volatile Organic Compounds (VOCs)		13F
Organic Compounds	Emission		07C	
Volatility		Particulate	20M	
Particles		Acid Rain	14G	

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

ABSTRACT

Under Title IX of the Clean Air Act Amendments (CAAA) of 1990, the U.S. Environmental Protection Agency (EPA) is required to assess international air pollution prevention and control technologies that may have beneficial applications to the U.S. air pollution control efforts. This report presents results of a study that identifies new and innovative air pollution prevention and/or control technologies, of selected industrialized countries, that are not currently extensively used in the United States. The technologies may be entirely new to the U.S., or they may be technologies currently in limited use in the U.S. that either achieve a higher level of control than existing technologies or achieve the same level of control more cost-effectively.

In accordance with the Title IX requirements, the study specifically addressed technologies that prevent or control the emissions of the following pollutants from each of four sources of air pollution:

- Urban emissions: Ozone precursors to include nitrogen oxides (NO_x), volatile organic compounds (VOCs), particulate matter (PM), and air toxics.
- Motor vehicle emissions: NO_x, carbon monoxide (CO), and PM.
- Toxic air emissions: Any one of the 189 compounds on the list of hazardous air pollutants (HAPs) in the 1990 CAAA (Title III).
- Acid deposition: NO_x, sulfur oxides (SO_x), and to a lesser extent, VOCs.

This report describes the approach taken to identify potentially useful technologies, the results of the technology search and review, and a description of the selected technologies.

ACKNOWLEDGEMENTS

Richard D. Stern, the former Senior Technical Advisor for International Technology Liaison at the Air Pollution Prevention and Control Division (APPCD), was instrumental in collection and analysis of the candidate technologies, and for final selection of technologies included in this report. Michael A. Maxwell coordinated the external peer reviews and preparation of the final report. Support is also gratefully acknowledged from the staff of EPA's Air Pollution Prevention and Control Division, Office of Air Quality Planning and Standards, and Office of Mobile Sources from which valuable guidance and review of the technologies were received during the course of the study. ERG, formerly Radian Corporation, is acknowledged for their role in data gathering and compilation of candidate technologies.

METRIC CONVERSION TABLE

EPA policy requires the use of metric units; however, at times, nonmetric units are used for the reader's convenience. Readers more familiar with the metric system may use the following factors to convert to that system.

Nonmetric	Times	Yields Metric
cfm	0.000472	m^3/s
ft	0.305	m
ft_2	0.0929	m^2
gal	0.00379	m^3
	3.79	L
in.	2.54	cm
lb	0.454	kg
oz	0.0283	kg
ton	907	kg
	0.907	tonne

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1.0 INTRODUCTION

Under Title IX of the Clean Air Act Amendments (CAAA) of 1990, the U.S. Environmental Protection Agency (EPA) is required to assess international air pollution prevention and control technologies that may have beneficial applications to the U.S. air pollution control efforts. Specifically, EPA is required to:

> ...conduct a study that compares international air pollution control technologies of selected industrialized countries to determine if there exist air pollution control technologies in countries outside the United States that may have beneficial applications to this Nation's air pollution control efforts. With respect to each country studied, the study shall include the topics of urban air quality, motor vehicle emissions, toxic air emissions, and acid deposition.

This report presents the results of the study. An executive summary of this report is contained in Volume 1.

2.0 SCOPE OF REPORT

This report presents results of a study to identify new and innovative air pollution prevention and/or control technologies of selected industrialized countries, that are not currently extensively used in the United States. The technologies may be entirely new to the U.S., or they may be technologies currently in limited use in the U.S. that achieve either a higher level of control than existing technologies, or the same level of control more cost effectively.

In accordance with the Title IX requirements, the study specifically addressed technologies that prevent or control the emissions of the following pollutants from each of four sources of air pollution:

- Urban emissions: Ozone precursors to include nitrogen oxides (NO_x), volatile organic compounds (VOCs), particulate matter (PM), and air toxics.
- Motor vehicle emissions: NO_x, carbon monoxide (CO), and PM.
- Toxic air emissions: Any one of the 189 compounds on the list of hazardous air pollutants (HAPs) in the 1990 CAAA (Title III).
- Acid deposition: NO_X, sulfur oxides (SO_x), and, to a lesser extent, VOCs.

This report describes the approach taken to identify potentially useful technologies, gives results of the technology search and review, and describes the technologies meeting the selection criteria. Within each of the categories described above, the technologies meeting the selection criteria are described with the following information:

- Vendor,
- Country of origin,
- Applicable industries and developmental status of the technology,
- Pollutants controlled and secondary impacts (if any),

- Detailed process description, limitations of the technology, and case studies,
- Control costs, and
- Comparisons to existing U.S. technologies.

The information in the technology descriptions was provided by the vendors, often after multiple discussions for clarification, during the course of the study. Despite these iterations, some technologies have incomplete information in terms of the items listed above. A serious attempt was also made to identify independent sources of information to corroborate vendor claims, and what limited information identified has been presented in this report. Based on the information available, potentially useful technologies were grouped into two categories: 1) technologies currently available for consideration by U.S. industry and 2) technologies which warrant further attention (monitoring/tracking, research, etc.) by U.S. industry in order to acquire additional data for future consideration.

3.0 TECHNICAL APPROACH

The technical approach used in the study included:

1. A preliminary identification of key industrial emission sources in the U.S. that are in need of air pollution control.

2. Development of criteria for a technology search strategy for these sources.

3. Identification of key foreign countries to be addressed for potential technologies.

4. Conduct of an international search to identify potentially promising technologies.

5. Collection of detailed information for the technologies that appeared to meet the goals of the study.

6. Final review of potential beneficial technologies.

This section describes in more detail the technical approach used for these efforts.

3.1 Identification of Key Emissions Sources

To define the U.S. air pollution prevention and control needs in each of the four emission categories (urban air quality, motor vehicle emissions, toxics air emissions, and acid deposition), a list of high polluting U.S. industries in each category was developed. However, since motor vehicles are major urban emission sources and acid deposition sources, the motor vehicle source category was incorporated within the urban air quality and acid deposition categories for this study, including development of the list. Various publications/studies were reviewed to develop the list for each category, as follows:

Urban Air Quality:

For the Urban Air Quality category, the list of pollution sources was developed from an EPA study: Evaluation of Hazardous Air Pollutant Inventories from Three Major Urban Areas (1). This study showed the expected dependence of urban air quality problems on the kinds of industries that have developed in and around three major urban areas. Since many of the pollution sources from the three study areas are common to most urban areas, these sources formed the basis for the list of high polluting industries identified for the urban air quality category. As stated earlier, motor vehicle emissions, a major source of urban emissions, were also included under this category.

Toxic Air Emissions:

The key sources of toxics air emissions were determined from the results of an EPA study that ranked sources of toxics air emissions based on environmental effects data (2). The study was conducted in 1993 by EPA's Office of Air Quality Planning and Standards (OAQPS) in support of the Clean Air Act Amendments of 1990. In this study, approximately 175 emission source categories were ranked according to their national emissions of HAPs and the environmental effects of their emitted HAPs. The environmental effects included: human toxicity, aquatic toxicity, bioconcentration potential, and environmental persistence.

Acid Deposition:

The key emission sources in the acid deposition category were identified from a U.S. National Acid Precipitation Assessment Program (NAPAP) study on acid deposition (3). The NAPAP study included a national inventory of point and area emission sources for the year 1985, conducted by the EPA. Major air pollutant emission sources were ranked by their combined national emissions of three key pollutants contributing to acid deposition: SO_2, NO_x, and VOCs. As stated earlier, motor vehicle emissions, a major source of acid deposition, were also included under this category.

Control Division (APPCD). The OAQPS reviewers included the Associate Director of Science, Policy and New Programs and the staffs specializing in chemical and petroleum emissions and industrial studies within the Emission Standards Division. The APPCD reviewers included the staffs specializing in organics control, combustion research, gas cleaning technology, indoor air, and radon mitigation. Exhibit 1 presents the final list based on the inputs from these review groups. Thirty specific source categories (most important for each of the three major source category groups) are identified. However, since each of the studies used to develop the key source lists shown in Exhibit 1 stressed that there were many uncertainties in the source's relative emissions impact, the source categories identified as major sources in their respective categories are listed in alphabetical order. They are not ranked in order of importance.

3.2 Development of Criteria for Technology Search

To ensure proper screening and prioritization of the foreign pollution prevention and control technologies, specific technology selection criteria were developed as follows:

1. The technology must be applicable to an air pollution source listed in Exhibit 1. This ensured that the search remained focused on those foreign technologies potentially benefitting key emission sources in the United States. Applicability of technology to multiple sources/pollutants was also considered.

2. The technology search would include both clean technologies (pollution prevention) and "end-of-pipe" (pollution control) technologies. Clean technologies include process modifications that result in the minimization or elimination of certain pollutant emissions.

EXHIBIT 1

Key U.S. Emission Sources
Urban Air Quality Automobiles (including heavy-duty and off-road vehicles) Boilers, Turbines, and Heaters Chemical Manufacturing Degreasing/Dry Cleaning Gasoline Distribution (bulk stations and terminals) Petroleum Marketing (vehicle refueling/spillage) Plastics Manufacture Solid Waste Disposal Surface Coating Woodstoves and Fireplaces
Toxic Air Emissions Cyanide Production/Coke Ovens Industrial Boilers Lead Smelting Petroleum Refineries Phosphoric Acid Manufacturing Polycarbonates Production Resins Production (amino and acetal) Solid Waste Treatment, Storage, and Disposal Facilities Surface Coating Synthetic Organic Chemicals Manufacturing Industries (SOCMI)
Acid Deposition Asphalt Paving Automobiles (including heavy-duty and off-road vehicles) Bakeries Cement Manufacture Chemicals Manufacturing Fossil Fuel-Fired Boilers Gasoline Station Evaporation Loss Petroleum Refining Primary Metals Manufacture Solvent Evaporation (dry cleaning, degreasing, printing, etc.)

3. The technology was to have attained at least a large pilot-scale demonstration status to ensure that sufficient technical information would be available to review the potential for the selected technologies to meet the U.S. immediate air pollution control needs. This last criterion ensured that the technology review would be based on realistic performance and cost information rather than estimations of projected performance and costs that are generally optimistic.

3.3 Countries Included in the Study

Initially, the information search was focused on environmental technologies developed in Japan, Germany, the United Kingdom (UK), and Canada. However, the study was expanded to include Scandinavian and other Western European countries in recognition of the strong environmental technology development programs initiated in these countries. Later, Australia, New Zealand, South Africa, Brazil, and Argentina were also added to the study in recognition of their specific areas of expertise.

3.4 Technology Identification and Review Methods

Several methods were used to solicit technical information on candidate foreign technologies. Contacts were established with:

- Scientific counselors at 19 key foreign embassies in the United States (shown in Attachment A);
- Representatives and/or publications from six international organizations: the United Nations (UN), the Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET)*, the World Bank, the UN Environmental Program (UNEP), the European Bank for Reconstruction and Development (EBRD), and the World Environment Center (WEC) (listed in Attachment B).

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*CADDET functions as the International Energy Agency (IEA) center for dissemination of information on end-use technology demonstration projects for all IEA-CADDET member countries. The IEA implements the energy program within the framework of the Organization for Economic Cooperation and Development (OECD).

- Fifty-four consultants and/or indigenous (in-country) contacts/researchers (listed in Attachment C) who were knowledgeable about recent developments in foreign technologies;

- Eight international technology vendors (listed in Attachment D) who initiated discussions in addition to sending literature; and

- On-line searches of four key scientific databases [Energy Science and Technology (ES&T), National Technical Information Service (NTIS), Air and Waste Management Association (A&WMA), and Japanese patent (JAPIO) databases] and several national and international publications.

The results of this technology assessment produced over 100 leads for potential technologies and over 200 abstracts and articles to review. From the literature and contacts made, over 300 initial candidate technologies were identified to be reviewed for applicability to the project goals. This screening process, which involved evaluating each technology based on the criteria presented in Section 3.2, produced an initial list of 30 potentially innovative candidate technologies.

This initial slate of 30 candidate technologies that emerged from the first phase of the information search were reviewed by the same staff groups at EPA that reviewed the pollution source category lists (Section 3.1). These same groups were selected because of their knowledge of air pollution problems and current emerging technologies. These briefings were used to identify additional promising technologies, from the original list of 300, which should be added to the candidate technologies slate and to remove technologies, as appropriate, based on EPA knowledge regarding state-of-the-art technologies.

As additional information from various vendors was received and reviewed, 22 additional technologies were identified. By the end of this phase of the study, a total of 52 technologies were identified and their vendors contacted. These 52 technologies corresponded to 10 foreign countries: Australia (1), Denmark (2), Finland (1), Germany (11), Japan (12), the Netherlands (3), Norway (2), Poland (1), Sweden (4), and the UK (15).

3.5 Information Gathering

In this next phase of the study, letters were sent to the vendors of the 52 technologies requesting more detailed information needed to further review the technologies. Eleven specific information needs were requested from the vendors of the technologies as follows:

1. A detailed description of the technology.
2. A statement of the current status of the technology: e.g., research stage, later development, full-scale demonstration, commercially available/existing full-scale applications.
3. Case study descriptions.
4. Identification of the applicable industries/sources and any limitations of the technology within each industry.
5. A list of specific pollutants the technology controls or eliminates.
6. Test data that document the performance of the technology.
7. All requirements for operation of the technology (e.g., feedstock, fuel consumption, energy, space).
8. Quantification of cost information, including capital cost, estimated payback period, and operating and maintenance costs.
9. Secondary pollution impacts (e.g., wastewater discharges, solid waste generation).
10. Any available comparisons of performance and cost reviews with competing U.S. state-of-the-art technologies for similar applications.
11. How the technology performance and cost vary with changes in input parameters.

Our information requests also stressed the value and need for independent data corroborating the information developed by the vendor. In some cases, information obtained

from vendors did not provide enough detail to adequately review the technology with respect to the criteria developed for this study.

Follow up calls were made to the vendors to encourage their participation in the study. At the request of 10 of the vendors/foreign representatives, meetings were held in the U.S. and England to present details of their technology. Twenty-eight technologies were selected for potential inclusion in the final list.

3.6 EPA Final Review of Potentially Promising Technologies

The 28 technologies were reviewed by EPA staff in OAQPS, APPCD, and the Office of Mobile Sources, who were selected for their expertise in the specific areas of technology. The EPA staff reviewed the technologies based on the information provided for the study and their knowledge of the technologies currently available to address the same source pollutant problem. The 21 technologies that reviewers believe may be useful to U.S. industry appear in Exhibit 2.

Although EPA identified technologies which may be useful to U.S. industries in general, it is important to note this report does not evaluate the applicability of these technologies to any specific U.S. industrial facility. Rather, the report serves as a survey of potentially applicable technologies, and does provide an independent evaluation of vendor information by EPA. EPA review of information provided by vendor does not include an evaluation of technologies relative to their potential for application to segments of relevant U.S. industries or to the individual U.S. industrial facilities, or the ability of the technology to meet current or anticipated Federal requirements. In addition, these technologies were not compared to current U.S. technologies or to U.S. technologies under development, to determine where the U.S. has a clear competitive advantage, since this was beyond the scope of the report.

In light of the nature of the review performed, readers are encouraged to contact individual vendors for more specific information related to the potential application of a technology for any individual facility operator's or pollution control agency's needs.

4.0 RESULTS

Exhibit 2 presents the 21 air pollution prevention and control technologies that were identified in this study, as potentially beneficial technologies to bring to the attention of U.S. industry. For each technology, the information in Exhibit 2 includes a short descriptive title; a brief description; the vendor name; country of origin; the applicable industries and/or emission sources; the pollutants controlled; the development status; and available information on performance, cost, and secondary impacts. It is important to stress that information presented in Exhibit 2 was obtained from the vendor and may, in some cases, lack detail or the objectivity needed for an in-depth comparison of technologies. Readers are encouraged to contact individual vendors for more specific information relating individual technologies to their specific application.

This table is divided into two sections. The first section (Technologies A1-A14) presents those technologies for which enough information was available to determine that the technology is worthy of current consideration by U.S. industry. The second part of the table (Technologies B1-B7) presents technologies that are believed to be feasible and innovative and which may have potential benefits for U.S. industry but which lacked sufficient information for current consideration. However, these technologies should be watched for future consideration as more information becomes available. Details for each technology presented in Exhibit 2 can be found in Attachment E.

The applicability of the technologies identified in this study relative to the 3 major source categories is summarized in Exhibit 3, which shows the 30 specific source categories under the three major source category groups, and the number of international pollution control or pollution prevention technologies that were identified for each source category.

EXHIBIT 2

Potentially Beneficial Pollution Prevention and Control Technologies

Technology Number*	Technology Name and Brief Description	Vendor/Country of Origin	Developmental Status/Sites in Use	Targeted Pollutants and Sources, and Secondary Impacts	Performance Levels	Costs
A-1	Zinc Oxide Process--Waste gas cleaning technology that offers effective removal of SO_2 while producing no wastewater effluent. The Zinc Oxide absorbs the pollutants from annealing and drying kilns in a two-stage countercurrent flow absorber. In the absorber, a zinc oxide suspension is added to the top of the column in a concentration above stoichiometric. The waste gas, which is cleaned of most of its dust and aerosols in venturi scrubbers prior to column entry, enters the column near the bottom. The hydrogen sulfide and the sulfur dioxide react with the zinc oxide absorber to form $Zn(HSO_3)_2$, $ZnSO_4$, $ZnSO_3$, and ZnS.	Sachtleben Chemie GmbH Dr. Hans-Dieter Bauerman Duisburg Germany	Two sites in Germany.	Pollutants: SO_x Sources: Chemical Manufacturing (ADP) Secondary Impacts: None	90% reduction in SO_2.	$1,080/ton of SO_2 removed.
A-2	SOLINOX process for the reduction of SO_2--This process comprises a two-step scrubbing process with its primary objective the reduction of SO_2 emissions. A proprietary organic adsorbent (polyethylene-glycol-dimethylether) removes the SO_2 by selective (physical) absorption. The organic adsorbent can be regenerated without any losses. The recovered concentrated SO_2 (90 percent) is cooled and compressed, and can be sold.	Sachtleben Chemie GmbH Dr. Hans-Dieter Bauerman Germany	4 facilities in 3 countries: Austria, Germany, Poland.	Pollutants: SO_2, PM, HC's, HCl and other halogen compounds Sources: Primary metals (ADP) Industrial Boilers (TAE, UAP, ADP) Chemical Manufacture (ADP) Secondary Impacts: Recovered SO_2 and wastewater	97% SO_2 removal. 85% dust removal.	For 70,000 Nm^3/hr plant: Capital costs = $11.8M operating costs = $1.4M/yr.
A-3	LINKman Expert-System--Used to optimize the cement manufacturing process and thereby reduce emissions. The process is optimized by continuous monitoring of NO_x, CO, and O_2 emission levels, key temperatures, and the power required to turn the kiln.	Image Automation Ltd. Mr. D.W. Haspel UK	Over 60 plants worldwide in 16 countries (2 U.S.)	Pollutants: NO_x Sources: Cement Manufacture (ADP) Chemical manufacture (ADP) Secondary Impacts: None	NO_x emissions reduced from 500 ppm to 200 ppm. Some SO_2 reductions also claimed. 9% capacity increase, 3% fuel savings, and 40% reduction in offspec. material produced.	Capital investment $350,000 for 1.1 M ton clinker plant. Payback period less than 3 months. $1.50 savings/ton clinker.

