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Pollution Prevention Research Strategy

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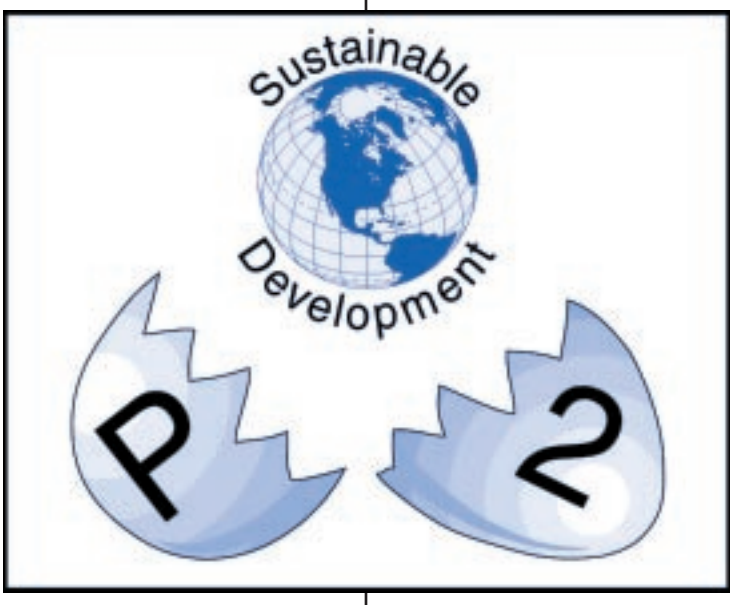

On the cover: Two dimensional graphic of sustainable development emerging from the pollution prevention (P2) egg. The graphic demonstrates the critical role that P2 plays in advancing the concept of sustainable development. It builds upon the important message delivered in *Choosing a Sustainable Future: The Report of the National Commission on the Environment* (NCE, 1993) that "[t]echnology for sustainable development must focus on pollution prevention." The NCE message goes on to emphasize a total systems approach that stresses prevention and minimization using materials and processes which are non-polluting, and ultimately results in products that are recyclable. The graphic was conceived of by Ivars Licis and refined by Teresa Harten and Jonathan Herrmann, all of the National Risk Management Research Laboratory (NRMRL). It was drafted for the cover of the *Pollution Prevention Research Strategy* by John McCready, also of NRMRL.

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Pollution Prevention Research Strategy

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Notice

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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 Office of Research and Development 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 1996 Strategic Plan for the Office of Research and Development (ORD) sets forth ORD's vision, mission, and long-term research goals. As part of this strategic process, ORD used the risk paradigm to identify EPA's top research priorities for the next several years. The ORD Strategic Plan thus serves as the foundation for the research strategies and research plans that ORD has developed, or is in the process of developing, to identify and describe individual high-priority research topics. One of these high priority research topics is pollution prevention and new technologies for environmental protection.

This publication describes ORD's strategy for conducting a research and development program in pollution prevention. The research strategy describes the goals and strategic objectives that will be addressed over the coming five years. The strategy is an important accountability tool because it makes clear the rationale for, and the intended products of, EPA's pollution prevention research. This research strategy is also an important budget tool, enabling EPA to clearly track progress toward achieving its pollution prevention research goals, as required by the 1993 Government Performance and Results Act.

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Peer Review

Peer review is an important component of research strategy development. The peer review history for this research strategy is as follows:

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ORD Science Council:	Final clearance, February, 1997
Lead Reviewers:	Judy Graham, NERL Hal Zenick, NHEERL
Submitted for Comments to the Committee on Environment and Natural Resources – Agency Principals and Subcommittee Chairs	June, 1997
External Peer Review:	June 30 – July 3, 1997: Cincinnati, OH

Reviewers:

Calvin Chien, Chair	DUPONT Company
Edgar Berkey	Concurrent Technologies Corporation
Lois Epstein	Environmental Defense Fund
Terry Foecke	Waste Reduction Institute
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Final Acceptance by ORD:	September, 1998
ORD Executive Lead:	E. Timothy Oppelt, NRMRL

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Acknowledgments

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Acronyms

ACS	American Chemical Society
AMD	Acid Mine Drainage
APPD	Atmospheric Pollution Prevention Division
BIA	Bureau of Indian Affairs
BMPs	Best Management Practices
CEA	Council of Economic Advisors
CENR	Committee on Environment and Natural Resources
CFCs	chlorofluorocarbons
CMAQ	Congestion Mitigation and Air Quality Improvement Program
CPSC	Consumer Product Safety Commission
CRDA	Cooperative Research and Development Agreement
CSI	Common Sense Initiative
DfE	Design for the Environment
DOA	Department of Agriculture
DOC-NIST	Department of Commerce - National Institute of Science and Technology
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOT	Department of Transportation
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ETV	Environmental Technology Verification
FDA	Food and Drug Administration
GHGs	greenhouse gases
GPRA	Government Performance and Results Act
GWP	Global Warming Potential
HAPs	hazardous air pollutants
HFCs	hydrofluorocarbons
HFEs	hydrofluoroethers
HUD	Department of Housing and Urban Development
HVAC	heating, ventilation, and air conditioning
IC	integrated controls
ISTEA	Intermodal Surface Transportation Efficiency Act
LCA	life cycle assessment
MACT	Maximum Achievable Control Technology

MEPs	Manufacturing Extension Partnerships
NAS	National Academy of Sciences
NCE	National Commission on the Environment
NEXTEA	National Economic Crossroads Transportation Efficiency Act
NIST	National Institute of Standards and Technology
NRC	National Research Council
NREL	National Renewable Energy Laboratory
NRMRL	National Risk Management Research Laboratory
NSTC	National Science and Technology Council
OAR	Office of Air and Radiation
OECA	Office of Enforcement and Compliance Assurance
OPPTS	Office of Prevention, Pesticides, and Toxic Substances
ORD	Office of Research and Development
OSM	Office of Surface Mining
OSTP	Office of Science and Technology Policy
OSWER	Office of Solid Waste and Emergency Response
OW	Office of Water
P2	pollution prevention
PBTs	persistent, bioaccumulative, and toxic chemicals
PCSD	President's Council on Sustainable Development
PERC	perchloroethylene
PESP	Pesticide Environmental Stewardship Program
PPNT	Pollution Prevention and New Technology
PPOAs	Pollution Prevention Opportunity Assessments
SAB	Science Advisory Board
SAN	Sustainable Agriculture Network
SARE	Sustainable Agriculture Research and Education
SBIR	Small Business Innovative Research
SRRP	Source Reduction Review Project
TEWI	Total Equivalent Warming Impact
TRI	Toxics Release Inventory
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USPS	United States Postal Service
UV	ultraviolet light
UV/TiO_2	ultraviolet light/titanium dioxide
VOCs	volatile organic compounds
WCED	World Commission on Environment and Development
WRITE	Waste Reduction Innovative Technology Evaluation
XL	Environmental Excellence and Leadership

Executive Summary

The U.S. Environmental Protection Agency's (EPA's) Office of Research and Development (ORD) prepared a strategic plan which includes two priority long-term goals addressing prevention: to provide common sense and cost-effective approaches for preventing and managing risks, and to provide leadership and encourage others to participate in identifying emerging environmental issues, characterizing the risks associated with these issues, and developing ways of preventing or reducing these risks.

Based on these goals, ORD developed a Pollution Prevention Research Strategy that elaborates on the directions in the strategic plan and provides a framework to guide investments in pollution prevention research and development over the next five years. The strategy contains four chapters: Chapter 1 sets the context; Chapter 2 outlines a strategic pollution prevention rationale; Chapter 3 describes four long-term goals and accompanying strategic objectives to be addressed and includes activities to be pursued as part of the research strategy; and Chapter 4 describes the implementation approach for the goals and objectives presented in Chapter 3. This executive summary is a capsule of the full document.

Context

Historically and currently, ORD has used EPA's definition of pollution prevention as "source reduction." In a broader sense, the National Commission on the Environment (NCE) offers a description of environmental sustainability that includes pollution prevention. The EPA definition and the NCE description were both central to the development of this research strategy. They provided the context from which ORD developed its strategic rationale for the research and development program that is outlined below.

ORD's pollution prevention activities in the early years focused on developing and evaluating technologies primarily through extramural funding of contracts, Cooperative Agreements, and Interagency Agreements. Once pollution prevention was established as an ORD program in 1988, this extramural focus began slowly shifting toward an in-house program devoted to research on tools, methodologies, and technologies. This shift has accelerated in the 1990s with ORD's strategic move to an expanded in-house research program to transform the labs into research institutions. The push to in-house research has enabled ORD to focus on a smaller set of high priority activities where ORD scientists and engineers can make a significant contribution based on their unique knowledge, expertise, and capabilities. This has been complemented with a competitive extramural grant program to address cutting edge process and synthesis research as well as research on socio-economic issues.

As pollution prevention implementation has advanced in the past ten years, many of the problems most easily addressed by using a preventative approach have been solved. The practice of pollution prevention is now at a crossroads. Although progress in pollution prevention over the next ten years may not proceed as rapidly as in the past ten, the results can be even more significant, both in terms of research and development, and implementation.

Since these next advances will represent more fundamental changes in individual lifestyle, industrial process design, consumer products, and land use, future research and development must focus on quantum leaps instead of incremental improvements. These advances will not be achieved without a commitment by the public and private sectors to support long-term research that can, if carefully planned, produce the needed technologies and tools that take pollution prevention to the next level.

Strategic Rationale

ORD's pollution prevention research strategy has been guided by a number of influential "voices" — among them, the National Academy of Sciences, the Committee on Environment and Natural Resources, the National Research Council, the President's Council on Sustainable Development, and the American Chemical Society. ORD also used the Science Advisory Board's past contributions to the pollution prevention dialogue with the Agency to further focus its research strategy.

After considering guidance from the above organizations and narrowing the scope of the potential program to a subset of environmental problems and types of research and development where the Agency can play a meaningful role, ORD investigated which issues were considered a high priority by EPA's Program Offices and Regions. The following themes emerged:

- Life cycle assessment and costing research to provide the scientific basis for comparing alternative risk management approaches
- Techniques to measure pollution prevention effectiveness and verify the performance of pollution prevention technologies
- Pollution prevention approaches for the agricultural sector
- Pollution prevention approaches to reduce greenhouse gases, including alternative energy (renewable) sources
- Pollution prevention approaches for targeted industries (In most cases, these were aligned with specific regulatory programs or Agency initiatives.)

Many of these themes are reflected in the final research strategy. In addition to the outcome of consultations with EPA Programs, ORD determined that five priority setting criteria will drive choices in research emphasis. Research priorities need to: 1) address high risk human health or environmental problems; 2) respond to the needs of stakeholders; 3) fill important research and development gaps not being addressed by others; 4) leverage resources with other organizations; and 5) provide potentially effective research. The cumulative process led to the choice of the four goals and the associated strategic directions and priorities.

Goals and Program Emphases

Goal I: Deliver tools and methodologies that can be applied across all economic sectors: agriculture, manufacturing, transportation, energy, consumer products, mining, construction, and municipal.

ORD will develop, test, and provide tools and methodologies which improve individual and organizational decision making, to reduce or eliminate emissions, effluents, and wastes from products, processes, and activities.

Objective: *Develop and test user-friendly tools and methodologies for improved decision making.*

Research and Development Activities

New Activity — Integrate risk assessment and risk management tools and methodologies:

- Linking risk assessment and pollution prevention tools

Increased Emphasis — Improve and develop generic tools and methodologies:

- Improving environmental engineering economics and cost tools
- Improving the utility of life cycle assessments (LCAs), including development of P2 measurement methods
- Developing process simulation tools
- Developing impact assessment tools

Continued Emphasis — Improve and develop targeted tools and methodologies:

- Providing decision support tools for municipal solid waste
- Developing improved selection tools for surface treatment

Goal II: Develop and transfer technologies and approaches that can be applied across economic sectors, but are primarily focused on the manufacturing and consumer products sectors.

ORD will develop, test and transfer pollution prevention technologies and approaches that are applicable across economic sectors, and evaluate products, technologies and approaches that are targeted at preventing high-priority human health and environmental problems in support of the Agency's regulatory and compliance programs.

Objective A: *Research, design, and assess novel and advanced environmentally benign approaches for industrial processing and manufacturing.*

Research and Development Activities

Continued emphasis — Investigate chemistry for pollution prevention:

- Supporting fundamental engineering research in addressing green chemistry
- Developing and testing improved synthesis pathways

Continued emphasis — Investigate engineering for pollution prevention:

- Supporting pre-competitive engineering research
- Developing separations for metals recycling/recovery
- Developing membranes for organic recycling/recovery

Continued emphasis — Develop process feedback techniques for pollution prevention:

- Developing intelligent controls for process operations

Objective B: *Develop and test technologies and approaches targeted at specific environmental problems.*

Research and Development Activities

Continued Emphasis — Address problems associated with global warming to reduce Total Equivalent Warming Impact (TEWI):

- Investigating TEWI alternatives

Continued Emphasis — Address problems associated with VOCs and hazardous air pollutants (HAPs) by improving coating and cleaning operations:

- Developing new and innovative coating and cleaning chemistries and equipment
- Adapting environmentally friendly coating and cleaning chemistries and equipment

Increased Emphasis — Address problems associated with products used indoors:

- Developing test methodologies and models
- Supporting research on low-emitting materials and technologies

Objective C: *Demonstrate and evaluate pollution prevention in support of Agency and Program Office priorities.*

Research and Development Activities

Continued Emphasis — Address problems associated with medium- and small-sized industries that pose high risks:

- Working in the metal finishing sector
- Working in the printing sector
- Working in the computer and electronics sector
- Working in the auto refinishing sector
- Working in the dry-cleaning sector

Continued Emphasis — Support Agency rule makings and initiatives that encourage pollution prevention:

- Partnering with Program Offices

Goal III: Verify the performance of selected cleaner products, technologies, and approaches, focusing initially on the manufacturing, consumer products and municipal sectors.

