United States
Environmental Protection
Agency

EPA 600/S 07/001 | October 2007 | www.epa.gov/sustainability

Sustainability Research Strategy




EPA 600/S-07/001 | October 2007

Sustainability Research Strategy

Office of Research and Development
U.S. Environmental Protection Agency
Washington, D.C.

To download this report
and learn more about
EPA programs
that support
sustainability,
please visit
www.epa.gov/sustainability

Foreword

Within the U.S. Environmental Protection Agency, the Office of Research and Development (ORD) has a central role in identifying, understanding, and helping to solve current and future environmental problems. The Sustainability Research Strategy (SRS) describes ORD's approach to some of the most pressing current and future national environmental issues. Science and technology are two key elements in ensuring that people understand the full environmental implications of their actions and will help ensure that sound decisions are made by individuals, communities, companies, and government agencies. ORD presents this Sustainability Research Strategy to improve understanding of the earth's natural and man-made systems, to assess threats to those systems, and to develop and apply new technologies and decision support tools.

The focus on sustainability research recognizes the changing nature of environmental challenges that society faces today. In the past EPA focused its actions more directly on specific pollutants, their sources, and causes. More recently, and into the future, the Agency must provide information to help address a broader set of environmental issues involving population and economic growth, energy use, agriculture, and industrial development. Capably addressing these questions, and the tradeoffs they will entail, requires the new systems-based focus on science and analysis outlined in the Sustainability Research Strategy.

EPA is an agency with a strong internal research capability. The ability to directly link research and policy in one agency puts EPA in a good position to lead on environmental sustainability. ORD leads the research element in that linkage; by thinking and operating strategically, it plays a vital part in forming and driving the policy element. This research strategy recognizes that system-wide thinking is required to ensure our goal of promoting and achieving environmentally sustainable decisions at home and around the world.

George Gray
Assistant Administrator for Research and Development

Acknowledgments

We acknowledge and thank the drafting team of Gordon Evans, Douglas Young, Heriberto Cabezas, Michael Gonzalez, Frank Princiotta, Cynthia Gage, and Tim Johnson (National Risk Management Research Laboratory); Diana Bauer and Julie Zimmerman (National Center for Environmental Research); Anita Street (Office of Science Policy); and Donna Perla, Richard Iovanna, and Edward Fallon (Office of the Assistant Administrator) for preparing this research strategy.

Gary J. Foley
Director, National Center for Environmental Research

Sally Gutierrez
Director, National Risk Management Research Laboratory

Alan D. Hecht
Director, Sustainable Development

Peer Review History

Peer review is an important component of developing a research strategy. The following is the peer review history for this document:

Office of Research and Development Science Council
September 7, 2005

EPA Science Policy Council
November 21, 2005

External Peer Review Science Advisory Board (SAB):
June 13-15, 2006

Environmental Engineering Committee Augmented for Sustainability Advisory
Dr. Michael J. McFarland, Utah State University, Logan, UT, Chair

Chartered SAB Members
Mr. David Rejeski, Woodrow Wilson International Center for Scholars, Washington, DC
Dr. Thomas L. Theis, University of Illinois at Chicago, Chicago, IL
Dr. Valerie Thomas, Georgia Institute of Technology, Atlanta, GA

Members of the Environmental Engineering Committee
Dr. Viney Aneja, North Carolina State University, Raleigh, NC
Dr. David A. Dzombak, Carnegie-Mellon University, Pittsburgh, PA
Dr. T. Taylor Eighmy, University of New Hampshire, Durham, NH
Dr. Michael Kavanaugh, Malcolm Pirnie, Inc., Emeryville, CA
Dr. Catherine Koshland, University of California, Berkeley, Berkeley, CA
Dr. Reid Lifset, Yale University, New Haven, CT
Dr. Mark Rood, University of Illinois, Urbana, IL
Dr. John R. Smith, Alcoa Technical Center, Alcoa Center, PA

Member of SAB Ecological Processes and Effects Committee
Dr. William Mitsch, Ohio State University, Columbus, OH

Member of SAB Environmental Economics Advisory Committee
Dr. Anna Alberini, University of Maryland, College Park, MD

Peer Review Coordinator
Ms. Kathleen White, Designated Federal Officer, EPA SAB Staff, Washington, DC

Acronyms

BOSC	Board of Scientific Counselors
CNS	Collaborative Science and Technology Network for Sustainability
EDS	Environmental and Decision Sciences
EERS	Environmental Economics Research Strategy
GEOSS	Global Earth Observation System of Systems
ISA	Integrated Systems Analysis
LCA	Life Cycle Assessment
LTG	Long-Term Goals
MFA	Material Flow Analysis
MYP	Multi-Year Plan
NACEPT	National Advisory Committee for Environmental Policy and Technology Policy
NEPA	National Environmental Protection Act
NPD	National Program Director
ORD	Office of Research and Development
P3	People, Prosperity, and Planet Student Design Program
RoE	Report on the Environment
SAB	Science Advisory Board
SRS	Sustainability Research Strategy
STS	Science and Technology for Sustainability

Table of Contents

Executive Summary

Chapter 1. Introduction and Purpose

We make decisions on a daily basis that affect the quality of our own lives as well as the lives of future generations. These decisions determine how sustainable our future will be. To assist governments, businesses, communities, and individuals in making sustainable choices, our Sustainable Research Strategy aims to develop an understanding of the earth as a natural system and craft models and tools to support sustainable decision making. Our strategy incorporates both core research that advances fundamental understanding of key biological, chemical, and physical processes underlying environmental systems, and problem-driven research that targets specific environmental problems or customer needs. The research strategy draws on and integrates across the many research programs within the Office of Research and Development and focuses this research to support sustainable decision making.

Chapter 2. Rationale for the Strategy

A combination of forces—including unprecedented growth in population, economy, urbanization, and energy use—are imposing new stresses on the earth's resources and society's ability to maintain or improve environmental quality. In order to improve environmental protection, human health, and living standards, our generation must move to mitigate or prevent the negative consequences of growing population and economy. The increasing stresses require new approaches to environmental protection that go beyond end-of-pipe control strategies concerned principally with pollutant emissions. Based on our understanding that environmental problems are rarely contained within a single resource or geographic area, we must develop and implement integrated and systems-based approaches to meet society's needs today and ensure a more sustainable future.

Chapter 3. Definition and Scope

The concept of sustainable development marries two important insights: environmental protection does not preclude economic development; and economic development must be ecologically viable now and in the long run. Sustainable development, which requires an integration of economic, social, and environmental polices, cannot be achieved by any single federal agency, because it relies on policy coherence across government agencies. EPA's contribution to sustainability is to protect human health and the environment for both this and future generations. Our Sustainability Research Strategy rests on the recognition that sustainable environmental outcomes must be achieved in a systems-based and multimedia context that focuses on the environment without neglecting the roles of economic patterns and human behavior. This recognition begets a fundamental change in research design. In a systems-based approach, the traditional goals of achieving clean air or water or protecting ecosystems and human health can be fully understood only through a multimedia approach. EPA and its partners will develop integrating decision support tools (models, methodologies, and technologies) and supporting data and analysis that will guide decision makers toward environmental sustainability and sustainable development.

Chapter 4. Six Research Themes

Emphasizing an integrated and systems-based approach to achieving sustainability, we focus on six broad research themes.

1. Renewable Resource Systems. The sustainability of natural systems is critical to protecting human health, supporting our economy, and maintaining our quality of life. Sustainability demands that we determine how best to obtain the benefits that renewable resources provide, while considering the system-wide effects their use has on the regenerative capacity of the entire system. Three of our research strategy aims are especially relevant to renewable resources: (1) defining clear measures of sustainable renewable systems, (2) improving understanding of ecosystem processes and services, and (3) developing and applying advanced systems models and tools for decision making.

2. Non-Renewable Resource Systems. The extraction, processing, and use of fossil fuels, minerals, and other materials are critical elements of our economic life. Sustainability calls for greater conservation and efficient use of these non-renewable resources, as well as greater reliance on renewable energy, development of substitutes for toxic and dangerous materials, and an emphasis on management of materials rather than disposal of waste products. Our strategy seeks to promote sustainable management of non-renewable resource operations and to support the shift to renewable resources. The research will include life cycle assessment and material flow analysis; application of models to assess the regional impacts of various energy sources on emissions and air quality; and development of alternative chemicals and new industrial methods. Climate change research and assessment, a major global sustainability issue, will continue to be a collaborative effort of many programs at EPA and other agencies.

3. Long-Term Chemical and Biological Impacts. The intergenerational dimension of sustainability means that society must be mindful of the long-term threat posed by chemical and biological impacts on the environment. Improving our use of materials, shifting to environmentally preferable materials, and protecting human health all rely on assessing and eliminating the long-term impacts posed by harmful chemical and biological materials. Our research will aim to develop alternate chemicals and new industrial processes, as well as decision support tools for evaluating the environmental dimensions of the new chemicals and processes. It will also employ life cycle assessment and material flow analysis to evaluate environmental releases from industrial systems and nanomaterials.

4. Human-Built Systems and Land Use. The growth of urbanized areas over the past century has shown that human-built systems can significantly harm ecosystems and undermine their ability to provide critical services. This strategy will include research on topics such as sustainable building design and efficiency, management of urban systems, life cycle assessment for building design and land use, and decision support tools for urban land development and revitalization. ORD scientists and engineers will work directly with key customers and stakeholders who can most benefit from our research capabilities in these areas—such as those at state and local levels responsible for myriad decisions on urban development, land use, and provision of public services.

5. Economics and Human Behavior. Since the sustainable management of natural and man-made systems depends on human behavior and choice, our research strategy is closely linked with research in economics and behavioral science, such as developing ecosystem valuation methods and analyzing the role of incentives in decision making and the causes of market failures. Research in this area is led by ORD's Economics and Decision Science Research Program. Activities in the Sustainability Research Strategy will be closely coordinated with this program.

6. Information and Decision Making. The establishment of an information infrastructure of sustainability metrics and environmental monitoring is a necessary component of any strategy advancing sustainability. EPA's *Draft Report on the Environment (RoE)* provides snapshots of the existing environmental state. Metrics are defined in relation to clearly stated questions such as, "What are the conditions and current trends of surface waters?" and, "What are the trends in the ecological processes that sustain the nation's ecological systems?" As EPA moves toward identifying a set of clearly articulated questions related to sustainable outcomes—such as, "How sustainable are the nation's water supplies?"—research can focus on identifying appropriate indicators and ensuring their quality. Our strategy is also closely linked with the Global Earth Observation Systems of Systems (GEOSS) program. GEOSS will effectively take the pulse of the planet by compiling a system of all relevant databases (or systems), thus revolutionizing our understanding of how the earth works. Over time, GEOSS will contribute greatly to sustainability by providing important scientific information for sound policy and decision making in every sector of society.

Chapter 5. Research Objectives

The five principle research objectives of our research strategy represent areas of strong ORD competence. Our research aims first to advance systems understanding—to better comprehend the interconnections, resilience, and vulnerabilities over time of natural systems, industrial systems, the built environment, and human society. Second, our research aims to further develop decision support tools to assist decision makers. A third key element of our strategy is to develop and apply new technologies to address inherently benign and less resource-intensive materials, energy sources, processes, and products. Fourth, our research is committed to collaborative decision making. We aim to develop an understanding of motivations for decision making and to craft approaches to collaborative problem solving. Fifth and finally, our research strategy emphasizes developing metrics and indicators to measure and track progress toward sustainability goals, to send early warning of potential problems to decision makers, and to highlight opportunities for improvement

Chapter 6. Roadmap for Implementation

Our Sustainability Research Strategy builds on ORD's traditional focus on risk assessment and risk management and dovetails with EPA's commitment to stewardship and sustainable outcomes. The strategy supports shifts by program offices toward developing sustainable water infrastructure, managing materials rather than waste, managing ecosystems and ecoservices, and emphasizing green chemistry and urban sustainability (including green building design and low-impact development). To implement this research strategy we will take the following steps:

- Demonstrate the value of sustainability research by identifying key national issues where application of sustainability approaches can be most effective in promoting sound and sustainable economic growth.
- Advance core sustainability research and development of new tools and methodologies by transitioning the current Pollution Prevention and New Technologies Research Program into the Science and Technology for Sustainability Research Program.
- Leverage all ORD resources by coordinating and integrating research across ORD that builds a critical knowledge base for sustainability, such as identifying synergies, gaps to be filled, and high-priority emerging areas among existing research strategies.
- Leverage all EPA resources by coordinating and strengthening collaborations and partnerships—with EPA program and regional offices, other federal agencies, state and local governments, communities, industry, nonprofit organizations, universities, and international partners—that address critical sustainability issues and stimulate broader progress toward sustainability in both research and implementation.