(continued)

EXHIBIT 2 (Continued)

Technology Number[a]	Technology Name and Brief Description	Vendor/Country of Origin	Developmental Status/Sites in Use	Targeted Pollutants and Sources, and Secondary Impacts	Performance Levels	Costs
A-4	Fluidized-Bed Sintering System for Pollution Prevention through Energy Efficiency in Iron and Steel Production (DIOS Project)--DIOS process uses fine and granular non-coking coal and iron ore directly for making molten iron without resorting to the coking and sintering operations required in the traditional blast furnace process. DIOS dispenses with coking coal and can utilize non-coking coal directly, thereby ensuring a wider selection of resources to be used in ironmaking. The agglomerating process (sintering and coking) is eliminated, thereby reducing capital expenditures and energy costs. Sulfur emissions are "scarcely measurable" since the sulfur charged is either dissolved into the melted slag and metal, or absorbed onto dust and collected. DIOS uses less energy than a conventional blast furnace and, as a result, less emissions will be associated with the combustion of fuels.	Center Clean Coal Utilization Mr. Elichi Yugeta Japan	500 tpd pilot plant under study	Pollutants: SO_2, CO_2, and other energy related pollutants Sources: Primary Metals Manufacture (ADP) Secondary Impacts: None	"Scarcely measurable" sulfur emissions and 5-10% reduction in CO_2.	Costs reduced due to elimination of sintering and coking.
A-5	Cerafil Low Density Filter Elements--This technology utilizes low-density ceramic filter elements, called Cerafil elements, that are comprised of man-made mineral fibers bonded with organic and inorganic materials to form a porous filtration medium. Particulate matter (PM) in the flue gas forms a dust cake on the outside of the elements. The dust cakes are removed via reverse pulse-jet cleaning. The elements are temperature resistant to 900°C and resistant to acid and alkali contaminants in the flue gas. For flue gases above 250°C, the Cerafil filter plant eliminates the necessity of gas cooling equipment. Cerafil will also control HCl and SO_2 with the use of a sorbent material (e.g., calcium hydroxide).	Cerel, Ltd. Andy Startin UK	Several full-scale units in use throughout Europe.	Pollutants: SO_2, HCl, PM Sources: Cement Manufacure (ADP) Industrial Boilers (UAP, TAE, ADP) Solid Waste Disposal (UAP, TAE) Chemical Manufacturing (UAP, ADP) Primary Metals Manufacture (ADP) Secondary Impacts: None	99.7% PM control. No data on SO_2.	$16.2 per ACFM of flue gas treated.
A-6	Cool Sorption Vapor Recovery Units--Controls evaporation losses. When a road tanker is filled, gasoline displaces vapor in the tank. The vapor is piped into the cool sorption unit, washed in a counter-current of cooled kerosine. The mixture is stabilized then fed into a splitter where the kerosine and gasoline (liquid) are separated. Kerosine is cooled and recycled; gasoline is returned to the storage tank. Operation is fully automatic. Active charcoal filter can be added as 2nd stage air purifier.	Cool Sorption A/S Mr. Morten Reimer Hamfrem Glostrup Denmark	Commercial in use in Europe at more than 60 units	Pollutants: VOCs Sources: Petroleum Marketing (UAP) Gasoline distribution (UAP) Secondary Impacts: Wastewater	Meets or exceeds EPA requirements.	Capital costs range from $600K to 12M. Savings due to product recovery.

(continued)

EXHIBIT 2 (Continued)

Technology Number*	Technology Name and Brief Description	Vendor/Country of Origin	Developmental Status/Sites in Use	Targeted Pollutants and Sources, and Secondary Impacts	Performance Levels	Costs
A-7	High Combustion Efficiency Woodstove with Downdraft Combustion--Downburning combustion woodstove used to burn smoke (particulate), carbon monoxide, and hydrocarbons that would in a conventional stove be emitted to the atmosphere. This method of burning not only reduces pollution (by almost 90 percent as compared to a conventional stove), but also increases net stove efficiency. The CRE woodstove is designed to pull air from outside the top of the stove down into the combustion zone and then completes combustion in a secondary chamber.	CRE Group, Ltd UK	Prototype tested in Russia.	Pollutants: VOCs, PM, CO Sources: Woodstoves and Fireplaces (UAP) Secondary Impacts: None	78% reduction of ordinary stove emissions. 65% reduction of conventional catalytic stove emissions.	$1.50 per ton of smoke reduced. $185/yr savings over typical catalytic stoves.
A-8	Burning Image analyZER (BIZER)--Combustion control in kraft pulp mill recovery boilers by use of infrared fire-room cameras to view smelt pile and digital image processing to provide presentation of burning information in a clear form. Can be used for automatic burning control, and automatic prevention of disturbances in the fuel bed.	ABB Industry Oy Mr. Raimo Sutinen Finland	Commercially available in Indonesia	Pollutants: VOC, CO, NO_x, PM (through energy efficiency) Sources: Industrial Boilers (UAP) Solid Waste Disposal (UAP) Secondary Impacts: None	Maximizes energy efficiency.	Payback 1-2 years. Capital costs 500,000 - $2 M.
A-9	ELSORB process--Wet scrubbing method which utilizes a phosphate buffer for absorption of SO_2 from flue gas. Buffer is stable, nonvolatile, nontoxic, easily available and is continuously recycled to the process after removal of SO_2 by evaporation. Process produces concentrated SO_2 for further processing either to H_2SO_4, or elemental S, or liquid SO_2.	Elkem Technology, Inc. Mr. Frank Fereday Pittsburgh, PA Norway	Demonstration at U.S. facility in NM--1995. Current Austria and Norway full-scale facilities	Pollutants: SO_2 Sources: Industrial Boilers (ADP) Petroleum Refineries (ADP) Secondary Impacts: Minor amounts of water and wastewater	>95% control.	$479/ton SO_2 removed. Savings potential for H_2SO_4 recovered at $30/ton recovered.
A-10	Water-based Liquid Resins--Proprietary resin dispersion technology used for applying water-based resin adhesives. Resins are free from organic solvents, proteins and starches. Adhesives are nontoxic and can generate higher levels of adhesion through penetration of absorbent substrates	Blueminster Ltd. Mr. Trevor Jones United Kingdom	In use by major European/Int'l manufacturers	Pollutants: VOCs Sources: Resins Production (TAE) Solvent Evaporation (ADP) Surface Coating (UAP) Secondary Impacts: Wastewater and resin disposal	Eliminates VOC emissions from adhesives. Saves drying energy requirements.	Cost savings due to reduced solvent requirements.

(continued)

EXHIBIT 2 (Continued)

Technology Number*	Technology Name and Brief Description	Vendor/Country of Origin	Developmental Status/Sites in Use	Targeted Pollutants and Sources, and Secondary Impacts	Performance Levels	Costs
A-11	Airborne 10 Absorption/biodegeneration Agent--A proprietary blend of surfactants that when atomized with water, increases the effective surface area or interface area of the water droplet by 500,000 percent. When introduced into an exhaust gas, the Airborne 10 droplet collides with a pollutant aerosol and absorbs the pollutant. The Airborne 10/pollution aerosol falls to the ground where it is broken down by the natural bacteria present. The high droplet surface area and volume allows for more effective gas contact, scrubbing, and, consequently, more effective air pollution control.	Impex U.K. Ltd. J.P. Edgar, Managing Director UK	Available and in use throughout Europe	Pollutants: VOCs, toxics Sources: Solid Waste TSDF (TAE) Chemical Manufacturing (UAP, ADP) Synthetic Organic Chem. Mfr. (TAE) Plastics Manufacture (UAP) Bakeries (ADP) Secondary Impacts: Water quality	99.8% removal of emissions.	$0.37 savings per ton waste processed over traditional scrubbing mechanisms.
A-12	Oilless, Dry Centrifugal "leak free" Compressors--Dry gas seals offer the advantage of very little leakage, which eliminates the need for a sophisticated seal oil supply system. Enables increased reliability, energy savings, and maintainability, which is required in some fugitive leaks standards. Energy savings by use of magnetic bearings can offer a speed increase of the rotor and a size reduction of the casing.	Hitachi Ltd. Mr. Yasyo Fukushima Hitachi U.S. Mr. Peter Bellavigna Japan	One full scale commercial application at a petroleum refinery	Pollutants: VOC (process fugitives and through energy efficiency), CO, NO_x, PM (through energy efficiency) Sources: Petroleum Refineries (TAE) Chemical Manufacturing (UAP) Synthetic Organic Chem. Mfr. (TAE) Secondary Impacts: None	100% control of fugitive compressor emissions.	Relative to typical reciprocal compressor: capital costs 21% less, operating costs 4% less.
A-13	Degreasing with Alkaline Cleaning--Traditional trichloroethylene degreasing process replaced by an alkaline cleaning process. Totally reduces need for solvent.	Thorn Jarnkonst AB Mr. Egon Conrad Sweden	One site participated in study.	Pollutants: VOCs Sources: Degreasing/Dry Cleaning (UAP) Solvent Evaporation (ADP) Secondary Impacts: Wastewater	100% reduction in solvent emissions.	20% less than using solvents.

(continued)

EXHIBIT 2 (Continued)

Technology Number*	Technology Name and Brief Description	Vendor/Country of Origin	Developmental Status/Sites in Use	Targeted Pollutants and Sources, and Secondary Impacts	Performance Levels	Costs
A-14	QSL Process--Designed to treat all grades of lead concentrates and secondary materials. Reactor consists of a horizontal, slightly-sloped cylinder which is divided into oxidation and reduction zones. Raw material is introduced in the oxidation zone where the lead sulfides are oxidized forming primary lead bullion and a slag containing about 20-25% PbO. The PbO is reduced to metallic Pb in the reduction zone by the use of pulverized coal or coke. The off gas which contains a high concentration of SO_2 and dust is treated before it is exhausted. The process is designed to include recovery of Cd, Zn, and H_2SO_4.	Lurgi Metallurgie Dr. Andreas Siegmund Germany	Commercial operation in Germany, Korea, Canada, China	Pollutants: Lead, Cd, SO_2 Sources: Lead Smelting (TAE) Secondary Impacts: Process waste and wastewater	>90% reduction in Pb and Cd emissions. 98% reduction in SO_2 emissions, compared to conventional plants.	$70M capital costs for 75,000 T/yr lead production plant.
B-1	Envirotreat Modified Clays for the Control of VOC in Waste Air Streams--This technology utilizes a range of modified clays that readily react with pollutants contained in waste gas streams. The clays act as a filter to remove the VOCs in the air stream. The Envirotreat clays (E-clays) were developed initially for use in land remediation, but the high reactivity of the clays made them well suited for air pollution as well. The equipment required for implementation is similar to that used with activated carbon processes. Unlike activated carbon which, once saturated with VOCs, must be treated to avoid the reversal of the adsorption process, the E-clays do not require treatment and will not desorb the pollutants back into the environment.	Rowe Technology, Ltd R.M. Weir, Director UK	Prototype under development	Pollutants: VOCs, toxics Sources: Solvent Evaporation (ADP) Surface Coating (TAE) Chemical Manufacturing (UAP, ADP) Synthetic Organic Chem. Mfr. (TAE) Secondary Impacts: Solid waste (spent clay)	High efficiency expected.	$90/ton of pollutant removed.
B-2	Fluidized-bed Cement Kiln Technology--The technology utilizes multiple fluid beds to improve the combustion and heat transfer characteristics of the cement production process, enabling better control of the sintering temperature; reducing Nox and CO2 emissions. The fluidized bed system also enables lower grades of coal to be used (low carbon and high hydrogen content).	Center Clean Coal Utilization Mr. Elichi Yugeta Japan	Under study since 1986. Pilot plant testing began 1995 (200 ton/day plant)	Pollutants: NO_x and CO_2 Sources: Cement Manufacture (ADP) Industrial boilers (ADP) Secondary Impacts: None	NO_x levels reduced one-half to one-third compared to typical cement kilns. Reduces CO_2 (by 10%), fuel consumption, and pollution.	Reduces construction costs by 30%, saves 70% of usual space requirements, reduces fuel consumption 10%.

(continued)

EXHIBIT 2 (Continued)

Technology Number*	Technology Name and Brief Description	Vendor/Country of Origin	Developmental Status/Sites in Use	Targeted Pollutants and Sources, and Secondary Impacts	Performance Levels	Costs
B-3	Oxidation Low Temperature Catalyst for Catalytic Combustion Deodorization/odor Abatement Systems--Catalyst has unique high activity at low temperatures, allowing for low temperature odor treatment, which eliminates the possibility of NO_x formation. Catalyst can resist temperatures up to 800°C, allowing for greater catalyst life and lower operating costs (fewer regenerations/replacements).	Babcock Hitachi KK Mr. Hiroshi Ichiryu Japan	Two full-scale systems in operation; acrylic acid and styrene monomer plant	Pollutants: NO_x Sources: Chemical Manufacturing (ADP) Secondary Impacts: None.	Produces less thermal NO_x with 90% reduction of target pollutants at 350°C with no deterioration at 3,000+ hours of catalyst service.	Capital costs: $1.3M for 20,000 Nm^3/hr acrylic plant and $2.8M for 60,000 Nm^3/hr styrene monomer plant.
B-4	Fluidized-bed Heat Treatment of metal components--A gas phase heat treatment process using a fluidized bed of alumina particles. A mixture of gases is used to produce the fluidizing atmosphere for heat treatment of the material immersed in the fluidized bed. Hydrocarbon gases are used for carburizing, ammonia for nitrating, and nitrogen for neutral hardening. The bed is heated by electricity or gas, and quenching is also carried out in a fluidized bed. Because the process areas are enclosed, fugitive emissions can be easily controlled when compared to current molten salt bath heat treatment methods.	Quality Heat Treatment Pty Ltd. Mr. Ray W. Reynoldson Australia	Four facilities in 3 countries: Australia, Indonesia, Malaysia (2)	Pollutants: Metals, CN, VOC's, Halogens Sources: Primary Metals Manufacture (ADP) Secondary Impacts: None	100% control of chemicals replaced.	For 100-275 kg/hr plant, cost savings of $87,000/yr, two-year capital cost payback period.

(continued)

EXHIBIT 2 (Continued)

Technology Number*	Technology Name and Brief Description	Vendor/Country of Origin	Developmental Status/Sites in Use	Targeted Pollutants and Sources, and Secondary Impacts	Performance Levels	Costs
B-5	"BIOTON" Biofilter--Biofilter works by providing an environment in which the microorganisms can thrive. The construction of this environment begins with organic-bearing material, such as compost, surrounded by a thin film of water. The compost serves as the nutrient source for the microorganisms until the polluted gas stream becomes the food source. One cubic meter of filter material can provide approximately 10 million particles, and each particle can house up to 100,000 microorganisms.	PPC Biofilter/Clair Tec Mr. Scot Standefer Longview, Texas Netherlands	20+ facilities in Europe	Pollutants: VOCs, toxics Sources: Chemical Manufacturing (UAP, ADP) Petroleum Refineries (TAE, ADP) Synthetic Organic Chem. Mfr. (TAE) Surface coating (TAE) Secondary Impacts: Disposal of aged filter material	80-90% control.	$15-100 per cfm of air cleaned.
B-6	Ecoclean Cleaning Machines--Batch solvent cleaning machines. The cleaning chamber is hermetically sealed during the cleaning cycle. After completion of the cleaning cycle, the solvent vapor is a evacuated from the chamber through a solvent recovery system.	Durr Industries/ Automation, Inc. Mr. David Townsend and Mr. Joseph Scapoelilti Germany	Commercially available throughout Europe	Pollutants: VOCs, toxics Sources: Degreasing/Dry cleaning (UAP) Solvent evaporation (ADP) Secondary Impacts: None	99% reduction in solvent use when compared to the conventional open-top vapor cleaners being used in the U.S.	$30/ton of load degreased.
B-7	F-1 Clean--Ultrasonic cleaning and drying batch solvent cleaning machine. Cleaning chamber is closed during cleaning and drying is performed under vacuum with recovery of residual solvent vapors.	Tiyoda Mfg. Mr. Mickey Ohkubo Japan	Commercial use in Japan by many large companies.	Pollutants: VOCs, Toxics Sources: Solvent Evaporation (ADP) Degreasing/Dry Clean (UAP) Secondary Impacts: Sludge from filters	99.99% control.	Capital costs $200K - 250K.

* A- = Technology is worthy of current consideration by U.S. industry; B- = Technology may have potential benefits for U.S. industry, but sufficient information is lacking.

(continued)

EXHIBIT 3

Applicability of Identified Technologies		
	Applicable Air Pollution Prevention and Control Technologies	
Emission Source	Pollution Control	Pollution Prevention
Urban Air Quality		
Automobiles (also heavy-duty and off-road vehicles)	0	0
Boilers, Turbines, and Heaters	A-2, A-5	A-8, A-12
Chemical Manufacturing	A-5, A-11, B-1, B-5	A-12
Degreasing/Dry Cleaning	B-6, B-7	A-13
Gasoline Distribution (bulk stations and terminals)	A-6	0
Petroleum Marketing (vehicle refueling/spillage)	A-6	0
Plastics Manufacture	A-11	0
Solid Waste Disposal	A-5	A-8
Surface Coating	0	A-10
Woodstoves and Fireplaces	0	A-7
Toxic Air Emissions		
Cyanide Production/Coke Ovens	0	0
Industrial Boilers	A-2, A-5	A-12
Lead Smelting	0	A-14
Petroleum Refineries	0	A-12
Phosphoric Acid Manufacturing	0	0
Polycarbonates Production	0	0
Resins Production (amino and acetal)	0	A-10
Solid Waste Treatment, Storage, and Disposal Facilities	A-5 A-11	0
Surface Coating	B-1, B-5	0
Synthetic Organic Chemicals Manufacturing Industries (SOCMI)	A-11, B-1, B-5	A-12
Acid Deposition		
Asphalt Paving		
Automobiles (including heavy-duty and off-road vehicles)	0	0
Bakeries	A-11	0
Cement Manufacture	A-5	A-3, B-2
Chemicals Manufacturing	A-1, A-2, A-5, A-11, B-1, B-5	A-3, B-3, B-4
Fossil Fuel-Fired Boilers	A-9, A-5	A-12, B-2
Gasoline Station Evaporation Loss	0	0
Petroleum Refining	A-9	0
Primary Metals Manufacture	A-2, A-5	A-4, B-4,
Solvent Evaporation (dry cleaning/degreasing, printing)	B-6, B-7, B-1	A-10, A-13, B-3
	0	0

* From the list of 21 technologies shown in Exhibit 2, listed here by technology number.

5.0 REFERENCES

1. Jones, J. W., D. Campbell, P. Murphy, and R. Smith. *Preliminary Analysis of Hazardous Air Pollutant Emission Inventories from Three Major Urban Areas.* (EPA-600/A-94-007). (NTIS PB94-139508). Presented at the Joint A&WMA/CARB/SCAQMD Conference. Pasadena, California. October 18-20, 1993.

2. French, C. *Schedule for Standards: Methodology and Results for Ranking Source Categories Based on Environmental Effects Data.* (EPA-453/R-93-053). (NTIS PB95-187993). Research Triangle Park, North Carolina. September 1993.

3. U. S. Environmental Protection Agency. *Acidic Deposition: State of Science and Technology, Volume IV.* Ed. P. M. Irving. U. S. National Acid Precipitation Assessment Program (NAPAP). Washington, DC. 1990.