As part of its Environmental Technology Verification (ETV) Program, ORD will serve as a catalyzing organization to propel into the marketplace the most promising commercial-ready pollution prevention products and technologies from both the public and private sectors.

Objective: *Build a high-quality and efficient program to verify the performance characteristics of pollution prevention products and technologies.*

Research and Development Activities

Continued Emphasis — Verify commercial-ready products and technologies which substantially reduce or eliminate air, water, and waste streams:

- Hazardous Waste Pollution Prevention and Treatment ETV Pilot
- Industrial Coatings ETV Pilot
- Metal Finishing ETV Pilot
- Indoor Air ETV Pilot
- Climate Change ETV Pilot
- Air Pollution Prevention and Control ETV Pilot
- Source Water Protection ETV Pilot

Goal IV: Conduct research which addresses the economic, social, and behavioral aspects of pollution prevention.

Through its extramural grants program, ORD will continue to sponsor economic, social, and behavioral research to improve decision making and foster the adoption of pollution prevention by the public and private sectors at all levels.

Objective: *Develop and integrate social science and socioeconomic information and research products into environmental decision making.*

Research and Development Activities

Increased Emphasis — Develop economic, social, and behavioral tools to improve environmental policies and programs:

- Understanding organizational decisions related to human health and environmental protection
- Understanding the economic benefits of pollution prevention policies and programs
- Understanding the economic costs of pollution prevention policies and programs
- Developing relationships between economic growth and environmental quality

Implementation

This research strategy provides the framework for implementing a program for systematic research and development activities to carry pollution prevention into the 21st Century and toward the realization of sustainable development. The success of the program will be dependent on a number of variables, not the least of which is engagement and partnership with key stakeholders. It is essential that ORD work more closely with those who are directly involved in the implementation of pollution prevention approaches or influential in advancing the concept and routine consideration and use of preventive risk management. This includes EPA's Program Offices and the following stakeholders:

- The industrial community. ORD will provide tools and technologies for employing pollution prevention in various economic sectors as an option for cost-effectively improving compliance and going "beyond compliance" where it makes sense economically and environmentally.

- States, communities, and tribes. ORD will better understand those situations at the community level where pollution prevention might best be employed; thereby raising the profile of pollution prevention as a routine part of the Agency's approach to community-based environmental decision making.

- Federal organizations. ORD will identify what research and development is needed to enhance the use of pollution prevention at federal facilities. ORD will also stress testing pollution prevention tools, methodologies, technologies, and approaches at government sites where they can be evaluated in real-world settings.

- The international community. ORD will exchange information with the international community on pollution prevention research and development and its implementation, and will also provide perspectives on what other countries are doing to advance pollution prevention in the broader context of sustainable development.

ORD will use electronic technology (e.g., Internet home pages, distance learning) to the maximum extent possible as a means of engagement with stakeholders. The research products developed by ORD will be designed to be available electronically, and ORD intends to be a major provider of pollution prevention research and development products via the Internet.

Chapter 1. Introduction

The U.S. Environmental Protection Agency's (EPA's) Office of Research and Development (ORD) has prepared a strategic plan which includes prevention as an important theme (1996a; 1997a). Two of the strategic plan's long-term goals specifically mention prevention as a priority:

- To provide common sense and cost-effective approaches for preventing and managing risks.

- To provide leadership and encourage others to participate in identifying emerging environmental issues, characterizing the risks associated with these issues, and developing ways of preventing or reducing these risks.

Based on the prominence of prevention in these two goals, it will be an integral part of ORD's future research program. The purpose of this document is to elaborate on the pollution prevention strategic directions outlined in the ORD strategic plan and to provide a framework within which to guide investments in pollution prevention research and development over the next five years.

What is Pollution Prevention?

The first step taken in developing this research strategy was to determine the types of activities which should be included in it. Generally, pollution prevention requires changes in raw materials and processes which result in reduced pollution (EPA, 1991). In this strategic plan, ORD has made judgements on the scope of activities to include based on its interpretation of EPA's working definition of pollution prevention (Habicht, 1992) (See Appendix I for the full definition):

> Pollution prevention means "source reduction" as defined under the Pollution Prevention Act, and other practices that reduce or eliminate the creation of pollutants through: (1) increased efficiency in the use of raw materials, energy, water or other resources, or (2) protection of natural resources by conservation.
>
> The Pollution Prevention Act defines "source reduction" as any practice which: (1) reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and (2) reduces the hazards to public health and the environment with the release of such substances, pollutants, or contaminants.

Pollution prevention is national policy, embodied as "source reduction," in the Pollution Prevention Act of 1990 (West Publishing Co., 1992), and EPA's Administrator has declared pollution prevention to be the "guiding principle" of all EPA programs (EPA, 1993).

In a broader context, the National Commission on the Environment (NCE) (1993) described the role of pollution prevention in sustainable development (i.e., meeting the needs of the present without compromising the ability of future generations to meet their own needs [WCED, 1987]):

> Technology for sustainable development must focus on pollution prevention. This requires a total systems approach that prevents pollutants from being created in the first place or minimizes undesirable wastes and obviates the need for many controls. A preventive approach involves using fewer or non-polluting materials, designing processes that minimize pollutants or that direct them to other useful purposes, and creating recyclable products. The preventive/systems approach requires examining the full life-cycle of products and practices.

The NCE description integrates pollution prevention with environmental sustainability and offers the greatest opportunity for pollution prevention research and development in the future. A systems approach, where pollution prevention plays a critical role, is especially helpful in solving many of the remaining human health and environmental problems resulting from dispersed sources and individual activities. Both the EPA definition and the NCE description are central to the development of this research strategy.

The Evolution of ORD's Pollution Prevention Program

ORD has conducted a variety of research and development projects and programs over the last ten years that are consistent with the EPA definition of pollution prevention and the broader concept of sustainable development described above. The following are examples of research that have been conducted or are currently sponsored that further the goals embodied in the EPA definition and the NCE description:

> **CFC Alternatives:** Following the Montreal Protocol, under which the US agreed to reduce chlorofluorocarbon (CFC) use, ORD undertook a research program to identify and evaluate substitute chemicals. New chemicals were

synthesized (e.g., hydrofluorocarbons [HFCs], hydrofluoroethers [HFEs]) and measurements were taken to establish thermodynamic and thermophysical properties and to determine flammability, toxicity, and material compatibility. Performance in refrigeration and air conditioning applications and as foam blowing and fire extinguishing agents were also evaluated. Similar activities were performed by industry for other chemicals. This collaborative effort resulted in a number of EPA and industry HFCs being successfully used in new equipment.

Waste Reduction Innovative Technology Evaluation (WRITE) Program: Over seven years in the late 80s and early 90s, ORD, in collaboration with six states and a county in New York, evaluated a number of waste minimization technologies to measure their pollution prevention effectiveness and costs. The targets were technologies for use by medium- and small-sized companies (electronics, printing, metal plating and finishing) and the evaluations addressed a number of processes (e.g., coating, painting, surface cleaning). Many of the technologies reduced or eliminated waste streams and resulted in cost savings. It was also found that technology benefits (waste minimization and cost) were largely application-specific and that broad generalizations about technology application could not be made.

LCA Advancement: Life cycle assessment (LCA) principles provide an important conceptual framework within which to evaluate pollution prevention alternatives. ORD has been working to improve LCA tools and methodologies over the past five years and has undertaken a number of specific assessments to advance the understanding and application of life cycle thinking. As just one example, ORD worked with the lithographic printing industry to evaluate solvent substitutes to reduce volatile emissions. The findings of that effort revealed that a switch to low-VOC solvents can increase energy use and increase loading to air and water. The switch, in effect, resulted in shifting environmental burdens from the printers to elsewhere within the production system. ORD has developed LCA-oriented tools (e.g., P2 Factors Methodology, P2 Progress Methodology) as a means of advancing the cause of pollution prevention more broadly within an LCA framework.

Pollution Prevention Opportunity Assessments (PPOAs): ORD pioneered the development and application of PPOAs. PPOAs are a comprehensive examination of the operations at a facility with the goal of minimizing all types of waste products. Options are identified for the use of materials, processes, or practices that reduce or eliminate the creation of pollution or wastes at the source. Once a prevention option is identified, it is evaluated for technical, economic, and environmental feasibility. This analysis is not directly related to compliance standards, but by eliminating or reducing the sources of pollutants, the standards are automatically met or at least the compliance burden is reduced. Numerous PPOAs have been developed over the past ten years (e.g., Fort Riley, Kansas; photo finishing facility; truck assembly plant) and these assessments have been widely adopted by the federal sector (e.g., DOE, DOD, USPS) for use at government facilities.

Source Reduction Review Project (SRRP) Support: Over the past five years, ORD has supported the Agency's efforts at multimedia rule making under SRRP. SRRP is an effort to review Agency regulations during their earliest stages of development so that source reduction measures and multimedia issues are considered. SRRP encourages source reduction over add-on control technologies as the preferred approach to achieving environmental compliance. ORD has worked with the Office of Water (OW) to evaluate alternatives to chlorine bleaching in the pulp and paper industry and with the Office of Air and Radiation (OAR) to evaluate alternatives in reinforced plastics composite manufacturing, printing and publishing and wood furniture manufacturing.

Reducing Solvent and Propellant Emissions from Consumer Products: In some cases, an appropriate risk management strategy for reducing exposure to indoor air pollutants may be to develop a generic technology that will facilitate private sector development of low-emitting materials. A successful example of this is the development and evaluation of a new spray dispenser at Purdue University that was supported under an EPA Cooperative Agreement. The new design allows manufacturers to reformulate certain aerosol consumer products — using air and water in

place of solvents and hydrocarbon propellants while still maintaining acceptable product characteristics. Dispenser design guidelines will be available for use by small and large manufacturers worldwide.

In the early years, many of ORD's research and development activities focused on creating guidance documents and tools that other government agencies and the private sector could use to identify pollution prevention opportunities (e.g., PPOAs, LCA Advancement), and on conducting evaluations of pollution prevention technologies through agreements with outside contractors or cooperators (e.g., WRITE Program, SRRP). A small percentage of the pollution prevention research program in the 1980s was focused on in-house research (e.g., CFC Alternatives). During this time, funding for pollution prevention research and development was provided from many dispersed sources and had to compete against all other important ORD research within a specific program area. Pollution prevention was formally established as a program within ORD in 1988 and received increased attention across the Agency (EPA, 1990b, EPA, 1992b). In the early to middle 1990s, ORD's pollution prevention research and development program primarily supported numerous EPA initiatives (e.g., 33/50 Program, SRRP, Common Sense Initiative) established to promote pollution prevention as the preferred approach for human health and environmental protection.

For the past several years, the ORD pollution prevention program has undergone a transition from an extramural program that promoted pollution prevention using broad-based technical assistance and information transfer to a more targeted in-house program complemented by a closely related extramural program. The new program is devoted to scientific and technical research on pollution prevention tools, methodologies, technologies, and approaches. While this reorientation has not been seamless, it is well underway and will continue into the foreseeable future.

Concomitant with a shift to an in-house research and development program, resource allocations have been strategically targeted to support post-doctoral researchers, master's-degree assistants, technicians, and analytical services to build the in-house capabilities of ORD scientists and engineers. ORD has used this shift as an opportunity to reevaluate its pollution prevention research and development priorities and to focus on a smaller set of high-priority activities where it can make a significant contribution based on its unique expertise and capabilities. At the same time, ORD has initiated a competitive extramural grants program that looks to expertise outside of ORD's laboratories, particularly in academia, for capabilities not resident within ORD. ORD also provides funding to support development of pollution prevention technologies through the Congressionally-mandated Small Business Innovative Research (SBIR) Program.

Where is ORD's Pollution Prevention Research and Development Program Going?

Pollution prevention continues to offer great opportunity for gains in human health and environmental quality, both in terms of research and development and in its application throughout all economic sectors. ORD believes that pollution prevention progress in the next ten years must proceed more rapidly than in the past ten and that this progress must be even more powerful in moving the global economy towards sustainability. The next wave of pollution prevention can provide economic and environmental benefits in a host of situations. Since these advances will represent nothing less than fundamental changes in individual lifestyle, industrial process design (e.g., clean technologies), consumer products (e.g., benign chemicals), and land use, future research and development must focus on quantum leaps instead of incremental improvements. ORD will only be able to contribute meaningfully to this future direction if it concentrates on longer-term research which will produce a new generation of tools and technologies to move pollution prevention beyond the "low hanging fruit." These advances will not be achieved without a commitment by both the public and private sectors to support long-term research programs which can, if carefully planned, produce the technologies and tools that are needed.

Structure of this Research Strategy

This research strategy, while oriented toward the classic Agency definition of pollution prevention, recognizes that over the longer term, pollution prevention should be viewed in the context of sustainable development, and must move in the direction of addressing the highest priority human health and environmental problems. It is divided into four chapters with Chapter 1 (this chapter) setting the scene and arguing for a broad view of pollution prevention research and development. Chapter 2 presents an analysis of the pollution prevention research and development situation and provides summary results of an ORD review of what pollution prevention research activities are being carried out by various organizations, primarily those activities that are government supported. Criteria for judging which programs to undertake are also provided. Chapter 3 describes four goals and accompanying objectives that will be addressed by ORD; this chapter includes the research and development activities and project areas that will be pursued as part of this research strategy. Finally, Chapter 4 describes, in general terms, the allocation of resources and emphases over the coming five years for the four goals and associated objectives presented in Chapter 3.

Chapter 2. Strategic Rationale for the ORD Pollution Prevention Research and Development Program

One of the great strengths of pollution prevention is that it has a place in addressing most all pollution problems. With very few exceptions, notably remediation actions, environmental problems have a pollution prevention solution, even if it is as simple as stopping the activity that creates the waste. This wide-ranging quality is what makes the prevention ethic and its implementation so important, creating an imperative for ORD prevention research. Ironically though, this strength becomes problematic when a research strategy must be developed. The breadth of pollution prevention and the possibilities for the research and development needed pose a significant challenge. The question is: Which problems should ORD focus on? ORD, as is true with any research organization, can conduct only a limited number of research and development activities; financial and resource limitations require this. Chapter 2 of the research strategy explains the rationale used by ORD to select priority areas for the next five years.