Chapter 1. Introduction and Purpose

This chapter relates the Sustainability Research Strategy to the mission of the Office of Research and Development and describes the research strategy's goals, outcomes, and organization.

Sustainability and the ORD Mission

From the perspective of the Office of Research and Development, the science of sustainability is developing the underlying knowledge base that allows decision makers to make sustainable choices. For natural resource managers, this means how to manage our resources to provide maximum services today and in the future. For urban planners, this means how to build cost-effective and efficient urban systems that protect both human health and the environment. For decision makers in industry, this means how to enhance economic growth while minimizing industry's footprint on the environment. The science of sustainability aims to anticipate problems and promote innovation. A 1997 National Academy of Engineering report suggests the path to sustainability "involves the creative design of products, processes, systems and organizations, and the implementation of smart management strategies that effectively harness technologies and ideas to avoid environmental problems before they arise."[1]

ORD conducts cutting-edge research and fosters the use of sound science and technology to fulfill the Agency's mission of protecting human health and safeguarding the natural environment. ORD research is a mix of (1) *core research* that seeks to advance fundamental understanding of key biological, chemical, and physical processes that underlie environmental systems; and (2) *problem-driven research* that focuses on specific environmental problems or customer needs. The Sustainability Research Strategy encompasses both core and problem-oriented research, aiming first at understanding biological, physical, and chemical interactions through a systems approach; and second, developing effective models, tools, and metrics that enable decision makers to achieve sustainable outcomes.[2]

This important goal of helping society make good decisions was identified by the 1998 House Committee on Science report, *Unlocking Our Future*:

> While acknowledging the continuing need for science and engineering in national security, health and the economy, the challenges we face today cause us to propose that the scientific and engineering enterprise ought to move toward center stage in a fourth role; that of helping society make good decisions. We believe this role for science will take on increasing importance, as we face difficult decisions related to the environment.[3]

Recent external reviews of two other ORD research programs have re-emphasized the theme of this congressional guidance. The 2005 reviews by ORD's Board of Scientific Counselors (BOSC) of the Ecological Research Program and Global Change Research Program both emphasized a need for activities that lead to "wise decision-making" and that are "demand-driven and participatory."[4]

---

1 National Academy of Engineering. *The Industrial Green Game: Implications for Environmental Design and Management*. Washington: National Academies Press, 1997

2 National Research Council, *Building a Foundation for Sound Environmental Decisions*. Washington: National Academies Press, 1997.

3 *Unlocking Our Future: Toward a New National Science Policy*. Washington: House Committee on Science. September 24, 1998.

4 The BOSC review of ORD's Global Change Research Program noted: "Two underlying themes have surfaced in the Program's approach to its work. The first is that its emphasis now and for the future should be on decision support—improving the ability of those who control actions to make wise choices in the face of global change through provisions of useful research and activities. The Subcommittee concludes that this is the right emphasis and that it should be a guiding star for the efforts of this Program. The second emphasis is on stakeholder involvement—being 'demand-driven' and participatory." Board of Scientific Counselors, *Review of the Office of Research and Development's Global Change Research Program at the U.S. Environmental Protection Agency: Final Report.* (March 27, 2006). www.epa.gov/OSP/bosc/pdf/glob0603rpt.pdf

Purpose of the Strategy

Recognizing its responsibility to lead EPA in science applications for decision making, ORD management identified two objectives for this research strategy:

- Develop a crosscutting sustainability research plan that will tie together the ORD multi-year plans (MYPs) that concern component parts of sustainability; and
- Develop a revised MYP for Pollution Prevention (P2), entitled "Science and Technology for Sustainability," that will identify new annual and long-term goals and annual performance outcome measures to better focus pollution prevention and innovative technology on sustainability.

In moving to establish an integrated sustainability research program across ORD, management recognizes three challenges: (1) defining clear and comprehensive sustainability goals that are meaningful to EPA and that connect the dots among existing ORD research strategies; (2) initiating and leveraging new activities within a limited range of budget options; and (3) overcoming a tradition of media-specific ("stovepipe") approaches to environmental problems.

Through this strategy, ORD aims to address these challenges by defining sustainability within EPA and identifying research priorities and management steps necessary to achieve the dual national goals of supporting a growing economy and advancing environmental protection.

Stakeholder Input and Strategy Goals and Outcomes

This Sustainability Research Strategy was derived from input gathered through internal and external activities:

- Consultation with regional and program offices on the types of research that can provide the greatest benefit to their programs,
- Recommendations of the EPA Science Advisory Board (SAB) and Board of Scientific Counselors (BOSC),
- Review of the sustainability research literature and consultation with outside experts,
- Review of EPA-sponsored workshops related to sustainability, and
- Review and consultation with other national governments, the European Commission, and multilateral organizations.

Economic Benefits

The economic benefits of applying sustainable management practices for current and future energy construction, greenhouse gas emissions, material and chemical use, ecosystems services, and health protection are only now being fully appreciated. For example, by 2030 new and replacement building development will amount to 204.1 billion square feet, equal to almost 90 percent of the built space that existed in 2000. All of this amounts to about $30 trillion in total new development (including infrastructure) that will occur between 2000 and 2030. A new focus on biofuels as an energy source will demand new infrastructure and transportation systems in nearly all ecozones of the United States. Rebuilding the aging U.S. water infrastructure will translate into billions of dollars. EPA's *Clean Water and Drinking Water Infrastructure Gap Analysis* (2002)[5] estimated that if capital investment and operations and maintenance remain at current levels, the potential funding shortfall for drinking water and wastewater infrastructure could exceed $500 billion by 2020.

[5] www.epa.gov/waterinfrastructure

Aiming to affect present and future economic development and encourage sound taxpayer and public investment, the research strategy seeks to advance these goals:

- Improve understanding of earth systems to better protect human health, manage natural resources, and design cost-effective and sustainable policies;
- Enable EPA, states, and communities to more successfully envision, plan, develop, manage, and restore their infrastructure and spaces so that human health and quality of life, and the quality of air, water, and land are protected for the future; and
- Design, manufacture, and manage chemicals and materials so as to protect the environment and public health, prevent pollution, and conserve resources, while advancing global competitiveness and societal objectives.

Criteria for measuring the success of this research strategy and the companion ORD MYPs are outlined in Goal V of the *2006-11 EPA Strategic Plan*.[6]

Goal V of the EPA Strategic Plan for 2006-2011

Objective 5.4: Enhance Society's Capacity for Sustainability through Science and Research. Conduct leading-edge, sound scientific research on pollution prevention, new technology development, socioeconomics, sustainable systems, and decision-making tools. By 2011, the products of this research will be independently recognized as providing critical and key evidence in informing Agency polices and decisions and solving problems for the Agency and its partners and stakeholders

Sub-objective 5.4.2: Conducting Research. Through 2011, conduct leading-edge, sound scientific research on pollution prevention, new technology development, socioeconomics, sustainable systems and decision-making tools. The products of this research will provide critical and key evidence in informing Agency policies and decisions affecting the Agency programs in Goal 5, as well as EPA partners and stakeholders.

---

6 www.epa.gov/ocfo/plan/plan.htm

7 www.epa.gov/indicators/roe

Chapter 2. Rationale for the Strategy

A host of far-reaching, interrelated, and complex factors—such as growing human populations, increases in waste production, growing energy demands, and land development—are all contributing to stresses on the earth's natural systems. Protecting human health and safeguarding the natural environment in the face of these stressors is a national priority—and a daunting challenge.

To meet this challenge, EPA's Sustainability Research Strategy explores an integrated, scientific approach to defining and achieving sustainability goals in six key natural resource systems: energy, air, water, materials, land, and ecosystems.

Given the breadth of existing ORD research activities, this chapter explains the rationale for the new strategy, concluding that a more crosscutting and system-oriented research strategy is needed to address existing and emerging environmental problems.

Externalities Affecting the Environment

Water, air, land, and energy research are interrelated and affected by a host of externalities related to economic growth, demographic changes, and energy use. Economic growth is essential for maintaining social well-being; how this growth is achieved determines a society's quality of life. Most countries have clearly learned that sustainable environmental polices are an essential component of sound economic growth. Research that supports this goal is thus an area of national priority.

When EPA was founded in 1970, the U.S. population was just over 203 million; in 2006 it reached 300 million, reflecting a 35-year increase of nearly 50 percent. This growth, however, has not been distributed evenly. About one-third of the U.S. population resides in the 17 Western states, which include seven of the nation's 10 fastest growing states. Through 2030 the population of the Southwest is projected to increase as a proportion of the U.S. population. The population increase has already greatly affected the allocation and use of resources. Approximately one acre of land becomes urbanized or otherwise developed for each additional U.S. inhabitant. Many Western and Southwestern states with rapidly expanding population are also experiencing urban expansion, increasing energy demand, and diminishing water resources.[8] The U.S. population is also aging, thereby creating new needs for health and human services. These changes require a heightened awareness of potential future challenges, especially increasing demand for water and energy in much of the nation.

World population and economic growth will expand rapidly during the coming decades. Global population is expected to increase by nearly 40 percent by 2050. By 2030 more than 60 percent of the world's population will live in cities, many in Africa, Asia, and Latin America, where the urban populations will grow from 1.9 billion people to 3.9 billion people. Economic growth in the "BRIC" countries (Brazil, Russia, India, and China) will significantly impact future global and trans-boundary environmental issues. Over the next 30 years, while the U.S. per capita GDP is expected to increase by 60 percent, the per capita GDP in China and India is projected to increase nearly tenfold.[9] Together these changes will place considerable stress on the earth's resources and on humanity's ability to maintain or improve environmental quality. Unless steps are taken to address the consequences of growing populations and economies, the resilience of the global ecosystem will be undermined. The challenge is to prevent or minimize the potential negative consequences.

8 Population data is taken from Mark T. Anderson and Lloyd H. Woosley, Jr., *Water Availability in the Western United States*. U.S. Geological Survey Circular 1261. Washington: USGS, 2005. http://pubs.usgs.gov/circ/2005/circ1261

9 Dominic Wilson and Roopa Purushothaman, *Dreaming with BRICS: The Path to 2050*. Goldman Sachs Global Economics Paper No. 99. October 2003. www.gs.com/insight/research/reports/report6.html

Table 2.1. Proposed Sustainable Outcome Measures [10]

Natural Resource Systems	Sustainable Outcomes
Energy	Generate clean energy and use it efficiently.
Air	Sustain clean and healthy air.
Water	Sustain water resources of quality and availability for desired uses.
Materials	Use materials carefully and shift to environmentally preferable materials.
Land	Support ecologically sensitive land management and development.
Ecosystems	Protect and restore ecosystem functions, goods, and services.

Achieving Sustainability

This challenge means that achieving sustainable environmental outcomes must be a long-term national environmental goal. This is a key goal of the new EPA report, *Everyday Choices: Opportunities for Environmental Stewardship*, in which senior EPA managers identify sustainable outcomes in six resource systems relevant to the Agency's mission. The report is the first explicit statement of EPA senior leadership focused on recommendations for sustainability outcomes that the nation should seek. While much more discussion and debate will be needed to refine these goals, the report's linkage of stewardship with sustainable outcomes has set a direction for future policy development and research. The sustainable outcomes outlined in the report are listed in Table 2.1.

The possibility of achieving these outcomes will be greatly affected by the trends presented in Table 2.2. For example, growing population and GDP will significantly impact the six resource systems. Population increases will affect how and where land is developed and thus the viability of ecosystems. Population growth has historically led to increased use of energy, water, and materials—and increased production of waste, leading to greater pollution of air, water, and land, with associated negative consequences for ecosystems and human health.

Economic growth has usually required greater quantities of energy, materials, and water from expanded agriculture and industry, leading to more waste, toxics, and pollution of air and water. The land and ecosystems change as materials are extracted, goods produced, infrastructure built, and wastes disposed of.