Attachment A

List of Embassies Contacted

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Attachment B

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Attachment C

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(continued)

Attachment C

Continued

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(continued)

Attachment C

Continued

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Attachment D

List of Foreign Technology Vendors Contacted

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Attachment E

Details of the 21 Technologies Identified for Consideration by U. S. Industry

Technology No.	Title	Page
A-1	Zinc Oxide Process for SO_2 Emission Control in Chemical Manufacturing	E-3
A-2	Solinox Process for Reduction of SO_2	E-9
A-3	Linkman Kiln Control System	E-15
A-4	DIOS (Direct Iron Ore Smelting Reduction) Process	E-21
A-5	Cerafil® Low Density Filter Elements	E-25
A-6	Cool Sorption Cold Liquid Absorption Vapor Recovery Process	E-30
A-7	Bioreactor for Remediation of Low-to-Medium Level VOC Emissions	E-37
A-8	BIZER Process for Combustion Control in Recovery Boilers by Digital Image Processing	E-41
A-9	Elsorb® Process for Reduction of SO_2	E-44
A-10	Blueminster Production Process of Water-based Liquid Resins and Resin Dispersions	E-51
A-11	Airborne 10 Absorption Agent Chemical Technology	E-55
A-12	Oilless, Dry Centrifugal Leak-free Compressors for Fugitive Emission Control and Energy Efficiency	E-60
A-13	Degreasing with Alkaline-based Cleaners	E-65
A-14	QSL Lead Smelter Reactor	E-69
B-1	Use of Envirotreat Modified Clays for the Control of VOC in Waste Air Streams	E-76

Technology No.	Title	Page
B-2	Fluidized-bed Cement Kiln Technology	E-80
B-3	Low-temperature Catalytic Incineration	E-85
B-4	Fluidized-bed Heat Treatment of Metal Components	E-90
B-5	Bioton Biofilter for Control of Air Pollutants	E-97
B-6	Ecoclean Cleaning Machines 80S, 81S, and 83S for Degreasing	E-100
B-7	F-1 Clean Ultrasonic Cleaning Machine for Degreasing	E-104

TECHNOLOGY NUMBER: A-1

ZINC OXIDE PROCESS FOR SO_2 EMISSION CONTROL IN CHEMICAL MANUFACTURING

Vendor: Sachtleben Chemie GmbH
Duisburg, F.R.G.

1.0 PROCESS DESCRIPTION

The Zinc Oxide process is a waste gas cleaning technology that offers effective removal of H_2S and SO_2 while producing no wastewater effluent. It was developed for compliance with German air regulations at the vendor's lithopone (a zinc sulfide white pigment) plant. The process uses the Zinc Oxide process to absorb the pollutants from annealing and drying kilns in a two-stage countercurrent flow absorber. A predecessor technology was implemented at Sachtleben's titanium dioxide pigment facility in 1991; this facility also uses a Zinc Oxide absorption system in addition to a sulfuric acid and peroxide absorption system.

In the absorber, a zinc oxide suspension is added to the top of the column in a concentration above stoichiometric. The waste gas, which is cleaned of most of its dust and aerosols in venturi scrubbers prior to column entry, enters the column near the bottom. The hydrogen sulfide and the sulfur dioxide react with the zinc oxide absorber to form $Zn(HSO_3)_2$, $ZnSO_4$, $ZnSO_3$, and ZnS.

The scrubbing liquor overflow from the top column section is sent to the bottom section where the excess absorbent is used to complete the reactions. A demister is included at the column top, which uses process water to remove suspension droplets carried in the gas stream. The two sections of the column are packed with a conventional plastic packing material that has high efficiency and low pressure loss. The material discharging from the bottom of the column is a mixture of zinc sulfate, zinc sulfide, zinc sulfite, and excess zinc oxide. This mixture is pumped to a zinc liquor treatment tank and reused in the production process.

At the titanium dioxide facility, following the removal of dust and sulfuric acid aerosols, the gas stream passes through two absorption columns. In this system , the type and design of the absorption agent is variable to market conditions (i.e., the availability of the various absorption agents). The first column has the flexibility to utilize a sulfuric acid/hydrogen peroxide mixture,

a zinc oxide slurry, or a caustic soda solution for the conversion of sulfur dioxide to sulfuric acid, which is recovered for use or for sale. The second column typically uses zinc oxide slurry or caustic soda solution for the conversion of hydrogen sulfide and sulfur dioxide into zinc sulfate and zinc sulfide, which can be used in another facility, or marketed. If the zinc products cannot be used or marketed, the zinc oxide can be recovered, generating a pure sulfur dioxide stream which can then be used or marketed as a raw material.

The existence of process waste at zinc smelting facilities is a primary concern. Typical components of the waste are: 7 percent zinc, 50 percent iron, and 10 percent sulfur. The use of the Wälz process to recover zinc from this residue is a possible use of this waste. In the Wälz process, zinc products react to form zinc oxide in the presence of coal in a rotary kiln. The zinc oxide is removed from the exhaust gas of the kiln by filters. The exhaust gas contains normal combustion products and 3-6 g/Nm^3 sulfur dioxide. To remove the sulfur dioxide, the Sachtleben Process is used. A one stage countercurrent absorption column running with a zinc oxide slurry absorbs the sulfur dioxide to form zinc sulfite. The zinc sulfite bottoms is then roasted to produce zinc oxide and almost pure sulfur dioxide, which can be then further reacted to form sulfuric acid. This process can similarly be used to clean the tail gas from a sulfuric acid plant.

2.0 CURRENT STATUS

The technology is currently utilized by its manufacturer, Sachtleben Chemie, at its Duisburg location in two factories:

- Since 1991, for the exhaust gas from the titanium dioxide factory.
- Since 1994, at the lithopone plant for the exhaust gas from its annealing and drying kilns.

3.0 CASE STUDY

The lithopone factory has been in full scale operation since the end of 1994, with approximately 98 percent availability (operational capacity) during its initial seven months. The titanium dioxide plant has been 92 percent available since 1991. The data for the lithopone and titanium dioxide facilities are listed in the table below.

Table 1-1.

Parameter	Value	
	Lithopone Plant	Titanium Dioxide Plant
Gas flow (Nm^3/hr)	58	61,000
Inlet loading (mg/Nm^3)		
SO_2	1700	6.6 - 4.4
SO_3	92	1.4 - 0.8
H_2S	300	0.2 - 0.18
Dust	105	1.2 - 0.38
Outlet emissions (mg/Nm^3)		
SOx	<180	SO_2 <20
		SO_3 <22
H_2S	<3	<2.5
Dust	<30	<20

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Chemical Manufacture

Limitations:

- High capital requirements (particularly in the case where the raw absorption products cannot be reused and a zinc oxide recovery process must be added.
- Maximum inlet pollutant concentrations

5.0 CONTROLLED POLLUTANTS

- SO_x (SO_2 and SO_3)
- H_2S

6.0 TEST DATA

The testing information was acquired from the performance of the technology at the two Sachtleben facilities in 1991 and 1993-94. Cold tests of the operations were performed to resolve control behavior difficulties and any other spurious engineering problems. The inlet and outlet streams of the absorption columns were monitored continuously. According to monitoring data, the target of reducing the waste gas pollutant load was achieved almost immediately.

A June 6, 1995, report was done by the German testing firm RWTÜV on the Sachtleben Lithopone facility at Duisburg to the test emissions of the waste-gas cleaning system. The test was performed by placing continuous emission monitors in six sites on and around the plant. The gas stream was measured for velocity of flow, stack pressure, gas temperature, and humidity. A gravimetric evaluation was also performed. The CEMs were initially tested for sensitivity using NO_2, SO_2, NO, CO, and CO_2. Samples were also taken from filters strategically placed in the gas stream. Three examinations were run on the process. Test results show that the waste gas cleaning process successfully lowered SO_x concentrations from 1665-2045 mg/m^3 to 13-19 mg/m^3.

7.0 OPERATIONAL/PROCESS PARAMETERS

The lithopone and titanium dioxide plants have the process requirements shown in the table below.

Table 1-2.

Parameter	Lithopone Plant (58 Nm^3/hr)	Titanium Dioxide Plant (61,000 Nm^3/hr)
Gas		
Electrical power	1585 kW	750 kW
Process water	10 m^3/hr	15 m^3/hr
Zinc oxide	130 kg/hr	540 kg/hr
Hydrogen peroxide	--	160 kg/hr

8.0 COSTS

The following data was provided for the Lithopone plant:

Table 1-3.

Parameter	Value
Capital cost	$15.82 million
Operating costs	$2.03 million/yr
Cost basis	DM

For a typical plant, the following cost data were provided by the vendor:

Table 1-4.

Parameter	Value
Capital cost	$4.0 million
Payback period	10 years
Interest rate	8-10 percent
Maintenance (annual)	$200,000/yr
Operation (annual)	
Electrical power	$425,200
Compressed air	$36,700
Water	$106,000
Washing agent	$216,000
Personnel	$800,000
Miscellaneous	$175,000
Cost per ton of pollutant	$1,080/ton
Currency Basis	DM 1995

9.0 SECONDARY IMPACTS

No secondary impacts if the absorption by-products of zinc sulfate, zinc sulfide, zinc sulfite, and excess zinc oxide are all reused.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

No comparisons available.

11.0 VARIATIONS

For a constant flowrate, a rise of pollutant concentration (H_2S, SO_2) has the following effects:

- More of the ZnO slurry will be needed.
- The scrubbing sections will require more plastic packing material.
- The increased pressure drop from the increased packing corresponds to a increased power for the exhaust fan.

12.0 COMMENTS

- Looks like a technology that would be potentially applicable to the metallurgy industry
- Does seem to have a high potential for negative secondary environmental impacts

TECHNOLOGY NUMBER: A-2

SOLINOX PROCESS FOR REDUCTION OF SO_2

Vendor: Sachtleben Chemie GmbH
Duisburg, F.R.G.

1.0 PROCESS DESCRIPTION

The SOLINOX process comprises a two-step scrubbing process with its primary objective the reduction of SO_2 emissions.

In the first step of the Solinox process, the flue gas is cooled by a water spray which also removes most of the dust, halogenated hydrocarbons (HF, HCl), and heavy hydrocarbons. The cooled flue gas enters a second nonaqueous scrubbing column in which SO_2 is removed with a proprietary organic adsorbent (polyethylene-glycol-dimethylether) by selective (physical) absorption. The organic adsorbent can be regenerated without any losses. The regeneration of the organics is achieved by heating the rich adsorbent to 100-1400°C and passing through a packed separator. The recovered concentrated SO_2 (90 percent) is cooled and compressed, and can be sold.

This process is capable of controlling SO_2 in flue gases meeting TA-Luft (FRG) standards. The SOLINOX process is also a cost efficient alternative as SO_2 concentrations in flue gases increase, maintaining performance as concentrations vary, even as operation exceeded design capacity 25 percent.

2.0 CURRENT STATUS

The SOLINOX technology has been installed at a number of facilities as shown in the table below.

Table 2-1.

Status	Country	Facility	Flue Gas (Nm^3/hr)	Year
Full scale	Austria	Zinc and lead smelter	30,000, and 50,000	1986/ 1988
Full scale	Austria	Cellulose (pulp) factory	100,000	1987
Full scale	Germany	Spar roaster	25,000	1990
Full scale	--	Coal-fired boilers and sulfuric acid plant	225,000	1993
Full scale	Germany	Rotary kilns Ba2S production (Sachtleben)	70,000 (design)	1993
Full scale	Poland	Copper foundry (Legnica)	250,000	1993 (est)

The SOLINOX processes at the above facilities were first installed on a pilot scale basis and then developed into full scale units. At two locations, the units are no longer in operation due to process changes that do not require SO_2 control.

3.0 CASE STUDY

Sachtleben Chemie GmbH (Duisburg)

This facility produces titanium oxide and other white pigments on a zinc-barium base (lithopones) for paints. Its operations include a reduction-oxidation reaction in which concentrated barium sulfate (92-93 percent) is reacted with cokes in a natural gas-fired rotary kiln, and SO_2 is formed as an undesired by-product (up to 0.5 percent of the flue gas). The concentration of SO_2 was found to vary considerably as uncontrollable process conditions change (in addition to operational load). Halogen and hydrocarbon levels also were to be controlled to meet German standards.

In order to control the volume of flue gas and hence reduce the capital costs of the Solinox control technology, natural gas was combusted with pure oxygen. This reduced the volumetric flue gas flow rate to 2,000 m^3/hr and improved operation of the kiln.

Prior to SO_2 removal, dust was removed by an electrostatic precipitator from flue gas that had been cooled from 600°C to 350°C.

The emission reductions achieved by the Solinox process at Sachtleben were:

SO_2	-	97 percent (0.12 g/m^3 exhaust)
dust	-	85 percent

Regeneration of the rich organic adsorbent was achieved by heat exchange of waste heat (steam) available from other processes in this facility. The recovered SO_2-rich gas product, which also contains co-absorbed hydrocarbons, was converted to H_2SO_4 in an existing plant.

Other case study information was available for lead and zinc mills in Austria. The Solinox process was used to achieve 97.7 percent SO_2 control at the lead facility at 96.1 percent SO_2 control at the zinc facility.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Primary Metals industry
- Chemical Manufacture (pulp, pigment)
- Industrial Boilers (coal-fired)

Limitations:

- Best suited for gas with a high concentration of pollutants
- Minimum level of SO_2 in flue gas is 0.3 volume percent (technical) or 2000 ppmv (economic)
- Cost effectiveness will improve as sulfur dioxide fraction increases
- Degree of control depends on design
- Deposition of sulfur in heat exchangers and columns (pebble filter) might be a concern, and is dependent on fraction of H_2S in adsorbent

5.0 CONTROLLED POLLUTANTS

- SO_x (SO_2 and SO_3)
- Hydrocarbons (such as benzene and naphthalene)
- Halogen compounds, such as HCl
- Particulate matter

6.0 TEST DATA

Tests performed at the Sachtleben facility on November 11, 1991, and December 13, 1993, show the following control efficiencies for gas flows of 25.8 and 20.1 Nm^3/hr respectively.

Table 2-2.

	Control Efficiency (percent)	
Pollutant	Gas Flow: 25.8 Nm^3/hr	Gas Flow: 20.1 Nm^3/hr
SO_2	99.8	98.5
HCl	97.7	99.2
HF	92.5	78.6
Benzene	89.9	57.7
PM	48	18.4

7.0 OPERATIONAL/PROCESS PARAMETERS

The following table shows the operating parameters from the Sachtleben facility.

Table 2-3.

Parameter	Value
Design capacity	70,000 Nm^3/hr
Temperature (inlet)	300°C
Pressure absorbent regeneration	0.5 bar
SO_2 mass flow	250 kg/hr
SO_2 mass flow variation (inlet)	100-400 kg/hr
Dust mass flow (inlet)	5 kg/hr

8.0 COSTS

The costs presented below are from the Sachtleben facility (design capacity 70,000 Nm^3/hr).

Table 2-4.

Parameter	Value
Capital costs (investment)	$11.8 million
Operating costs	$1.4 million/yr
Cost year/basis	1990 (DM, at 1.40 DM/$)
Interest (inflation) rate	2 percent (assumed)

9.0 SECONDARY IMPACTS

- Recovered concentrated SO_2, (80-90 volume percent), that also contains some VOCs, must be refined for reuse or disposed.
- Wastewater from bottom of aqueous scrubber will require further treatment.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

None available.

11.0 VARIATIONS

Solinox process maintains stable performance as SO_2 levels in flue gas vary.

12.0 COMMENTS

- Potentially feasible for high sulfur coal application

TECHNOLOGY NUMBER: A-3

LINKMAN KILN CONTROL SYSTEM

Vendor: Image Automation Ltd.
London, U.K.

1.0 PROCESS DESCRIPTION

The Linkman system is an automated expert kiln control system designed to mimic best operating practices and maintain optimum process conditions in the production of cement. Typical emission reductions of NO_x are 25 percent; up to 50 percent has been demonstrated.

Cement is made by burning fuel together with limestone and clay, shale or slate, yielding a clinker which is then ground with gypsum to produce cement. The process is carried out in large rotating kilns and as it is complex, it is easy to lose control and make sub-standard product. To obtain a good quality product the temperature of the kiln must be regulated. A stable kiln process is reached between the temperatures of 1,400 and 1,600°C; at higher temperatures, energy consumption is high due to both the increased level of heat and the energy required to grind the hard clinker produced. To achieve a softer high quality clinker, the process must be operated at the lower end of the temperature range, thereby reducing both NO_x and SO_x levels which increase with higher temperatures. Therefore, in a more controlled system the temperature is kept lower, hence lower emissions and savings in energy use.

In the Linkman system, data from the plant relayed to the control center includes:

- Percent O_2, CO, and NO at kiln inlet and /or preheater exit
- Percent O_2 and CO at precalciner outlet
- Raw material feed rate
- Coal feed rate kiln burner
- Coal feed rate precalciner burner
- Air flow rates cooler fans
- Kiln amps
- Kiln hood pressure

- Pressure under the first grate cooler chamber
- First grate cooler speed
- Kiln speed
- Tertiary air temperature
- Gas temperature outlet at the different cyclones
- Preheater waste gas temperature
- Gas temperature at kiln inlet
- Burning zone pyrometer
- Position of tertiary air damper
- Stack emissions
- Position of IDF damper

Laboratory data that is relayed to the control center includes:

- Lime feed, silica ratio, and alumina ratio
- Kiln feed percent calculation
- Clinker free lime per unit weight
- Clinker volatiles (SO_3, K_2O, etc.)

2.0 CURRENT STATUS

The Linkman technology has been introduced in over 60 cement plants world-wide and is diversifying into other processes where this type of control is needed, including a lubrication oil plant run by BP and float glass lines run by Pilkington Glass. Table 3-1 lists a few of these facilities.

In addition to the facilities mentioned above, there are also facilities in the following countries: Australia (1), Brazil (7), Chile (1), Costa Rica (1), Ecuador (2), France (1), Germany (2), India (2), Indonesia (1), Italy (2), Mexico (6), South Africa (3), South Korea (2), Switzerland (2), U.K. (9), and U.S. (2).

Table 3-1

Site/Company	Controlled Process
Blue Circle Cement Aberthaw, U.K.	1 preheater kiln
National Cement Co. Lebec, U.S.A.	1 long dry kiln, cooler
Ciments d' Obourg SA Obourg, Belgium	2 wet process kilns
Ciments Lafarge Havre-Saint Vigor, France	1 preheater kiln
Çanakkale Cimento Sanayi AS Mahutbay, Turkey	1 precalciner kiln, cooler
Orissa Cement Ltd Sundagarh, India	1 precalciner kiln, cooler, raw mill
Cementeria di Merone SPA Merone 1, Italy	1 Lepol kiln, cooler
Bünder Cementwerke AG Untervaz, Switzerland	1 preheater kiln, mill
Ssang Yong Industrial Dong Hae, South Korea	1 precalciner kiln
Blue Circle Cement Lichtenburg, South Africa	1 preheater kiln
PT Semen Cibinong Narogong, Indonesia	1 precalciner kiln, 2 preheater kilns, coolers
St. Lawrence Cement Mississauga, Canada	1 twin-tower precalciner kiln, cooler, mill

These Linkman operations total over 1.3 million hours of on-line closed loop control in the cement industry from fully commercially operating systems.

3.0 CASE STUDY

Blue Circle Cement, Hope Works, Kent, U.K.

In the early eighties, the Energy Efficiency Office set up a project to demonstrate how, by the use of high level computer control, a consistent maximum output of high quality could be produced from a kiln at minimum operating costs. The project involved several companies, the

host company, Blue Circle Industries Plc; the monitoring contractor, WS Atkins Management Consultants; and the equipment manufacturer, SIRA Ltd.

In March 1985, high level control was applied as an experiment to one of the two kilns at Hope Works, which produce 1.1 million tons of concrete clinker per year. Using the existing proprietary process control system, a maximum of 60 percent availability of time on high level control was reached.

In the summer of 1986, in conjunction with SIRA, a new system was developed and named Linkman. It provided much greater availability and reliability, and by February 1987, high level control was operational for 70-90 percent of the time. Using NO_x as an indicator of kiln temperature, the process reduced specific energy consumption and increased clinker production. The life span of the kiln refractory lining was also increased. By reducing the operating temperature, NO_x emissions were reduced by 25 to 50 percent.

In addition to increased output and improved clinker quality, a reduction of 7.7 percent in kiln fuel consumption was achieved. A U.K. government energy audit identified a cost saving of $1.5/ton of clinker, giving an annual saving of approximately $1,500,000 and a payback period of less than three months, for 1.1 million tons of cement clinker produced per year.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Cement Manufacture
- Chemical Manufacture (titanium dioxide)
- Other industries:
  - De-asphalting plant
  - Catalytic cracker
  - Lime-recovery plant
  - Lubricating oil production
  - Float-glass production
  - Any industry where process performance is dependent on that of the operator

5.0 CONTROLLED POLLUTANTS

- NO_x (reduced by 25 and 50 percent)
- Particulate matter emissions minimized (not quantified by vendor)

6.0 TEST DATA

None available.