Why is Pollution Prevention An Important Future Research Priority?

While significant advances have been made, many gaps in knowledge still impede the widespread adoption of preventive risk management. Pollution prevention research and development is a relatively new field of endeavor when compared to other areas such as research and development of end-of-the-pipe control technologies. Pollution prevention research and development has largely focused on the industrial sector of the economy. Numerous authors (Freeman, et. al., 1992; Freeman, 1995; INFORM, 1995; Pelley, 1997) stress the important role that pollution prevention plays in reducing toxic releases and exposure to chemicals in wastes. According to the 1995 Toxics Release Inventory (TRI) (EPA, 1996b) billions of pounds of chemicals were released, transferred, or disposed of in wastes from industrial facilities that year (Appendix II). Because TRI reporting requirements are expanding, reported releases will grow in the coming years (Federal Register, 1996). The TRI has been effective in the past in alerting companies and communities about toxic chemical releases and has also provided a strong impetus for companies to reduce releases. With the expansion of TRI reporting there is an increased opportunity for pollution prevention to play a role in reducing newly reported releases.

Protecting human health and the environment into the 21st century must stress the prevention of pollution before it occurs, and should realistically look beyond the TRI-listed chemicals for ways to contribute to reducing human health and environmental risks. Ehrenfeld and Howard (1996) make the point that a number of American industries have already recognized the need to address environmental protection in a more holistic and systematic manner by emphasizing design for the environment (DfE) and industrial ecology. Hart (1997) identifies pollution prevention as the first step (Stage One) that most companies take when moving away from pollution control. Stage Two is product stewardship (e.g., DfE, life cycle assessment). Stage Three is clean technology — where fundamental shifts in both products and processes are designed and implemented — a stage that may require several decades before being broadly accepted and practiced. In addition, EPA has promoted the use of approaches which go “beyond compliance” and end-of-pipe treatment to achieve environmental improvement. These approaches include implementation of creative voluntary initiatives such as the Common Sense Initiative and Project XL (Environmental Excellence in Leadership). The Agency has recognized that the command and control approach will most likely be inadequate to achieve necessary environmental gains and improvements in risk management. Pollution prevention approaches will be critical to achieving sustainable development.

Guidance on Pollution Prevention Research Priorities from External Organizations

An important consideration in designing this research strategy was the determination of where ORD could make the most significant contributions to the field. The first factor considered was the role of federal research and development in addressing issues of national concern. The National Academy of Sciences (NAS, et.al. 1995) provided its perspective on this issue when it stressed that resources invested by the federal government in science and technology help build the base of scientific and technical knowledge and expertise used by both government and industry. This knowledge and expertise is then used to address important national goals (e.g., national defense, space exploration, economic growth, and protection of public health and the environment). The National Science and Technology Council (1994) supported a similar perspective when it identified the important role the federal government plays in funding basic and applied research and development keyed to future generations of environmental technologies. This latter report also stressed the role that the federal government can play in facilitating private sector investment by reducing the uncertainties caused by regulatory, verification, and permitting processes.

Based on these broad national level perspectives, ORD has concluded that there is a need for federal research to facilitate the development and acceptance of new products, processes, or management practices which pose less of a hazard to human health and the environ-

ment. The ultimate goal is to ensure that adequate research and development has been conducted which will provide the information and data required to design new products and processes that are inherently less polluting. ORD is in a unique position to focus federal pollution prevention investments because: (1) it is the only federal research organization with the broad mission to ensure that the pollution prevention adopted provides maximum human health and environmental protection, and (2) it has direct links to the regulatory and compliance offices of EPA to ensure that pollution prevention research and development activities are focused on the nation's highest priority human health and environmental problems.

Pollution Prevention in Strategic Plans and National Strategies

In the past three years, a number of committees, councils, academies, and EPA have offered their opinions on strategic directions for environmental protection (EPA, 1994; CENR, 1995; PCSD, 1996; ACS, 1996; NRC, 1996). There is a mix of pollution prevention priorities in these directions. Clearly, EPA's five-year strategic plan views pollution prevention as an overarching means of accomplishing a number of environmental goals, from improving air quality to promoting worker safety. Strategies of the Committee on Environment and Natural Resources (CENR), the American Chemical Society (ACS), and the National Research Council (NRC) stress technological solutions via cleaner chemicals, clean technology, environmentally preferable products, prevention technologies and practices, industrial ecology, chemical-specific separations, and catalytic systems. The President's Council on Sustainable Development (PCSD) and the NRC strategies also support the development of improved analytical tools including cost/benefit analysis associated with risk assessment. Both of these strategies address the need for economic, social, and behavioral research that advances the concept of sustainable development.

Pollution Prevention and the Science Advisory Board

Over the years, the EPA's Science Advisory Board (SAB) has provided guidance on the relative risks of environmental problems. ORD has reviewed its most recent report on this topic (EPA, 1990a) to further focus its proposed strategy on the most important environmental problems. Figure 1 lists these high-priority problem areas. In addition to studies which rank the relative importance of environmental problems, the SAB has also provided commentaries on past Agency pollution prevention reports and strategies and on a draft version of the present strategy. These commentaries provided insights on what the SAB considered to be important pollution prevention research and development activities, and identified the highest priority environmental problems that EPA should emphasize. The first commentary (EPA, 1989) was prepared as part of the SAB's review of a draft of the *Pollution Prevention Research Plan: Report to Congress* (EPA, 1990b). The second commentary (EPA, 1992a) was prepared as part of the SAB's review of a draft of the *Pollution Prevention Research Program* (EPA, 1992b). The SAB stressed the need for social science research (non-technological) in both of its commentaries, as well as the need for a means of measuring the progress of pollution prevention. The need to address non-industrial pollution prevention was raised with respect to mining and agricultural practices, with a particular concern regarding pesticides. There was also a call for increased coordination with other organizations to advance pollution prevention and to facilitate communication and technology transfer. Finally, there were calls for product research, environmental professional training, anticipatory research on future environmental problems, and consistency in prioritizing research activities. These commentaries and the relative ranking of environmental problems influenced the priorities detailed later in this document.

A third report from the SAB commented on a May,1997 draft of this pollution prevention research strategy. The SAB's report of June 24, 1998 (EPA, 1998a) on the draft strategy recommended making the process of developing the strategy more transparent. The SAB also recommended more involvement of external organizations in the process. Generally, the SAB did not take issue with the proposed topical areas of research and the goals identified in the original draft of this strategy. In this final version of the strategy, ORD has attempted to revise the document in accordance with the SAB's recommendations.

The draft version was also circulated to the interagency Committee on Environment and Natural Resources (CENR) and the White House Office of Science and Technology Policy (OSTP) for review and comment. Reviewers were asked to comment on the significance of the environmental problems discussed, the merit of the approach, the complementarity to research programs and priorities in other agencies, and opportunities

High-Priority Human Health Risks

- Ambient Air Pollutants
- Worker Exposure to Chemicals in Industry and Agriculture
- Indoor Air Pollution
- Pollutants in Drinking Water

High-Priority Risks to Natural Ecology and Human Welfare

- Habitat Alteration and Destruction
- Species Extinction and Overall Loss of Biological Diversity
- Stratospheric Ozone Depletion
- Global Climate Change

Figure 1. High Priority Human Health and Environmental Risks Identified by the SAB (EPA, 1990a).

for collaboration with other agencies. Comments received were similar to the SAB's in that technical areas identified as priorities by ORD were generally supported. Several agencies, particularly the United States Geological Survey, were helpful in identifying collaborative projects. Comments resulting from the review process have been addressed in this final strategy document.

Guidance on Pollution Prevention Research Priorities from Internal Organizations

After carefully considering the guidance from outside organizations, the scope of the potential pollution prevention program which ORD plans to conduct was narrowed to a subset of environmental problems and types of research and development where the federal government can play the most effective and significant role (i.e. broadly applicable tools and methodologies, generic and enabling technologies and approaches). The next step was to investigate which of these problem areas or types of research were considered a high priority by other organizations within EPA. ORD conducted a survey of selected staff in the Office of Prevention, Pesticides and Toxic Substances (OPPTS), Office of Air and Radiation (OAR), Office of Enforcement and Compliance Assurance (OECA), Office of Policy, Planning and Evaluation (OPPE), Office of Water (OW), Office of Solid Waste and Emergency Response (OSWER) and the Regions. By engaging Program Offices and Regions, ORD was able to sharpen its focus. The following themes emerged from the survey:

- ORD research should emphasize *life cycle assessment and costing research* in order to provide the scientific basis for comparing alternative risk management approaches.
- Techniques to *measure pollution prevention effectiveness and verify the performance of pollution prevention technologies* are needed to assess the environmental reductions which are being achieved.
- Pollution prevention approaches are needed for the *agricultural sector* to reduce releases into several media.
- Pollution prevention approaches to reduce *greenhouse gases,* including alternative energy (renewable) sources are needed.
- Pollution prevention approaches are needed for *targeted industries in the industrial sector.* (In most cases these were aligned with specific regulatory programs or Agency initiatives.)

The Program Offices were very consistent in identifying needs in several areas. First, there was a need to develop and test tools and methods to measure the performance of various pollution prevention approaches and to verify pollution prevention technology performance. Second, there was a clear desire for ORD to work closely with the Program Offices in advancing pollution prevention either voluntarily, or as part of a rule making or compliance activity. In addition to targeting industries, there was a call to address greenhouse gas emissions and agriculture via pollution prevention research, and to conduct research in partnership with industry and other stakeholders.

Sector-Based Approach to Identifying Environmental Problems

As a next step, a sector-based approach was used to organize and evaluate recent research and development activities already occurring for pollution prevention. An economic sector can be defined as a grouping of enterprises that produce similar goods and services. Table 1 presents the EPA Science Advisory Board's (EPA, 1990a) view of which economic sectors contribute to each of the high-priority human health and environmental risks. The sectors identified by the SAB were: industrial, agricultural, consumer, energy, and transportation.

Criteria for Setting Pollution Prevention Research and Development Priorities

Given that the SAB's assessment of high priority human health and environmental risks still presents too large a universe for an effective and feasible ORD pollution prevention research program, ORD convened a group of pollution prevention practitioners from within ORD and selected EPA offices. This group represented two divisions of ORD's National Risk Management Research Laboratory.

One of the key outputs of this group was a list of criteria by which ORD should judge potential areas of pollution prevention research. After many iterations, and input from others, including ORD management, the Office of Enforcement and Compliance Assurance (OECA), the Office of Pollution Prevention and Toxics (OPPTS) and input provided by the SAB during review of the May, 1997 draft strategy, the following list of five criteria was developed to select topical areas for the pollution prevention research program. Each area chosen would have to meet the three essential criteria in order to become a priority. Meeting the remaining two criteria is seen as added incentive.

Criteria for Choosing Topical Areas

Essential Criteria

1. *Addresses High-Risk Human Health or Environmental Problems* - To develop research programs and conduct projects targeted at high-risk human health and environmental problems. This does not exclude a problem based solely on the lack of available data indicating high risk.

Table 1. The Economic Sectors that Contribute to the SAB's High-Priority Human Health and Environmental Risks.

The SAB's High Priority Human Health and Environmental Risks (EPA, 1990a)	Contributing Economic Sectors					
	Industrial Sector	**Agricultural** Sector	**Consumer** Sector	**Energy Sector**	**Transportation Sector**	**Pollution** Prevention
Human Health Risks						
Ambient Air Pollutants	√	√	√	√	√	**Yes**
Worker Exposure to Chemicals in Industry and Agriculture	√	√		√		**Yes**
Pollution Indoors	√		√		√	**Yes**
Pollutants in Drinking Water	√	√	√	√	√	**Yes**
Environmental Risks						
Habitat Alteration and Destruction	√	√	√	√	√	**Yes**
Species Extinction and Overall Loss of Biological Diversity	√	√	√	√	√	**Yes**
Stratospheric Ozone Depletion	√	√	√		√	**Yes**
Global Climate Change	√			√	√	**Yes**

2. *Responds to the Needs of Stakeholders* - To conduct research and development activities that are relevant to those with a stake in the pollution prevention arena. For stakeholders within EPA, there are often very specific research needs and short-term deadlines associated with laws, regulations, policies and initiatives. In addition, non-EPA stakeholders will increasingly help set the pollution prevention agenda as the Agency moves to a community-based approach for environmental protection.

3. *Fills Important Research and Development Gaps not being Addressed by Others* - To avoid duplication of pollution prevention research and development activities being conducted by others. This recognizes that either for regulatory reasons, or because there are no other champions, ORD will be the organization that conducts a variety of pollution prevention research and development activities.

Desirable Criteria

4. *Leverages Resources with Other Organizations* - To extend resources and capabilities with others. This recognizes that not all pollution prevention research and development activities can, or will, be supported by the various stakeholders.

5. *Provides Potentially Effective Research* - To reduce pollution and protect human health and the environment. In many cases, effectiveness will be enhanced by development of precompetitive technologies which

have wide applicability that others can build upon or tailor to meet specific technological problems.

Survey of Pollution Prevention Research by Economic Sector and Opportunities for ORD Contributions

While pollution prevention solutions are needed for all problems identified by the SAB, ORD must understand what pollution prevention research is already ongoing to identify where ORD can play a value-added role researching solutions. In response to Science Advisory Board comments on the draft of this strategy (EPA, 1998a) ORD surveyed recent and current programs in pollution prevention research for the major economic sectors identified by the SAB as contributing to high-risk human health and environmental problems. The purpose of the survey was to identify recent and current work for each sector and determine where ORD could contribute. Research opportunities are identified in this strategy based on survey results and the above criteria for developing programmatic priorities: high-risk problem, stakeholder needs, research gaps, leveraging resources, and providing potentially effective research.