EPA's 2003 and 2007 draft reports on the environment outlined U.S. successes in environmental protection and identified many remaining challenges and data gaps. Table 2.2 lists examples of trends identified in this report for each of the six resource areas, revealing a few of the many potential stresses stemming from the expected U.S. population and economic growth. Other potential impacts of stressors on the environment have been identified through a survey of EPA senior program officers and from external future studies.[11]

[10] *Everyday Choices: Opportunities for Environmental Stewardship*, Innovation Action Council Report to the Administrator, November 2005. www.epa.gov/epainnov/pdf/rpt2admin.pdf

[11] www.epa.gov/indicators

Table 2.2. Potential Consequences of Growing U.S. Population and GDP

Natural Resource Systems	Current Trends [12]	Consequences Projected Over 20 Years
Energy	In the last 30 years energy consumption has increased by 42%. Between 1982 and 2001, NOx emissions rose by 9%, primarily from increased diesel fuel use.	Demand for petroleum, natural gas, and coal each will increase by 25-40%. Passenger miles driven and number of road vehicles will increase by 30-40%. CO2 emissions will grow by 28%.13
Air	133 million people live in areas with air quality not meeting NAAQ standards (indoor air pollution is associated with asthma in children).	Increased transportation demand will increase NAAQS exceedances; between 23 million and 33 million additional housing units will be needed.
Water	408 billion gallons of water per day are withdrawn. Excess nitrogen and phosphorus have degraded aquatic life in 2.5 million acres of lakes and 84,000 miles of rivers and streams.	In some areas, existing water supplies will be inadequate to meet demands for people, cities, farms, and the natural systems and biota.14 Reduced water availability is projected to impede electric power plant growth.15
Materials	MSW over the last decade MSW has leveled at 4.5 lbs/person/day. Waste systems are managing growing quantities of toxic chemicals.	Under "business as usual" scenarios, a 24% projected increase in population will result in a comparable increase in total waste generation.
Land	The pace of land development between 1992 and 1997 was more than 1.5 times the rate of the previous 10 years.	About 10% of forested land is expected to be converted to urban and developed use.16
Ecosystems	Coastal wetland area has decreased by 8% since the 1950s. One third of native species are at risk.	Flux of nitrogen to coastal ecosystems will increase by 10-20% worldwide. Species extinction rates are projected to be ten times higher than current rate.17

[12] Extracted from the *2003 Draft Report on the Environment Technical Document*. Washington: EPA, 2003. www.epa.gov/indicators/roe/html/tsd/tsdTOC.htm

[13] Department of Energy. *Annual Energy Outlook 2004*. DOE/EIA-0383(2004). January 2004. www.econstats.com/EIA/AEO2004.pdf

[14] Department of the Interior, "Water 2025: Preventing Crises and Conflict in the West." www.doi.gov/water2025

[15] Electric Power Research Institute, 2001. www.epri.com

[16] Climate Change Science Program, 2003

[17] United Nations, *Millennium Ecosystem Assessment*. Washington: Island Press, 2005. www.millenniumassessment.org/en/index.aspx

Table 2.3. Linkages Among Resource Systems

Resources Under Stress	Potential Response to the Stressed Resource System					
	Energy	**Air**	**Water**	**Materials**	**Land**	**Ecosystems**
Energy (increased use)		Increased pollutants	Increased demand	Increased extraction	Extraction impacts	Extraction impacts
Air (increased pollutants)	Increased energy for cleanup		Pollutant deposition from air	Increased demand, Degradation	Waste disposal	Increased negative impacts
Water (increased pollutants)	Increased energy for cleanup	Transfer of pollutants from water		Increased demand, Degradation	Waste disposal	Increased negative impacts
Material (increased use)	Increased demand (processing energy)	Increased pollutants	Increased demand, Increased pollutants		Extraction impacts, Waste disposal	Increased negative impacts
Land (increased development)	Increased demand	Increased pollutants	Increased pollutants, Runoff	Reduction of resources		Reduction of resource
Ecosystems (decreased availability)	Increased energy for restoration	Reduced natural processing capacity	Reduced natural processing capacity	Reduced renewable resources	Erosion	

Even as population and GDP impact a particular resource system, that system in turn interacts with other areas in complex, dynamic, and interrelated ways. For example, since 1971 each 1 percent increase in worldwide GDP has resulted in a 0.64 percent increase in energy use. Most of the energy has been produced from fossil fuels, so the increased energy use has led to greater emissions of air pollutants from the combustion of these fuels. Nearly half of U.S. water withdrawals are used for cooling power plants and water is also used to scrub air pollutants from flue gas; so rising energy use increases both demand for and pollution of water. Extraction of fossil fuels from the earth requires use of more materials, changes the surrounding land, and produces more wastes (i.e. unwanted materials). Finally, increased energy use impacts ecosystems through such factors as silt runoff from energy extraction activities and the decline in water quality caused by runoff from mining facilities. Such response impacts are shown in the first row of Table 2.3. Interactions like these demonstrate forcefully that a systems approach offers the best strategy for understanding environmental impacts and for designing cost-effective and sustainable policy responses.

Sewerage provides another example of interaction among resource areas. As shown in Table 2.3, polluted sewer water requires energy for cleanup; air pollutants of methane and nitrogen compounds are produced, and solid waste is generated and typically sent to landfills. Finally, sewerage overflows can impact ecosystems. These examples illustrate how a change in one resource area can negatively reverberate through other areas.

The Need for a Systems Approach

Ensuring continued improvement in environmental quality and in the protection of human health under these increasing stresses requires new approaches. Fortunately, this is not without precedent, as approaches to environmental protection have evolved over the decades to meet emerging challenges and the advance of science.

In its early years, EPA developed end-of-pipe strategies that targeted emissions of pollutants from, for example, smokestacks and sewer lines. As these strategies matured, new problems were recognized, and were met accordingly with new upstream approaches, such as waste minimization and pollution prevention.

As additional environmental stressors were recognized, the evaluation and choice of pollution control and mitigation options required greater understanding of the overall context of problems. This led to the development of life cycle assessments, which demonstrated that the vast majority of environmental problems are not contained within a single resource area or within a single product's life cycle, but extend across multiple areas and timeframes. It is now clear that a more integrated approach to environmental protection is needed.

As environmental protection has become more complex, the Agency has evolved, moving from point-source pollution controls associated with particular industries to larger problems of regional emissions, such as those associated with agricultural operations, urban transportation, and emerging contaminants. Successfully meeting all of these challenges—significant increases in stressors, impacts across resource areas, emissions from diffuse sources, and emerging contaminants—will require a continued evolution in how environmental protection approaches sustainability.

Is the problem of sustainability urgent? Does it address the national interest? There is no doubt that improving the health and well-being of people today and in the future, while growing the economy and protecting natural resources, is a national priority. Prudent scientific management would suggest launching a program aimed at better understanding the linkages among the six resource systems and developing effective means to disseminate and apply the research results.

Chapter 3. Definition and Scope

ORD focuses its sustainability research portfolio on capturing and quantifying systems dynamics, assessing and managing variability, and understanding resilience of systems to stresses and disturbances, both expected and unexpected. Sustainability research is an essential foundation that incorporates new research approaches with the established foundation of ORD's existing research focused on individual media (land, air, and water).

Sustainability research will focus on six broad crosscutting themes that are coordinated with ORD's economic and behavioral science research and global monitoring programs.

Toward Sustainable Development

The concept of sustainable development marries two important insights: (1) environmental protection does not preclude economic development; and (2) economic development should be ecologically viable.[18] Sustainable development also addresses the question of trade-offs between the welfare of people today and the welfare of people in the future. In the words of the 1987 report *Our Common Future*—better known as the *Brundtland Report*—development is sustainable when it "meets the needs of the present without compromising the ability of future generations to meet their own needs."[19]

Sustainable development fosters policies that integrate environmental, economic, and social values in decision making. The National Environmental Protection Act (NEPA)—drafted in 1969 before EPA was established—provides that the federal government, in partnership with the states, should "use all practicable means and measures… to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans." This NEPA provision is implemented in today's federal policies and actions that promote stewardship and collaborative problem solving. Subsequent legislation and executive orders have directed federal agencies to pursue sustainable management of federal facilities and to measure and report on economic, environmental, and social responsibilities of their operations.[20] On January 24, 2007, President Bush signed Executive Order 13423, "Strengthening Federal Environmental, Energy, and Transportation Management," which sets goals in the areas of energy efficiency, acquisitions, renewable energy, toxics reductions, recycling, sustainable buildings, electronics stewardship, vehicle fleets, and water conservation. The order directs heads of federal agencies to implement sustainable practices in these areas, echoing the NEPA goals expressed in 1969 by specifying that "sustainable"means" "creat[ing] and maintain[ing] conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations of Americans."[21] The Government Accountability Office has also recently assessed the role that federal agencies are playing in complementing U.S. business goals of promoting global corporate social responsibility.[22]

---

[18] Dan Esty, "A Term's Limits." *Foreign Policy*. September/October 2001, pg. 74-75.

[19] World Commission on Environment and Development, *Our Common Future*. London: Oxford University Press, 1987.

[20] Emil J. Dzuray, et al., "Achieving Sustainability of Government Operations," *LMI Research Institute Report* IR 521 R1. September 2005

[21] www.whitehouse.gov/news/releases/2007/01/20070124-2.html

[22] Government Accountability Office. *Globalization: Numerous Federal Activities Complement U.S. Business Global Corporate Social Responsibility Efforts*. GAO-05—744. Washington: August 2005.

Environmental Sustainability

EPA has moved steadily over the past 36 years to ensure that its policies and programs are responsive to changing environmental stresses. U.S. environmental policies have evolved from reliance on laws and regulations requiring only compliance, to new emphasis on policies and incentives that encourage industry to go beyond compliance. Growing use of market-based economic instruments, voluntary programs, public reporting by industry, and creative public-private partnerships are bringing a new era of environmental management. Former Administrator William K. Riley, however, noted,

> I don't think we will be able to say, in the popular phrase of the moment, that we have attained a sustainable level of development until we function in harmony with these ecosystems, and learn to keep them productive… We are not, nor ought to be, fundamentally about reducing this effluent or that emission, but rather about protecting the totality of the environment.[23]

The *Brundtland Report* recognized that environmental protection is different from, but related to, sustainable development: "Environmental protection and sustainable development must be an integral part of the mandates of all agencies of government, of international organizations, and of major private-sector institutes."[24] Sustainable environmental policies are critical for achieving sustainable development. EPA and ORD are in position to lead those policies by developing a strong research foundation that contributes to policies supporting sustainable development.

This Strategy will *promote environmental sustainability* by seeking outcomes that protect and enhance the resilience of natural systems to environmental stress and that reduce the industrial and urban burdens on the environment.

Sustainability Research

The research strategy's definition of sustainability research can be clarified through an analogy with non-traditional research being conducted in the investment and insurance communities. Traditionally, these sectors allocated resources and managed risk with a principle focus on *short-term* performance and economic measures, ignoring a host of external social and environmental factors. Today they have a growing interest in the impact of extra-financial issues on *long-term risk* and investment. For example, Swiss Re, the leading reinsurance firm, has declared that "unsustainable development increasingly needs to be understood as having the potential to substantially change the risk landscape," and has launched an extensive research program on the early detection and assessment of environmental and health risks.[25]

In the investment world, asset owners and managers have formed the Enhanced Analytics Initiative, an international consortium aimed at encouraging better investment research, especially research focused on "… the alignment of management and board with long-term company value, the quality of human resources management, risks associated with governance structure, the environment, branding, corporate ethics and stakeholder relations."[26]

---

[23] William K Reilly. Oral History Interview, "Ecosystem Management." EPA 202-K-95-002. September 1995. www.epa.gov/history/publications/reilly/21.htm

[24] World Commission on Environment and Development, pg. 311.

[25] Swiss Re, *Sustainability Report 2004*. Zurich: Swiss Re, 2005 (p. 9). Swiss Re has built an extensive research program around detection and assessment of risks. Its SONAR research project (Systematic Observations of Notions Associated with Risk) is an extensive data analysis and systems study that can detect risk signals too weak to show up on the radar screen of a wider audience. See 2004 Report, page 9. www.swissre.com/INTERNET/pwsfilpr.nsf/vwFilebyIDKEYLu/MSTN-6DFKHP/$FILE/Sustainability_Rep_04.pdf

[26] The Initiative currently represents companies with managing assets of more than US$1 trillion (See www.enhancedanalytics.com/Fiesta/EDITORIAL/20060630/CommPresse/PR15_InvestecjoinsEAI_190506.pdf). Quote is from David Blood and Al Gore, "It is Essential that Investors Look to the Long Term," www. ft.com, July 6, 2005; *Financial Times*, July 7, 2005. www.generationim.com/media/pdf-ft-david-blood-al-gore-07-07-05.pdf.