7.0 OPERATIONAL/PROCESS PARAMETERS

Process requirements include adequate quality of existing instrumentation for implementation of the system and the requirement that all key supervisory control parameters are available through an appropriate sensor.

8.0 COSTS

Financial details are based on the case study (see Section 3) at the Blue Circle Cement plant in Kent, U.K., that produces 1.1 million tons of concrete clinker a year:

Table 3-2

Parameter	Value
Capital costs (investment)	$324,800
Estimated payback period	Less than three months
Operating costs and maintenance costs	Not available
Annual savings	$1,488,000
Savings per ton of clinker	$1.50
Cost year basis	1987 U.K. pound

9.0 SECONDARY IMPACTS

No data available.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

None available.

11.0 VARIATIONS

NO_x emissions may vary with different flame shape, burning zone material temperature, and other process dynamics. However, if the combustion system, NO_x monitor, and kiln gas sampling mechanism are all in good operating condition, and the oxygen target is high enough, then the Linkman system should be able to maintain a stable operation in the kiln.

12.0 COMMENTS

- Process controls described improve energy efficiency; however, there is not enough information to determine what makes this process control different from others.

TECHNOLOGY NUMBER: A-4

DIOS (DIRECT IRON ORE SMELTING REDUCTION) PROCESS

Vendor: Clean Coal Utilization
Tokyo, Japan

1.0 PROCESS DESCRIPTION

DIOS process uses fine and granular non-coking coal and iron ore directly for making molten iron without resorting to the coking and sintering operations required in the traditional blast furnace process. In DIOS, non-coking coal is charged into a smelting reduction furnace either directly or after cooling, while iron ore is charged into the furnace after prereduction in a fluidized bed to produce molten iron.

The following advantages are expected:

- While coking coal is a prerequisite to the blast furnace process, DIOS dispenses with coking coal and can utilize non-coking coal directly, thereby ensuring a wider selection of resources to be used in ironmaking.
- Start-ups and shut-downs of operations are easier with DIOS than the blast furnace process, thereby enhancing flexibility in production.
- The agglomerating process (sintering and coking) is eliminated, thereby reducing capital expenditures and energy costs.
- The export gas can be easily controlled, thereby optimizing operational efficiency.
- An approximately 10 percent reduction in production cost of molten iron is expected as compared with the blast furnace process.
- CO_2 emissions will be reduced by 5-10 percent in the heat-efficient DIOS process, as compared with the blast furnace process.
- Sulfur emissions are scarcely measurable since the sulfur charged is either dissolved into the melted slag and metal, or absorbed onto dust and collected.

DIOS uses less energy than a conventional blast furnace and, as a result, less emissions will be associated with the combustion of fuels.

In addition, DIOS does not require the horizontal coke ovens, sintering plant or pelletising plant normally required by a blast furnace. As a result, energy costs will be less and no pollutants associated with these operations will be produced.

2.0 CURRENT STATUS

DIOS is currently at the late development stage. The DIOS project is an 8 year program started in April 1988. The first three years of the project were conducted at five leading Japanese steel plants. Following these studies, a 500 t/d pilot plant was constructed at NKK's Keihin Steel Plant and completed in 1993. Operational tests are being conducted at this plant and are expected to be completed by March 1996.

3.0 CASE STUDY

Table 4-1·

Facility	Capacity	Country	Year	Status
Keihin Steel Plant	500 t/day 180,000 t/yr	Japan	1993-1996	Pilot

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Primary Metals manufacture (iron)

5.0 CONTROLLED POLLUTANTS

- SO_2
  - The sulfur is almost entirely absorbed in fine dust or iron ore in the preheating and pre-reduction furnaces. More than half of this is recycled to the smelting reduction furnace, with the remainder being passed through the cyclone prior to being collected by the scrubber. This is removed for commercial recycling.
- CO_2
  - Emissions will be (5-10 percent) less than those produced by a conventional blast furnace.

6.0 TEST DATA

Although it is claimed that gaseous sulfide was scarcely measurable in the exhaust, no details are provided.

7.0 OPERATIONAL/PROCESS PARAMETERS

The following table provides operational information for the DIOS and pilot plant in Japan.

8.0 COSTS

No financial details were provided, although the vendors believe that DIOS could operate at around 10 percent less than a conventional blast furnace due to the elimination of agglomerating process (sintering, and coking).

9.0 SECONDARY IMPACTS

No additional secondary impacts reported for the DIOS process as compared to conventional iron production.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

No comparison was presented, is available although it was noted that similar processes are under research by AISI in the U.S. and Hismelt in Australia.

11.0 VARIATIONS

No data provided.

12.0 COMMENTS

- The most significant advantage is the elimination of the traditional coke making process, which results in very hazardous emissions with an associated high risk.

Table 4-2

Equipment	Specifications
Production rate	500 t/d (21t/h)
Coal consumption	780-950 kg/t
Raw material feeding	
Iron ore	max 45 t/h
Coal	25 t/h
Flux	4.6 t/h
Preheating furnace	
Type	Fluidized bed
Temperature	500°C
Residence time	20 minutes
Pre-reduction furnace	
Type	Fluidized bed
Inner diameter	2,700 mm
Height	8,000 mm
Capacity	max 39 t/h
Temperature	700°C
Residence time	60 minutes
Smelting reduction furnace	
Type	Iron bath furnace
Inner diameter	3,700 mm
Height	9,300 mm
In furnace pressure	<2.0 $kgfcm^{-2}G$ (bar)
Oxygen rate	10,000 - 13,000 Nm^3/hr, max. 20,000 Nm^3/hr
Nitrogen rate	500 - 6,000 nm^3/hr
Gas reforming	
Fine coal addition	max 4 t/h
Tapping device	
Type	Opener-mudgun
Diameter	70 mm
Steady state	1-2 hours after start-up

TECHNOLOGY NUMBER: A-5

CERAFIL® LOW DENSITY FILTER ELEMENTS

Vendor: Cerel Ltd.
U.K.

1.0 PROCESS DESCRIPTION

This technology utilizes low-density ceramic filter elements, called Cerafil® elements, for the removal of smoke, dust, and fume particles from the flue gases generated by many industrial processes. Cerafil® elements are comprised of man-made mineral fibers bonded with organic and inorganic materials to form a porous filtration medium. These individual elements are loaded into cells that comprise the filtration plant.

The flue gases are drawn through the elements, such that the particulate matter (PM) collected forms a dust cake on the outside of the elements. The dust cakes are removed via reverse pulse-jet cleaning. The advantages of the Cerafil® filter elements over traditional fabric media are:

- Temperature resistant to 900°C.
- Thermal shock resistant.
- Resistant to acid and alkali contaminants in the flue gas.
- Can operate under variations in gas velocity and temperature.

For flue gases above 250°C, the Cerafil® filter plant eliminates the necessity of gas cooling equipment that would typically be required for operation of fabric filters. Also, the Cerafil® filter produces a dry waste in comparison to the sludges generated by liquid scrubbers.

Cerafil® will also control HCl and SO_2 with the use of a sorbent material (e.g., calcium hydroxide).

2.0 CURRENT STATUS

This technology is commercially available and in several full-scale industrial applications throughout Europe. Five are listed in the table below.

Table 5-1

Application	Location
Soil remediation	NBM Bodemsanering B.V., the Netherlands
Clinical waste incineration	Alexandra Hospital, U.K.
Waste tire incineration	Avon Tires Ltd., U.K.
Coal processing	Coal Products, Ltd., U.K.
Secondary aluminum processing	Brent Smelting Works, U.K.

3.0 CASE STUDY

Coal Products, Ltd., Coventry, U.K.

Coal Products, Ltd. decided to use a Cerafil® filter bed plant to control their particulate emissions. The facility manufactures a smokeless fuel derived from coal. The fuel, called Homefire, is produced by eliminating the low-temperature tars which make coal smoke when burning. Particulate emissions emanate from the Coal Products, Ltd. process waste gas that is incinerated in two boilers at the facility. The gas contains tars, volatiles, coal fines, methane, hydrogen, and carbon monoxide.

A Cerafil® filter plant was fitted to the exhaust stream of one of the boilers in October 1991, after an extensive pilot plant trial period. The filter contained 2400 Cerafil® S-1000 elements, and had a design capacity of 25,000 Nm^3/hr and a temperature range of 250-300°C. Inlet dust loading on the filter varied from 3.0-30.0 g/m^3, with particle sizes ranging from 1.9 to 54 μm, and 50 percent less than 7.2 μm. The outlet dust loading was typically in the 2.0-4.0 mg/m^3 range.

Difficulties occurred when incomplete combustion of the waste gas produced fires in the Cerafil filter plant. The Cerafil filter plant was refitted in January 1993, with modifications to ensure fire suppression and filter bypass. The Cerafil filter plant has operated trouble free since, with an outlet dust concentration of less than 4 mg/m^3.

A second filter plant was installed on the second boiler in August 1992, incorporating the changes to the unit on the first boiler. This second boiler has operated with the Cerafil filter control system with only minor difficulties since installation.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Cement Manufacture
- Industrial Boilers
- Solid Waste Disposal
- Primary Metals Manufacture

Limitations:

- Gas must be dry, since liquid will damage the filter
- Temperature must be less than or equal to 900°C

5.0 CONTROLLED POLLUTANTS

This technology is designed to control:

- Particulate
- HCl and SO_2 (with the use of a sorbent material)

6.0 TEST DATA

The vendor provided information for a smokeless fuel manufacturing facility, where the inlet dust concentration was 500 mg/m^3 and mean particle size was 4.8 μm. At this facility, the outlet dust concentration was found to be 1.5 mg/m^3, for a control efficiency of 99.7 percent.

7.0 OPERATIONAL/PROCESS PARAMETERS

For a 24,000 ACFM filter plant the following are required:

- Electric power for draft fan and reverse jet pulse cleaning, at 50 kW/yr
- Compressed air for pulse cleaning, at 2 liters of air per cleaning

8.0 COSTS

For a filter plant that treats 24,000 ACFM, contains 1,512 filter elements, and operates 8 hr/day, 5 days/week:

Table 5-2

Parameter	Value
Capital cost of filter plant	$400,000
Cost per element	$38 per element
Percent of capital cost for elements	14.5 percent
Cost per ACFM of flue gas treated	$16.15
Electricity	$10,810
Daily inspection	$370
Maintenance	$820
Replacement elements	$24,000 (1 set every 4 years)
Currency basis	British pound, 1995 ($1.6/pound)

9.0 SECONDARY IMPACTS

No secondary impacts are found in excess of the usual dust disposal common to other particulate control devices, such as fabric filters and ESPs.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

For a control device serving a 200 ton/day glass furnace and treating 21,700 ACFM of flue gas at 200°C, comparisons of Cerafil® to traditional dust cleaning are shown in the table below.

Table 5-3

Control Device	Relative Cost	
	Capital Cost	Operating Cost
Electrostatic precipitator	1.89	0.71
Electrified granulate bed filter	1.68	0.91
Bag filter	0.95	1
Cerafil® filter	1	1

The data above was based on a survey by the Energy Efficiency Office in the U.K. Although the flue gas temperature was only 200°C, the ceramic filters compared favorably to the existing technologies.

As compared to electrostatic precipitators, the ceramic filter is smaller, less expensive, and more adept to handling surges in particle loading. When compared to fabric filters, ceramic filters can operate at higher flue gas velocities and temperatures (up to 900°C), with only a slight increase in capital cost.

11.0 VARIATIONS

No significant variations in filtration efficiency with changes in flue gas particulate loading.

12.0 COMMENTS

- Feasible for high temperature applications
- Long term stability may be a question
- Need more information to determine applicability for gas treatment of acid deposition emission sources

TECHNOLOGY NUMBER: A-6

COOL SORPTION COLD LIQUID ABSORPTION VAPOR RECOVERY PROCESS

Vendor: Cool Sorption A/S
Glostrup, Denmark

1.0 PROCESS DESCRIPTION

Cool Sorption's Cold Liquid Absorption (CLA) vapor recovery process provides a cost effective alternative to reduce VOC emissions from gasoline and crude oil handling operations. This process is well-suited for processes such as fuel terminals, with large vapor flows. The system is very efficient, particularly for larger (heavier) hydrocarbon molecules.

In the CLA process, incoming vapors, that consist of a mixture of hydrocarbons and air, pass through an absorber column packed with rings. In the column, the mixture is scrubbed by the counter-current flow of a cold absorbent (often kerosene) which removes up to 98 percent of the hydrocarbon content. The absorption of the hydrocarbons is dependent on both the vapor pressure and the temperature of the absorbent. The temperature of the absorbent is maintained at -25°C, which facilitates the condensation of higher hydrocarbons. Other factors affecting the efficiency are the ratio of absorbent to vapor flow, the height of the column, and type of packing material. In addition, a feed-forward control can achieve a quick response if the volume of vapor entering the unit varies significantly. This occurs most often during road tanker loading operations, and is less necessary during ship loading.

The rich absorbent from the column is then directed to a splitter, where the hydrocarbons are stripped. The two-stage splitter column is packed with rings and operates on the reflux principle. The reflux condensator at the top of the column prevents the absorbent from being carried over.

The top product of the splitter column is condensed and absorbed in a re-absorber column. In this column, the vapors are washed in a counter-current flow of liquid gasoline or crude oil at ambient temperature. The lean absorbent from the splitter vessel is cooled by a heat exchanger and a chiller in connection with a standard industrial refrigeration unit. (Ammonia is used as the refrigerant.) The process unit is intrinsically safe, although a flame arrester may be installed on the outlet of the absorption column.

2.0 CURRENT STATUS

The CLA process was developed and patented in 1982. Currently, the process is applied by most European oil companies. The vendor claims that in 1991 more than 60 units were in operation. Some example installations are shown in the table below.

Table 6-1

Status	Facility/Application	Capacity	Vapor Recovery	Country
Pilot plant	Shell/refinery	500 m^3/hr	0.8 liters/m^3	Denmark
Full-scale	DSM/chemical plant	--	>99 percent	the Netherlands
Full-scale	Exxon U.K./road tanker terminals	--	>90 percent	United Kingdom
Construction of world's largest vapor recovery unit	OTS* Sture Terminal/ ship tanker loading operations	17,000 m^3/hr 400 tankers/yr	50,000 m^3 liquid hydrocarbons/yr	Norway

* OTS = Oseberg Transport system which is owned by Statoil (majority share), Norsk Hydro (operator), Saga, Elf, and Mobil

3.0 CASE STUDY

Exxon Research Center in the U.K. tested two CLA units at road tanker loading terminals in 1988. These units were operating directly on vapor displaced from bottom loading of road tankers. There were no vapor returns from top loading bays or storage tanks. Three out of four tests showed average control efficiencies >95 percent, which met the US EPA emission limit of 35 mg hydrocarbon/l of product loaded. Kerosene was used as the absorbent and cooled to -20°C. Test data are presented in section 6.0.

Tests of a prototype CLA unit for North Sea crude oil showed that methane was the most significant remaining pollutant in the resulting emissions.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Petroleum Marketing
- Gasoline Distribution (road tankers and ships).

Limitations:

- The process does not achieve optimum control for diluted vapors, such as those from industrial painting operations (e.g., car painting).
- The efficiency of the unit decreases with falling molecular weight and inlet concentration.
- The CLA technology requires road tankers and ships to be fitted with the appropriate equipment.

5.0 CONTROLLED POLLUTANTS

- VOCs

-	Gasoline vapors	Control efficiency of 96-99 percent Exhaust emissions of 25-30 g hydrocarbons/m^3
-	Crude oil vapors	VOC emissions primarily generated during ship loading operations can be controlled with an efficiency of 85-90 percent. Tests indicate that most of the remaining hydrocarbon emissions consist of methane.

6.0 TEST DATA

Test data for two Exxon (UK) road tankers loading terminals with Cool Sorption CLA units are shown below.

Table 6-2

Parameter		Exxon Test Data			
		Birmingham		Manchester	
		Test 1	Test 2	Test 1	Test 2
CONDITIONS					
Test date		3/10/88	4/10/88	5/10/88	6/10/88
Test period		53 mins	775 mins	317 mins	313 mins
Duration of test period with loading		44 mins	297 mins	168 mins	158 mins
Number of trucks loaded		6	35	21	22
Mogas temperature (mean)		12.5°C	13°C	14.3°C	14.3°C
Air temperature		9°C	7-14°C	7°C	6-9°C
Total loaded	m^3 (to CLA)	188.9	1044.8	675.1	671.1
Total 4* loaded	m^3 (to CLA)	150.9 (79.9%)	830.8 (79.5%)	523.5 (77.5%)	542.0 (80.8%)
Total 2*loaded	m^3 (to CLA)	13.0 (6.9%)	71.4 (6.8%)	33.0 (4.9%)	50.4 (7.5%)
Total ULP loaded	m^3 (to CLA)	5.0 (2.6%)	14.0(1.3%)	10.0 (1.5%)	14.0 (2.1%)
Total diesel loaded	m^3 (to CLA)	20.0 (10.6%)	128.6 (12.3%)	108.6 (16.1%)	64.6 (9.6%)
Total loaded	m^3 (not to unit)		256.3		
Total 4* loaded	m^3 (not to unit)		222.7		
Total 2* loaded	m^3 (not to unit)		19.6		
Total ULP loaded	m^3 (not to unit)		0.0		
Total diesel loaded	m^3 (not to unit)		14.0		
RESULTS					
Mean vapor flowrate to CLA	m^3/min	4.3	3.5	4.0	4.3
Total vapor volume	to CLA m^3	188.8	1045.2	675.8	671.6
Mean HC concentration	to VRU volume percent	17.4	17.2	9.5	9.6
Mean HC vapor flowrate	to VRU m^3/min	0.75	0.605	0.38	0.41
Total HC vapor volume	to VRU m^3	32.9	179.8	64.2	64.5
Mean HC concentration	from VRU volume percent	1.6	0.84	0.27	0.14
Mean HC vapor flowrate	from VRU m^3/min	0.056	0.024	0.010	0.0053
Total HC vapor volume	from VRU m^3	2.5	7.3	1.65	0.85
Mean recovery efficiency (Percent)		91.7	96.2	97.4	98.8
Product recovered over test period (m^3 liquid)		0.137	0.778	0.28	0.29
Product recovered over test period (kg liquid)		82.9	470	169	172
Product recovered as percent of product loaded		0.0725	0.0745	0.0415	0.0432
EMISSION RATES (EPA limit: 35 mg/l) mg emitted/liter product loaded		36	19	7	4

Note: 2* and 4* are two gasoline grades.

7.0 OPERATIONAL/PROCESS PARAMETERS

The following table shows the process parameters for a CLA unit.

Table 6-3

Parameter	Value
Energy demand	<0.5 kWh/l recovered product ±10 percent of recovered product needed as fuel (steam and electricity) for cooler
Absorbent	kerosene
Recommended temperature absorbent	-25°C
Absorbent to vapor flow ratio dependent on:	• vapor composition and concentration; lighter hydrocarbons require more absorbent. • temperature of the absorbent; lower temperatures will require less absorbent. • type of absorbent.
Pressure loss	There is almost no pressure drop in the CLA system if no flame arresters are applied, and the connecting piping is reduced to a minimum by placing the absorber column next to the ship. In this case, there is no need for compressors or blowers to transport the vapor.

8.0 COSTS

Capital costs are dependent on the unit design and therefore may vary considerably. The control efficiency and, hence, costs are a function of:

- Vapor composition and concentration
- Type of absorbent
- Absorbent temperature
- Absorbent to vapor flow ratio (l/g ratio)

- Dimensions of absorber column (height and packing)
- Remaining small hydrocarbons in absorbent

Three cost examples provided by the vendor are shown below.