The sectors surveyed paralleled the sectors identified by the SAB as presenting high environmental risk. They were: 1) industrial, the manufacturing and mining subsectors, 2) agricultural, 3) consumer, 4) energy and 5) transportation. Although not discussed here, other sectors were surveyed for their potential relevance to EPA's pollution prevention strategy. These included the municipal and construction sectors. The municipal sector is not discussed in detail below because the high-risk problems from this sector will be ameliorated by implementing pollution prevention in the other sectors. For example, source water protection for public drinking water supplies requires pollution prevention action for pollution emanating from the manufacturing, agricultural and transportation sectors. The construction sector was also addressed in the full survey, but is not discussed below. The primary problem from that sector is indoor air and this topic is covered under the consumer products sector.

The full reporting of the survey results of pollution prevention research activities for all sectors is contained in an internal ORD report "Pollution Prevention Research Survey and Opportunity Assessment" (EPA-NRMRL, 1998). The findings of the full survey report are summarized below and opportunities for ORD are presented in Table 2. The survey results are heavily weighted to research supported by the Federal government because outputs from this research are usually in the public domain and available on pollution prevention databases. In contrast, private sector research is often kept confidential and is not published. Clearly, companies, especially larger ones, are researching ways to improve process and product efficiency and effectiveness that have corollary reductions in waste generation. However, the research is not necessarily being done in the name of pollution prevention; rather it's just doing things better.

The survey showed that pollution prevention research is being supported by several Federal agencies and departments, including Department of Energy (DOE), Department of Defense (DOD), Department of Commerce-National Institute of Standards and Technology (DOC-NIST), Department of Transportation (DOT) and Department of Agriculture (DOA). Generally, EPA's unique mission compared to other agencies is that environmental protection, both human health and ecological, is the primary motivator. For other agencies, other motivators have primacy, leaving environmental protection as important, but secondary. An example is the DOE Industries of the Future Program in which industries are selected because of their high energy use. The focus of the research initiated under this program is energy efficiency and since energy efficiency and material use efficiency often go hand in hand, waste reduction and pollution prevention research are included as goals for the overall research programs developed for the targeted industries. The following discussion summarizes the important points made in the survey for each sector.

Industry Sector

Manufacturing Subsector

Survey Results. The major federal funders of pollution prevention research for the manufacturing sector are DOE, DOD, DOC-NIST, the National Science Foundation (NSF), the EPA, and DOA. To summarize:

DOE's Office of Industrial Technology under the Industries of the Future program conducts pollution prevention research related to the following industries: forest products, steel, metalcasting, glass, chemicals, petroleum refining, aluminum, and agriculture. DOE's analysis had shown that these industries are the most energy intensive and the most polluting. Many of the research objectives identified within industry-generated vision statements and "roadmaps" can be classified as pollution prevention objectives. Databases for pollution prevention projects also indicate that DOE has been active in funding projects in other industries as well; these include food, textiles, lumber and wood products, furniture and fixtures, paper and allied products, printing, rubber and plastics, primary metals, fabricated metals and electrical and electronic equipment. Projects in cross-cutting or "generic" technologies have also been funded: separations, coatings, cleaning, recycle/recovery, process engineering software tools and life cycle analysis tools.

DOD's Strategic Environmental Research and Development Program (SERDP) has supported the bulk of DOD's pollution prevention research, and it has been dedicated to avoiding environmental problems resulting from manufacture, deployment, and decommissioning of weapons and military transportation equipment. The industry sectors receiving attention and support from SERDP in-

Table 2. Summary of Pollution Prevention (P2) Research by Sector and Opportunities for ORD.

Industrial-Manufacturing Subsector	**Current Research:** The major entities supporting P2 research in the manufacturing sector are DOE, DOD, DOC-NIST and NSF. DOE has selected industries of interest in its Industries of the Future Program. DOC-NIST budget amounts to some $135 million for Advanced Technology partnerships which support work in developing advanced (usually incorporating P2 concepts) technologies of immediate commercial interest. Much of DOD's P2 research is conducted through SERDP to support P2 for weapon systems manufacturing and maintenance. **Potential ORD Role:** EPA's P2 research should address high-risk problems, the solutions for which have wide applicability. EPA's role is to partner with other established funded programs, both governmental and non-governmental, and conduct P2 research for risk management and generic tools and technologies that support manufacturing decision makers.
Industrial-Mining Subsector	**Current Research:** The major entity supporting P2 research in the mining sector is the Dept. of Interior (DOI). Best Management Practices (BMP) for the industry stress more P2 activities. **Potential ORD Role:** Possible role for ORD in research to support development of new effluent guidelines if they are developed by Office of Water. Pollution Prevention Act requires that P2 be considered in development of regulations.
Agriculture	**Current Research:** The most prominent entities supporting P2 research in the agriculture sector are within the federal government with USDA taking the lead. Primary areas of interest covered by USDA and other agencies are: reduction in pesticide and fertilizer use; conservation and soil management; nutrient and non-point source P2; and others. **Potential ORD Role:** ORD's role is to partner with USDA for technology transfer, developing and demonstrating P2 decision-making tools and methods for determining environmental impacts, costs and risks. In addition, the EPA's regulatory role in establishing upcoming nutrient loading (i.e. nitrogen and phosphorus) numeric criteria for waterbody types suggests ORD involvement in research for nutrient management and reduction; this research would be accomplished most effectively in partnership with USDA.
Consumer	**Current Research:** The consumer sector is extensive and includes the entire distribution system of goods and services. Government and industry are involved in P2 research which support decision making at all levels for the design, production, consumption and disposition of goods and services. **Potential ORD Role:** ORD's contribution for this sector should be to support the producers and consumers of goods and services by developing and demonstrating test methods to evaluate products for indoor air pollution potential. In addition, ORD can develop and test LCA tools and methods, including streamlined tools and methods, in the design and manufacture of products.
Energy	**Current Research:** The DOE is the preeminent organization for research in the energy sector, and some of its research activities are directed at P2. A variety of energy efficiency and conservation research, as well as alternative energy research, is being performed at the National Laboratories. **Potential ORD Role:** ORD activities are supporting overall DOE activities where ORD has the environmental expertise, facilities and experience. Some examples of these areas include intelligent controls for improving efficiency of motors, biomass conversion to fuel, and photovoltaics. ORD's role should be to continue this support and offer P2 tools and technologies to systematically approach energy issues which often overlap P2 issues.
Transportation	**Current Research:** Transportation P2 research is part of established programs with DOT, DOE, and DOD. **Potential ORD Role:** EPA's role in transportation P2 is the development and application of P2 decision-making tools and methods. ORD tools and methods could also be used to guide the P2 research direction of the lead agencies and departments.

clude primary metals, fabricated metals, machinery, electrical and electronic equipment, and transportation. Generic areas supported by DOD have been separations, coatings, stripping, cleaning, and life cycle analysis.

DOC-NIST has offered the Advanced Technology Program as its major avenue of pollution prevention-type research. The stated purpose of this program is to invest in technologies which show strong commercial potential and which would enhance the nation's economic growth through products for the world market. Projects are chosen based on their potential economic impact and the likelihood of commercialization. While pollution prevention and clean technology is not a stated objective, many of the technologies under development, being more efficient than existing technologies, have collateral environmental benefits that can be classified as pollution prevention. Focus areas are typically crosscutting and apply to a number of industry sectors, with an emphasis on high technology, information-intensive areas of interest. Focus program areas with implications for manufacturing are: catalysis and biocatalysis, component based software, digital data storage, manufacturing composite structures, materials processing for heavy manufacturing, motor vehicle manufacturing, vapor compression refrigeration technology, and selective membrane platforms. In addition, new programs are being established in the following areas: intelligent controls, microelectronics, and photonics. NIST is also involved in funding projects for the following industries: chemical, primary metals, fabricated metals, electric and electronic, and transportation equipment. Generic or crosscutting areas of interest to NIST are separations, process monitoring and control, and new materials. NIST also has an increasing role in pollution prevention technology transfer activities through its network of Manufacturing Extension Partnerships (MEP) centers.

USEPA's program in pollution prevention research for the manufacturing sector has been broad and has included projects for all the manufacturing industries. The strongest emphasis by industry has been on fabricated metals, chemical, electrical and electronics, and furniture. In addition there has been a focus on generic technologies for pollution prevention and recycling such as cleaning, stripping, coatings, separations, and tools for process simulation, pollution prevention measurement, and LCA.

The USDA through the Forest Service's, Forest Products Laboratory has conducted a large amount of research related to the pulp and paper industry. State pollution prevention programs have typically centered on providing technical assistance to small- and medium-size businesses in implementing pollution prevention. Compliance and reduction of wastes to improve bottom line profitability have been of primary importance in these programs. A few states have established pollution prevention research centers, usually associated with a state university. In these cases, industrial categories of interest are those that are of most significant economic import to the state.

Private sector efforts in pollution prevention research for the manufacturing sector are not captured in available data bases as yet. In mid-1997, the American Institute of Pollution Prevention (AIPP) began an effort to establish a database of work supported by trade associations and this will be available to incorporate into future research strategies. Clearly, much work is being done by the private sector to make environmentally-relevant improvements to products and processes. However, since it is not often described as pollution prevention research by the companies, it is not captured in databases of pollution prevention projects.

ORD Opportunities. According to the manufacturing facilities required to report for the 1996 TRI report (EPA, 1998b) 2.43 billion pounds of toxic chemicals were released to the environment in that year. This figure underestimates the actual amount of toxics released to the environment because only those manufacturers using above-threshold amounts of these chemicals are required to report, and all toxics are not on the list to be reported. While more needs to be done to quantify and prioritize risk resulting from these releases, ORD believes that these releases do represent a high risk to human health and the environment. The Agency and its Program Offices, as ORD's stakeholders, have shown interest in reducing these releases through pollution prevention approaches. Examples of several programs are the Common Sense Initiative, the 33/50 program and the Source Reduction Review Project. These offices and programs also identify specific industry sectors to ORD which then carries out pollution prevention research on them.

Although many other federal agencies and departments are devoting resources to pollution prevention research for the manufacturing sector, interest in environmental benefits is a secondary consideration with other factors such as agricultural productivity (DOA), business competitiveness (DOC-NIST), energy efficiency (DOE), having primary importance in supported research. ORD holds a unique role in researching pollution prevention for the manufacturing sector because ORD's work elevates environment as the most important consideration. In addition, research in the private sector is usually focused for the benefit of the sponsoring company. Results are kept confidential and only the sponsoring company benefits immediately. However, results of government research usually are in the public domain unless prior agreement under the Cooperative Research and Development Act (CRADA) prevents the public release of results.

Because of the wide range of high risk problems in the manufacturing sector amenable to pollution prevention research, ORD will use the above criterion "provide potentially effective research" to narrow its program to generic tools and technologies. These, by definition, will be widely applicable and therefore likely to be effective technological solutions to many environmental problems having their origins in the manufacturing sector. Examples of these tools and technologies are life cycle

inventorying and impact assessment, separations for recycle/recovery technologies, and green chemistry and engineering.

Mining Subsector

Survey Results. The principal federal department involved in mining activities is the Department of the Interior (DOI) with a variety of suboffices including the Office of Surface Mining (OSM) and the Bureau of Indian Affairs (BIA). In pollution prevention research efforts for the industry, the EPA and OSM tend to place emphasis on best management practices (BMPs) and only recently have stressed more rigorous pollution prevention technologies. BMPs applicable to mine discharges can be divided into two general areas: construction/reclamation and management/housekeeping. The two areas of principal concern to all levels of government and industry are acid mine drainage (AMD) with its intrinsic load of toxic metals, and nonpoint source pollution prevention and control. Prevention of AMD requires control of oxygen, water, bacteria, and sulfide minerals. Within a mine, oxygen levels cannot be controlled, so AMD prevention measures focus on control of the other three parameters, particularly on water flows. One promising technique for controlling AMD is the use of constructed wetlands. There are currently approximately 400 such systems in operation, mostly as a result of Bureau of Mines (BOM) research programs. Constructed wetlands systems have been particularly effective at removing iron from acid mine water. For the problem of nonpoint source runoff (abandoned mines), the new remedies include water diversion, dewatering, capping, grouting, or other techniques to reduce inflow, and remining or reprocessing to recover metal values.

ORD Opportunities. EPA's Office of Water may elect to develop new effluent guidelines, practices and standards for either or both hard rock and soft rock mining. If this does occur, the Pollution Prevention Act mandates that pollution prevention alternatives be developed alongside more traditional treatment solutions. ORD could play an active role in the research needs for these promulgations. A Congressionally-directed program exists, is funded at $6 million/year, and is technically directed by ORD. Since this program addresses abandoned mines, there is little opportunity to apply pollution prevention approaches. Pollution prevention opportunities exist largely in modifying current mining practices and processing to use less-polluting chemicals (e.g. substituting alternative chemicals for sodium cyanide to leach mountain size piles of low-grade gold ore).

Agriculture Sector

Survey Results. The most prominent entities supporting pollution prevention research in agriculture are within the federal government with the DOA taking the lead and to a lesser extent the FDA, USGS and EPA. The DOA's "Sustainable Agriculture Research and Education (SARE)" program and the Forest Products Laboratory program include a number of research areas: source reduction of pesticides, fertilizers and other agricultural chemicals; pesticide alternatives; biological alternatives for insect and disease control; conservation and soil management; non-point source pollution prevention; ecological management for crops and dairy production; cultivation technology and photo-control of weeds; nutrient management; integrated crop management; water management; livestock grazing; and timber management. In addition to the federal program, the University of California supports the Sustainable Agriculture Network (SAN), a computer-based technology transfer activity. Other universities are notable contributors to this network.

EPA-ORD, EPA-OPPTS, and EPA-Region VII are involved in some of the research areas above. ORD-NRMRL supported agriculture pollution prevention research in varied capacities such as conducting joint DOA/EPA pollution prevention opportunity assessments, conducting national workshops on pesticides management, producing pollution prevention guidance documents on pesticides formulation, and conducting research to reduce wastes in agriculture production and processing. OPPTS represents the Agency in partnership with DOA and FDA for the Pesticide Environmental Stewardship Program (PESP) to reduce pesticide use and risk in agriculture and non-agriculture settings. The Ag Center at Region VII is an EPA compliance-oriented site that provides environmental and pollution prevention information on agriculture.