The insurance and investment sectors are both promoting "better research for better investment decisions"—an approach based on *future projections*, capturing *system dynamics* and points of leverage, and *assessing and managing variability and uncertainty*. EPA can learn and benefit from such forward-looking, system-oriented research that broadens the application of risk analysis to reflect a wider range of environmental and social issues.

ORD's Sustainability Research Strategy mirrors the expanded research goals of cutting-edge insurance and investment firms, because sustainability research similarly seeks "to promote more informed and sustainable decisions." Like the financial sectors, ORD must project the impact of future economic and demographic changes on natural and man-made systems to help decision makers attain more sustainable outcomes.[27] Research in the realms of insurance, investment, and environmental protection aims to connect the dots to better understand how systems work and how they are affected by change. ORD sustainability research aims to capture system dynamics, manage variability and uncertainty, and understand system resilience to foreseen and unforeseen stresses. Improved scientific understanding must be translated into useable outcomes. To do this, EPA and its partners will develop integrating decision support tools (i.e. models, methodologies, and technologies) that produce the data and understanding to help decision makers shift toward practices promoting environmental sustainability, and ultimately, sustainable development.

Emphasizing a systems approach to achieving sustainable environmental management, we focus on six broad research themes.

- Renewable Resource Protection
- Non-Renewable Resource Conservation
- Long-Term Chemical and Biological Impacts
- Human-Built Systems and Land Use
- Economics and Human Behavior
- Information and Decision Making

[27] "Shaping our Environmental Future: Foresight in the Office of Research and Development." Washington: EPA, 2007. www.epa.gov/osp/efuture.htm


MILLER & LONG
LEVIS

Chapter 4. Six Research Themes

To promote the integration of research across disciplines and existing ORD research programs, and to underscore the importance of a systems approach to future planning, this chapter serves three important functions:

- It identifies priority research topics related to the sustainable outcomes presented in Table 2.1 and the six research themes described in Chapter Four.
- It identifies existing ORD and EPA research programs that relate to the research questions (Table 4.1).
- It describes how this Research Strategy and the focus on sustainable environmental outcomes advance ongoing EPA efforts.

Achieving any one of EPA's proposed sustainable outcome measures (shown in Table 2.1) will be a formidable challenge, for there are no technological "quick fixes" offering simple solutions to any of these outcomes. Instead, research across physical science, economics, social science, and other disciplines must be combined in meaningful ways. In turn, the resulting science must be made available to decision makers and integrated into effective public policy.

By itself, ORD can address only a small part of the overall research required to advance sustainability, but it can partner with program and regional offices and other federal and state agencies and can use its research results, methods, and tools to assist clients both inside and outside EPA in pursuing sustainable outcomes.

Table 4.1. Sustainability Research Themes Addressed by Multi-Year Plans

● - Some Association ● ● - Strong Association

National Program Director (NPD) Area	Multi-Year Plan	Renewable Resources	Non-Renewable Resources	Chemical & Biological Impacts	Human-Built Environment	Economics & Behavior	Information & Decisions
Air	Air Toxics		●		●		
	Particulate Matter		●		●		
	Tropospheric Ozone		●		●		●
Global Change & Mercury	Global Change	●	●		● ●	●	●
	Mercury		●	● ●			
Water Quality	Water Quality	● ●		●			
Drinking Water	Drinking Water				● ●		
Human Health	Human Health			● ●			●
Ecological Risk	Ecological Research	● ●		●			●
Pesticides, Toxics, & ECDs	Endocrine Disruptors			● ●			
	Safe Pesticides			● ●			
	Toxics			● ●			
(not an NPD area)	Computational Toxicology			● ●			
Contaminated Sites/ Resource Conservation	Contaminated Sites						
	Hazardous Waste			● ●			
	Economics and Decision Sciences					● ●	● ●

Table 4.2 shows the extent of existing ORD multi-year plans. The following sections discuss how these programs relate to each other and to the sustainability research questions. An example of the possible integration (and leveraging of resources) among existing ORD research strategies—the coordination of the Sustainability Research Strategy and the Economics and Decision Sciences Strategy—is illustrated in Figure 4.1 near the end of this chapter.

1. Natural Resource Protection (Air, Water, Ecosystems)

The health and well-being of all societies depends on ecosystems and the services they provide. Natural resources are an essential support for a nation's economy and quality of life. Where natural systems are undermined, the economic and social well-being of people is threatened. This is true at local levels, where the expansion of urbanized areas is undermining the ecological integrity of ecosystems by bringing about declines in biological diversity, degradation of water quality, and loss of other ecological services. It is also true at regional levels, where unsustainable industry and urban development are threatening the long-term health of great water bodies like the Chesapeake Bay and the Great Lakes. And it is certainly true on a global scale, where widespread ecosystem loss may affect global atmospheric processes and human health.

The natural resource basis is a complex and dynamic system of plants, animals, and the physical environment that interact with each another. Lessons learned over the years on different approaches and techniques for managing natural resource systems, at both small and large scales, demonstrate the need to better understand the resilience of a natural system to "tolerate disturbances while retaining its structure and function."[28] Achieving sustainability in managing natural systems therefore requires a better understanding of the complexity of these systems, including their critical thresholds, resilience, and adaptability.

In a sustainable world, society greatly benefits from ecosystem services at all levels, from local flood control to global climate protection. A critical test of society's ability to sustainably manage its natural resource base is fast approaching. The president's "Twenty by Ten" goal is to reduce gasoline usage by 20 percent over the next ten years, with 15 percent of the reduction achieved through use of renewable or alternative fuels and 5 percent from vehicle efficiency improvements.[29] A longer-term research and technology goal is to make cellulosic ethanol cost-competitive with corn-based ethanol by 2012 and to replace at least 30 percent of the 2004 level of gasoline demand by 2030.[30] These transitions will require large supplies of sustainable feedstock, major feedstock and conversion technology advances, large-scale integrated biorefinery demonstrations, and massive new infrastructure development that will affect land use and ecosystems. Given these policy directions, it will be important for EPA and ORD to assess how to produce, harvest, and deliver current biomass, or an estimated 1 billion dry tons of cellulosic biomass, in an economically and environmentally sustainable way.

---

[28] Joseph Fiksel, "Designing Resilient, Sustainable Systems," *Environmental Science & Technology*. 37 (December 2003), 5330-5339.

[29] Regarding the 15 percent from renewable or alternative fuels, the 35 billion gallon would be required if all the fuel were ethanol. However, replacement and alternative fuels are expected to include ethanol and biodiesel, as well as fossil based alternatives such as coal-to-liquids, gas-to-liquids etc, and also include domestic production as well as imports.

[30] See: www.whitehouse.gov/stateoftheunion/2007/initiatives/energy.html and *Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda.* Washington: DOE /SC-0095, 2006

None of these challenges are new to EPA, which has made healthy communities and ecosystems one of its five key long-term goals. Existing EPA programs extend from protecting ecosystems from risks posed by the release of harmful substances, to expanding and restoring ecosystems. Filling gaps in current EPA and federal agency programs, the Sustainability Research Strategy aims to sharpen the focus on achieving sustainable management of renewable resources by setting three goals: (1) defining clear measures of sustainable renewable systems; (2) improving understanding of ecosystem processes and their impacts on human health; and (3) developing and applying advanced systems models and tools to assist decision makers.

Efforts to achieve the first goal are tied to building consensus within EPA on terms and definitions. ORD is leading an EPA-wide effort to more clearly define outcome goals and measures. Efforts to achieve the second goal depend on greater coordination of existing efforts across ORD, EPA program and regional offices, and universities. Efforts to achieve the third goal depend on expanded in-house ORD research and collaboration with ORD customers and stakeholders.

Current ORD systems research aims to address complex, long-term environmental problems in ways that go beyond traditional compliance and pollution prevention approaches to those that focus on sustainable outcomes. This effort builds on a growing body of academic research that has demonstrated how the integrated assessment of a sustainable system cannot be accomplished by simply linking together a collection of domain-specific models. Research on the bio-complexity in large lake systems shows that new modeling approaches are needed.[31] Frontier interdisciplinary research in EPA's Science to Achieve Results (STAR) program is exploring the relationship among anthropogenic stressors within ecosystems, changes in host or vector biodiversity, and infectious disease transmission.[32]

This new research focuses on understanding the environmental and social factors that contribute to biodiversity change, the population dynamics of animal reservoirs and vectors of disease, biological mechanisms that influence transmission of diseases to humans, and the processes by which infectious diseases emerge and spread. Research on the links between anthropogenic stressors, biodiversity, and infectious disease can have an important impact on our view of biodiversity, the services provided by natural ecosystems, and how we manage these resources to protect human health and the environment.

PRIORITY RESEARCH TOPICS

- Demonstrating and quantifying the value of ecosystem services in environmental protection and human health (informing decision makers).
- Understanding long-term chemical and biological interactions and cycles among air, land, and water resources and their impact on biodiversity (systems analysis).
- Exploring interactions among natural resource systems that may lead to unrecognized side effects of management initiatives, such as loss of soil resilience due to over-harvesting of biomass (systems analysis).
- Modeling linkages between human-built and natural resource systems in terms of material and energy flows (systems analysis).
- Understanding the resilience and adaptability of ecosystems to change (resilience and vulnerability).
- Improving understanding and quantification of natural carrying capacity under various environmental conditions and human activity patterns (forecasting).
- Developing early warning signs of critical system overloads beyond natural variability (forecasting).
- Identifying trends that have been and are expected to continue affecting ecological processes that sustain ecosystems (forecasting).
- Developing future regional scenarios and models integrating land, water, and ecosystems to assess impact on ecosystem services (forecasting).

[31] See Conference Report on "Toward Sustainable Systems." Ohio State University, March 2-3, 2006.

[32] See http://es.epa.gov/ncer/rfa/2007/2007_biodiversity_health.html

2. Non-Renewable Resource Conservation (Energy and Materials)

Each phase of non-renewable energy production (exploration, extraction, refining, transporting, and storing) and manufacturing affects the quality of air, the quality and availability of water, global climate, short- and long-term use of land, and resiliency of ecosystems. For these resources and processes, sustainability requires greater focus on conservation and enhanced use of renewable energy, greater emphasis on managing materials rather than disposing of waste products, and finding substitutes for toxic and dangerous materials. The historic consequences of unsustainable non-renewable resource management are evident in landscape modification, growth of greenhouse gases in the atmosphere, and climate change. Fossil fuel use, with its potential effects on climate change and environmental and human health, constitutes a vital long-term global sustainability issue. EPA's role in addressing climate change is prescribed by the interagency U.S. Global Change Research Program.[33] Complementing this interagency program, the Sustainability Research Strategy will promote more sustainable management of nonrewable resource operations and enhance a shift to greater use of renewable resources.

A new vision of how to sustainably manage nonrenewable resources is needed. The 1997 National Academy of Engineering report, The Industrial Implication for Environmental Design and Management, suggests that the path to sustainability "involves the creative design of products, processes, systems and organizations, and the implementation of smart management strategies that effectively harness technologies and ideas to avoid environmental problems before they arise." In Grand Challenges in Environmental Sciences (2001), the National Academy of Sciences recommended, "develop[ing] a quantitative understanding of the global budget of materials widely used by humanity and how the life cycles of these materials… may be modified."[34]

These concerns prompted the Office of Solid Waste proposal to shift its emphasis from managing waste to managing materials, and the Office of Pesticides and Toxics' efforts to reduce toxic chemical use through green chemistry and other new technologies. Looking ahead, regulatory actions may further enhance a movement toward sustainable resource management. Several directives of the European Union that target reductions of hazardous materials and toxics and promote recycling may serve to promote additional research in use of alternative material, green chemistry, and life cycle analysis.[35]

Consequently this research strategy will initially focus on core research methodologies, models, technology, and technological processes that can help to assess the impacts of energy and material use on the environment and to identify low-impact and other sustainable approaches to renewable resource management.