Table 6-4

Parameter	Values		
	Example 1	Example 2	Example 3
Type of facility	Crude oil shiploading	Crude oil and gasoline shiploading	Gasoline loading truck terminal
Size	Large	Small	Medium
Capacity			
m^3/yr	42,000,000	8,000,000	1,400,000
m^3/day	400,000	120,000	7,000
m^3/hr	17,000	5,000	900
Product RVP	1.1	0.8	Not specified
Efficiency			
Liters removed Product per m^3 vapor	1.1	0.8	1.8
Total annual recovery (m^3)	45,000	6,400	2,520
CLA plant cost	$12 million	$4 million	$600,000

Typical annual operating costs are estimated as follows:

- Maintenance: 2 percent of capital costs, per year
- Energy: 0.5 kWh/l recovered product

In general, large CLA units are more cost effective than smaller units. Since the costs of the unit are dependent on size and design, the payback period may vary from several months to years. Vendor notes that Exxon U.K. purchased their cool sorption equipment to be able to earn money on their U.K. sites.

9.0 SECONDARY IMPACTS

- Wastewater (<0.1 m^3/day), as condensate water, that is contaminated with additives and hydrocarbons

10.0 COMPARISON WITH U,S. TECHNOLOGIES

- Flaring - no product recovery; and therefore, not a cost effective option.
- Carbon adsorption achieves a better control efficiency than the CLA process. However, large scale carbon adsorption applications are not as cost effective as the CLA because of the (high) price of activated carbon. In addition, activated carbon used to collect ketones can lead to spontaneous ignition.

11.0 VARIATIONS

Originally, the CLA technology was developed for gasoline applications, but currently it is also used to recover vapors from chemical and crude oil handling operations. The control efficiency of the CLA vapor recovery process is dependent on:

- Vapor components and concentration,
- Absorbent temperature,
- Absorbent to vapor flow ratio (l/g ratio),
- Dimensions of absorber column (height and packing), and
- Residual small hydrocarbons in absorbent (i.e., temp. of de-absorber column).

Dependent on vapor components and concentration, the other four parameters may be varied in order to obtain optimum cost/control efficiency performance.

12.0 COMMENTS

- Provides better performance over flaring since no recovery occurs with flaring
- More details on construction/installation and operational costs are needed to accurately quantify cost-effectiveness

TECHNOLOGY NUMBER: A-7

BIOREACTOR FOR REMEDIATION OF LOW-TO-MEDIUM LEVEL VOC EMISSIONS

Vendor: Sutcliffe Crenshaw, Ltd.
Lancashire, U.K.

1.0 PROCESS DESCRIPTION

This technology utilizes monocultures of a specially selected and developed strain of naturally occurring microorganism supported in a reactor (Bioreactor SC) to degrade a wide range of chemicals commonly present in industrial effluent air streams. The bacterial strains can handle relatively high concentrations (up to 1000 mg/m^3) of individual VOCs or VOC mixtures.

The bacteria, or biocatalysts , are held in a specially designed and prepared support in a chamber into which the waste gas stream is passed. This gas stream is preconditioned such that its humidity and temperature are within a suitable range for interaction with the bacteria. Residence time in the bioreactor is comparatively low (only a few seconds). The bioreactor includes a panel-type smoothing filter that serves to moderate temporary solvent peaks.

The waste gas stream enters the reactor, flowing over the microorganisms that are located on the support. The microorganisms use the waste air stream as a food source, biodegrading the contaminants and converting them to less harmful products plus CO_2 and water.

2.0 CURRENT STATUS

This technology is commercially available throughout the U.K. and Europe.

3.0 CASE STUDY

Commercial case study data was too sensitive at this time to be made available by the vendor.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Solvent Evaporation
- Surface Coating

Limitations:

- Not effective on air streams with extremely high concentrations of pollutants (> 1000 mg/m^3).
- Certain pollutants (toxics) can adversely affect bacteria.

5.0 CONTROLLED POLLUTANTS

- VOCs, including chlorinated hydrocarbons

6.0 TEST DATA

No test data were available at this time, although data may be accessible by early 1996.

7.0 OPERATIONAL/PROCESS PARAMETERS

Based on an example installation with an airflow of 10,000 Nm^3/hr, an influent VOC concentration of 300 mg/m^3, and 1,920 operating hours per year, the process requirements are:

Table 7-1.

Parameter	Value
Space	9 m^2
Electrical power	20,000 kWh (nominal)
Water	42 m^3/yr
Steam	266,800 kg/yr
Nutrients	565 kg/yr

8.0 COSTS

Based on the above example installation (airflow 10,000 Nm^3/hr, VOC concentration 300 mg/m^3, operating 1,920 hours per year) the costs of the bioreactor are:

Table 7-2

Parameter	Value
Capital costs	$144,000-$168,000
Payback period	3.8 years
Electrical power	$1,200
Water	$18
Steam	$6,450
Nutrients	$181
Total utility	$7,890
Cost per ton of pollutant controlled	$1.39/ton
Currency basis	British pound (1995)

9.0 SECONDARY IMPACTS

The annual cleaning of the biocatalyst bed uses wash water that requires wastewater treatment.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

According to a September 1993 *Environmental Business* report, running costs are shown to be 85 percent less than activated carbon, 93 percent less than incineration, and 67 percent less than scrubbing.

11.0 VARIATIONS

The bioreactor efficiency may vary with pollutant type and concentration.

12.0 COMMENTS

- Technology appears feasible but more test data would be useful to more accurately determine performance

TECHNOLOGY NUMBER: A-8

BIZER PROCESS FOR COMBUSTION CONTROL IN RECOVERY BOILERS BY DIGITAL IMAGE PROCESSING

Vendor: ABB Industries Oy
Helsinki, Finland

1.0 PROCESS DESCRIPTION

The Burning Image Analyzer (BIZER) is a system that utilizes digital image processing to calculate and supervise smelt bed conditions in recovery boilers. BIZER monitors the interior of the recovery boiler by fire-room cameras. The recorded video information is then converted to digital form by digital image processing techniques. The analyzing system has been designed to identify and quantify important features of the camera picture and present the obtained information to the boiler operator.

The first step in this process transfers a standard video signal from the fire-room cameras to the analyzer's grabbing module and digitizes it. The second consists of reducing the image information and filtering out noise and momentary disturbances. The next step is a contrast reduction of the image signal that emphasizes the desired image features by digital enhancement. Lastly, this information is used to search a histogram of desired elements characteristic of combustion and recommend changes to optimize the combustion.

BIZER can be an independent monitoring system or work as an integrated part of a recovery boiler control system. The system supervises and calculates smelt bed conditions such as bed height, form, area, symmetry, and temperature gradients. It includes functions for the calculation of burning parameters such as droplet size index, viscosity index, symmetry index, and heat input parameter, and also includes functions for the calculation of heat flow entered in the furnace, burning performance analysis, and knowledge-based Burning Expert modules.

BIZER presents the variables describing the performance of burning on a scale ranging from poor to excellent. It can display the variables describing smelt bed burning and behavior in trend form to calculate bed trends. The actual shape of char bed is compared with target images stored in the system's memory. The system generates a synthetic, colored image of the smelt bed for display and gives visual alarms to indicate different degrees of plugging of the camera openings.

BIZER has the flexibility to include other parameters, variables, etc. for calculation and analysis and can be integrated with a recovery boiler control system to optimize smelt bed conditions and combustion.

2.0 CURRENT STATUS

Stand alone versions of BIZER are commercially available and are being used in Indonesia. Integration of BIZER and AutoRecovery, another ABB system which is used to optimize recovery boiler operation, has been done only in laboratory studies, but more development is planned.

3.0 CASE STUDY

No specific case study information was presented.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Industrial boilers
- Recovery boilers in the pulp and paper industry.
- Solid fuel fired grate boilers (more development is needed for this application).

Limitations:

- None listed.

5.0 CONTROLLED POLLUTANTS

The BIZER system is not designed to control any pollutants, per se. However, since the system optimizes smelt bed conditions, it reduces the products of incomplete combustion that are characteristic of inefficient systems. These pollutants are CO, VOC, NO_x, and PM.

6.0 TEST DATA

Although test information was collected during mill trials and installations, ABB does not have any publicly available test results.

7.0 OPERATIONAL/PROCESS PARAMETERS

The BIZER system includes a PC (IBM/PC/AT compatible), some dedicated image processing boards, and necessary software modules. Optional equipment includes a black and white monitor, a RGB color monitor, and additional process measurement instruments. The fire-room cameras can be included or purchased separately.

8.0 COSTS

The capital costs given by the manufacturer are for a completely integrated system of BIZER technology and their AutoRecovery control system. This cost depends on the scope of the processes installed; it can range between $500,000 and $2,000,000. The payback period is one or two years depending on instrumentation investment, energy prices, etc.

9.0 SECONDARY IMPACTS

There are no secondary impacts.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

ABB does not know of any competing U.S. firms with a comparable technology.

11.0 VARIATIONS

This system does not seem to be affected by variations in pollutant concentration or fuel type.

12.0 COMMENTS

- Initial expense is high but payback period is relatively short
- Technology is innovative because it combines photo digitizing/analysis and process optimization. It will also likely have wider applications.

TECHNOLOGY NUMBER: A-9

ELSORB® PROCESS FOR REDUCTION OF SO_2

Vendor: Elkem Technology, Inc.
Pittsburgh, PA

Elkem Technology AS
Kristiansand, Norway

1.0 PROCESS DESCRIPTION

The Elsorb process is a regenerable process for SO_2 recovery that utilizes chemical absorption followed by regeneration. Designed for treating flue gases at utility and industrial sites, the Elsorb process produces SO_2 which can be converted into liquid SO_2, sulfuric acid, or elemental sulfur. Over 95 percent control of SO_2 has been achieved with the process, although the efficiency can vary with SO_2 inlet gas concentration.

In the process, flue gas is first cooled to its adiabatic saturation temperature. The gas then passes through a pre-scrubber to remove HF, HCl, and dust. Contact then occurs between the flue gas and an aqueous sodium phosphate buffer, which flows counter-current in a packed absorption tower (pH of 5-6.5). The SO_2 is absorbed by the buffer and is recovered by evaporation at 115-120°C followed by condensation. The more tightly packed the absorber, the more SO_2 can be absorbed.

The phosphate buffer is regenerated back to its original, chemically stable form by heating with an external heat exchanger that uses steam as the heating medium. The buffer then passes through a vapor/liquid separator, where SO_2 is abstracted as a product. To remove SO_3, appropriate equipment must be included to reduce the amount of buffer being consumed in this stage. The buffer concentrate is then drawn off and sent back to the buffer tank.

2.0 CURRENT STATUS

The Elsorb process was tested in laboratory and bench scale models. Two pilot plants were also tested leading to two full-scale installations. These operations are listed in the table below.

Table 9-1

Facility	Status	Year	Country
Norwegian Institute of Technology	Laboratory	1985	Norway
Norwegian Institute of Technology	Bench scale	1988	Norway
Norwegian Institute of Technology	Pilot plant	1990	Norway
Coal-fired boiler	Pilot plant (109 Nm^3/hr)	1991	Czech Republic
Wellman-Lord ØMV refinery	Full scale	1993	Austria
Esso Slagentangen refinery	Full scale	1993	Norway
Public Service Co. of New Mexico San Juan Generating Station	(Proposed) full scale	1995	U.S.

3.0 CASE STUDY

Vitkovice Steel (Ostrava, Czech Republic) Pilot Plant

A pilot plant was connected to a boiler at the Vitkovice Steel plant. The boiler burned black coal with a sulfur content of 0.8-1.1 percent. Because of the low concentration of SO_2, it was decided that the test program should be carried out with an additional amount of SO_2 spiked from an SO_2 cylinder in order to obtain a concentration in the influent gas of about 3,000 ppmv. The test program at Vitkovice was completed with a long-term (100 hour) test of the process in the conditions listed in the table below.

Table 9-2

Parameter	Value
Flue gas volume	109 Nm^3/h
Concentration of SO_2 in gas	3,000 ppmv
Concentration of O_2 in gas	7.7 percent
Absorption temperature	55°C
Buffer volume to absorber	15 l/h

The testing assessed not only the efficiency of the absorption and regeneration units, but also the general operation of the equipment. During the 100 hours of continuous operation, the density of the buffer was also altered to observe the change in SO_2 absorption. The results obtained are shown in the table below.

Table 9-3

	Test #1	Test #2
Specific steam consumption	10.2 kg H_2O/kg SO_2	11.2 kg H_2O/kg SO_2
Mean concentration of SO_2 in clean gas	98 ppmv	115 ppmv
Control efficiency	96.7 percent	96.2 percent

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Fossil-fuel Fired Boilers.
- Petroleum Refining.
  - Claus plant tail gas.
  - Sulfuric acid plants tail gas.
  - Rehabilitation of Wellman-Lord plants.

Limitations:

- More suited to operations with high concentrations of SO_2.
- Control efficiency dependent upon the inlet gas SO_2 concentration.
- Extra equipment required for the removal of SO_3.

5.0 CONTROLLED POLLUTANTS

- SO_2
- Particulate matter
- HF and HCl (with a prescrubber)

6.0 TEST DATA

Bench-scale

A bench scale test program was carried out with 3,000 ppm_v SO_2 in the entering gas and 50°C absorption temperature. An absorption efficiency well above 95 percent, together with an SO_2 uptake of more than 1.0 mol/l, was generally observed when the liquid circulation rate was properly adjusted to the amount of SO_2 in the entering gas. The specific energy requirement(s) for regeneration of the buffer, expressed as kilograms of steam required per kilogram of SO_2 recovered, varied between 9 and 11. This refers to single-effect evaporation. If double-effect evaporation had been used instead, the S-value would be nearly halved. Also a higher SO_2 concentration in the feed gas, and a lower absorption temperature would reduce S.

A buffer oxidation experiment was carried out at a temperature of 55°C, by recirculating the gas and a given volume of SO_2 loaded buffer over the absorber for an extended time period. The concentrations of SO_2, NO, and O_2 in the gas phase were held at 3,000 ppm_v, 1,000 ppm_v and 5 volume percent, respectively. The corresponding concentration of SO_2 in the buffer was 1.5 mol/l. The test was run continuously for 24 hours. The results indicate a buffer oxidation loss of SO_2 at about 0.5 percent. With this low oxidation rate, it was concluded that full advantage could be taken of the high cyclic capacity of the buffer solution.

7.0 OPERATIONAL/PROCESS REQUIREMENTS

The operational requirements for a typical Elsorb process are shown in the table below.

Table 9-4

Parameter	Value
Chemicals	Sodium base and phosphoric acid
Steam @ 2.7 bar (130°C)	10.1 ton/hr
Electric power	9900 kWh/hr
Raw water	60 m^3/hr
Cooling water	196 m^3/hr
Particulate load	20-50 mg/Nm^3

8.0 COSTS

Elkem have modelled costs on the EPRI model plant. The plant parameters and corresponding costs for application of the Elsorb process are shown in the tables below.

Table 9-5

Parameter	Value
Plant size/type	300 MWE power plant (EPRI model plant)
Flue gas volume	1,450,000 Nm^3/h
Fuel	Pulverized coal
Sulfur content	2.6 percent
Flue gas SO_2 concentration	1,700 ppmv
Flue gas O_2 concentration	5 (volume) percent
Flue gas temperature	139°C
Flue gas pressure	99 kPa
SO_2 cleaning efficiency	95 percent
Oxidation of absorbed SO_2 to sulfate	1 percent
Annual operating hours	6,000 hrs/yr
Absorption temperature	51°C
Recovered SO_2	6,592 kg/hr
Oxidation product formed (dry)	417 kg/hr

Table 9-6

Parameter	Value[a]
Capital costs	approximately $300/kWe ($90,000,000 for example)
Estimated payback period	No data available
Annual operating costs	$3,800,000
Control cost	$479 per ton SO_2 removed
Annual operating income	$1,800,000
Savings potential	$30 per ton of sulfuric acid produced
Cost year basis	1994
Interest rate	9.6 percent

[a] Cost estimates were taken from costs for a Wellman-Lord process, due to Elsorb's similarity to this process.

9.0 SECONDARY IMPACTS

- Fly ash disposal: The collected particulates must be disposed.
- Wastewater: Small amounts of acidic effluent, with halides and solids from the prescrubber, need treatment before being discharged.
- Solid waste: Minor amounts of Na_2SO_4 are formed in the oxidation process but can be used in the fertilizer industry.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

A study (by Elkem) comparing the Elsorb process with the Wellman-Lord process claims that the Elsorb process offers:

- Less chemical consumption
- Less waste disposal
- More SO_2 produced
- Less problems dealing with the buffer
- Less scaling in the evaporator system

11.0 VARIATIONS

Control efficiency (90-98 percent) variable with SO_2 inlet gas concentration.

12.0 COMMENTS

- Capital costs may be considered too high for the utility market, therefore, cost-effectiveness may be an issue.

TECHNOLOGY NUMBER: A-10

BLUEMINSTER PRODUCTION PROCESS OF WATER-BASED LIQUID RESINS AND RESIN DISPERSIONS

Vendor: Blueminster Ltd.
Kent, U.K.

1.0 PROCESS DESCRIPTION

Blueminster has developed a low-energy technology for the production of water-based, high solids adhesives and resin dispersions. This technology will eliminate the use of solvents, including both toxic and non-toxic (chlorinated) hydrocarbons, during the resin and polymer blending phase. The technology developed by Blueminster is based on two key processes discussed below.

Production of Liquid Resin X and Resin XE in a resin kettle

Resin X is manufactured in a stainless steel resin kettle in which rosin reacts with a blend of glycols. The reaction takes place at a maximum temperature of 240°C and takes ±24 hrs. The kettle is heated by electricity or super-heated steam. Liquid Resin X tackifier/plasticizer contributes to the low temperature performance of adhesives. The liquid resin (Resin X) is modified by the addition of surfactants to form Resin XE. Resin XE is a self-emulsifying tackifier that can be added directly without solvent and with simple stirring to a variety of latexes (polymers) to produce water-based adhesives (see below).

Production of Water-based Resin Dispersions in a Dispersion Kettle

Water-based resin dispersions with high solids content (58-62 percent) are produced from Resin XE. Rapid inversion takes place in a heated stainless steel kettle fitted with a sweep stirrer and a special stirrer. The dispersions are blended (without solvent) with a variety of latexes including styrene butadiene rubber, acrylic, modified acrylic, E.V.A., polychloroprene, P.V.A., and natural rubber, to produce water-based adhesives. Resin XE dissolves higher melting resins to produce dispersions with an improved higher temperature performance. The softening point is increased to 115°C. This technology may also be applied to resin derivatives, hydrocarbon resins, terpene and terpene phenolic resins, coumarone and coumarone indene resins, styrenated resins. The resin to polymer ratios are:

- Liquid resin: 20 parts of resin to 80 parts of polymer. A higher ratio of liquid resin gives a softer adhesive.
- Resin dispersions: One part of resin to one part of polymer

Wastewater treatment will be required for the wash water. The treatment consists of neutralizing and filtering out precipitated resinous material. Waste generated during this process is non-toxic resinous material and can be incinerated.

2.0 CURRENT STATUS

Major European/international adhesive manufacturers are utilizing the technology on a commercial scale. Several U.S. manufacturers are currently evaluating the technology. No details were provided on the scale of this trend.

3.0 CASE STUDY

No information available.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Solvent evaporation: production of pressure sensitive and contact adhesives to be used in the following manufacturing industries:
  - tapes and labels
  - coatings
  - flooring
  - leather
  - wood (including furniture)
  - foam
  - vinyl
  - closures, paper, fabrics
  - food packaging (since water-based adhesives are non-toxic, these adhesives are particularly suitable for this source category).

Limitations:

- The technology does not produce adhesives that can be exposed to total immersion in water for prolonged periods.
- The drying process of water-based adhesives is slow compared with solvent based adhesives.