ORD Opportunities. It is clear that environmental risk from the agricultural sector is great. Control of nutrient runoff from agricultural feed operations and from agricultural lands generally, has been elevated to high priority in EPA's Clean Water Action Plan (EPA, 1998c). Nutrient loadings to watersheds have posed special risk to environmental aquatic habitats. A potentially unique area for ORD involvement with DOA and others such as DOE or DOD is in developing and demonstrating pollution prevention tools and methods, especially in life cycle inventorying and impact assessment to determine relative environmental impacts, costs and risks posed by employing varying alternatives. An example is pest and fertilizer management for farming operations that generate pollutants. This activity would meet the criteria described above by targeting a research gap for high risk, stakeholder driven problems; in addition, opportunity to leverage resources through efforts of other agencies would be assured.

Consumer Sector

Survey results. Because of the magnitude of this sector, an in-depth, comprehensive survey of all pollution prevention research activities was not conducted. Rather, examples of the types of pollution prevention activities supported by the federal government, often in partnership with states and industry, are provided. The U.S. Consumer Product Safety Commission (CPSC) is the federal organization whose mission includes oversight

of consumer products. Over 15,000 consumer products fall under CPSC's jurisdiction. As an example, this organization was instrumental in removing lead from paint.

Other agencies of the federal government, especially EPA, play an active role in pollution prevention in the consumer sector. For example, the EPA's Office of Air and Radiation's (OAR) Atmospheric Pollution Prevention Division (APPD) has a number of voluntary programs designed to prevent air pollution caused by consumer products. Two relevant APPD programs are 1) the Energy Star Residential Heating and Cooling Program in which manufacturers agree to manufacture and market high-efficiency heating, cooling, and control products; and 2) the Green Lights Program which is aimed at promoting energy efficiency through investment in energysaving lighting. APPD has also teamed up with the DOE in an effort to label various groups of energy efficient products under the Energy Star program. In related work, EPA's Office of Pollution Prevention and Toxic Substances (OPPTS) is working with the General Services Administration on identifying "environmentally preferable products." OPPTS and OAR are also working on an Indoor Air Source Ranking Database which uses available data to conduct a screening level risk assessment to identify potentially high-risk sources. Latex and alkyd paints as well as carpeting have been consumer products of note in OPPTS efforts.

There have been numerous industry efforts to study products they produce and attempt to reduce or eliminate adverse environmental and health impacts. Reduction in air emissions from products has been a particular focus of manufacturers whose products have received a lot of media attention for their potential to pollute indoor air. These include products such as photocopiers, carpet, and engineered wood. Formaldehyde levels in floor underlayment have been reduced in compliance with a new US Department of Housing and Urban Development (HUD) emission standard for floor underlayment. In another example, Canon, a major manufacturer of printers and copiers, redesigned one of its printer engines to substantially reduce ozone emissions.

In an effort toward energy efficiency, the Electric Power Research Institute (EPRI) has developed and evaluated technologies to improve lighting and refrigeration systems. EPRI has evaluated alternatives to CFCs developed by the chemical industry. These alternatives can also be ozone-depleting and methods are needed to evaluate impact.

ORD Opportunities. The consumer products area offers opportunities to ORD for pollution prevention research which is stakeholder driven and would fill gaps in methods and research on cleaner consumer products. ORD can continue developing essential test methods for evaluating various consumer products of interest to EPA's program offices. In addition, the work being done in ORD in life cycle inventorying and impact assessment and in pollution prevention measurement can be applied to consumer products to evaluate relative environmental impacts of products. These methods can also be used in clean product design by identifying ways of making improvements to products so that they have less impact. An example is in the testing and evaluation of low total equivalent warming impact (TEWI) technologies.

Energy Sector

Survey Results. The DOE is the preeminent organization for research in pollution prevention for the energy sector. Much of the work is performed in association with states and industry and is directed at alternative energy sources: nuclear, geothermal, wind, solar, biomass and clean coal. Under all of these areas, there are a variety of activities being performed at various labs including the Federal Energy Technology Center, Argonne National Laboratory, the National Renewable Energy Laboratory (NREL), and others.

In nuclear energy, emphasis has been on development of fusion energy. In geothermal, work has been to reduce costs and improve efficiencies of these technologies to make them more competitive with fossil fuels. In wind research, DOE's efforts have been focused on the design and testing of new wind turbines. In solar energy, DOE works in both the photovoltaic and solar thermal arenas. In photovoltaics, which directly generate electricity, DOE is active in crystal growth research, materials research to improve efficiency, and performance evaluations of cells. In solar thermal, DOE is also advancing technology for solar power towers, parabolic collectors, and other advanced processes.

In biomass, DOE has been evaluating and developing technologies for gasification (to produce biogas) with some lesser efforts for pyrolysis (to produce liquid fuels). DOE is also working to develop formulations for biomass conversion to ethanol for use in fuel cells. Argonne National Labs provides a site for evaluating the performance of alternative fuel vehicles (methanol, ethanol, electric, and hybrid electric) that are built by industry. In direct combustion of biomass, DOE works to increase efficiency and reduce emissions from these systems and works on advanced turbine systems for high efficiency gas-powered turbines. With the DOA, DOE is working to develop energy crops to provide renewable fuel for power generation. NREL is also a major actor in renewable energy research.

In clean coal, DOE develops and evaluates technologies such as gasification and liquifaction. They also work on low-emission coal boiler systems, high-efficiency gas turbines, and the sequestering and recycling of greenhouse gases from coal combustion. Some of these clean coal efforts are in cooperation with private sector companies such as Eastman Chemical and Westinghouse.

ORD Opportunities. Clearly, DOE is active in pursuing pollution prevention options for the energy sector via its alternative fuels program. There are still a few research

gaps for high risk problems which can be addressed by ORD. The primary pollutants of concern from the energy sector are greenhouse gases and ozone depleters. An opportunity for ORD research is investigating alternative, acceptable fluids for heat pumps used in waste heat collection. ORD has expertise and facilities which can be used for this work.

Another opportunity is in the application of intelligent controls for increasing motor efficiencies in a variety of applications, including wind turbines, combustion operations and industrial motors. ORD has some of the first patents in the area of intelligent controls and could use the existing expertise and facilities to pursue this work.

In solar energy, work is required in improving the efficiencies of solar cells to make them cost- competitive with existing power generating technologies. ORD has expertise in photovoltaic system demonstration and evaluation for the purpose of quantifying pollution prevention capabilities of these systems. In biomass, several opportunities exist in waste biomass utilization, in development of biomass-derived methanol, and in small-scale demonstrations (<5 megawatts). ORD has in-house expertise and facilities which can be used to meet both of these needs.

ORD also has the opportunity to use its expertise in developing and testing pollution prevention measurement tools, as well as life cycle analysis and impact assessment tools, to weigh and compare the various energy alternatives. Cost, technical performance and efficiency, and environmental consequences can be compared using these methods.

Transportation Sector

Survey Results. Reduction of emissions from the transportation sector is being researched by many organizations, both within and outside the federal government. Mention should first be made of the large research programs being conducted by private industry, mostly automotive companies. Research efforts have been undertaken to meet regulatory air quality goals that include pollution prevention approaches. Examples of automotive industry research are development of the catalytic converter, low-emission vehicles, zero-emission vehicles, hybrid gasoline/electric vehicles, and fuel cell power systems.

Within the federal government, many programs supported by the Departments of Transportation, Energy, and Defense promote the achievement of pollution prevention objectives. Some EPA mobile source emission regulations implemented by EPA, state and local agencies involve pollution prevention approaches. A limited discussion of federal agency and other programs is given below to provide examples of the largest programs.

The U.S. Department of Transportation is involved in many transportation, energy, and environmental activities through the Federal Highway Administration, the Federal Transit Administration, and the Federal Aviation Administration. The Intermodal Surface Transportation Efficiency Act of 1990 (ISTEA) started many programs related to reducing pollution from automobiles, improving community involvement in transportation planning, implementing effective travel demand management measures, and encouraging public transit. The newer six-year, $175 billion National Economic Crossroads Transportation Efficiency Act (NEXTEA) program is funded to continue building and operating a safe, efficient and environmentally-sound surface transportation system into the next century. To help protect the environment, NEXTEA increases funding for the Congestion Mitigation and Air Quality (CMAQ) Improvement Program to $1.3 billion annually, increases transportation enhancements funding by more than 25 percent and continues funding for bicycle transportation and pedestrian walkways. In contrast to these large programs, DOT is also involved in smaller projects; in one project the DOE helped the US Postal Service prepare employee trip reduction plans for 110 postal facilities in metropolitan New York.

The DOE Office of Transportation Technologies works with the transportation industry, energy supply industry, and other research and development organizations to develop and promote advanced transportation vehicles and alternative fuel technologies that will reduce oil import requirements, and minimize criteria pollutant emissions and greenhouse gases. The Office of Advanced Automotive Technologies conducts research programs aimed at the personal transportation systems of the future—hybrid vehicles using multiple energy/power sources, alternative fuel vehicles operating on non-petroleum fuels, and electric vehicles powered by advanced batteries or fuel cells. The Office of Heavy Vehicle Technologies focuses its research activities on improving the energy efficiency and reducing the emissions from advanced diesel engines and on developing non-petroleum fueled diesel engines. The Office of Alternative Fuels Development sponsors research, development, and demonstration activities focused on cultivating agricultural and forestry feedstocks and on conversion systems for producing ethanol as a biofuel or fuel additive.

DOD's Air Force bases have studied pollution prevention opportunities for shops performing all types of vehicles maintenance and has researched ways of reducing reliance of Air Force weapon systems on ozone depleting chemicals and hazardous materials. Within EPA, OPPTS and ORD have supported research efforts relevant to the transportation sector. OPPTS's Design for the Environment (DfE) Program is stimulating private sector efforts to design products and services that reduce potential risk from chemicals; one industry sector of importance to the DfE program is the aerospace industry. ORD has past research efforts in conducting waste reduction technology evaluations that are applicable to vehicle manufacture in private and defense industries and has a current life cycle design project with the Saturn Corporation.

Local government efforts for the sector are significant and growing at a fast pace due to concerns about Clean Air Act requirements and traffic congestion generally. To meet the requirements of Clean Air Act Amendments, and potentially tougher diesel regulations in the future, metropolitan transit authorities have begun to consider the use of alternate fuels for their mass transit vehicles. More than 30 transit authorities have participated in a program to evaluate biodiesel as an alternative fuel. Biodiesel (methyl esters) is a cleaner burning fuel made from natural, renewable resources such as vegetable oils. Air transportation systems have also received attention. At the new Denver International Airport, the solution to airport waste generation was for a collaboration of EPA's Region VIII, the City of Denver, and airport designers to develop pollution prevention and waste management techniques before the airport opened.

An example of an academic program performing pollution prevention research for the sector is the University of Wisconsin Engine Research Center. The goal of this center is to better understand engine combustion phenomena in order to improve power density and fuel economy while meeting emission standards.

ORD Opportunities. Given the resources devoted to researching pollution prevention opportunities for this sector within other federal agencies, especially the Department of Transportation and the DOE, there are few gaps in the overall research being conducted for the sector. Since most of the work is federally funded, the research results are in the public domain and can be used by all. One opportunity for ORD, in which we have unique capability to meet a gap in existing research, is to support the development of design tools to allow for better environmental assessment of transportation choices and improved design of transportation products. The example offered above for life cycle design of automobiles for the Saturn Corporation provides a prototype for this kind of effort.

Development of Research Goals

The above summary helps ORD focus on particular research problems it should be addressing. To carry out a pollution prevention research program and to plan for new problems that may arise, the following four research goals, representing competency to do work in all the above areas and the flexibility to meet new research needs, are proposed as a way of structuring the pollution prevention research program. Specific sector research is identified with each goal.

Goal I — Deliver tools and methods. For all sectors the program will develop tools and methods which can be used to promote pollution prevention across the problems listed above. ORD will invest in this area because it has substantial experience developing such tools and methods, and in several areas (e.g., life cycle analysis, process simulation) ORD staff are recognized for their expertise and capabilities. The unique Agency mission to advance the use of prevention and ensure that the tools and methods effectively consider multiple environmental impacts makes this an inherently EPA research and development responsibility.

Goal II — Develop and transfer technologies and approaches. For the manufacturing and consumer sectors the program will develop, evaluate, and transfer pollution prevention technologies and approaches. Within the manufacturing sector, there is a particular need for research to support medium- and small-sized businesses that are geographically dispersed (e.g., dry cleaners, metal finishing, printing). This is also true for larger companies that have difficulty in meeting compliance requirements. ORD has resident expertise which can be applied to the environmental problems associated with the manufacturing and consumer sectors and intends to maintain that expertise in the coming years. In many of these areas, ORD has internationally recognized scientific and technical staff who can make contributions in the science and technical arenas leading to resolution of regulatory and compliance issues.

Increasing emphasis will be on generic technologies and approaches which have the potential to cut across a number of sectors, and ORD is the logical champion for such developmental work. Industry and other government agencies are focused more on developing pollution prevention options for specific processes which are of the greatest concern to them. ORD can be very influential in catalyzing the development of technologies and approaches through leveraging resources and partnering with stakeholder organizations.

Goal III — Verify selected pollution prevention technology. For the manufacturing, consumer products and municipal sectors, the program will verify the performance of pollution prevention alternatives in order to fully demonstrate their efficacy, particularly as noted by the Program Offices. This is a critical research need because one of the most significant factors limiting the use of pollution prevention approaches is the lack of confidence by both industry and regulators that they can achieve required reductions through pollution prevention. Over the past five years, ORD has developed a capability to verify commercial-ready technologies and products. ORD will maintain this capability over the coming five years, and if needed, grow in areas where verification can make a contribution to human health and environmental protection. Under the Environmental Technology Verification (ETV) Program, pilot verification entities have been funded to support technology verification targeted at high-priority human health and environmental risks.