PRIORITY RESEARCH TOPICS

Core functions:

- How can life cycle assessment be made more efficient, reliable, and comprehensive so that it will more effectively inform design decisions that lead to reducing or eliminating the use of non-renewable resources?
- What innovative technologies or processes can be developed to improve the efficiency of non-renewable resource consumption (e.g., closed-loop recycling or energy efficiency in manufacturing and consumer products)?

---

33 EPA's research role in the U.S. Global Change Research Program is to assess the potential consequences of climate change for air and water quality, ecosystems, and human health. This program seeks to improve the scientific basis for evaluating the risks and opportunities presented by global change in the context of other stressors. A suite of EPA voluntary programs such as Climate Leaders develop industry strategies aimed at reducing the overall emissions of greenhouse gases.

34 EPA Science Advisory Board, *Commentary on Industrial Ecology*, 2002. www.epa.gov/sab/pdf/eecm02002.pdf. Also *SAB Review of Science and Research Budgets* for FY 2007, March 30, 2006. www.epa.gov/sab/pdf/sab-adv-06-003.pdf

35 The Directives are Restriction of Hazardous Substances Directive (RoHS), Waste Electical and Electronic Directive (WEEE), and Directive on Registration, Evaluation and Authorization of Chemicals (REACH)

- For different sectors, what re-engineering processes can be designed to manage production and supply chains, reducing or eliminating the use of fossil fuels and other non-renewable resources?
- How can material flow analysis and related methods provide better insight into opportunities for reducing or eliminating the use of non-renewable resources?
- What tools can be used to operationalize the concept of industrial ecology, enabling systems-based understanding of energy and material flows?

Material Balance:

- What are the patterns and driving forces of societal use of non-renewable resources?
- How can global scenarios of future industrial development and associated environmental implications be developed?
- In what materials, products, places, and time scales can we expect significant change in material and energy use or their impacts?

Energy:

- What opportunities exist to replace non-renewable with renewable feedstocks and materials in an environmentally beneficial manner?
- How can we ensure that societal shifts in material use—such as from petroleum to renewable feedstocks for energy and materials—do not lead to unforeseen and unsustainable consequences?
- What tools are needed to develop, test, and measure the life cycle of a full suite of energy conversion technologies (using renewable and non-renewable energy sources)?

3. Long-Term Chemical and Biological Impacts (Using Non-Toxic Materials Sustainably and Protecting Human Health)

The intergenerational dimension of sustainability means that society must be particularly mindful of the long-term threat posed by chemical and biological impacts on the environment. Protecting environmental and human health from chemical toxicity has long been central to EPA's mission. The inability of the environment to assimilate certain chemical compounds over time has serious implications for sustainability. A chemical pollutant released to the environment at a rate greater than the environment's ability to recycle, absorb, or render it harmless is considered to be persistent. Other chemical compounds have a tendency to concentrate in the tissues of living organisms in the process of bioaccumulation. Chemicals that are either persistent or bioaccumulative increase the potential for adverse effects on human health or the environment, or both, because they can result in high levels of exposure. Chemicals that are both persistent and bioaccumulative result in the highest levels of exposure and thus present the greatest challenge to sustainability. Achieving sustainable outcomes will rely on prudent material use and shifting to environmentally preferable materials in order to protect human health by assessing and eliminating the long-term impacts of harmful chemical and biological materials.

Research on long-term chemical and biological impacts (complementing research on resource conservation) addresses two major areas: (1) assessing chemical and biological impacts; and (2) substituting benign chemicals for toxic chemicals through green chemistry, nanotechnology, genomics, and other new technologies. Achieving sustainable outcomes will be aided by the enhanced ability offered by these technologies to detect and measure chemicals in humans and animals and to provide new ways of designing and manipulating new materials.

ORD's work in computation toxicology—using the latest advances in mathematical and computer modeling and genomics to prioritize, screen, and evaluate chemicals and predict potential toxicities—offers great potential for developing more sustainable products.[36] ORD and other EPA researchers are also assessing the application of nanotechnology for developing more efficient and sustainable products. In a recent white paper assessing the risks and benefits associated with nanotechnology, EPA scientists recommended that the Agency "engage resources and expertise to support approaches that promote pollution prevention, sustainable resource use, and good product stewardship in the production and use of nanomaterials."[37] Important new research efforts in ORD and in EPA program and regional offices are evaluating the green production of nanomaterials, including a life cycle assessment of nanomaterial production, and are developing decision support tools for bench chemists to evaluate the environmental dimensions of new chemicals and production processes.

Key sustainability research goals thus include further developing new technologies that reduce or replace the use of toxic chemicals and measuring the potential environmental effect of these new technologies. The research topics listed below build on ORD's development of research aimed at creating new catalysts to significantly improve the environmental effects of chemical manufacturing, innovative reactors and intensification techniques, and novel oxidation technologies that will allow the pulp and paper industry to meet new emission regulations.

PRIORITY RESEARCH TOPICS

- Develop and apply innovative chemical transformations utilizing green and sustainable chemistry and engineering.
- Improve the yield, safety, and specificity of chemical processes by identifying appropriate solvents, controlling thermal conditions and purity, and recovering process catalysts or byproducts.
- Formulate products that reduce waste and that are environmentally benign.
- Develop life cycle tools to compare the total environmental impacts of products generated from different processing routes and conditions.
- Develop improved or accelerated methods for understanding the toxicology, kinetics, fate, and persistence of chemical substances.
- Develop and implement models for the efficient application of life cycle analysis methods to new products and technologies including nanomaterials, green chemistry, and engineering.
- Develop and implement systems-level methodologies and technologies for applying material flow analysis to complex industrial networks.
- Develop improved methods for systems analysis of material flows that reflect the differences in health and environmental impacts of different substances.

4. Human-Built Systems and Land Use

In the past, little or no concern was given to how human-built systems might seriously impair or destroy the natural infrastructure and "ecosystem services" provided by the infrastructure, such as the ability to absorb and break down pollutants, cleanse air and water, and prevent flood and storm damage. However, the growth of urban populations over the last century has provided evidence that human-built systems can cause significant harm to ecosystems and to their ability to provide these critical services. Building on undeveloped land destroys and fragments habitat, displacing or eliminating wildlife communities.

[36] See ORD, "A Framework for Computational Toxicology." EPA 600/R-03/065 November 2003.

[37] See www.epa.gov/osa/nanotech.htm

The construction of impervious surfaces such as roads and rooftops leads to the degradation of water quality by increasing runoff volume, stream sedimentation and water acidity, altering regular stream flow and watershed hydrology, and reducing groundwater recharge. A one-acre parking lot produces a runoff volume almost 16 times as great as would an undeveloped meadow of the same size. Achieving urban sustainability is clearly a challenge being addressed by many programs of EPA and other federal agencies. In this research strategy, research on urban sustainability and land use focuses on three key areas: building design and efficiency, urban land revitalization, and sustainable management of urban systems.

Within urban communities, green building design is a crucial factor for sustainability since buildings account for 65 percent of electricity consumption, 36 percent of total energy use, and 30 percent of greenhouse gas emissions. According to recent studies, in 2030 about half of the buildings in which Americans live, work, and shop will have been built after 2000. In 2030, there will be 106.8 billion square feet of new development, about 46 percent more built space than existed in 2000—a remarkable amount of construction to occur within 30 years. About 97.3 billion square feet of existing space will be replaced. New and replacement-related development will amount to 204.1 billion square feet, equal to almost 90 percent of the built space that existed in 2000. All of this amounts to about $30 trillion in total new development (including infrastructure) that will occur between 2000 and 2030.[38] Research in indoor environmental management underway in ORD's National Risk Management Research Laboratory is already well positioned to help shape the design of future indoor engineering systems.

Research related to Built Environment and Land Use, while primarily directed toward sustainable land management, also serves to integrate nearly all of the sustainability goals discussed in Chapter 2. The operation of numerous and diverse human-built systems (e.g., buildings, cities, water distribution, energy, agriculture, and transportation) is fundamentally dependent on the health of the natural systems that provide critical ecosystem services.

While broad in content, this theme focuses on land renewal and restoration, decision support tools for urban land development, and life cycle assessments for land use and building design. Research under this theme complements research described previously under Natural Resource Protection. Key elements of the implementing Science and Technology for Sustainability Multi-Year Plan (MYP) will focus on environmental impact modeling, including development of new impact models to characterize land use and smog formation, and on collaborative partnerships with many government and non-government entities to directly apply innovative systems-based approaches to urban and tribal planning.

Direct ORD-supported research can address these immediate research questions:

- What tools can decision makers use to assess the potential impacts of land use, landscaping, and building design decisions on community well-being and environmental quality?
- What levels and types of human activities can be conducted within a given spatial area (such as a watershed or ecosystem) without critically and adversely altering biogeochemical cycles and ecosystem functioning?
- What sustainability criteria should be developed to guide urban land development and future revitalization efforts?
- What core set of principles can best be used to guide the design, construction, and management of human systems (such as land use, buildings, and transportation systems) in a manner that protects natural systems (such as habitats) and their properties (such as biodiversity) and functions?

---

[38] Arthur C. Nelson, "Toward a New Metropolis: The Opportunity to Rebuild America." Washington: *Brookings Institution Metropolitan Policy Program Survey Series*, 2004. See www.brookings.edu/metro/pubs/20041213_rebuildamerica.htm; and Arthur C. Nelson, 2006, "America Circa 2030: The Boom to Come," *Architect Magazine* (October 15, 2006): www.architectmagazine.com/industry-news.asp?sectionID=1006&articleID=385542

- How do systems of land use, transportation, trade, and commerce contribute to the spread of invasive species and exotic pathogens? What actions can EPA take to manage this process?

- What applications of new and emerging technologies can promote efficiencies in building design and restoration of contaminated sites?

- What are the tradeoffs between resilience of the built environment (e.g., capacity to survive natural disasters) and ecological resilience?

The growing enthusiasm for sustainability at state and local levels presents both new challenges and opportunities for ORD research, which has the technical, monitoring, and analytic capability to help decision makers at all levels of government choose courses of action that will lead to achieving sustainable outcomes.[39] For example, ORD has been working with the German Federal Ministry for Education and Research since 1990 on models of land restoration and development. Work under this bilateral agreement is now moving toward development of sustainability criteria for revitalization activities, and has resulted in the Sustainable Management Approaches and Revitalization Tools-electronic (SMARTe) program. SMARTe, which is now in beta testing, is an open-source, Web-based decision support system for developing and evaluating future reuse scenarios for potentially contaminated land.[40] SMARTe includes guidance and analysis tools for all aspects of the revitalization process, including planning and environmental, economic, and social concerns.

The emphasis in this research strategy on developing decision support tools and helping decision makers reach wise decisions, challenges our scientists and engineers to work directly with key customers and stakeholders who can most benefit from ORD research capabilities. In many ways, ORD's ability to identify research to inform stewardship solutions is intimately tied to partnering and collaborating with state, local, and tribal decision makers. An example is the Sustainable Environment for Quality of Life (SEQL) program, in which ORD is a key player, developing scientific models such as the Regional Vulnerability Assessment (ReVA) to support sustainable land development. ORD's research supports quantification of potential and actual impacts, including cross-sectoral and cross-jurisdictional analyses and analyses of "what-if" scenarios.

SEQL and similar projects are successful because of the available suite of decision support tools and the direct participation by ORD scientists in community meetings and policy planning. This direct involvement is essential for applying ORD research to direct use. The BOSC review of the Ecological Research Program noted the successful use of ORD decision support tools, emphasizing that further applications "will require commitment of resources to technology transfer through both in-person and online training."[41]

5. Economics and Human Behavior

The sustainable management of natural and man-made systems is partly a question of choice and behavior. For this reason, economics and the behavioral sciences are key elements in EPA's overall approach to implementing the goals of Everyday Choices and achieving sustainable outcomes. The Office of Management and Budget (OMB) is requiring more and better economic analyses as essential components of the policy process used in EPA program and regional offices and in other federal regulatory agencies.