5.0 CONTROLLED POLLUTANTS

- VOC
- Energy-related emissions (CO, SO_x, NO_x, PM)
  - Vendor claims that the water-based adhesives require three to five times less drying energy for application than solvent-based adhesives.

6.0 TEST DATA

None available.

7.0 OPERATIONAL/PROCESS PARAMETERS

Table 10-1

Parameter	Value
Maximum temperature	240°C
Reaction time	±24 hrs
Equipment	Stainless steel kettle needed with appropriate flow and head space
Energy	Electricity or super heated steam
Space (10 T resin and 5 T dispersion kettles)	1000 ft^2 floor 20 ft head

8.0 COSTS

Costs are defined below for a production unit with a 10 T resin kettle and 5 T dispersion kettle.

Table 10-2

Parameter	Value
Capital costs	$560,000
Estimated payback period	1-1.5 years
Operating and maintenance costs	$80,000/yr
Cost ($)/T pollutant removed	Given the current market price of solvents and the relatively low operational costs of this new technology, it is likely that the water-based resin may be produced at lower cost compared with current solvent-based adhesives, resulting in a cost savings (with less pollution).
Cost basis	U.K. pound, 1995 (exchange rate of $1.60/£)

9.0 SECONDARY IMPACTS

- Wastewater from wash water.
- Non-toxic resinous waste from wastewater treatment.
- Combustion products from the incineration of resinous waste.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

Blueminster claims that there are no directly comparable state of the art technologies available in the U.S.

11.0 VARIATIONS

Energy, fuel consumption, and space are dependent on batch size, that ranges from 0.5 to 20 tons.

12.0 COMMENTS

- Limitations regarding exposure to water and longer drying times may limit the applicability, but otherwise it appears promising.

TECHNOLOGY NUMBER: A-11

AIRBORNE 10 ABSORPTION AGENT CHEMICAL TECHNOLOGY

Vendor: Impex Ltd.
Herts, U.K.

1.0 PROCESS DESCRIPTION

This technology was developed as a method of controlling odor-causing pollutants (VOCs) from industrial and agricultural facilities. Airborne 10 is a proprietary blend of surfactants that when atomized with water, increases the effective surface area or interface area of the water droplet by 500,000 percent. When introduced into an exhaust gas, the Airborne 10 droplet collides with a pollutant aerosol and absorbs the pollutant. The Airborne 10/pollution aerosol falls to the ground where it is broken down by the natural bacteria present. The high droplet surface area and volume allows for more effective gas contact, scrubbing, and, consequently, more effective air pollution control.

The Airborne 10 is fed from a tank through a Dosatron proportional injector to the sprayhead. The sprayhead, a REDCO 200/400/500 Series Atomizer Head, consists of an electrically driven rotary machine that produces 80 percent of the sprayed volume in the desired droplet size.

2.0 CURRENT STATUS

Airborne 10 is commercially available and in use in Europe.

3.0 CASE STUDY

At North West Water's Wastewater Treatment Plant in the U.K., the Sludge Storage and Transfer facility successfully used Airborne 10 in lieu of a biofilter system to eliminate odors. For biofilter system installation, the price tag has been estimated at $800,000[1]. For the Airborne 10 system, consisting of two atomizers, installation costs were $6,400[1] and annual costs were $1,600.[2]

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[2]Based on an estimated $1.6/British pound conversion rate.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Solid Waste Treatment and Disposal
- Chemical Manufacturing
- Plastics Manufacture
- Bakeries (food industry)

Limitations:

- Only applicable where Airborne 10 outfall can be safely degraded by natural bacteria on the ground, unless mist eliminators are fitted. The collected solute would then have to be treated as a secondary pollutant (by bioremediation/biodegradation or disposal of in accordance with local regulations).

5.0 CONTROLLED POLLUTANTS

- VOCs
- Toxics

6.0 TEST DATA

The vendor cited toxicological test data from a 1993 U.S. testing company report that showed Airborne 10 to be nontoxic and innocuous. The vendor also supplied test data that compared Airborne 10 to a U.S. product for hydrogen sulfide removal from air, as shown in the table below.

Table 11-1

Product	Dilution Rate	Initial Concentration (ppm)	Final Concentration (ppm)		
			On Contact	5 min	15 min
U.S.	375:1	48	40	7	<2
Airborne 10	400:1	500+	<1	--	--

7.0 OPERATIONAL/PROCESS PARAMETERS

- A clean water supply of <200 ppm total dissolved solids, with a minimum water pressure of 0.5 bar (7.5 psi.)
- A power supply of 70 watts per spray head.
- A sufficient number of heads to obtain dispersal and coverage.
- A Dosatron, or other automatic proportional dosing equipment.

8.0 COSTS

For a 1,500 ton/day waste reclamation plant:

Table 11-2

Parameter	Value
Capital cost	$5,768
Payback period	1 month
Operating and maintenance costs:	
Chemical	$9,000 per year
Electricity	$50 per year
Water	$75 per year
Miscellaneous	$175 per year
Annual refurbishing	$2,700 per year
Total	$12,000
Cost saving per ton processed	$0.37 per ton
Currency basis	U.S. Dollar (1995)

See also Section 3 (case study) for wastewater treatment plant costs.

9.0 SECONDARY IMPACTS

- Wastewater: Because Airborne 10 relies on natural bacteria to degrade byproducts, it is possible that ground contamination could result from toxic or otherwise undesirable byproducts that are either toxic to the naturally occurring bacteria or are not degraded. In this case, mist eliminators could be fitted on the unit. Collected solute would be treated as secondary pollutant using bioremediation, biodegradation, or as specified by local regulations.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

The Airborne 10 control technology is far less expensive (up to 90 percent less) than scrubbing towers, packed column scrubbers, and cyclonic scrubbers; Airborne 10 is much less expensive than biofiltration.

For the reclamation plant discussed in Section 8 (costs) above, a comparison to a typical biofiltration system is as follows:

Table 11-3

Parameter	Value	
	Biofilter	Airborne 10
Capital cost	$375,000	$5,767
Financing cost	$250/yr @ 15 percent	Not necessary
Operating and maintenance costs	$60,900 per year	$11,990

See also Section 3 (case study) for a cost comparison at a wastewater treatment plant.

11.0 VARIATIONS

For wastewater treatment plants:

Table 11-4

Plant Size	Amount of Airborne 10 Needed
2.5 MMGal/day	2 fl. oz. per hour
36 MMGal/day	5.4 gal per month
50 MMGal/day	25 gal per month

12.0 COMMENTS

- Major concerns are pollutant media transfer from one media to another
- Fallout control at small sites or on windy days may be problematic

TECHNOLOGY NUMBER: A-12

OILLESS, DRY CENTRIFUGAL LEAK-FREE COMPRESSORS FOR FUGITIVE EMISSION CONTROL AND ENERGY EFFICIENCY

Vendor: Hitachi Ltd.
Tokyo, Japan

1.0 PROCESS DESCRIPTION

This technology utilizes magnetic bearings and nitrogen gas seals in an oilless, dry, centrifugal, leak-free (ODCC) compressor that controls fugitive emissions normally associated with compressors in petroleum refining.

The magnetic bearings in the compressor allow the compressor to be smaller in size and less expensive to operate. The conventional oil-fed bearings require a constant source of oil to maintain lubrication. In addition, the magnetic bearing allows the compressor to take full advantage of a high-speed supercritical rotor, that allows for smaller compressor design with decreased cost and power usage. A dry-gas seal used in the compressor's interstage labyrinths prevents complications that accompany lubricated or water-cooled seals. The gas medium (nitrogen) also is used to cool the seals. The amount of nitrogen is controlled via proportional and integral derivative (PID) process controls that are protected by a secondary nitrogen seal.

An automatic balancing system (ABS) is also used in the ODCC. The ABS system employs a tracking filter which synchronizes with the rotating speed and can change or reduce the gain (stiffness) at the rotating speed. In effect, this can reduce vibration due to imbalance by allowing the shaft to rotate about its axis of inertia.

The Hitachi centrifugal compressor has the following advantages:

- Minimizes space requirements for the compressor
- Can utilize a steam turbine driver to optimize the plant's utility balance and reduce energy usage
- Reduces plant construction cost as well as running expenses

2.0 CURRENT STATUS

A Hitachi compressor was put into commercial operation in December 1992 at an Okinawa Sekiwu Seisei Co. (Japan) petroleum refinery. The compressor has run trouble free (8,000 hours) since installation. There have been many other commercial applications since.

3.0 CASE STUDY

Okinawa Oil Refinery.

At this petroleum refinery, a net gas booster compressor was required for the Continuous Catalytic Regeneration-Platforming Process in the production of high quality gasoline to pressurize the hydrogen-rich gas to the plant header in the refinery.

Normally, a reciprocating compressor is used due to the low molecular weight of the gas and the required high-pressure ratio. However, in order to lower the inlet pressure of the process and to increase the inlet volume of the compressor, three (4-cylinder type) reciprocating compressors (2 operating and 1 spare) would be required, each handling 50 percent of the gas flow and operating in parallel. This type of arrangement usually takes up a large amount of space, which was a major concern during the planning stages since space was at a premium.

On the other hand, a conventional centrifugal compressor would take up far less room, solving the spacing problem. However, conventional oil-type centrifugal compressors for this application would have required at least three casings, which would have been a disadvantage in terms of both initial cost and operating expenses.

At this stage, a magnetic bearing type compressor was proposed, which would only require a two-casing construction. In order to reduce the number of compressor casings to two, a higher rotational speed was required above the capability of standard impeller materials. Table 12-1 below shows the design of the compressors. Tests performed on the compressors demonstrated the suitability of the ODCC for the intended purpose (see also Section 6, Test Data).

The machine was put into commercial operation in December 1992, and has been running without any major trouble for over 8,000 hours. The client's operator and maintenance staff are fully satisfied with this machine because there is no need to change any oil filters; no need for cleaning around the machine area; and because of easy machine monitoring in the control room console, especially for bearing temperature, vibration, and current in the bearing. Also,

capital costs, operating costs, and space requirements were all lower with the ODCC as compared to a reciprocating and conventional centrifugal compressor (see also Section 10 costs).

Table 12-1

Parameter	Low Pressure Casing	High Pressure Casing
Hydrogen flow (Nm^3/hr)	43,691	43,486
Suction volume (m^3/hr)	15,369	6,311
Suction pressure (kg/cm^2)	3.4	8.1
Discharge pressure (kg/cm^2)	9.3	20.3
Speed (1/min)	10,600	
Shaft power (kW)	4,120	
Speed range (1/min)	9,265 - 11,445 (85 percent - 105 percent)	
Driver rating	5,300 kW condensing turbine	

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Petroleum Refineries
- Chemical Manufacture
- Synthetic Organic Chemical Manufacturing

Limitations:

- Due to inexperience with magnetic bearings, problems with heat accumulation occur.

5.0 CONTROLLED POLLUTANTS

- VOCs (process fugitives)
- NO_x, PM, CO_2, CO (through increased energy efficiency)

6.0 TEST DATA

The compressor at the Okinawa refinery was shop performance tested in accordance with ASME PTC-10 and was subject to a mechanical running test in accordance with API 617.

7.0 OPERATIONAL/PROCESS PARAMETERS

For the two-stage 44,000 Nm^3/hr hydrogen compressor at the Okinawa Refinery:

- A 5,300 kW condensing turbine for power
- Nitrogen for the gas seals
- A PID (proportional-integral-derivative) controller for the seals and magnetic bearings

8.0 COSTS

See relative cost data below (Section 10).

9.0 SECONDARY IMPACTS

No secondary pollution impacts.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

According to Hitachi's economic evaluation, the ODCC compares well in terms of cost and space requirements to other compressor types. Table 12-2 shows the comparisons developed by the vendor.

Table 12-2

Parameter	Relative Costs		
	Reciprocal	Centrifugal	Dry Centrifugal
Capital (equipment) cost	1	0.9	0.79
Operating cost	1	1.15	0.96
Space requirement	1	0.43	0.39

In addition, the oilless compressor accomplishes equal performance to the reciprocal and centrifugal compressors without the cleaning required for the lubricated-type compressors.

11.0 VARIATIONS

None given.

12.0 COMMENTS

- Cost analysis is limited to capital costs; information provided doesn't address operating cost differences
- Heat accumulation may be a problem

TECHNOLOGY NUMBER: A-13

DEGREASING WITH ALKALINE-BASED CLEANERS

Vendor: Swedish Environmental Protection Agency
TEM Foundation
Lund, Sweden

1.0 PROCESS DESCRIPTION

Alkaline degreasing was proposed as a pollution prevention alternative to conventional degreasing with trichloroethylene during a Swedish study conducted from 1987-1991 at a number of small to medium Swedish industrial facilities. A firm that produces lighting fittings and fixtures, Thorn Jarnkonst AB, successfully switched from trichloroethylene to alkaline degreasers for the study. Alkaline degreasers were found to have the following advantages:

- No discharge of solvents to the atmosphere
- Major reduction in the amount of hazardous waste
- Improved working environment with less solvent vapors

See details of the process in the case study below.

2.0 CURRENT STATUS

Commercially available.

3.0 CASE STUDY

Thorn Jarnkonst, Sweden.

Thorn Jarnkonst produces 600,000 units of lighting fixtures for indoor use and 150,000 units for outdoor use. The total number of employees was 400 and their revenues in 1993 were $38.4 million.

The main pollution source at Thorn was air emissions from an organic solvent, trichloroethylene, used during parts cleaning. Previous to the study, 16 tons of trichloroethylene were used, with air emissions of 11 tons and 5 tons of hazardous waste.

A changeover to vegetable oils was first performed to make degreasing easier. Substitution of alkaline degreasers for trichloroethylene reduced air emissions of trichloroethylene to zero with no corresponding increase in other air pollutants. Wastewater was generated, however, that required neutralization and sludge separation. This wastewater treatment was performed at the on-site wastewater treatment facility. Hazardous waste decreased from 5 tons of trichloroethylene sludge to 1-2 tons of oil bearing sludge that was below the permitted maximum load.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Degreasing
- Solvent evaporation

Limitations:

- None provided

5.0 CONTROLLED POLLUTANTS

- Trichloroethylene
- VOCs (chlorinated)

6.0 TEST DATA

No test data were provided.

7.0 OPERATIONAL/PROCESS PARAMETERS

- Alkaline reagent
- Water
- Energy

8.0 COSTS

The following table shows the costs of using alkaline degreasers versus trichloroethylene at the Thorn Jarnkonst site.

Table 13-1

Cost Item	Value
Chemicals	$3,400
Water	$13,500
Energy	$18,600
Labor	$75,900
Cleaning Equipment	$2,500
Total Annual Costs	$113,900
Cost Basis	$ 1990

9.0 SECONDARY IMPACTS

- Wastewater (neutralization and sludge separation).

10.0 COMPARISON WITH U.S. TECHNOLOGIES

The following table compares the cost of using alkaline degreasers at the Thorn Jarnkonst facility to the prior use of trichloroethylene at the same site.

Table 13-2

Cost Item	Value	
	Trichloroethylene	Alkaline Degreasers
Chemicals	$3,400*	$3,400
Water	~ 0	$13,500
Energy	$6,700	$18,600
Labor	$75,900	$75,900
Cleaning Equipment	$33,700*	$2,500
Capital Costs	$16,900*	None
Total Annual Costs	$136,600	$113,900
Cost Basis	$ 1990	

* For recycling of trichloroethylene

11.0 VARIATIONS

No data provided.

12.0 COMMENTS

- Technology is cost-effective where water and treatment are available.

TECHNOLOGY NUMBER: A-14

QSL LEAD SMELTER REACTOR

Vendor: Lurgi Metallurgie
Frankfurt am Main, F.R.G.

1.0 PROCESS DESCRIPTION

The QSL process is a continuous treatment of metal sulfide concentrates with oxygen. The process is designed to treat all grades of lead concentrates as well as secondary materials. This technology is applicable to the lead smelting industry. The QSL reactor replaces conventional smelting units (sinter plant and blast/shaft furnaces). The lead recovery rate is estimated to be ±98 percent.

The QSL process utilizes a bath smelting process that includes submerged high-pressure injection of oxygen and fossil fuels. Two types of redox reactions take place in the process, as shown below.

- Autogenous (exothermic) roast-reaction smelting of raw materials containing sulphur and lead:

  $PbS + 1\frac{1}{2} O_2 = PbO + SO_2$

  $PbS + 2 O_2 = PbSO_4$

  $PbS + O_2 = Pb + SO_2$

  $PbS + 2 PbO = 3 Pb + SO_2$

  $PbS + PbSO_4 = 2 Pb + 2 SO_2$

- Carbothermic (endothermic) reduction of metal from the slag:

  $PbO + CO = Pb + CO_2$

  $C + CO_2 = 2 CO$

The reduction zone is separated from the oxidation zone by a partition wall which has an underflow for the exchange of slag and metallic lead and an opening for the process gas.

Post combustion of the oxidation and reduction gases is achieved by injection of oxygen-enriched air or oxygen into the reactor via lances. These lances are located in the roof of the reactor. The exhaust with a high concentration of SO_2 and some dust leaves the reactor at a temperature of 1150-1200°C. Dust can then be largely removed by an electrostatic precipitator. Precipitated flue dust can be recycled to the process or partially withdrawn to recover cadmium contained in the dust. Heat may be recovered by waste heat boilers. Emissions are further controlled by directing the exhaust through a scrubber and sulfuric acid plant. The process is capable of smelting both concentrates and secondary lead-bearing materials like Pb/Ag-residues, Zn-residues, glasses, slags, and battery paste together.

If raw materials contain a high amount of zinc, a separate uptake in the reduction zone may be installed for the recovery of zinc as zinc oxide fume. Under stronger reduction conditions, zinc is partially fumed off. After cooling the exhaust, the oxide dust containing a mixture of zinc and lead oxide is collected in a bag filter. Cadmium, found mainly in the flue dust from the oxidation zone, can be recovered as cadmium-carbonate by bleeding the flue dust to treatment in a separate leaching step.

If flue gas heat will be recovered in a convective boiler, the temperature is reduced from 1000 to 650°C. This may be achieved by heat exchange in a radiant heat boiler followed by quenching of the gases. At temperatures in excess of this level in the convective section, flue dust becomes sticky and causes clogging.

The advantages of the QSL process are:

- Direct recovery of lead during the oxidation of the sulfide
- Lower amount of slag due to the direct recovery of lead
- Lower gas exhaust volume
- Less generation of materials to be recycled
- High process flexibility
- Possibility of zinc, cadmium, and SO_2 recovery
- Lower capital cost than conventional smelting
- Lower operating cost than conventional smelting

2.0 CURRENT STATUS

The QSL process is based on patents obtained in 1973 for direct smelting of metals from metal sulfide with oxygen in one smelting unit. German regulations adopted in the mid-1980s made it cost-effective to replace conventional lead smelters with QSL technology. The first full-scale commercial lead smelters came into operation in the early 1990s.

Table 14-1

Status	Type of Facility	Lead Production (T/yr)	Country	Year
Pilot	Batch process	5,000	Germany	1976 - 1979
Demonstration	Continuous smelting	30,000	Germany	1981 - 1986
Full scale[a]	Lead smelter	120,000	Canada	Nov. 1989 - Mar. 1990
Full scale/ commercial	Lead smelter	75,000	Germany	1990
Full scale[a]	Lead smelter	52,000	China	Dec. 1990 - Mar. 1991
Full scale/ commercial	Lead smelter	60,000	South Korea	1992

[a] Natural gas was used instead of the prescribed coal; this caused a sufficient amount of problems to require shutdown.

3.0 CASE STUDY

The case studies include the following processes:

- Full-scale lead smelter in commercial operation in Germany (75,000 T/yr)
- Full-scale lead smelter in commercial operation in South Korea (60,000 T/yr)

The early tests and pilot plants primarily focused on the problems associated with the flow behavior of the slag, chemical and physical processes in the area of the reducing nozzles, and service life of various parts of the reactor (injectors, refractory lining). The following is a description of these two facilities.