Goal IV — Conduct economic, social and behavioral research. For all sectors the program will investigate the economic, social, and behavioral (i.e., non-technical) aspects of pollution prevention to better understand, and then ameliorate, the barriers to the adoption of pollution prevention technologies and approaches in the future. Such has been called for by several of the national

strategies and the SAB. There is very limited capability within ORD to address these issues (e.g., economics), but because there is such a strong need for this research the extramural grants program, at least initially, will be used to address this important area. ORD resident capabilities will be expanded in economics, while other social science capabilities will be garnered through the competitive grants program. ORD expects to continue its partnership with the NSF to leverage resources in the social science arena.

Each of these major areas is developed in greater detail in Chapter 3 in the context of a research goal with associated objectives. Each objective includes a set of research and development activities that will be undertaken along with brief descriptions of project areas that will be pursued.

Chapter 3. ORD'S Pollution Prevention Research and Development Program

Vision

This research strategy is designed around the following vision of where ORD's Pollution Prevention Research and Development Program should be going in the future:

> *Scientifically based pollution prevention research and development products will be used routinely by communities, industries, governments, and other stakeholders for improved environmental decision making on high-risk human health and environmental problems, and as part of a move toward sustainable development in the 21st Century.*

Mission

In moving toward this vision, ORD's Pollution Prevention Research and Development Program mission is:

> *To advance scientific research and develop cost-effective tools, methods, technologies, and approaches which expand the availability and use of pollution prevention by both the public and private sectors.*

Goals

In support of our vision and mission, and in concert with the strategic approach identified in Chapter 2, the following will be pursued in this research strategy:

> *I. ORD will deliver broadly applicable tools and methodologies for pollution prevention and sustainability.*
>
> *II. ORD will develop and transfer pollution prevention technologies and approaches.*
>
> *III. ORD will verify selected pollution prevention technologies.*
>
> *IV. ORD will conduct research to address economic, social, and behavioral research for pollution prevention.*

Additional details on each of the four goals are provided in this section including specific objectives that ORD will pursue over the next five years. For each objective, details are provided on: (1) why the research is important (Rationale), (2) what the current situation is with respect to the goal and objective (Current Situation), and (3) what research and development activities are planned. Each goal description concludes with a discussion on projected resource allocations (Resource Allocation and Emphasis).

Goal I: Deliver Tools and Methodologies

ORD will develop, test, and deliver tools and methodologies which improve individual and organizational decision making to reduce or eliminate emissions, effluents, and wastes from products, processes, and activities. These tools will be applied across all economic sectors generating pollution: manufacturing, mining, consumer products, energy and transportation.

Objective: *Develop and test user friendly tools and methodologies for improved decision making.*

Rationale

As many of the human health and environmental problems most amenable to pollution prevention are addressed, the need for scientifically sound, user friendly tools and methodologies to assist in making decisions on complex risk management problems becomes increasingly important. These tools and methodologies can be of invaluable assistance for identifying and evaluating technologies and approaches that are less polluting when compared to each other, or to more traditional end-of-the-pipe treatment. For pollution prevention to play a key role both now and in the future, tools and methodologies must be developed that are more quantitative in nature. Developing and testing pollution prevention tools and methodologies that are easy to use and meaningful to stakeholders allows for improved decision making at all levels. These tools and methodologies can often be applied across economic sectors and, therefore, have wide applicability to many environmental problems resulting from agricultural, industrial, mining, transportation, and energy related activities.

Current Situation

All too often, environmental impacts are not considered beyond a very narrow realm, and risk management options are not thoroughly characterized using such tools as life cycle assessment, process simulation, and cost/benefit analysis. What on the surface appears to be the best option, may not consider either the complete life cycle of a product or process, or the risks of trading one pollution problem for another.

Research and Development Activities

1. New Activity — Integrate risk assessment and risk management tools and methodologies

Increasingly, EPA is being asked by Congress, the Administration, and the public to consider risk when promulgating regulations and developing rules. Past research and development efforts have improved the ability of the Agency to use quantitative risk assessment in making decisions on highrisk human health and environmental problems. The ability to link risk assessment and risk management tools that permit the analysis of possible options, both environmentally and economically, is now being called for by the National Research Council (1996). Such an approach is a logical next step in using scientific and technical information to make more informed decisions on risks and risk management. ORD's National Center for Environmental Assessment and National Risk Management Research Laboratory will develop and pursue a joint program to link, and if appropriate, integrate risk assessment methodologies and pollution prevention tools (e.g., LCA, cost/benefit analysis) to improve decision making on important human health and environmental problems.

2. Increased Emphasis — Improve and develop generic tools and methodologies

Technologies and approaches for preventing or reducing human health and environmental risks should be reliable, cost-effective, technically sound, and acceptable. ORD must assist public officials and the private sector in making decisions on which new technologies and approaches will be the most effective, both economically and environmentally. The research and development conducted will (1) improve engineering economy and cost tools, (2) refine and advance the utility of life cycle analysis, (3) develop process simulation tools, (4) develop pollution prevention progress measurement methodologies, and (5) develop and improve impact assessment tools.

3. Continued Emphasis — Improve and develop targeted tools and methodologies

ORD has a continuing commitment to support various Program Offices in the development and evaluation of tools and methodologies that advance pollution prevention in specific areas or for specific problems. The research and development to be conducted will be in support of (1) the Office of Solid Waste and Emergency Response (OSWER) on municipal solid waste, and (2) the Office or Air and Radiation (OAR) on volatile organic chemical substitutes. ORD will support other Program Offices that would benefit from the tools and methodologies under development and testing by ORD scientists and engineers as the need arises.

Resource Allocation and Emphasis

Goal I will receive increased emphasis under this research strategy. Providing user friendly tools and methodologies for improved decision making on pollution prevention risk management alternatives is extremely important. This is particularly true as the Agency moves to environmental decision making at the community level. ORD is well positioned to conduct research in this area in terms of staff knowledge, expertise and experience, and supporting financial resources. Increased staffing and financial resources will be directed into the tools and methodologies area and, if necessary, additional resources will be solicited as part of the Agency's planning and budgeting process to ensure progress in meeting this long-term goal.

Goal II: Develop and Transfer Technologies and Approaches

ORD will develop, test, and transfer pollution prevention technologies and approaches that are applicable across economic sectors, and evaluate products, technologies and approaches targeted at preventing high-priority human health and environmental problems in support of the Agency's regulatory and compliance programs. The focus of this work will be the manufacturing and consumer products sectors.

Objective A: *Research, design, and assess novel and advanced environmentally benign approaches for industrial processing and manufacturing.*

Rationale

Sustainable development has been defined as development that meets the need of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). Technology can have a profound effect on the environment both positively and negatively. The challenge is to use technology in such a way that it does not lead simply to short-term advances in productivity at the expense of long-term resource viability. A new generation of cleaner industrial manufacturing and processing technologies is needed to support pollution prevention, efficient resource use, and industrial ecology. Such a strategy can help the U.S. economy become more competitive by lowering resource and energy needs, reducing waste and emissions control costs, and fostering sustainable development.

Current Situation

According to the U.S. Council of Economic Advisers (1995), an investment in research and development has a private rate of return of 20 to 30 percent (i.e., benefit that accrues to the inventor) and a social rate of return approaching 50 percent (i.e., benefit that accrues to others). Research and development is the source of new products that improve the quality of life and new processes that enable firms to reduce costs and become more efficient and competitive. Yet, most new chemical science and engineering technologies are focused on improving operations, increasing efficiency in the use of raw materials, and continuing to balance environmental and economic considerations. Until recently, few research and development resources have

been devoted to the design of alternative synthetic pathways for green chemistry, or the development of improved reactor, catalyst, or process designs in order to increase product yield, improve selectivity, or reduce unwanted reaction byproducts.

Research and Development Activities

1. Continued emphasis — Chemistry for pollution prevention

The goal of this research effort is to improve existing chemical design practices by developing more environmentally benign chemical synthesis (i.e., green chemistry) and safer commercial substances. Green chemistry research was established to promote fundamental and innovative chemical methodologies that accomplish pollution prevention and have broad application in the industrial sector. It is the use of chemistry for source reduction, the highest tier of the risk management hierarchy. Green chemistry encompasses all aspects and types of chemical processes (e.g., synthesis, catalysis, analysis, monitoring, separations, and reaction conditions) that reduce negative impacts on human health and the environment relative to the current state of the art. Emphasis will be on (1) an extramurally-focused program on green chemistry, and (2) an in-house program on improved oxidation pathways.

2. Continued emphasis — Engineering for pollution prevention

Novel engineering approaches are being pursued to prevent and/or reduce pollution from industrial manufacturing activities — both continuous and discrete processes. The scope of this research includes: equipment and technology modifications, reformulation or redesign of products, substitution of alternative materials, and in-process changes. Although these methods are often thought of in relation to the chemical, biochemical, and materials processing industries, they can also be utilized in many other industries such as semiconductor manufacturing, metals processing and other fabrication industries. ORD will continue to support pre-competitive engineering research in a variety of industries. Potential areas include improved reactor, catalyst, or process designs in order to reduce unwanted byproducts.

In addition, to be sustainable, engineering processes will increasingly rely on technologies which allow them to achieve at or near “zero releases” of wastes. In-process recycling is an important part of the Agency’s definition of pollution prevention and may be the best way to approach “zero releases” via direct recycling of a process stream back into the process from which it was generated. It enables recovery of valuable products, and can prevent or minimize releases of both toxic metals and organics. In-process recycling is best accomplished using separations technologies such as adsorption, membranes, filtration, distillation, or a combination of these. In ORD’s research program, emphasis will be on developing separations technologies for recycle and recovery of toxic metals and organics. Results are expected to be widely applicable across industrial, and possibly, economic sectors.

3. Continued emphasis — Feedback techniques for pollution prevention

ORD will design approaches for predicting the performance of intelligent controls (IC) in pollution prevention applications. IC computational approaches based on fuzzy logic, neural networks, and generic algorithms are broadly applicable technology which can be used in many processes and sectors to reduce pollution from all media. IC-based approaches have the potential to make a major impact by preventing releases and increasing energy efficiency at affordable costs. As part of this effort, ORD will develop and demonstrate intelligent controllers in the laboratory and at pilot-scale facilities with various industrial, commercial, and consumer product partners (e.g., states, universities, environmental agencies, manufacturing and commercial industries, utilities, trade associations, and federal organizations).

Objective B: *Develop and test technologies and approaches targeted at specific environmental problems.*

Rationale

Problems persist that pose high risks to both human health and the environment. The challenge is to develop economically attractive technologies and approaches that result in significant reductions in pollution over the longer term (e.g., the next 10 to 20 years), while providing the maximum amount of human health and environmental protection. The federal government plays a critical role in advancing technologies and approaches to the point of joint, pilot- and full-scale evaluation and demonstration. Government-supported research and development of cutting edge preventive technologies and approaches helps companies of all sizes, but is particularly beneficial to medium- and small-sized companies which have neither the capability nor the resources to conduct their own programs.

Current Situation

While specific companies may address many important knowledge gaps related to pollution prevention, the private sector does not generally sponsor research to address human health and environmental problems that cut across economic sectors, nor do they transfer proprietary technologies and approaches that give them an advantage over their competitors. Problems associated with persistent, bioaccumulative, and toxic chemicals (e.g., chlorinated compounds, metals) and volatile organic compounds (VOCs) exist in a number of industries and result from a variety of processes. Technologies and approaches that have the potential to yield marked improvements in preventing these pollutants can languish for years because the problem is owned by everyone and no one. Merely requiring industries to meet a

regulatory limit or compliance standard does not guarantee their ability to do so. Medium- and small-sized companies, in particular, can suffer from a lack of capital with which to conduct research and development, and a lack of expertise with which to interpret and then employ technologies and approaches that are preventive in nature.

Research and Development Activities

1. Continued Emphasis — Address problems associated with global warming to reduce Total Equivalent Warming Impact (TEWI)

The application and demand for hydrofluorocarbons (HFCs) are increasing every year as these chemicals have become the simplest choice for replacing the ozone-depleting chlorofluorocarbons (CFCs) used in refrigeration and air conditioning applications. The decision to use HFCs has been driven by the need to stop ozone depletion, with less consideration given to their other potential environmental impacts. Although HFCs presently account for only 1 percent of the greenhouse gas (GHG) emissions, these are the fastest growing GHG emissions component and are expected to reach 6 percent by the year 2010. Many of these chemicals have long atmospheric lifetimes (between 20 to 100 years) and have global warming potentials (GWP) several thousand times greater than CO_2. ORD will research and develop approaches to measure and minimize the TEWI performance of technologies using HFCs and HFC alternatives.

2. Continued Emphasis — Address problems associated with VOCs and hazardous air pollutants (HAPs) by improving coating and cleaning operations

Surface coatings (e.g., paints, adhesives, inks, gel coats, lacquers, mold release agents) are an aspect of almost all manufactured items. Many of these surface coatings (and stripping or cleaning materials) were and still are manufactured with chemical solvents which improve ease of application. Because almost all of these chemical solvents are VOCs and HAPs, their release to air, water, and in wastes creates environmental problems that have become the focus of many domestic and international regulations and initiatives. The pressure of current and pending environmental regulations has spurred the development of many new, low-VOC/HAP surface coating systems. While these new coatings are making major inroads into markets that were at one time dominated by low-solids solvent-borne coatings, product development issues continue to limit the commercial availability and use of these systems in many applications. In ORD's research program, innovative, cost-effective, and low-pollution coating and cleaning materials and application technologies will be developed and evaluated. ORD will also test and evaluate the applicability of environmentally friendly coating and cleaning technologies to other industries, substrates and applications.

