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Assessment of International Air Pollution Prevention and Control Technology

Volume 1. Executive Summary

U.S. Environmental Protection Agency
Office of Research and Development
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TECHNICAL REPORT DATA

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15. SUPPLEMENTARY NOTES APPCD project officer is Michael A. Maxwell, Mail Drop 60, 919/541-3019. (Richard D. Stern, the initial project officer, is no longer with the Agency.) Volume 1 is an executive summary; Volume 2 is the full report.

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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NOTICE

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

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.

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BACKGROUND

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.

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 summary describes the approach taken to identify potentially useful technologies, and the results of the technology search and review. The full report is in Volume 2.

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.

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 important U.S. industries in each emission category was developed. However, since motor vehicles are major urban emission sources and also acid deposition sources, the motor vehicle source category was incorporated within the Urban Air Quality and Acid Deposition categories for the purposes of this study.

Initial lists of key pollution sources in each of the three areas described above were developed and revised by the U.S. EPA's Office of Air Quality Planning and Standards (OAQPS) and Office of Research and Development (ORD). Exhibit 1 presents the final list of thirty (30) specific source categories (most important for each of the three major source category groups) identified. The source categories identified as major sources in their respective categories are listed in alphabetical order. They are not ranked in order of importance.

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.

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.

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.)

Countries addressed in the study include Japan, Germany, the United Kingdom (UK), Canada, Australia, New Zealand, South Africa, Brazil, Argentina, and other Western European countries.

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.
- Representatives and/or publications from six (6) international organizations, that included 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).
- Fifty-four (54) consultants and/or indigenous (in-country) contacts/researchers who were knowledgeable about recent developments in foreign technologies.
- Eight (8) international technology vendors who initiated discussions in addition to sending literature.
- On-line searches of four (4) key scientific databases: 1) Energy Science and Technology (ES&T), 2) National Technical Information Service (NTIS), 3) Air and Waste Management Association (A&WMA), and 4) 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 based on the criteria already presented.

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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).

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).

Specific information needs were requested from the vendors of the 52 technologies to further review their potential for use in the U.S. This information included detailed design, costs, and performance data based on full-scale demonstration units. 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.

EPA experts in the respective technologies 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 not provide an independent evaluation of vendor information by EPA. EPA review of information provided by vendors 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.

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.

Exhibit 2 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 section (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.

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	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 anthropogenic 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.

(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-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.
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.

(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-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.
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, Malayasia (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.

(continued)

EXHIBIT 3. Applicability of Identified Technologies

Emission Source	Applicable Air Pollution Prevention and Control Technologies	
	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.