Table 14-2

Parameters	German Facility	Korean Facility
Production Capacity (T/yr) (lead output)	60,000	75,000
Reactor Dimensions (meters)		
Total Length/diameter	41	33
Oxidation Zone	13 x 4.5	11 x 3.5
Reduction Zone	28 x 4.0	22 x 3.0
Feed (dry) (tons per year)		
Raw material	22.7	20.8
Silica	-	0.004
Limestone	2.7	0.3
Recirculating oxygen fumes	5.0	4.3
Recirculating leach residue	1.3	-
Coal fines	2.8	1.9
Raw Material Feed Mixture (percent)		
Concentrates	53	63
Residues	47	37
Composition Raw Material (percent)		
Lead	35.0	45.0
Zinc	10.0	5.0
Copper	0.6	0.7
Arsenic	0.3	0.3
Antimony	0.3	0.4
Cadmium	0.3	0.05
Gases to reactor		
Oxidation (oxygen) (Nm^3/hr)	7300	4700
Reduction (coal dust) (T/hr)	1.4	0.9
Slag		
Production (T/hr)	8.8	7.1
Pb content (percent)	2.0	2.5
Lead bullion (T/hr)	7.9	9.6
Exhaust Gas Stream		
Volume (Nm^3/hr)	22,000 - 24,000	30,000 - 32,000
Temperature (°C)	±1,200	NA
Dust (T/hr)	±6	7 - 8
SO_2 (percent)	8 - 10	9 - 10
Cadmium	0.001 mg/Nm^3	
Mercury	<0.0005 mg/Nm^3	
SO_2	0.01 mg/Nm^3	
Lead	0.1	
Copper	0.01	
Arsenic	<0.0005	

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Primary Lead industry

Limitations:

- Although originally a lead content in primary slag of 40-50 percent was required, experience has shown that a level of 25-35 percent is possible without substantial increase in flue dust.
- High levels of PbO in the primary slag reduce the generation of lead fume.
- The PbO content in the primary slag governs the slag fall (addition of fluxes) and the amount of reductant required.

5.0 CONTROLLED POLLUTANTS

- Lead
- Arsenic, cadmium, and SO_2 (due to reduced mass flow of recycled material)
- Energy-related pollutants (NO_x, PM, CO, and possibly SO_x)

6.0 TEST DATA

Emissions tests were performed at a German lead smelting plant. Significant emission reductions of lead, cadmium and SO_2 were found. The QSL technology was shown to meet German air quality standards. The table below presents data for the QSL process and compares the data to a conventional plant.

Table 14-3

Parameter	Reduction	100,000 TPY Lead Production	
		QSL	Conventional
Lead	>50 percent	87 g	400 g
Arsenic	±70 percent	--	--
Cadmium	±70 percent	--	--
SO_2	±90 percent	2.6 kg	40 kg
Energy per ton of lead produced	±50 percent	1.028 10^3 kcal	2.055 10^3 kcal

7.0 OPERATIONAL/PROCESS PARAMETERS

The only additional parameter needed for the QSL process is a source of oxygen-enriched air. See Table 14-2 above for the process parameters used in the case studies (Section 3.0).

8.0 COSTS

Both the German and Korean operations described in Table 14-2 above have reported that the capital and operating costs of the QSL process are lower than with the conventional primary lead smelting process (sinter/furnace process) built new. However, no details were provided. It should be noted that retrofit of existing conventional furnaces is not possible with the QSL process.

The capital costs for the QSL facility in Germany were estimated by the vendor at $70 million (100 million DM). No details are included on what these costs include (e.g., smelter, sulfuric acid facility, power generating plant, control equipment).

9.0 SECONDARY IMPACTS

- Process waste contains cadmium, arsenic trioxide, and H_2SO_4 (that can be recycled into sellable products).
- Process wastewater contains sulfuric acid (that may be recovered and used in other on-site processes.)
- Slag that must be disposed of.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

A comparison to the standard lead production process (used in the U.S.), that uses sinter machines and blast furnace, was performed by German authorities. It was found that emissions with the QSL process were 92.6, 93.3, and 98.3 percent, respectively, of the emissions of lead, cadmium, and SO_2 at conventional lead production facilities.

11.0 VARIATIONS

Primary/secondary lead ratio may be varied dependent on the plant design.

12.0 COMMENTS

- High initial capital investment may make this technology more feasible for new construction rather than retrofits.

TECHNOLOGY NUMBER: B-1

USE OF ENVIROTREAT MODIFIED CLAYS FOR THE CONTROL OF VOC IN WASTE AIR STREAMS

Vendor: Rowe Technology, Ltd.
N. Yorks, U.K.

1.0 PROCESS DESCRIPTION

This technology utilizes a range of modified clays that readily react with pollutants contained in waste air streams. The clays act as a filter to remove the VOCs in the air stream. The Envirotreat clays (E-clays) were developed initially for use in land remediation, but the high reactivity of the clays made them well suited for air pollution as well. The equipment required for implementation is similar to that used with activated carbon processes. Unlike activated carbon which, once saturated with VOCs, must be treated to avoid the reversal of the adsorption process, the E-clays do not require treatment and will not desorb the pollutants back into the environment.

The E-clays work by forming a series of complex chemical bonds with the organic materials in a process that is irreversible. The end material formed by the reaction between the clays and the organic compounds is safe and stable. The E-clays will absorb twenty to thirty times their own weight of organic contamination.

This technology is best applied in cases where there are a number of contaminants in the exhaust stream and it is not economical to recover and separate them. It is also effective in the case of a high volume air stream with a low concentration of pollutants. E-clays can also be used in conjunction with activated carbon systems, because long chain organics that typically reduce carbon bed lifespan and reduce efficiency are controlled by the E-clays.

2.0 CURRENT STATUS

The E-clays are fully developed and in use as a remediation technology for contaminated land. A prototype design for air pollution has been completed and will be constructed in the near future, at which point full testing on polluted air streams will commence.

3.0 CASE STUDY

No case study information available.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Surface Coating
- Solvent Evaporation
- Chemical Manufacture

Limitations:

- As E-clay bonding process is irreversible, industries that rely on solvent recovery would not be suitable.

5.0 CONTROLLED POLLUTANTS

- VOCs
- Dioxins

6.0 TEST DATA

The filter media (E-clays) have been tested using the U.S. TCLP (Toxic Characteristic Leaching Procedure) to prove that the clays can be safely deposited in standard landfill sites. However, no tests have been performed at full-scale sites with loaded clays, since a prototype has not been constructed.

7.0 OPERATIONAL/PROCESS PARAMETERS

The following are the operational/process requirements for an E-clay system:

- Electric power for the air extraction fan
- E-clay replacement, that varies according to use, i.e., concentration of pollutants in air stream
- Clay filter vessels that range in size from 33' x 25' (airflow of 235 cfm) to 100' x 100' (airflow of 15,000 cfm)

8.0 COSTS

The following are costs for typical E-clay units:

Table 1-1

Parameter	Unit Size	
	Large	Small
Capital cost	$25,000	$5,000
Clay replacement (annual)	$3,000	$100
Cost basis	U.S. dollar, 1995	
Cost per ton of pollutant removed	$90	

9.0 SECONDARY IMPACTS

- Solid waste: Spent clay must be disposed of at standard landfill sites. The material formed in clay-organic bonding process is stable and safe, and the clays are permeable.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

The organo-clays that have been developed in the U.S. were not developed for pollution control, but for other industries. The average cost of these products is $3,000 per ton versus $1,800 per ton for the E-clays. Also, the E-clays are more reactive than U.S. organo-clays and will handle a wider range of contaminants.

11.0 VARIATIONS

The capital cost of an E-clay filter is governed by two factors--air flow and the concentration of pollutants. The greater the air flow and/or concentration of the pollutants, the greater the volume of clay required.

12.0 COMMENTS

- The high volume, low concentration application provided by this technology is extremely important and is presently without effective and economic control technologies.

- Other potential applications could include air streams from groundwater stripping, odor control for rendering plants, fabricated rubber products.

- The bed thickness of 0.1 inches that is required for this technology could be extremely difficult to manufacture. Breakthrough due to non-uniformity could be a problem.

- Other potential limitations could include hazardous waste disposal costs, solid waste disposal costs.

- Many costs were not considered in the analysis including power for the blower, operation and maintenance costs, and waste disposal costs.

TECHNOLOGY NUMBER: B-2

FLUIDIZED-BED CEMENT KILN TECHNOLOGY

Vendor: Center for Clean Coal Utilization
Tokyo, Japan

1.0 PROCESS DESCRIPTION

This technology sinters cement clinker in a fluidized-bed kiln system, comprised of a spouted-bed kiln (granulation), a fluidized-bed kiln (sintering), and a fluidized-bed quencher cooler. This system was developed to improve cement production that is traditionally performed in rotary kilns. The Japanese technology improves the combustion and heat transfer characteristics of the cement production process, enabling better control of the sintering temperature. Unlike rotary kilns, the fluidized-bed kiln has no fire flames and the levels of NO_x are therefore very low. When compared with a rotary kiln, the fluidized bed system produces only a third of the NO_x, when heavy oil is used as a fuel, and one half when coal is used. Compared with the traditional rotary cement kilns, this technology also cuts energy consumption, thereby reducing CO_2 emissions.

The fluidized bed system also enables lower grades of coal to be used (low carbon and high hydrogen content). This, combined with reduced fuel consumption, results in a 1-12 percent reduction in CO_2 emissions.

The key features of this new technology are:

- Improves combustion (sintering) efficiency by 5 percent or more (from 55 percent to 60 percent).
- Reduces fuel consumption by 10-12 percent.
- Reduces CO_2 emissions by 10-12 percent.
- Saves natural resources by expanding the grades of coal which can be used.
- Reduces construction costs by 30 percent.
- Saves installation space by 70 percent.

2.0 CURRENT STATUS

The program to develop the fluidized-bed kiln was started in 1986 by the Japanese Ministry of International Trade and Industry. A large scale production plant (200 t/day) is under construction and a test operation was to have been started in January 1996. The development schedule is shown below:

Table 2-1

Stage	Capacity	Country	Year	Comments
Feasibility study		Japan	1986	
Pilot Plant Design and Construction	20 t/day	Japan	1987-1988	1/100 scale of actual plant
Pilot Plant testing		Japan	1989-1992	
Production Plant Design and Construction	200 t/day	Japan	1993-1995	1/10 scale of actual plant
Production Plant testing			1995-1997	

3.0 CASE STUDY

As this technology is in the development stage, case studies of a commercial system are not available. The details given below are based on a 20 t/day pilot plant operation.

In the pilot study, it was found that clinkers can be continuously granulated in the spouting bed kiln (SBK) with no need for seed clinkers. The process was found to be unaffected by the type of fuel used (heavy oil or coal). The diameter of the granules was found to be dependent on the temperature of the SBK and was therefore easily controlled. The size of the granules obtained was found to be very uniform and, consequently, their fluidity in the fluidized-bed kiln (FBK) was easily maintained. In the FBK, the quality of the clinkers was found to be equal in quality to those produced in a rotary kiln. Once again clinker quality was found to be unaffected by the type of fuel used.

The system uses a fluidized-bed quenching cooler for maintaining clinker quality and a packed-bed cooler for recovering waste heat. In the pilot plant, the efficiency of waste heat recovery exceeded 80 percent, more than 20 percent higher than in conventional systems. Heat recovery was affected by flow rate in the cooler, clinker size, and cool air intake.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Cement Manufacture

Limitations:

- None cited.

5.0 CONTROLLED POLLUTANTS

- CO_2
- NO_x

6.0 TEST DATA

Performance testing on the pilot plant (20 t/day) was carried out from June 1989 to March 1993. NO_x emissions test results are shown below. The NO_x tests were performed during granulation and sintering of clinkers for normal Portland cement.

Table 2-2

	NO_x Emissions*	
System	Heavy oil fuel	Pulverized coal
Fluidized-bed cement kiln	60 - 100 ppm	230 - 270 ppm
Rotary kiln (traditional)	180 - 220 ppm	350 - 450 ppm

* At conditions with 10 percent O_2

7.0 OPERATIONAL/PROCESS PARAMETERS

The specifications of the 20 t/day pilot plant are shown in the table below.

Table 2-3

Parameter	Value
Granulating unit: spouted-bed kiln (SBK)	
Operating temperature	1,300 to 1,350°C
Sintering unit: fluidized-bed kiln (FBK)	
Operating temperature	1,400 to 1,450°C
Cooling unit: fluidized-bed quenching cooler (FBQ)	
Cooling range	1,400°C to 1,450°C
Packed-bed cooler (PBC)	
Cooling range	1,000 down to 100°C
Heat input	670 kcal/kg clinker

8.0 COSTS

Although no cost data was supplied, the developers claim that this technology is cost competitive with traditional rotary cement kilns. A feasibility study will be carried out after the test run of the 200 t/day production plant.

9.0 SECONDARY IMPACTS

No additional secondary impacts reported as compared to the traditional process.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

As far as the developers are aware, there are no similar technologies elsewhere in the world.

11.0 VARIATIONS

The clinker quality is expected to be unaffected by the type of fuel used.

12.0 COMMENTS

- While technology looks promising, it should be run at production plant level for a period of time to ensure feasibility and cost-effectiveness.

- Energy savings are the driver for this technology.

TECHNOLOGY NUMBER: B-3

LOW-TEMPERATURE CATALYTIC INCINERATION

Vendor: Babcock Hitachi KK
Tokyo, Japan

1.0 PROCESS DESCRIPTION

Various catalysts have been developed to facilitate the incineration of pollutants in exhaust streams with low calorific values at low combustion temperature (room temperature to 800°C). This catalytic incineration process provides a means of oxidizing low concentrations of (organic) pollutants by an improved combustion process utilizing noble metals, base metal oxides, and transition metals as catalysts. In the catalytic incineration process, thermal NO_x production is also suppressed, as opposed to normal incineration.

The catalytic combustion system is composed of a catalytic combustor, heat exchanger, waste energy recovery unit, starting preheater, fan and stack. The catalyst used in the process is in a honeycomb form, thus allowing the gases to flow in a laminar state with a low pressure drop through the catalyst. The catalytic combustor is lined with refractory material and has a framework for dispersing the gases uniformly.

In the process, the emission gas is boosted to the required pressure by a blower. In order to achieve complete combustion, the exhaust gas is passed through a heat exchanger to the catalytic combustor. For inlet gases with very low calorific values, the inlet temperature to the combustion chamber must be raised to ensure that the material reaches the complete combustion temperature. A plate type heat exchanger is used for temperatures below 800°C, while shell and tube type heat exchangers may be used for higher temperatures. An auxiliary burner, installed between the heat exchanger and combustion chamber, can be used for this purpose. The combustion heat is further recovered in a waste heat boiler prior to the release of combustion products to the atmosphere.

2.0 CURRENT STATUS

Development of the system began in 1982 and it is now available commercially. Two full-scale systems for the treatment of emission exhaust gases have been installed:

- At an acrylic acid plant; estimated gas flow is 20,000 Nm^3/hr.
- At a styrene monomer plant; estimated gas flow is 60,000 Nm^3/hr.

3.0 CASE STUDY

No data provided.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Chemical Manufacturing
- Plastics Manufacture
- Bakeries (food industry)
- Any industry with low hydrocarbon emissions.

Table 3-1

Industry	Types of Emissions	Target Chemicals
Chemical	Vent and purge gas	Hydrogen, CO, propane, methanol, organic acids
Plastics	Byproduct gas Solvents	Styrene, butadiene
Food	Kitchen emissions	Trimethylamine, formalin
Paint	Solvents	Acetone, toluene, methanol, formaldehyde
Adhesive	Solvents	Toluene, benzene, acetone, methanol

Limitations:

- Process limited to exhaust gases with low concentrations of pollutants.

- To prevent poisoning of the catalyst, potential poisons must be removed prior to combustion. (See Table 3-2 below.) New catalysts are being developed to deal with poisonous chemicals.

Table 3-2

Potential Catalyst Poisons	Poison Mechanism	Effects
Metals -- Hg, Pb, Sn, Zn	Chemical combination with active sites	Permanent poisoning
Non metals -- P, Sb, Bi, As, Si	Chemical combination with active sites	Permanent poisoning
Halogens -- Cl, F, Br	Adsorption on active sites	Regeneration of catalyst by high temperatures
Sulphur compounds -- SO_2, SO_3, H_2S, thiols	Adsorption on active sites and chemical combination with carrier	Regeneration of catalyst by high temperatures
Tar materials	Deposit on catalyst surface blocking pores	Regeneration by incineration removal

5.0 CONTROLLED POLLUTANTS

The vendor states that the catalytic combustion process is applicable to the following gases:

- Inorganic gases: hydrogen, carbon monoxide
- Organic gases: methane, ethane, propane, butane
- Alkenes: ethene (ethylene), propene (propylene), butene
- Aromatics: cyclopentane, cyclohexane, benzene, toluene, xylene, ethylbenzene
- Alcohols: ethanol, methanol, propanol
- Ethers: dimethyl ether, diethyl ether
- Aldehydes: formaldehyde, acetaldehyde
- Ketones: acetone, methyl ethyl ketone
- Acids/esters: ethanoic acid, acrylic acid, ethyl acetate

6.0 TEST DATA

No full-scale test data were provided. Laboratory endurance test results showed that the catalyst can achieve 90 percent conversion of all targeted chemicals at approximately 350°C

and does not deteriorate beyond this level after 3000 hours of service. The conventional catalysts tested in conjunction with the Hitachi catalysts quickly deteriorated after initial exposure so that after 400 hours of exposure an inlet temperature of at least 500°C was required, with an inlet temperature of 800°C required after about 1000 hours of exposure.

7.0 OPERATIONAL/PROCESS PARAMETERS

The following are process parameters for the Hitachi catalysts.

Table 3-3

Parameter	Requirement
Energy potential of gas to be heated	40-400 kcal/Nm^3 (167.4-1673.6 kJ/Nm^3)
Fuel and power	Electricity and small amounts of LPG or kerosene for the auxiliary burner
Combustion temperature	400-800°C (depends on catalyst)
Space	
20,000 Nm^3/hr system	12 x 15 m (180 m^2)
60,000 Nm^3/hr system	19 x 15 m (285 m^2)

8.0 COSTS

The following are the costs of the Hitachi catalysts.

Table 3-4

	Plant Size (Nm^3/hr)	
Parameter	20,000	60,000
Capital costs	$1,300,000 (1990)	$2,800,000 (1993)
Operating costs	Small amount of electricity	Small amount of electricity
Catalyst exchanging costs	$360,000 every 3 years*	$1,080,000 every 3 years*
Payback period	Vendor claims that the systems have not been running long enough to determine this	

* Assumed.

9.0 SECONDARY IMPACTS

- Since the process requires electricity for the blower, and fossil fuels may be used in the auxiliary burner, energy-related air pollution can occur.
- The catalyst needs to be replaced periodically and the spent catalyst disposed of.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

No data available.

11.0 VARIATIONS

Various catalysts have been developed for different applications (see table below). However, it should be noted that reductions in temperature and pressure below the optimum range of the catalyst can lead to incomplete combustion.

Table 3-5

Catalyst Type*	Application	Controlled Pollutants (example)
LT1	Active at low temperatures (100-500°C)	Aldehydes, alcohols, ammonia, amines, CO, etc.
LT2	Active at room temperature (adsorption and dissociation)	Methyl mercaptan, trimethyl amine, methyl sulfide, H_2S
HT2	Heat resistant up to 1,000°C	Alkanes, aromatics, various solvents, organic acids, etc
HT2	Heat resistant up to 800°C	VOC streams
HT3	Heat resistant up to 800°C in very steamy conditions	VOC streams (containing steam)
SX1	Resistant to SO_2 poisoning	VOC (containing SO_2)
SX2	Resistant to halogen poisoning	VOC (containing halogens)

* LT = Low Temperature
HT = High Temperature
SX = Non-metal Poisoning Resistant

12.0 COMMENTS

- High catalyst cost and catalyst poisoning are both of concern.