3. Increased Emphasis — Address problems associated with products used indoors.

Consumer products and building materials (e.g., architectural coatings; dry cleaning spotting preparations; specialty cleaners and sanitation products; adhesives, caulks, and sealants; shoe polish and leather care products) can emit high levels of indoor contaminants known to pose a significant risk to human health. A study by EPA (Wallace, 1987) identified indoor air pollution as one of the most important environmental risks to the nation's health because (1) indoor pollution levels are 2 to 5 times higher than outdoors, (2) after some activities, indoor pollution levels can be up to 1000 times higher than outdoors, and (3) in new, nonresidential buildings, levels of VOCs are as much as 100 times higher than outdoors. Test methods and models can be used to better understand the emissions from these products and stimulate development and commercialization of lower-emitting products. ORD's program will identify products that emit high levels of indoor contaminants known to pose a significant risk to human health, develop appropriate test methods and models that can be used to better understand emissions from these products, and stimulate development and commercialization of lower-emitting products.

Objective C: *Demonstrate and evaluate pollution prevention in support of Agency and Program Office initiatives and priorities*

Rationale

Supporting the Agency's regulatory and compliance programs with objective, scientifically sound pollution prevention technologies and approaches is an extremely important role that ORD plays. Both large and small companies can have significant compliance problems, but complying with environmental regulations can be particularly difficult for small, geographically dispersed businesses. They do not have the capital or the technical capability to investigate, evaluate, or demonstrate pollution prevention technologies. In many cases, collaborative research between industry and government is necessary to ensure that less-polluting technologies are accepted and applied.

Current Situation

Billions of pounds of chemicals are released annually resulting in exposures that are both carcinogenic and mutagenic to human and animal life. Reductions in these releases to air, water, and in waste have resulted from concerted efforts by EPA and industry (e.g., 33/50, Design for the Environment). The chemical industry, in particular, has taken major steps to reduce the production of toxic chemicals and the impact of these chemicals and chemical byproducts on human health and the environment, but many industrial sectors still have difficulty in meeting Agency requirements. Efforts to solve medium-specific problems using a multimedia approach (e.g., Source Reduction Review Project) have had mixed

success. The Common Sense Initiative (CSI) promises to foster pollution prevention as an important part of its mission across the six CSI-targeted industries. The Administrator has directed the Agency to look for additional opportunities to adopt a sector approach to environmental protection.

Research and Development Activities

1. Continued Emphasis — Address problems associated with medium- and small-sized companies that pose high risk problems

ORD will continue to focus on medium- and small-sized companies with particular emphasis on those that are part of CSI. Because these companies are often poorly capitalized, run as small businesses, and geographically dispersed, they have difficulty in meeting regulatory and compliance requirements. They often do not have the expertise or the resources to devote to the research and development of advanced technologies and approaches that are less polluting, although they may be affiliated with a trade association that represents their collective interests. ORD has been successful in the past, and will continue to work in the future with those medium- and small-sized businesses and their trade associations which look to the Agency for assistance in reducing these risks. Emphasis will be on (1) metal finishing, (2) printing, (3) computers and electronics, (4) auto refinishing, and (5) dry cleaning.

2. Continued Emphasis — Support Agency rule makings and initiatives that encourage pollution prevention

ORD will continue to participate with the Office of Water, the Office of Solid Waste and Emergency Response, and the Office of Air and Radiation to investigate pollution prevention alternatives for those industrial categories involved in rule making or Agency Initiatives (e.g., Source Reduction Review Project, Common Sense Initiative). The projects will be nominated by the Program Offices and selected by ORD on the basis of their ability to achieve a meaningful and useful result with a broad applicability.

Resource Allocation and Emphasis

Goal II is an area of continuing emphasis under this research strategy. This area is one that has enjoyed support within the Agency and it is anticipated that it will continue into the foreseeable future. Research and development activities under Objective A will receive increasing emphasis as ORD enhances its in-house research and development program. Objective B, covering the development of generic technologies and approaches that prevent pollution, has the potential to be widely applied; ORD can play a unique role not likely to be filled by other public or private entities. Resources for this area are expected to remain steady. Most of the research and development activities under Objective C will continue to support high-priority EPA regulatory and regulatory re-invention efforts and will likely remain constant with some annual shifts in emphasis among industry sectors.

Goal III: Verify the Performance of Cleaner Products, Technologies, and Approaches

As part of its Environmental Technology Verification (ETV) Program, ORD will serve as a catalyzing organization to propel into the marketplace the most promising commercial-ready pollution prevention products and technologies from both the public and private sectors.

Objective: *Build a high-quality and efficient program to verify the performance characteristics of pollution prevention products and technologies.*

Rationale

Throughout its history, EPA has evaluated technologies to determine their effectiveness in monitoring, preventing, controlling, and cleaning up pollution. Such data are needed by technology buyers and permitters both at home and abroad to make more informed decisions. Since the early 1990s, numerous government and private groups have identified the lack of an organized and ongoing program to produce independent, credible performance data as a major impediment to the development and use of innovative environmental technologies. With respect to products and technologies that prevent pollution, regulatory officials and private industry can make more informed decisions when scientifically sound data are available. Verifying the performance of products and technologies that prevent pollution can have an important impact both nationally and internationally in reducing pollutant loads in the coming decades. Pollution prevention innovations which have been systematically verified under the ETV Program will be more widely accepted by both the public and private sectors and the technical results of the verifications will quantify their preventive nature.

Current Situation

ORD has developed a program to verify environmental technologies across a wide variety of human health and environmental problems (EPA, 1997b). Among the most hopeful approaches to pollution prevention are the numerous products and technologies which not only protect the environment, but also save money. While many opportunities for such products and technologies have been identified over the last few years, few industry, manufacturing, commercial and even community organizations are willing to change their normal way of doing business and accept these new opportunities without documented, credible data on their performance. For this reason, pollution prevention products and technologies have significant difficulties in penetrating domestic and international markets, and the potential for significant prevention of pollution goes unrealized.

Research and Development Activities

Continued Emphasis — Verify commercial-ready products and technologies that substantially reduce or eliminate the production of air, water, and waste products

Hazardous Waste Pollution Prevention and Treatment ETV Pilot. In October1995, ETV began one of its first pilot projects with the State of California to verify the performance of innovative technologies in hazardous waste pollution prevention, recycling, treatment and monitoring. This ETV pilot will continue operation with emphasis on outreach to the pollution prevention community and targeted industry groups being emphasized during 1997.

Industrial Coatings ETV Pilot. Based on the experience with the Hazardous Waste Pollution Prevention and Treatment Pilot, the ETV program began a pollution prevention pilot targeted at alternative products for one specific industry (i.e., industrial coatings) in October 1996. In response to recent solicitations, 32 coatings products and technologies have applied for verification; testing will begin for most by the end of 1998.

Metal Finishing ETV Pilot. Another ETV pilot targeted at a single industry (i.e., metal finishing) will be started in 1998. This industry is perceived to represent a substantial opportunity for pollution prevention technology alternatives and has the active backing of the Agency's Common Sense Initiative Committee. Verification of new technologies that promise to assist this small business sector will begin in 1999.

Indoor Air ETV Pilot. In this ETV pilot an extensive process to formulate a series of protocols to test products that impact the indoor air environment has been instituted. The initial focus is on office furniture, office machines, and room air filtration systems. As stakeholder groups for each of these areas are formed, ORD will support validation testing using the protocols over the next few years. Stakeholders will follow protocol development and select additional product categories for verification in 1998.

Climate Change ETV Pilot. In December, 1998 ETV will put in place a new pilot to assess commercial-ready technologies that reduce the emission of greenhouse gases. Initial efforts are likely to focus on methane gas recovery systems, innovative cookstove technologies (used by millions in third-world countries), and other alternative technologies, such as fuel cells.

Air Pollution Prevention and Control ETV Pilot. In October 1997, ETV selected a partner organization for its Air Pollution Prevention and Control pilot. This effort will have both pollution prevention and pollution control technologies as foci. EPA began this effort with an in-house evaluation of emulsified boiler and diesel fuels in 1997. Emulsified fuels are designed to significantly reduce the release of NO_x into the air.

Source Water Protection ETV Pilot. ETV will address the important area of prevention approaches to support sustainable community development in its recently funded Source Water Protection pilot. This pilot, which will formally begin in 1998, will evaluate technologies that prevent contamination of ground and surface waters by technologies such as septic tanks, pipelines, agricultural runoff control, and storage tanks.

Resource Allocation and Emphasis

Goal III is an area of significant emphasis and is particularly important since it is a Presidential Initiative. For the past several years it has been supported as a line item in the annual budget appropriation passed by Congress. The ETV program has been maintained at a level of approximately $10M since FY 1996, but the need for this level of funding is expected to decrease over the coming years as private sector developers of effective pollution prevention technologies come to value, and pay for, verification services. ETV sector-specific programs are expected to become largely self-sustaining by 2005. Technical staff currently dedicated to this effort will remain involved throughout the life of the pilot program. and continue appropriate quality assurance activities. With a shift into the outreach and information dissemination phase of the program in the coming years, increased financial resources will be directed toward, and staffed with, expertise in technical information to develop and deliver research products through a variety of venues.

Goal IV: Conduct Research to Address the Economic, Social, and Behavioral Aspects of Pollution Prevention

Through its extramural grants program, ORD will sponsor economic, social, and behavioral research to improve decision making and foster the adoption of pollution prevention by the public and private sectors at all levels. The results of the grant-sponsored work will be integrated into the decision-making tools developed under Goal 1. ORD will also expand its in-house capabilities to better address economic considerations of implementing pollution prevention.

Objective: *Develop and integrate social science and socioeconomic information and research products into environmental decision making.*

Rationale

With the Agency moving from a command-and-control approach of protecting the environment to one which is more collaborative and community based, old mind sets and ways of doing business must change. As a part of this change, EPA requires an improved understanding of why individuals and organizations make the decisions they do regarding both human health and environmental protection. As other organizations embrace a preventive

approach that goes beyond improved housekeeping and easy fixes, the social, economic, and behavioral barriers to, and incentives for, pollution prevention must be understood. An improved understanding of the factors which are influential in moving individuals and organizations toward preventive risk management will be of invaluable assistance in the evolving dialogue on environmental sustainability, both in the corporate boardroom and at the community level.

Current Situation

ORD initiated a research and development program in the area of economic, social, and behavioral research in 1995 as part of its newly created extramural grants program. This program of extramurally funded social science research and development will continue for the next several years. Such a program is particularly important to the Agency since many of its policies and programs must take into account both the benefits and the costs associated with Agency policies, rules, and regulations. Non-technical (i.e., economic, social, behavioral) data and information are increasingly a part of Agency decision making and this will continue to be the case well into the future. Unfortunately, there is a paucity of reliable, scientifically-based socioeconomic tools and methodologies available to assist Agency decision makers in collecting, analyzing, and then understanding such data and information. Much of the research to date under this program has focused on economic research, including techniques for valuation of ecosystems and of human morbidity and mortality. Social science is needed as well, but most of this has focused on broad environmental issues not specifically pollution prevention. In the future a stronger emphasis is needed on issues related to pollution prevention and sustainable development particularly in the community context.

Research and Development Activities

Increased Emphasis — Develop economic, social, and behavioral tools to improve environmental policies and programs

There is a general lack of accepted tools for determining the benefits and costs associated with environmental problems and issues. The federal government and EPA in particular are required to conduct cost/benefit analysis for all major regulations and legislative initiatives including those pertaining to pollution prevention. Government agencies responsible for policy analysis, statutory rules, regulatory decision making, and priority setting for environmental actions, including pollution prevention, will benefit from a set of systematic and credible tools for estimating the economic and social benefits and costs of a given action or set of actions. ORD can assist in providing this information through extramural research and development in such areas as environmental economics, public policy, alternative approaches to regulations, and the sociological (individual and organizational behavioral) dimensions of human health and environmental protection. A research focus will be developed that emphasizes “sustainable communities,” linking economic, environmental, and social issues that surround community level decision-making.

Resource Allocation and Emphasis

Goal IV will continue to receive significant emphasis under this research strategy. Providing research and development products on the economic, social, and behavioral aspects of pollution prevention is important if prevention is to be an effective risk management option in the future. This type of research will become even more important for the Agency as it moves to a community-based approach for environmental protection in the coming years. Research related to socioeconomic sectors that influence decisions at the corporate, individual, and community levels will be given increased emphasis. While all of this work will be conducted through the extramural grants program, ORD will consider developing an in-house capability for social science research. A decision on staffing and the nature of the in-house research is reserved until the results of the extramurally funded projects for the first several years are available.

Chapter 4. Moving Forward to Implementation

This research strategy provides guidance and direction for ORD's Pollution Prevention Research and Development Program over the next five years. It is designed to be the first step in what will become a world-recognized, ORD capability in providing the tools, methodologies, technologies, and approaches for advancing pollution prevention in the context of sustainable development well into the 21st century. The next step is to develop and conduct projects meeting the "essential" and "desirable" criteria described in Chapter 2.

General Resource Trends

The enactment of the Government Performance and Results Act (GPRA) in 1994 and its implementation by EPA in FY 1999, places increased emphasis on goals and objectives which are measurable and achievable. With a greater emphasis on meeting the goals, objectives, and subobjectives identified by the Agency in response to GPRA, increased stability in resource allocation and budgeting is anticipated. Pollution prevention is part of the Agency's Sound Science Goal and is described under that goal's Pollution Prevention and New Technology (PPNT) Objective. All of the research and development activities described in this research strategy fall under one of several of the PPNT Subobjectives.

The actual allocation of resources for the various objectives and research and development activities described in this research strategy is not specifically defined at this time. However, it is reasonable to project trends based on the information that has been presented in Chapter 3 (Table 3). Ultimately, the ability to sustain a research and development program in pollution prevention under GPRA will depend on the outputs and outcomes (e.g., products, accomplishments) described in the implementation plan and whether or not specific milestones have been met in a timely manner. As with all types of research and development programs, environmental research and development can offer no guarantees of success. Therefore, the resource trends identified in Table 3 are projections subject to a number of influences both internal and external.