---

39 See "Regional Summaries of State and Tribal Issues and Priorities for the 2006-2011 Strategic Plan Revision." www.epa.gov/ocfopage/plan/regions/index.htm

40 See www.smarte.org/smarte/home/index.xml

41 Board of Scientific Counselors, *Review of Ecological Research Program Review.* August 2005, pg. 18. www.epa.gov/osp/bosc/pdf/eco0508rpt.pdf

External reviews by the SAB and the National Academy of Sciences have shaped much of EPA's economic and behavioral research. For example, many recommendations from the National Academy of Sciences report commissioned by EPA and the National Science Foundation, Decision-Making for the Environment: Social and Behavioral Science Research Priorities, have been incorporated into ORD's Environmental Economics Research Strategy (EERS), published in 2005. Economists are beginning to address the question of environmental sustainability and human carrying capacity as central factors in economic development.[42] Economists and conservationists are also exploring ways to value ecosystem services and develop economic incentives for sustainable behavior. This is an important area for research since markets for ecosystem services do not generally exist. For example, owners of ecologically valuable land can generate more revenue from traditional land development than by providing ecological services. ORD-funded extramural research is also underway to understand why individuals, firms, and institutions behave as they do; what motivates them to change their behavior; and how government regulations, public information, corporate reporting, and public pressures interact to generate public policy.

The Sustainability Research Strategy (SRS) and the EERS research strategies are complementary in approach and significantly contribute to EPA's focus on stewardship and sustainability. The SRS presents a framework that highlights research areas of importance to support a forward-looking, integrated, and preventive approach to environmental protection. It guides the integration of relevant research across ORD and other offices, as well as connections outside of EPA. On the other hand, the EERS presents a focused analysis of Agency research priorities in Economics and Decision Sciences. EERS research priorities dovetail nicely with the SRS framework (see Chapter 6) and collectively can be used to address a number of important questions:

- What factors increase or reduce motivation for sustainable behavior among individuals, firms, and organizations? How can we better integrate economic and ecological models to inform environmentally sustainable decisions? What is the relationship between environmental sustainability indicators and measures of economic value?
- What are non-market ecosystem services, what is their value, and what ongoing factors are affecting their supply? To what extent can human-produced capital substitute for natural capital?
- How can economic instruments (e.g., trading schemes, auctions, and taxes) be devised that effectively incorporate society's concerns for sustainability in resource allocation decisions?
- What should be the role of intergenerational discounting in benefit-cost analysis?
- How can ecological resilience and the potential for major unforeseen events be incorporated in the selection and assessment of policy interventions?

[42] For rapporteur's summary and presenters' précis papers of the EPA-sponsored forum, "Sustainability, Well-Being, and Environment Protection: What's an Agency to Do?" see www.epa.gov/sustainability/econforum

6. Information and Decision Making

The goal of developing sustainability metrics builds on the research already conducted in support of EPA's Draft Report on the Environment (RoE). ORD researchers have played a significant role in identifying appropriate indicators and providing quality control in their development. Currently, the RoE provides snapshots of the existing environmental state. Metrics are defined in relation to clearly stated questions such as, "What are the conditions and current trends of surface waters?" and "What are the trends in the ecological processes that sustain the nation's ecological systems?" As EPA moves toward identifying a set of clearly articulated questions related to sustainable outcomes—such as, "How sustainable are the nation's water supplies?"—research can focus on identifying appropriate indicators and ensuring their quality.

The establishment of an information infrastructure is a necessary step on the path toward sustainability. This includes the development of sustainability metrics and environmental monitoring. Our strategy is therefore closely applied with the Global Earth Observation Systems of Systems (GEOSS) program. The GEOSS vision is of a future in which decisions and actions are informed by coordinated, comprehensive, and sustained earth observations and information. GEOSS will "take the pulse of the planet" by compiling a system of all relevant databases (or systems), thus revolutionizing our understanding of how the earth works. Over time, GEOSS will contribute greatly to sustainability by providing important scientific information for sound policy and decision making. EPA is contributing to GEOSS through its leadership in both the international Group on Earth Observations and the U.S. Group on Earth Observations and has launched the FY2006 Advanced Monitoring Initiative (AMI).

One of the keys to promoting sustainability is defining and communicating a clear understanding of proposed outcomes. In Everyday Choices, EPA senior managers identified sustainable outcomes in six resource areas relevant to EPA's mission (Table 4.1). The sustainability goals in energy, water, air, land, ecosystems, and materials provide an important starting point for discussion of appropriate sustainability goals and how they should be measured. A clear next step is to define these goals and metrics in sharper detail.

This strategy aims to establish a new set of scientifically based sustainability indicators that are readily comprehensible at multiple scales, relevant to decision makers, and easily accessible to the public.

ORD-supported research will address these research questions:

- What are appropriate sustainability goals for energy, water, air, land, materials, and ecosystems?
- What are the most appropriate trends, indicators, and metrics to measure society's progress towards reaching sustainable outcomes?
- What data are needed to construct sustainability indicators and metrics and how can the data be effectively and efficiently collected?

These questions will be addressed in two ways. First, we will review metrics currently in use to determine where gaps exist. A number of fairly simple sustainability indicators currently exist, and while these measures may inform the public on the general notion of sustainability, they often lack scientific vigor. If sustainability is to play a significant role in future environmental policy debates, the process of establishing benchmark values and measuring progress must be vastly improved. The second track, in collaboration with EPA partners and customers, will involve research to identify new indicators and metrics and apply them to problems in specific geographic regions, ecosystems, and watersheds. This work is expected to result in a new set of well-defined metrics, protocols, and software tools that can be used by decision makers. This direction of research will be a major element of ORD's new Science and Technology for Sustainability MYP.

Chapter 5. Research Objectives

Our research strategy has five objectives:

- Systems Understanding. Understand the interconnections, resilience, and vulnerabilities over time of natural systems, industrial systems, the built environment, and human society.
- Decision-Support Tools. Design and develop scientific tools and models to assist decision makers.
- Technologies. Identify and develop inherently benign and less resource-intensive materials, energy sources, processes, products, and systems, particularly for emerging technologies.
- Collaborative Decision Making. Develop an understanding of motivations for decision making and develop approaches to collaborative problem solving.
- Metrics and Indicators. Develop metrics and indicators to measure and track progress toward sustainability goals, to send early warning of potential problems to decision makers, and to highlight opportunities for improvement.

The logic diagram of Figure 5.1 on the following page illustrates how these five research objectives relate to customers and collaborators, as well as to outcomes: (1) Systems Understanding informs the development of research in (2) Decision Support Tools, (3) Technologies, and (4) Collaborative Decision Making. This research informs policies and programs implemented by Customers and Collaborators, who can use relevant (5a) Metrics and Indicators to inform their plans and decisions and lmeasure progress toward their sustainability goals. A second category of larger-scale (5b) Metrics and Indicators can help in measuring and assessing overall progress in Resource Sustainability Outcomes and Long-Term Outcomes in environmental and human health. The larger-scale metrics and indicators also feed back to enable adaptive understanding and research needs in Systems, Decisions, Technologies, and Collaborative Decision-making.

Figure 5.1. Logic Diagram Illustrating Research Approaches

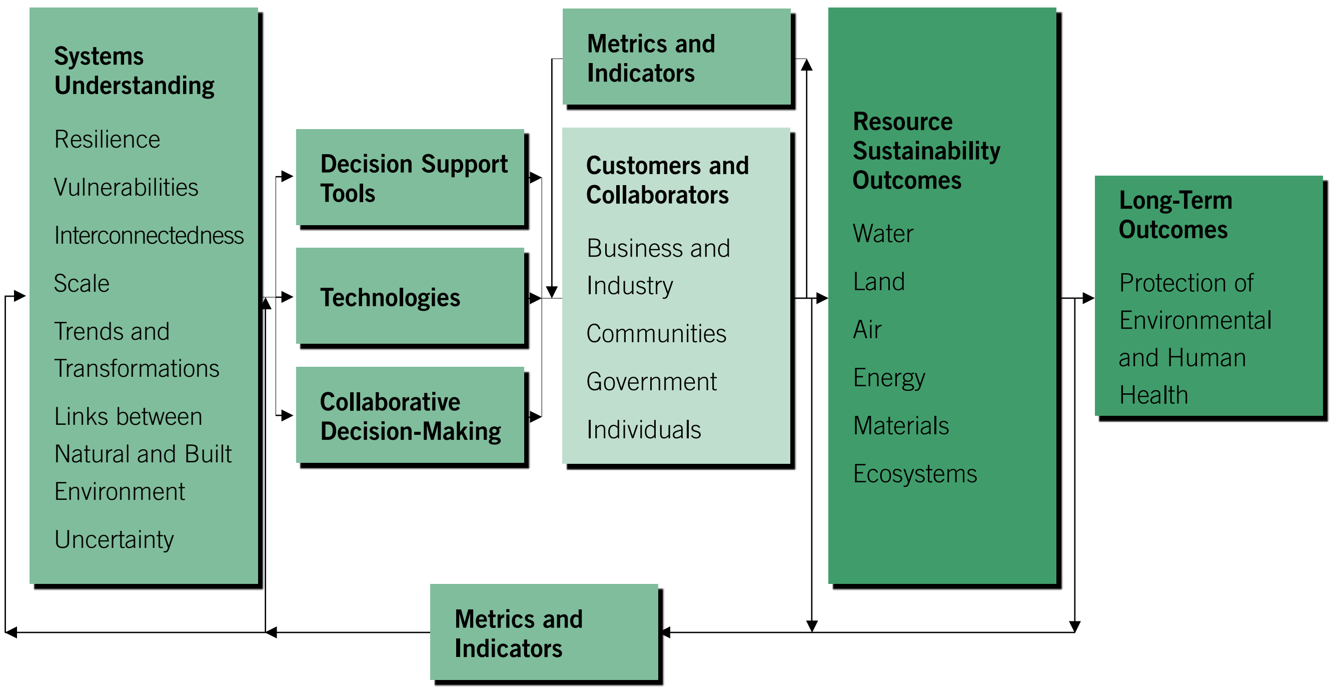


Table 5.1. Research Topics Addressing Sustainability Themes and Objectives

	System Understanding	Decision Support Tools	Technologies	Collaborative Decision Making	Metrics and Indicators
Renewable Natural Resource Systems	Ecosystem resilience; Limits on resource extraction rates	LCA; MFA; ISAs	Green engineering		Ecosystem resilience; Resource extraction rates
Non-Renewable Natural Resource Systems		LCA; MFA; ISAs	Green engineering		Material intensity
Long-Term Chemical and Biological Impacts		Chemistry design tools; Transport models	Green chemistry		Environmental accumulation of chemicals
Human-Built Systems	Understanding interactions between human-built systems and natural cycles	Design principles	Green buildings; Emerging technologies	ISA, Risk assessment models	Industrial sustainability indicators
Economics and Human Behavior		Agent-based models		Incentives and trading schemes	
Information and Decision Making	Limits; Measures of resilience		LCA	Understanding value of information	

Table 5.1 also relates the research objectives to the six research themes (defined in Chapter 4). For example, life cycle assessment (LCA) can inform understanding of a product's consumption of renewable and non-renewable resources and associated emissions over the product's life cycle. Material flow analysis (MFA) and integrated systems analysis (ISA) can be used to explore the possible implications of economy-wide patterns of consumption of renewable or non-renewable resources. ISA can also be used as a communication tool to enable collaborative decision making in the context of human-built systems. There are many relevant metrics and indicators in the theme areas, ranging from indicators of ecosystem resilience to sustainability indicators used by industry. The following sections further describe the various research objectives.