TECHNOLOGY NUMBER: B-4

FLUIDIZED-BED HEAT TREATMENT OF METAL COMPONENTS

Vendor: Quality Heat Treatment Pty Ltd.
Victoria, Australia

1.0 PROCESS DESCRIPTION

This technology utilizes fluidized beds for the heat treatment of tool metal. Tool metal is typically heat treated in salt baths or vacuum furnaces for the purpose of obtaining proper metal hardness and microstructure. A new technology developed by Quality Heat Treatment reduces the environmental impact of heat treatment of steel and other tool metals.

Steel is hardened by heat treating to improve its properties. Hardening, carburising and nitrocarburising are all steel heat treatment processes that use baths of molten salts, such as nitrites, nitrates, carbonates, cyanides, chlorides, or caustics. The combination of these chemicals and heat not only causes air pollution related health problems, but also creates environmental problems when disposing of the waste. Waste products all require treatment before release to the environment, with the disposal of cyanide salts at $3,300 per ton.

A mixture of air, ammonia, nitrogen, natural gas, liquefied petroleum gas (LPG), and other gases is used as the fluidizing gas to carry out a heat treatment in Quality Heat's Fluidized-Bed Heat Treatment technology. This technology:

- Reduces amounts of effluent
- Improves safety and working atmosphere
- Reduces the amount of energy used
- Improves quality and uniformity of the final product
- The use of 120 mesh or (105 μm) white aluminum oxide significantly reduces the usage of nitrogen.
- The computer controlled fluidization optimizes gas usage and heat transfer, reducing the amount of gases used.
- Can be run in a fast track line allowing all processes to be performed in line and quickly changed. Speed of heating and cooling is similar to salt baths and can be individually reduced to optimize the heat treatment of each part. Process times also can be reduced.

2.0 CURRENT STATUS

The technology is commercially available and is used throughout the world in countries such as Australia, New Zealand, Japan, Germany, Columbia, Egypt, Jordan, China, Malaysia, Indonesia, Taiwan, and Korea. Some locations are shown in the table below.

Table 4-1

Status	Country	Company
Full scale	Australia	Comalco
Full scale	Indonesia	PT Indal
Full scale	Malaysia	Fujisash
Full scale	Malaysia	Aluform

3.0 CASE STUDY

Chartered Metal Industries (CMI), Singapore.

For the toolroom at the Chartered Metal Industries (CMI) in Singapore, the standard heat treatment process was a cyanide salt bath. Disposal of cyanide salt typically cost $3,300 per ton. In addition, there are the environmental hazards that result from the use of toxic salts, including the neutralization of quench water, oil, cleaning water and washing water, as well as the off-gases that must be chemically scrubbed.

CMI replaced their existing salt bath line with Quality Heat fluidized beds. The advantages of the fluidized-bed furnaces included temperature uniformity, atmosphere control, and the environmental benefits of no longer using the cyanide salt. The fluidized beds showed significant cost savings versus the salt baths at approximately $87,000 per year.

The loading and handling capacities of CMI's Quality Heat fluidized bed are shown in Table 4-2 below.

Table 4-2

Parameter	Temperature (°C)		
	250	700	1100
Throughput (kg/hr)	275	180	100
Maximum load (kg)	300	220	150
Nitrogen (m^3/hr)	35	10	7

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Primary Metals manufacturing

5.0 CONTROLLED POLLUTANTS

- VOCs
- Halogenated compounds
- Metals
- Eliminates the use of cyanide (and barium) used in salt baths; therefore eliminates these potential emissions.

6.0 TEST DATA

None available.

7.0 OPERATIONAL/PROCESS PARAMETERS

The table below shows the operational parameters for the Quality Heat Treatment technology.

Table 4-3

Parameter	Value
Temperature	Ambient to 1100°C
Furnace size	Bed 700 mm diameter by 900 mm deep
Furnace volume (bed)	Load weight of aluminum oxide 615 kg
Production loading capacity (per bed)	See Table 4-4 below
Furnace heat up time (approx. from cold)	0.5 hours ambient to 200 °C 1.0 hours ambient to 360 °C 1.5 hours ambient to 500 °C 2.0 hours ambient to 720 °C 2.5 hours ambient to 900 °C 3.0 hours ambient to 1100 °C
Safety controls	
Low gas flow alarm	Shuts off heating if fluidizing gas supply fails
Power failure	An automatic nitrogen by-pass system is provided to protect work
Over temperature	Shuts down elements if set temperature is exceeded
Heating Electricity	125 kW
Fluidizing atmosphere (per bed)	See Table 4-5 below

Table 4-4

Throughput (Approximate)	Maximum Load*
225 kg/hr at 1100°C	300 kg
300 kg/hr at 1000°C	400 kg
350 kg/hr at 900°C	400 kg
400 kg/hr at 700°C	560 kg
500 kg/hr at 500°C	600 kg
600 kg/hr at 250°C	600 kg

* Recommended loading capacity based on load weight in steel, including baskets and fixtures, and sized so that no more than 50 percent of open area is occupied by the work load.

Table 4-5

Temperature (°C)	Fluidizing Air (m^3/hr)	Inert gas <10ppm O_2 (m^3/hr)	Carburising gas, Natural, Propane, or LPG (m^3/hr)	Ammonia/ Dry ammonia (m^3/hr)
Room Temperature	124 at 40kPa	124 at 40kPa	--	--
250	70-80	70-80	--	--
500	36-38	36-38	4 at 10 percent air flow	20 at 50 percent air flow
750	22-24	22-24	12 at 50 percent air flow	12 at 50 percent air flow
1000	15-17	15-17	2 at 10 percent air flow	2 at 10 percent air flow
1100	13-15	13-15	--	--

8.0 COSTS

Costs below are based on the system described in the CMI, Singapore, case study (Section 3.0):

Table 4-6

Item	Value
Capital costs (investment)	$180,000
Estimated payback period	2 years (approximately)
Operating and maintenance costs (per year)	$36,000
Energy and salt	$51,000
Total cost savings	$87,000
Cost year basis	U.S.$, 1994

9.0 SECONDARY IMPACTS

No data available.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

Quality Heat compared their fluidized bed process with similar processes from U.S. manufacturers, and claims that the Quality Heat process offers:

- Lower capital costs.
- More sophisticated systems.
- 20 percent less in hourly running costs.

For the cost example above ($180,000 in capital costs for the CMI System), the vendors estimated that the capital costs for atmospheric and vacuum furnaces performing the same processes would be $350,000 and $500,000, respectively. In general, when compared to vacuum furnaces, the Quality Heat System is estimated to have lower operating costs, at

$0.33/kg (estimated) as compared to $0.85/kg for vacuum furnaces; 2.5 times lower capital costs; and 1.5 times more capacity.

11.0 VARIATIONS

The total mass of metal that can be treated varies with temperature.

12.0 COMMENTS

- None provided.

TECHNOLOGY NUMBER: B-5

BIOTON BIOFILTER FOR CONTROL OF AIR POLLUTANTS

Vendor: ClairTech
Utrech, the Netherlands

1.0 PROCESS DESCRIPTION

This technology employs biofiltration to treat VOC (odor)-containing industrial exhaust. In Europe, it is a proven technology that is economical for high volume of gasses which have a low concentration of pollutants. The BIOTON system utilizes the natural process of VOC degradation by microorganisms, on compost.

The BIOTON biofilter works by providing an environment in which the microorganisms can thrive. The construction of this environment begins with organic-bearing material, such as compost, surrounded by a thin film of water. The compost serves as the nutrient source for the microorganisms until the polluted gas stream becomes the food source. One cubic meter of filter material can provide approximately 10 million particles, and each particle can house up to 100,000 microorganisms.

The industrial exhaust first passes over the filter, where the pollutants diffuse into the water phase that contains the microorganisms. The microorganisms subsequently biodegrade the pollutants by oxidation, producing by-products of water and carbon dioxide, the latter of which is emitted to the atmosphere. An alkane, for example, is oxidized to a primary alcohol, then to an aldehyde, and later to an organic acid. Once the hydrocarbon has been converted to an acid, it can be metabolized further to carbon dioxide. Control efficiency is estimated to be as high as 90 percent. During short periods, the concentrations of pollutants in the biofilter can be very high. In these cases, the biofilter will have a control efficiency of 80 percent. This control is achieved by mixing activated carbon through the filter material.

2.0 CURRENT STATUS

The BIOTON biofilter is widely used in more than 20 industrial facilities throughout Europe. Industrial facilities using the BIOTON system include Cyanamid, Coca-Cola, Ciba Geigy, Fuji Photo, AKZO Chemical, Cargill, and Novo Nordisk.

3.0 CASE STUDY

A large BIOTON filter (approximately 120 m^3) was purchased by AKZO Chemical's Sikkens facility in 1988 for control of their paint production process. The exhaust gas volume was typically 5,500 m^3/hr, but reached up to 12,000 m^3/hr. The gas stream components included xylene, toluene, methyl ethyl ketone, and many other solvents. The main source of these pollutants was cleaning solvents. The biofilter removed approximately 90 percent of the solvents.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Surface Coating
- Chemical Manufacture
- Synthetic Organic Chemical Manufacturing

Limitations:

- Low to medium inlet concentrations of air contaminants
- Temperature range of 18-41°C
- High concentrations of acid-forming pollutants limit filter material lifespan

5.0 CONTROLLED POLLUTANTS

- VOCs
- Toxics

6.0 TEST DATA

A series of tests were conducted at a Styrene-Butadiene-Rubber plant in Austria in 1989 by ClairTech. The biofilter was tested with an exhaust gas that had styrene concentrations ranging from 10 to 100 ppmv. Although the gas stream contained primarily styrene, smaller quantities of other solvents were also present. The pilot plant treated 128 m^3/hr of exhaust gas with a filter volume of 1.6 m^3. The residence time of the gas in the filter was approximately 45 seconds; the gas stream temperature was approximately 25°C. The average inlet pollutant concentration was 35 ppmv, with inlet concentrations ranging from 19 ppmv to

74 ppmv. Control efficiencies ranged from 91 percent (at 52 ppmv) to 100 percent. The average control efficiency was 98 percent.

7.0 OPERATIONAL/PROCESS PARAMETERS

This technology requires the following for operation:

- A fan to move the gas stream over the filter
- A recirculating pump in the humidifying column
- Water to bring the gas stream to 98 percent humidity.
- A temperature range of 18-41°C
- Filter water-phase pH of 7.

8.0 COSTS

- Capital cost: $15-100 per cfm of treated air

9.0 SECONDARY IMPACTS

- The aged filter material must be disposed of in a municipal dump or used in agricultural operations.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

No comparisons provided.

11.0 VARIATIONS

The biofilter is very sensitive to the concentration and nature of the pollutants. For example, benzene can be successfully biodegraded in a mixed gas stream, while pure benzene is poisonous to the microorganisms in concentrations above 10 ppmv.

TECHNOLOGY NUMBER: B-6

ECOCLEAN CLEANING MACHINES 80S, 81S, AND 83S FOR DEGREASING

Vendor: Durr Industries (Automation, Inc.)
F.R.G.

1.0 PROCESS DESCRIPTION

The Ecoclean cleaning machines are self-contained low-emission vapor degreasers (LEVD) that are an alternative to conventional vapor degreasers used throughout industry. The LEVDs are completely enclosed and airtight machines that significantly reduce air emissions and solvent loss. The Ecoclean LEVDs can reduce air emissions by over 99 percent. The machines are designed to use chlorinated solvents such as perchloroethylene, trichloroethylene, 1,1,1-trichloroethane, and methylene chloride. Wastewater discharges are small, and waste solids are equivalent to those currently generated by current vapor degreasing technology.

In conventional vapor degreasing, solvent vapors condense on parts, and this condensate drains off the part, carrying the contaminants to a sump. The solvent is re-used until the contaminants accumulate to the point where the solvent is no longer usable and must be discarded. It is estimated that up to 90 percent of the solvent is lost through air emissions.

The parts are placed in a basket that is lowered into the machine chamber that is then hermetically sealed shut. The machine proceeds through timed cleaning cycles that can be adjusted by the operator. In the first cycle, the degreasing cycle, solvent vapors are generated in a jacket that surrounds the working chamber. The solvent vapors then pass up through the working chamber, condensing and removing soils and other contaminants from the parts. The condensate passes to a water separator and on to the sump.

The next cycle is the condensation cycle, where the remaining solvent vapors are condensed by a refrigerated cooling coil at the bottom of the working chamber. The machine then enters an air recirculation stage, where the air-solvent mixture in the chamber is recirculated through a chiller to further condense out more solvent. The next stage is a carbon heat-up cycle, where the chamber air is heated by a fan and passed through a series of activated carbon filter mats. This cycle allows for solvent captured by the carbon mats in the last cleaning cycle to desorb and be collected in the sump.

To collect the solvent from each cleaning cycle, the chamber air is recirculated in the reverse direction, passing first through the chiller and then through the carbon mats in the adsorption stage. The cool solvent vapor is adsorbed by the carbon mats, allowing for almost no solvent vapor to exhaust out of the chamber when the workload of parts is removed.

2. 0 CURRENT STATUS

These machines have been commercially available in Europe, and now are commercially available in the United States through a U.S. affiliate.

3.0 CASE STUDY

The Ecoclean 83-S was tested in a case study performed by Battelle Institute, commissioned by the U.S. EPA under the Waste Reduction and Innovative Technology Evaluation (WRITE) Program. The LEVD was shown to reduce air emissions by over 99 percent. It was concluded that the LEVD was a cost-effective air pollution solution with pollution prevention capabilities.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Solvent Evaporation (degreasing and dry cleaning)

Limitations:

- Depending on the model, the weight of parts that can be cleaned is limited.
- Depending on the metal being cleaned, the weight of parts and the time required to clean them will vary. Aluminum, for instance, will reach the vapor temperature much more quickly than steel. This difference means that fewer aluminum parts can be cleaned per unit time than steel parts.

5.0 CONTROLLED POLLUTANTS

- VOCs
- Toxics

6.0 TEST DATA

Under the Battelle Laboratory program, product quality tests were run on the Ecoclean 83-S using perchloroethylene (PCE) solvent. The test was conducted on machined steel parts contaminated with various amounts of cutting oil. The machine was run through complete cycles nine times. Total cycle time varied considerably with workload mass, while degree of contamination appeared to have little effect. The parts were examined after each run to determine the level of cleaning. No contamination was found on the parts from any of these runs. Furthermore, there was less water combination of solvent that might lead to solvent depletion and acid formation by hydrolysis.

To measure emissions from the LEVD, a flame ionization detector (FID) was used. The first FID was inserted into the working chamber of the LEVD to measure the concentration of any residual perchloroethylene following a cycle run. The second FID was used to continuously monitor the emissions around the LEVD, to ensure leak-proof operation. The FID's were calibrated with PCE standards and monitored through a single data capture system. Throughout the test, the exterior FID read at ambient conditions. The interior FID read well below the target concentration of 150 ppm, within a range of 40-50 ppm. When the lid was opened, the exterior FID leaped to 6 ppm, but both FIDs leveled out at 3-4 ppm in a short period of time. In fact, elevated exterior levels did not occur often, and were often remedied with a simple adjustment of the LEVD seal pressure. The typical discharge of solvent, which occurred at the opening of the LEVD lid, was 0.00132 lb/cycle.

7.0 OPERATIONAL/PROCESS PARAMETERS

The following specifications are required for the Ecoclean 83-S:

- 93,725 kW-hrs per year electrical power.
- Operator time of 5 min/cycle.

8.0 COSTS

The Battelle economic evaluation lists the following costs for the Ecoclean 83-S:

Table 6-1

Parameter	Value
Capital cost	$210,000
Payback period	10 years
Operation and maintenance costs	$12,673 per year
Electricity	$0.04/kW-hr
Operator and maintenance labor	$8/hr
Currency basis	U.S. Dollar ($) - 1993
Cost of workload degreased	$30/ton

9.0 SECONDARY IMPACTS

- Sludge (landfill disposal) equivalent to conventional degreasers.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

According to the Battelle study, the LEVD reduced air emissions by over 99 percent compared with the estimated air emissions from a conventional open-top vapor degreaser of similar size. Furthermore, the Battelle economic evaluation showed that operating cost for the LEVD was $12,673 per year, versus $35,640 per year for the conventional degreaser. According to the evaluation, with a purchase price of $210,000 and payback period of 10 years, a composite savings of $22,967 results.

11.0 VARIATIONS

The type of part material dictates how much the LEVD can clean in a set period of time. Also, the amount of cleaning that can be accomplished per unit time is dependent upon how quickly the parts reach the solvent vapor temperature. According to the Battelle study, fewer aluminum parts can be cleaned per unit time, because of aluminum's lower thermal diffusivity than steel.

TECHNOLOGY NUMBER: B-7

F-1 CLEAN ULTRASONIC CLEANING MACHINE FOR DEGREASING

Vendor: Tiyuda Manufacturing
Aichi, Japan

1.0 PROCESS DESCRIPTION

This technology employs ultrasonic cleaning in conjunction with a vacuum-sealed hot and cold solvent wash for precision cleaning of parts such a printed circuit boards. The F-1 Clean is designed to use chlorinated solvents such as methylene chloride and trichloroethylene. Over 90 percent of the solvent is recovered through filtration, vapor condensation, and distillation. With the use of a regenerating carbon adsorber system, an overall solvent recovery of 99.99 percent is achieved.

The F-1 Clean process begins when the parts are placed into a cleaning chamber equipped with a lid. A vacuum seals the chamber automatically. In the first cleaning stage, warm solvent is introduced into the cleaning chamber. The parts then become completely submerged in the warm solvent. An ultrasonic vibration is then passed through the chamber to aid cleaning. The warm solvent is drained through a warm solvent filter and returned to a warm solvent tank. The next stage employs cold solvent in the same manner, also with ultrasonic vibration to aid cleaning. The cold solvent is drained and returned to a cold solvent tank through a cold solvent filter. The parts are rinsed in pure solvent vapor (generated from the warm solvent tank) and vacuum dried at 680 mmHg. The solvent vapors recovered in the initial venting of the cleaning chamber are recycled through a refrigerated condenser. The three subsequent ventings of the cleaning chamber are passed through a dual-bed, self-regenerating, activated carbon adsorber. Regeneration of the activated carbon occurs under vacuum, by indirect steam heating; the desorbed solvent is routed to a still. The desorbed solvent is distilled continuously from the still through two water separators and then is returned to either the cold or warm solvent tank. The warm solvent tank overflow is also directed to the still.

2.0 CURRENT STATUS

The F-1 Clean is in widespread commercial use in Japan by companies such as Hitachi, Hewlett Packard, and Fuji Electric.

3.0 CASE STUDY

No case study data supplied.

4.0 APPLICATIONS/LIMITATIONS

Industries:

- Degreasing and Dry Cleaning Operations
- Solvent Evaporation

Limitations:

- Compatible only with solvents whose boiling points at atmospheric pressure are under 88°C.
- Workload limited by size of working chamber.

5.0 CONTROLLED POLLUTANTS

This technology controls emissions of:

- VOCs (chlorinated)
- Toxics

6.0 TEST DATA

California's South Coast Air Quality Management District tested the F-1 Clean, Model No. YEV-452-71 using trichloroethylene degreasing solvent. The source test showed the efficiency of the F-1 Clean's system with a carbon adsorber was 99.99 percent.

7.0 OPERATIONAL/PROCESS PARAMETERS

Electricity and solvents are needed, based on the size of the unit.

8.0 COSTS

Capital costs were estimated at $200,000-250,000, depending on the size of the equipment.

9.0 SECONDARY IMPACTS

- Sludge from the solvent filters and tanks must be disposed of in a controlled landfill.

10.0 COMPARISON WITH U.S. TECHNOLOGIES

None provided.

11.0 VARIATIONS

None provided.

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