Engagement and Partnership

While not a key scientific or technical issue, it is clear that engagement and partnering with a variety of stakeholders will enhance the adoption of pollution prevention. Pollution prevention frequently works best when efforts at preventing pollution are collaborative, involving many individuals and organizations that have a stake in seeing it succeed. The Agency is moving from a command-and-control approach in protecting both human health and the environment to one that is based on environmental protection at the community level. As this happens, it becomes important for ORD to more fully engage a number of organizations in both the public and private sectors that are receptive to and supportive of pollution prevention research and development.

For pollution prevention to be adopted as the preferred approach for environmental protection, it is essential that ORD work more closely with individuals and organizations that are directly involved in the implementation of pollution prevention approaches. This is particularly true for organizations that are influential in advancing the concept and routine consideration and use of pollution prevention, in both the United States and around the World. This includes EPA's Program Offices and other stakeholders:

- Various industrial sectors in order to provide tools and technologies which employ pollution prevention in a variety of economic sectors to improve compliance, and then going "beyond compliance" where it makes environmental and economic sense.
- States, communities, and tribes, in order to better understand those situations at the community level where pollution prevention might best be employed. Implementation of the strategy will also raise the profile of pollution prevention as a routine part of the Agency's approach to community-based environmental decision making.
- Federal organizations, in order to identify what research and development is needed to enhance the use of pollution prevention at federal facilities. Implementation of the strategy will also stress testing pollution prevention tools, methodologies, technologies, and approaches at government sites where they can be evaluated in real-world settings.
- The international community, in order to exchange information on pollution prevention research and development and its implementation. Implementation of the strategy will also provide perspectives on what other countries are doing to advance pollution prevention in the broader context of sustainable development, including the International Organization for Standardization's ISO 14000 standards for environmental management.

Delivery of Research and Development Results

ORD will strive to deliver its pollution prevention research and development results to the broadest pos-

Table 3. Pollution Prevention Resource Trends for the Next Five Years (FY 1999 - 2003)

GOALS, OBJECTIVES, AND RESEARCH ACTIVITIES	ACTIVITY STATUS	RESOURCE TRENDS
Tools and Methodologies		
Tools and methodologies that are user friendly		
1. Integrate risk assessment and risk management	New Activity	Increasing
2. Develop broadly applicable tools and methodologies	Increased Emphasis	Increasing
3. Develop targeted tools and methodologies	Continued Emphasis	Steady
Technologies and Approaches		
Advanced, environmentally benign approaches		
1. Advance Green chemistry for pollution prevention	Continued Emphasis	Steady
2. Advance Engineering for pollution prevention	Continued Emphasis	Steady
3. Improve Measurement, assessment, and feedback techniques	Continued Emphasis	Steady
Technologies and approaches that target problems		
1. Address problems associated with global warmers	Continued Emphasis	Steady
2. Address problems associated with VOCs and HAPs	Continued Emphasis	Steady
3. Address problems associated with products used indoors	Increased Emphasis	Increasing
Pollution prevention for Agency and Program Office priorities		
1. Address small companies that pose high risks	Continued Emphasis	Steady
2. Support Agency pollution prevention activities	Continued Emphasis	Steady
Performance Verification		
Performance verification of pollution prevention products and technologies		
Verify commercial-ready products, technologies, process changes	Continued Emphasis	Decreasing
Social Science		
Research to address the economic, social, and behavioral aspects of pollution prevention		
Develop economic, social, and behavioral tools	Increased Emphasis	Increasing

sible audience. The goal is to enhance the access to, and use of, pollution prevention tools, methodologies, technologies, and approaches. To this end, ORD will use electronic technology (e.g., Internet home pages, distance learning) to the maximum extent possible. Electronic delivery offers a cost-effective, widely available means of delivering data, information, and results that can be easily accessed by both the public and private sectors. Pollution prevention research and development results developed by ORD will be designed to be available electronically, and ORD intends to be a major provider of pollution prevention research and development products via the Internet.

ORD will also utilize pollution prevention technical assistance organizations and industrial trade and professional organizations to transfer results. These organizations include the National Pollution Prevention Roundtable (NPPR), NIST Manufacturing Extension Partnerships (MEPs), the Business Roundtable (an organization of

chief executives of the largest U.S. corporations), the Small Business Assistance Programs and Small Business Development Centers. Examples of trade and professional organizations are the American Institute of Chemical Engineers, the American Electroplaters and Surface Finishers Society, the Air and Waste Management Association, and the Chemical Manufacturers Association.

A third and very important mechanism of results transfer is the establishment of cooperative research and development agreements (CRADAs) with private sector partners. By having these agreements in place with ORD for research products, companies can have exclusive rights to newly developed pollution prevention technologies. The profit motive provides strong incentives to companies with CRADA rights covering promising technologies and tools, to disseminate them through commercialization. Private sector companies are also likely to have skills in advertising new technologies and the necessary credibility with potential users.

Implementation of this Research Strategy

This research strategy stresses the importance that pollution prevention can play in addressing high-priority human health and environmental risks. It does so within a framework that is both visionary and pragmatic. It is visionary in terms of seeing pollution prevention's role in sustainable development, and it is pragmatic through its orientation to meeting the more immediate needs of ORD's important stakeholders, the Program Offices and Regions. Over the next five years, ORD will continue on the path laid out in this research strategy for performing research to identify pollution prevention solutions to environmental problems. In addition, as new areas of possible research present themselves within this timeframe, ORD will use the "essential" and "desirable" criteria expressed in this strategy to evaluate whether its involvement is appropriate.

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Appendix I

EPA's Definition of Pollution Prevention (Habicht, 1992).

Under section 6602 (b) of the Pollution Prevention Act of 1990, Congress established a national policy that:

- pollution should be prevented or reduced at the source whenever feasible;
- pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible;
- pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and
- disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner.

Pollution prevention means "source reduction," as defined under the Pollution Prevention Act, and other practices that reduce or eliminate the creation of pollutants through:

- increased efficiency in the use of raw materials, energy, water, or other resources, or
- protection of natural resources by conservation.

The Pollution Prevention Act defines "source reduction" to mean any practice which:

- reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and
- reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants.

The term includes: equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control.

Under the Pollution Prevention Act, recycling, energy recover, treatment, and disposal are not included within the definition of pollution prevention. Some practices commonly described as "in-process recycling" may qualify as pollution prevention. Recycling that is conducted in an environmentally sound manner shares many of the advantages of prevention—it can reduce the need for treatment or disposal, and conserve energy and resources.

In the agricultural sector, pollution prevention approaches include:

- reducing the use of water and chemical inputs;
- adoption of less environmentally harmful pesticides or cultivation of crop strains with natural resistance to pests; and
- protection of sensitive areas.

In the energy sector, pollution prevention can reduce environmental damages from extraction, processing, transport, and combustion of fuels. Pollution prevention approaches include:

- increasing efficiency in energy use;
- substituting environmentally benign fuel sources; and
- design changes that reduce the demand for energy.

Appendix II

Pertinent Data on TRI Chemicals Extracted from the Toxics Release Inventory (EPA, 1996b).

1. A total of 2.26 billion pounds of listed chemicals were released with approximately 1,556 million pounds released to the air (68.8%), 349 million pounds released underground (15.4%), 289 million pounds released to the land (e.g., landfills, surface impoundments) (12.8%), and 66 million pounds released to surface waters (e.g, rivers, lakes, streams) (2.9%).

2. A total of 3.8 billion pounds of listed chemicals were transferred to off-site locations with approximately 2,456 million pounds being sent for recycling (64.7%), 464 million pounds being sent for energy recovery (12.2%), 319 million pounds sent for treatment (8.4%), 298 million pounds sent for disposal (7.8%), and 255 million pounds sent to publicly-owned treatment works (6.7%).

3. The chemical industry (851 million pounds) and the primary metals industry (313 million pounds) were first and second in total releases in 1994, and their order reversed (primary metals - 1,142 million pounds and chemical industry (989 million pounds) for transfers.

4. Examples of chemicals released to the air — methanol, toluene, ammonia, and xylene, released underground — hydrochloric acid, ammonium nitrate (solution), ammonia, and methanol, released to surface waters — phosphoric acid, ammonia, methanol, ammonium nitrate (solution), and released to the land — zinc compounds, phosphoric acid, copper compounds, and manganese compounds.

5. The top ten carcinogens with the largest air/water/land releases were in descending order of quantity: dichloromethane, styrene, acetaldehyde, formaldehyde, chloroform, tetrachloroethylene, benzene, 1,3 butadiene, 1,2 dichloroethane, and chromium for a total release of approximately 177 million pounds.

6. A total of 26.5 billion pounds of TRI chemicals in wastes were managed by facilities in the following ways: treated on-site — 8,659 million pounds (32.6%), recycled on-site — 8,407 million pounds (31.7%), energy recovery on-site — 3,423 million pounds (12.9%), 2,515 million pounds released or disposed of — 2,515 million pounds (9.5%), recycled of-site — 2,517 million pounds — (9.5%), treated off-site — 557 million pounds (2.1%) and energy recovery off-site — 469 million pounds — 1.8%).

7. Examples of chemicals involved in: recycling — sulfuric acid (acid aerosols), copper, toluene, and lead compounds, treatment — hydrochloric acid, sulfuric acid(acid aerosols) methanol, ammonia, energy recovery — ethylene, propylene, methanol, mixtures and other trade names, and release/disposal — methanol, hydrochloric acid, ammonia, toluene.

8. Thirty-two percent of all TRI facilities reported at least one source reduction (pollution prevention) activity in 1994 with reductions attributed to good operating practices, inventory control, spill and leak prevention, raw material modifications, process modifications, cleaning and degreasing, surface preparation/finishing, and product modifications.

9. Since 1988, EPA's baseline year for TRI comparisons, releases have declined by 44.1% with the chemical industry reducing releases by 622 million pounds, multiple codes by 304 million pounds and primary metals industry by 202 million pounds.

10. The total releases from federal facilities was approximately 9.8 million pounds with 83.7% released to air, 9.2% released to land, 4.5% injected underground, and 2.5% released to surface waters. The Department of Defense released 72.7% of the total releases followed by the Department of Energy at 9.9%, the U.S. Enrichment Corporation at 7.6%, the Department of Agriculture at 5.8% and Others at 4.0%.

11. A total of 10.4 million pounds of listed chemicals transferred to off-site locations with approximately 5.2 million pounds being sent for recycling (50.1%), 0.6 million pounds being sent for energy recovery (5.7%), 1.6 million pounds sent for treatment (15.7%), 2.7 million pounds sent for disposal (25.5%), and 0.3 million pounds sent to publicly-owned treatment works (3.0%). Of this amount, 94.5% of the transfers were by the Department of Defense of which 71.0% of that amount was by Army facilities.

12. A total of 30.0 million pounds of TRI chemicals in wastes were managed by federal facilities in the following ways: treated on-site — 6.3 million pounds (21.0%), recycled on-site — 4.1 million pounds (13.7%), energy recovery on-site — 0.6 million pounds (2.1%), released or disposed of — 11.5 million pounds (38.5%), recycled of-site — 4.8 million pounds — (16.0%), treated off-site — 2,1 million pounds (6.9%) and energy recovery off-site — 0.5 million pounds — 21.0%).

13. Federal facilities projected a decline in TRI chemicals in wastes to 24.4 million pounds by 1996. Forty-eight percent of all federal facilities reported undertaking at least one source reduction activity in 1984.

Appendix III

Potential Adverse Human Health and Environmental Effects of the Top 25 TRI Chemicals with the Largest Air/Water/Land Releases, 1994 (EPA, 1996b).

CAS No. (1)	Chemical	Health Effects: Acute	Health Effects: Cancer (2)	Health Effects: Chronic	Health Effects: Developmental	Health Effects: Reproductive	Health Effects: Neurotoxicity	Environmental Effects: Other (3)	Environmental Effects: Ecotoxicity	Smog Formation	Ozone Depletion
67-56-1	Methanol			✓				✓			
7664-41-7	Ammonia	✓								✓	
108-88-3	Toluene						✓			✓(4)	
1330-20-7	Xylene (mixed isomers)									✓(4)	
75-15-0	Carbon disulfide			✓	✓	✓	✓				
---------	Zinc compounds	✓		✓	✓					✓	
78-93-3	Methyl ethyl ketone									✓	
7664-38-2	Phosphoric acid									✓	
7647-01-0	Hydrochloric acid	✓(5)		✓(6)							
75-09-2	Dichloromethane		✓	✓			✓				
7782-50-5	Chlorine	✓								✓	
---------	Glycol ethers	✓		✓	✓	✓					
---------	Copper compounds	✓		✓						✓	
---------	Manganese compounds	✓		✓			✓			✓	
100-42-5	Styrene		✓				✓				
71-55-6	1,1,1-Trichloroethane										✓
74-85-1	Ethylene							✓			✓
79-01-6	Trichloroethylene		✓								
71-36-3	n-Butyl alcohol			✓							
108-10-1	Methyl isobutyl ketone			✓				✓			✓
7664-93-9	Sulfuric acid (acid aerosols)			✓						✓	
---------	Chromium compounds	✓	✓(7)	✓	✓	✓				✓	
115-07-1	Propylene										✓
463-58-1	Carbonyl sulfide	✓						✓			
---------	Lead compounds	✓	✓(8)	✓	✓	✓	✓			✓	

Source of Data (9)

(1) Compound categories do not have CAS numbers (----).

(2) Distinctions among cancer classifications are discussed in the OSHA carcinogen section of this chapter.

(3) Toxicity resulting from the metabolite or degradation product of the parent compound.

(4) Contributes to ozone formation in the lower atmosphere; however, the extent of contribution to smog formation is unknown.

(5) Concentrated solutions are corrosive.

(6) Aerosol forms.

(7) Chromium VI is carcinogenic.

(8) Inorganic compounds.

(9) Sources: Integrated Risk Management System, Hazardous Substances Data Bank, PPT's Background Documents for Chemical Fact Sheets, EPCRA Section 313 Responses to Petitions, Agency for Toxic Substances and Disease Registry's *Toxicological Profiles*, and *Environmental Health Perspective*, Vol. 37, 1984.

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