Systems Understanding

An underlying understanding of complex environmental-societal systems and the attributes and conditions that make them sustainable is the foundation of sustainability research. Going beyond a traditional, single-media, pollution-control and compliance-enforcement approach, this research strategy recognizes that no environmental problems have a single cause. Application of systems research has the potential to break down longstanding single-media approaches to environmental management, an issue of concern to EPA since its inception.[43] Following the 2006 Science Advisory Board review of the Draft *Guidance on Environmental Models and Models Knowledge Base*, EPA is committed to enhancing interagency coordination on modeling issues and fostering a more integrated approach to modeling in environmental management.[44] Describing, representing, and designing sustainable systems encompasses several important aspects:

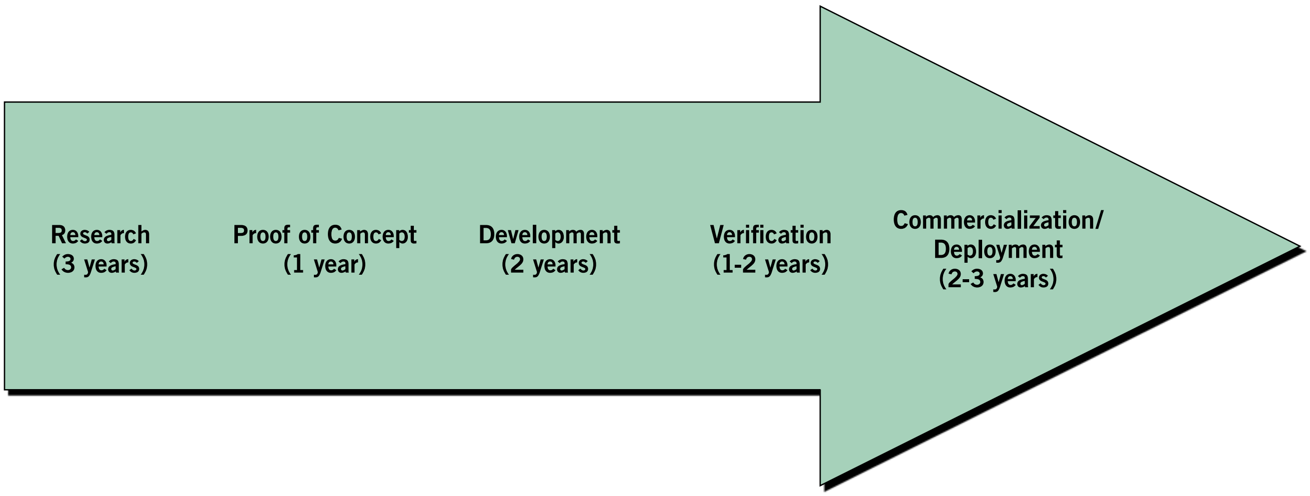
- addressing scale in time and space,
- capturing the dynamics of the system and of society's points of leverage or control over those dynamics,
- representing an appropriate level of complexity,
- managing variability and uncertainty,
- capturing the various perspectives and desired sustainability outcomes in important domains (e.g., ecological, economic, technological, legal, and organizational), and
- understanding the vulnerability or resilience of the system relative to both foreseen and unforeseen stressors and change.

A systems view can also strategically inform both research and implementation. It can identify barriers, point out gaps or redundancy in activity, and inform prioritization of existing or potential research and implementation in technology, decision support tools, and collaborative decision making.

[43] When President Nixon proposed the creation of EPA in 1970, he recognized the interconnectedness of the environment and the inherent cross-media nature of environmental protection. His plan to establish EPA noted that, for pollution control purposes, "the environment must be perceived as a single, interrelated system" (see www.epa.gov/history/org/origins/reorg.htm). EPA has struggled since then with how best to deal with the environment as an integrated system. At the Agency's 15th anniversary in 1985, Administrator Russell Train expressed his concern with its "compartmentalized nature" and resulting ineffectiveness in dealing with pollutants, which "tend to move readily among air, water, and land." Similarly, Administrator Lee Thomas stressed the need for cross-media reviews so that "we don't just transfer pollutants from one medium to another." (See "Views from the Former Administrators," *EPA Journal*, November 1985, available at www.epa.gov/history/topics/epa/15e.htm.) Administrator William Reilly encouraged cross-media approaches in the early 1990s by looking holistically at place-based issues, breaking down media barriers for risk assessment, providing cross-media training for staff, and conducting joint pilot studies with industry. Although EPA is today still organized along media lines, it recognizes the need to adequately address the cross-media nature of environmental problems. Sustainability concepts will help EPA break down barriers to its single-media-based program offices and look more holistically and systematically at integrated environmental challenges.

[44] See SAB report at: www.epa.gov/sab/panels/cremgacpanel.html

Figure 5.2. Technology Continuum



Technologies

Technology and technological systems are central for achieving sustainable use of renewable and non-renewable natural resources, as well as for developing alternative materials, chemicals, processes, and products that minimize or eliminate long-term chemical and biological impacts.

The underlying scientific research, development of designs and applications, technology demonstration, and technology verification form a 10-year continuum as illustrated in Figure 5.2. Various advisory bodies have argued that commercialization and deployment of sustainable technologies require that the entire continuum be supported over time. For example, EPA's National Advisory Committee for Environmental Policy and Technology Policy (NACEPT) has strongly endorsed EPA's current technology and verification program and recommended that EPA "should devote more attention and resources to those Agency programs that incorporate and encourage sustainability as one of the goals or criteria for technology development or implementation assistance."[45] The EPA administrator has further charged NACEPT to examine the issue of sustainability in more detail (in 2006-2007) and to make additional recommendations.

Several areas of technology research are particularly important. The fields of green chemistry and green engineering address the design of molecules, products, processes, and systems that (1) use safer chemicals and materials; (2) use materials, water, and energy efficiently; and/or (3) reduce the generation of waste at the source. Green engineering and green chemistry are generally applied on a product-by-product or a process-by-process basis. While some of this technology research is supported by industry, EPA has an important role in supporting research that underpins general methodologies or addresses specific environmental problems or emerging issues of concern.

[45] National Advisory Committee for Environmental Policy and Technology Policy (NACEPT), Subcommittee on Environmental Technology, *EPA Technology Programs and Intra-Agency Coordination*, Washington: EPA 100-R-06-004, May 2006.

More traditional technologies can also support progress towards sustainability. Technologies that provide safe drinking water and treat waste and storm water are prime examples. Aging water and wastewater infrastructure, together with a growing population, require the development of new technologies to provide cost-effective conveyance and treatment of drinking, waste, and storm water. In addition, the tightening of water supplies in parts of the United States and elsewhere in the world will require water conservation and reuse technologies to provide abundant, clean water for human consumption and the environment. To achieve this, both current and new technologies should be examined using a systems approach to assess their multimedia impacts over the long term to insure that they are compatible with environmental sustainability.

Technology and technological systems can also be looked at more broadly in time and space. An economy-wide understanding of material flow systems, for example, can illuminate, and hence prioritize, opportunities for efficient pollution prevention and material use. This could be particularly important for materials that are potentially deleterious to the environment, used in high volumes, or both.

Understanding the economic, informational, cultural, security-related, and other factors that can influence the development and adoption of new designs and technologies can inform research and development. In some cases these factors also relate to industrial organizational approaches, such as total quality management, the adoption of environmental management systems, or supply-chain management.

Future scenarios can assist in envisioning potential implications of technological systems that are emerging or undergoing transformation. Such systems are affected by emerging technologies (such as nanotechnology), potential industrial transformations (such as distributed manufacturing), and changing consumption patterns. Understanding of changes such as these can inform research that enables the technological systems to support sustainability.

Decision Making Tools

Many types of tools and analytical models can inform decisions that contribute to environmental sustainability. While the primary stimulus for model development is to improve scientific understanding within the scientific community, tools developed from these models can enhance sustainability in at least two ways: (1) by providing credible, relevant, and timely research results that inform EPA policy decisions; and (2) by assisting individuals, businesses, communities, and government to better understand the potential implications of their decisions,[46] thus enhancing the likelihood that decisions they make will be more environmentally sustainable.

Environmental models may be descriptive (describing knowledge about specific phenomena) or prescriptive (informing a design or identifying a course of action). They necessarily rely on data and information related to a wide variety of human activities:

- transportation, industry, agriculture, construction;
- protection and consumption of resources (water, energy, materials, ecosystems, land, and air);
- economics and characteristics of human behavior; and
- natural phenomena such as weather patterns, and environmental conditions.

[46] As an example, EPA has adopted the MARKAL (for MARKet ALlocation) model to assess current and future energy technology options. This comprehensive energy/economic model simulates a national, regional, or state-level energy system by representing the interactions between resource supply, conversion processes (e.g., refineries and power plants), end-use technologies (e.g., classes of light-duty personal vehicles or heat pumps), and demand for energy services (e.g., projected vehicle miles traveled or space heating). ORD is using its MARKAL model to help the Air Quality Assessment segment of EPA's Global Change Research Program develop and analyze scenarios of technological change in the transportation and electric power sectors. The research aims to understand how technological evolution could impact future air emissions and to develop and provide an in-house energy/technology assessment capacity.

Important areas for research include the collection and synthesis of required data and information and the incorporation into generalized models. ORD will also assist other collaborators and stakeholders in implementing models. The following paragraphs explore several types of analytical models that can lead to tools that are especially relevant to sustainable decision making.

Scenario models advance the understanding of environmental conditions over time through integrated systems analysis. These models allow users to dynamically explore the connection among choices over which society has some direct control (such as practices in transportation, energy, agriculture, and industry), broad societal trends (such as population and economic growth), and potential future environmental conditions.[47] These types of tools and models can help users understand critical thresholds and explore system response to abrupt change. They can also help diverse groups communicate about the future they desire and develop means and strategies to achieve this future.

Geographic-based analytical models, such as landscape simulators and urban growth simulators, enhance understanding of environmental stressors and conditions in space. These models are particularly useful for understanding the implications of land-use decisions, such as transportation planning, location of buildings, and agricultural practices. Geographic-based analytical models can be integrated with economic models in powerful tools to inform sustainable development.

Material flow-based models, such as life cycle assessment and material flow analysis, can link the use and processing of materials to potential implications for human health, environmental condition, and resource sustainability. They can inform improvements in the use of materials and design of products and also highlight opportunities for focused policy initiatives. In this regard, new methods that connect environmental impact analyses to material flow analysis would be especially useful.[48] Material flow-based tools can also be tied to life cycle cost analysis or economic input-output analysis so that environmental issues and costs can be seen in one view.[49]

Agent-based models offer insight into the implications of how the actions of individuals add up to organizational or multi-organizational behavior. As overall organizational behavior may contribute to or detract from resource sustainability, the models can illuminate policy opportunities to further motivate stewardship behaviors by individuals, communities, industry, and government.

The several varieties of models can be used in combination to develop powerful tools. All of the models can also be used in the context of uncertainty, such as through Monte Carlo simulations.

Assessing the impacts of future scenarios on environmental outcomes is a key element of model development.[50]

---

[47] Community Scale Air Quality Modeling (CMAQ) and Stream Water Quality Model (QUAL2K), both developed at ORD's National Exposure Research Laboratory (NERL), are good examples of the scenario modeling efforts that may assist in evaluating the impact of development patterns and industrial practices on air and water quality.

[48] ORD's National Risk Management Research Laboratory has been developing a very practical life cycle assessment tool that can aid scientists in developing more sustainable chemicals. The GREENSCOPE (Gauging Reaction Effectiveness for the Environmental Sustainability of Chemistries) indicator model was created to evaluate and compare the sustainability of chemical processes. If this model is applied on a large scale, as in the chemical industry, it can achieve sustainable outcomes.

[49] ORD's Office of Solid Waste and Emergency Response (OSWER) has recommended that ORD examine proposed new methodologies for assessing environmental impacts and provide guidance on appropriate support tools for policy-makers. Although material flow analysis is a valuable tool, its primary focus is on volumes and weights of materials. A clearer measure of environmental impact of 3R (Reduce, Reuse, Recycle) programs is needed.

[50] Two widely cited examples that link models and future planning are the 2002 "Willamette Alternates Future Analysis" available from the Western Ecology Research Laboratory of ORD's National Health and Environmental Effects Research Laboratory (www.epa.gov/wed/pages/researchprojects.htm) and the Sustainable Environment for Quality of Life Program (SEQL) program. ORD is a key player in SEQL, developing scientific models such as ReVA to support sustainable land development. ORD's research supports quantification of potential and actual impacts, including cross-sectoral, cross-jurisdictional, and "what-if" analyses. SEQL and similar projects are successful because of the available suite of decision support tools and the direct participation by ORD scientists in community meetings and policy planning.

EPA has begun to improve its modeling capability by considering scenarios including possible climate change, which may seriously impact future land use practices. Under the Integrated Climate and Land Use Scenarios (ICLUS) project, EPA is developing scenarios for land use, housing density, and impervious surface cover for the entire coterminous United States for each decade through 2100. These scenarios—which will be based on the social, economic, and demographic storylines of the Special Report on Emissions Scenarios prepared by the Intergovernmental Panel on Climate Change—aim to assess the effects of climate and land-use change across the United States and identify areas where climate-land-use interactions may exacerbate impacts or create adaptation opportunities. ICLUS scenarios will also be included in the forthcoming version of EPA's BASINS model (to be released in winter 2007), allowing users to consider the impact of changes in both land use and climate change on water quality.

Collaborative Decision Making

Developing effective, innovative polices that promote sustainability depends on having an understanding of the motivation for decision making by businesses, communities, government, and individuals. Such innovative policy approaches include combinations of incentives, market mechanisms, information and education, regulation, and collaborative approaches.

In an industrial context, effective and innovative policies depend on an understanding of the circumstances that encourage or discourage green product design and green supply chain management, and also an understanding of industrial supply-chain leverage points that underlie potential improvements in sustainability outcomes.

Effective and innovative policies targeting individuals and households depend on an understanding of the factors that encourage green consumption, such as cost, information, convenience, peer pressure, and regulations. Effective policies supporting sustainable decision making for communities and local governments depend on an understanding of drivers and hurdles relating to the layout of buildings and to the design and implementation of transportation and energy systems. Policies and approaches can be improved through better understanding of how social groups make innovative and effective decisions.

Because moving towards sustainability often requires negotiation and cooperation among stakeholders, collaborative approaches are particularly important. The related concepts of *collaborative problem solving, cooperative conservation*, and *stewardship* encourage stakeholders to come together to address common environmental issues.[51]

Scientists and scientific research can enhance and strengthen these collaborative approaches in two ways: (1) social science research can add to an understanding of the conditions under which collaborative approaches are effective; and (2) scientists and engineers can participate with policy makers and other decision makers in collaborative processes. These processes can also influence scientific direction by helping scientists to refine the scientific questions they ask and to more effectively communicate their research results.

EPA supports programs designed to encourage environmental stewardship through collaboration at the community and regional levels. ORD's Collaborative Science and Technology Network for Sustainability (CNS) (described in Chapter 6) is one of several programs that focus on collaboration and sustainability-related issues.

---

[51] All three concepts rely on strong scientific input to help decision-making achieve measurable and sustainable outcomes. Former EPA Administrator Michael Leavitt and current Administrator Steve Johnson have made *collaborating problem solving* an important element of EPA's governance agenda. Similarly, the concept of *collaborative conservation* as outlined in the Executive Order of August 26, 2004 requires EPA and four other agencies to actively engage all stakeholders when implementing conservation and environmental projects. Finally, EPA is promoting *environmental stewardship*—defined as shared values and responsibilities among stakeholders for environmental protection.

Metrics and Indicators

Metrics and indicators enable EPA, other government agencies, businesses, communities, and individuals to understand the nature and degree of progress being made toward environmental sustainability. Metrics and indicators enable us to measure and track progress toward societal sustainability goals, send early warning of potential problems to decision makers, and highlight opportunities for improvement at local, regional, and global scales. Effective metrics and indicators require collecting, synthesizing, and communicating appropriate data and information—which requires understanding both what to measure and how to measure it.

Understanding what to measure draws on an analysis of the flows, stressors, and changes over which decision makers have control. These flows, stressors, and changes can also be linked to resilience, vulnerability, warning signals, and limits to resource sustainability. Understanding how to measure can require research in sensors and sensor systems, statistical approaches to guide data collection and preliminary analysis, data mining, and other information technology approaches.

Metrics and indicators are applicable at different scales. At the smallest scale are indicators with a feedback rate that can enable real-time adjustment of consumption, such as of electricity, gasoline, or water for a household or industrial facility. At the largest scale, indicators describe the condition of the national or global environment. A system of connected indicators that collectively describe the condition of the overall system at a local, regional, or global scale can inform effective decisions and strategies for moving toward sustainability.

To begin to develop this multi-scaled system of connected indicators, this research strategy tentatively adopts the six proposed resource sustainability outcomes identified and defined by senior EPA managers in *Everyday Choices: Opportunities for Environmental Stewardship* and listed in Chapter 2 of this document:

- Energy: Generate clean energy and use it efficiently.
- Air: Sustain clean and healthy air.
- Water: Sustain water resources of quality and availability for desired use.
- Land: Support ecologically sensitive land management and development.
- Materials: Use materials carefully and shift to environmentally preferable materials.
- Ecosystems: Protect and restore ecosystems functions, goods, and services.[52]

These outcomes are a starting point for discussing and refining a set of sustainability outcomes and organizing sustainability indicators. ORD is leading a cross-Agency process that aims to refine and sharpen these desired outcomes at multiple scales and to assess whether currently available data and indicators are scientifically valid, useful, and sufficient.

The indicators will build on and connect to the *Draft Report on the Environment*, which employed indicators that are fundamental measures of environmental conditions. The indicators being developed seek to go beyond the *Draft RoE* indicators in four ways:

- An expansion from media and ecosystems, to include resources such as materials and energy, contributes to an increased understanding of the interactions between society and the environment.
- An increased focus on causal connections and correlations among indicators will enable better understanding of systems and will highlight opportunities for improvement.
- A significant focus will be given to indicators that can inform decision making, particularly at local and regional scales.
- The developed indicators may expand beyond the environment to social and economic dimensions.

52 www.epa.gov/epainnov/pdf/rpt2admin.pdf. The outcomes are described more fully in Appendix D of the *Technical Report for Everyday Choices* at www.epa.gov/innovation/pdf/techrpt.pdf

Chapter 6. Roadmap for Implementation

This research strategy will be implemented in several steps:

- Demonstrate the value of sustainability research by identifying key priority national issues where application of sustainability approaches can be most effective in promoting sound and sustainable economic growth.
- Transition the current Pollution Prevention and New Technologies Research Program into the Science and Technology for Sustainability (STS) Research Program.
- Coordinate and integrate research across ORD that builds a critical knowledge base for sustainability, such as by identifying synergies, gaps to be filled, and high-priority emerging areas among existing research strategies.
- Initiate and strengthen collaborations and partnerships—with EPA program and regional offices, other federal agencies, state and local governments, communities, industry, nonprofit organizations, universities, and international partners—that address critical sustainability issues and stimulate broader progress towards sustainability in both research and implementation.

ORD Organization and Multi-Year Plans

While the sustainability research focus is new for EPA, it complements ORD's traditional focus on risk assessment and risk management. ORD organizes its research into a number of media and cross-media MYPs, as shown in Table 6.1. MYPs identify long-term goals (LTGs), annual performance goals (APGs), and associated annual performance measures (APMs) for a 5-year period. MYPs are intended to be living documents and are updated as needed to reflect the current state of the science, resource availability, and Agency priorities. In ORD, MYPs are administered by national program directors (NPDs) who serve as ORD scientific leads for each subject area.

Table 6.1. ORD Multi-Year Research Plans Organized by EPA Strategic Goals

EPA Strategic Goals	ORD Multi-Year Research Plans
Goal 1: Air	Clean Air
Goal 2: Water	Drinking Water Water Quality
Goal 3: Land	Land Preservation and Restoration
Goal 4: Communities and Ecosystems	Ecological Research Human Health Human Health Risk Assessment Global Change Mercury Endocrine Disruptors Safe Pesticides/Safe Products
Goal 5: Compliance and Environmental Stewardship	Science and Technology for Sustainability Economics and Decision Science

This research strategy is designed to guide all ORD research programs and MYPs toward achieving measurable sustainable outcomes. Building on the vision of environmental stewardship, this strategy will engage in research activities that will study the sustainability of systems (e.g., ecological, technological, and human-built) from a life cycle perspective. The results of this effort can be adopted by EPA stakeholders and partners: (1) individuals (via consumer choices), (2) communities (via ecosystem protection and infrastructure planning and management), (3) government (via facility planning and management, technology demonstrations, policies and regulations), and (4) companies (via product design, supply chain management, facility design, and management). ORD leadership on sustainability complements and supports shifts by EPA program offices toward material management and urban revitalization (Office of Solid Waster and Emergency Response), green chemistry (Office of Prevention, Pesticides, and Toxic Substances), low-impact urban development (Office of Policy, Economics, and Innovation), and sustainable water infrastructure and ecosystem and watershed management (Office of Water).

Setting Priorities: Addressing National Issues

Addressing research prioritization within a broad subject area such as sustainability is challenging. Because this research strategy lays out a new research approach for ORD, prioritization is especially difficult. In order to give ORD research planners in the various MYPs more flexibility and autonomy in selecting priority research areas, this strategy identifies guiding factors for selecting research priorities, rather than directly identifying the priority areas. The individual MYPs and their NPDs will more specifically identify their priority sustainability research areas.

The report of the augmented SAB committee reviewing this research strategy made several recommendations on focus and priority:

> Recognizing that the Agency is poised to assume a global leadership role in sustainability research, the committee strongly recommends that, in light of ORD's limited budget, the following parallel activities be conducted immediately:
>
> 1. Conduct core research on sustainability focusing on the development of defensible sustainability metrics, and
> 2. Implement a small number of Agency-sponsored technology demonstration projects that provide ORD with the opportunity to achieve significant visibility within the sustainability research arena.
>
> It is important that these demonstration projects move away from waste/end-of-pipe approaches towards a broader, system-based perspective.[53]

Five factors can guide selection of topics and design of programs under the MYPs:

- *High impact.* The MYPs must pursue research with high scientific impact that addresses important national issues relevant to achieving sustainable outcomes. The development of knowledge in the theme areas discussed in Chapters 3 and 4 must enable the long-term and large-scale sustainability outcomes of the resource systems discussed in Chapter 2. Investing early to avoid or prevent problems is preferred.

[53] The SAB Committee proposed examples: "Examples of such projects might include an assessment from a sustainability perspective of: (1) biofuels policies and options, which are topical and encompass a broad range of issues and potential impacts on emissions of greenhouse gases, agriculture, dependence on imports of fossil fuels, etc. and may imply a variety of economic incentives; (2) a study of the hypoxic environment in the lGulf of Mexico or the Chesapeake Bay, and (3) wastewater practices and infrastructure needs in regions and cities with accelerated population growth." www.epa.gov/sab/pdf/sab-07-007.pdf

- *True to EPA's intramural and extramural research capabilities*. ORD intramural research capabilities serve a dual purpose of directly meeting program and regional office research needs and building capability for solving longer-term problems. Intramural programs can also serve as focal points for scientific and technical assistance centers to assist a variety of government and non-government stakeholders. ORD extramural research programs, such as the Science To Achieve Results (STAR) research grant program, can be used to explore new topical areas or research approaches and also to catalyze change in the broader national research communities. All of these capabilities can and should be drawn upon in an effective MYP.

- *True to EPA's role*. ORD should focus sustainability research in areas that are central to EPA's mission, while collaborating with other agencies and organizations in areas where missions intersect. For example, EPA has a central research role of informing the long-term protection of water quality in watersheds, and it can collaborate with the Department of Energy to advance understanding of the environmental implications of emerging energy technologies. An effective MYP will address both types of research.

- *Leveraging results*. Research that ultimately influences design, decision making, or policies leading to resource sustainability on a sufficiently large scale is preferred. Leverage can occur through partnering in initial research or through transfer and diffusion of knowledge, methodologies, and approaches.

- *In a systems context*. Research should be within a systems context. This is true for research leading to systems understanding but also for research leading, for example, to a decision-making tool that considers multimedia interactions within a geographic area, or to a technology that enables reduction of life cycle energy use for a class of products (see Figure 5.1).

Balancing Research Needs

In general, research needs far exceed available resources. Declining federal budgets for research and development require ORD to address conflicting needs and priorities and to establish a balance across research portfolios. Each MYP should consider each of the following criteria in its research portfolio:

- As frequently emphasized by EPA's SAB, there should be a balance between known and emerging issues and problems. For example, because it is well known that energy and the environment will continue to be interconnected and linked to sustainability, it is important that ORD continue to support research at the nexus of energy and the environment. Nanotechnology, with its environmental implications and applications, is an example of an issue that EPA and ORD correctly identified as an emerging issue several years ago.

- A balance among short- and long-term projects is also necessary. Investing in shorter-term projects permits more immediate demonstration of results, while wisely selected longer-term projects can represent valuable investments for the future.

- A balance is required between projects that are central to EPA's domain (such as watershed protection) and those that reside at the boundaries, such as the interplay between agriculture and the health of aquatic ecosystems. In the case of issues near the boundaries of EPA's responsibilities, collaboration with other government agencies or private-sector organizations is particularly important.
- A balance is needed between research that supports decision making within EPA program and regional offices and research that supports decision making in other local, state, or federal government organizations and in industry.
- Finally, there should be a balance between projects that directly solve problems and those that aim to stimulate others by catalyzing or leading them. An example of the latter is investing in new branches of academic disciplines, such as investing in green chemistry through an extramural research program.

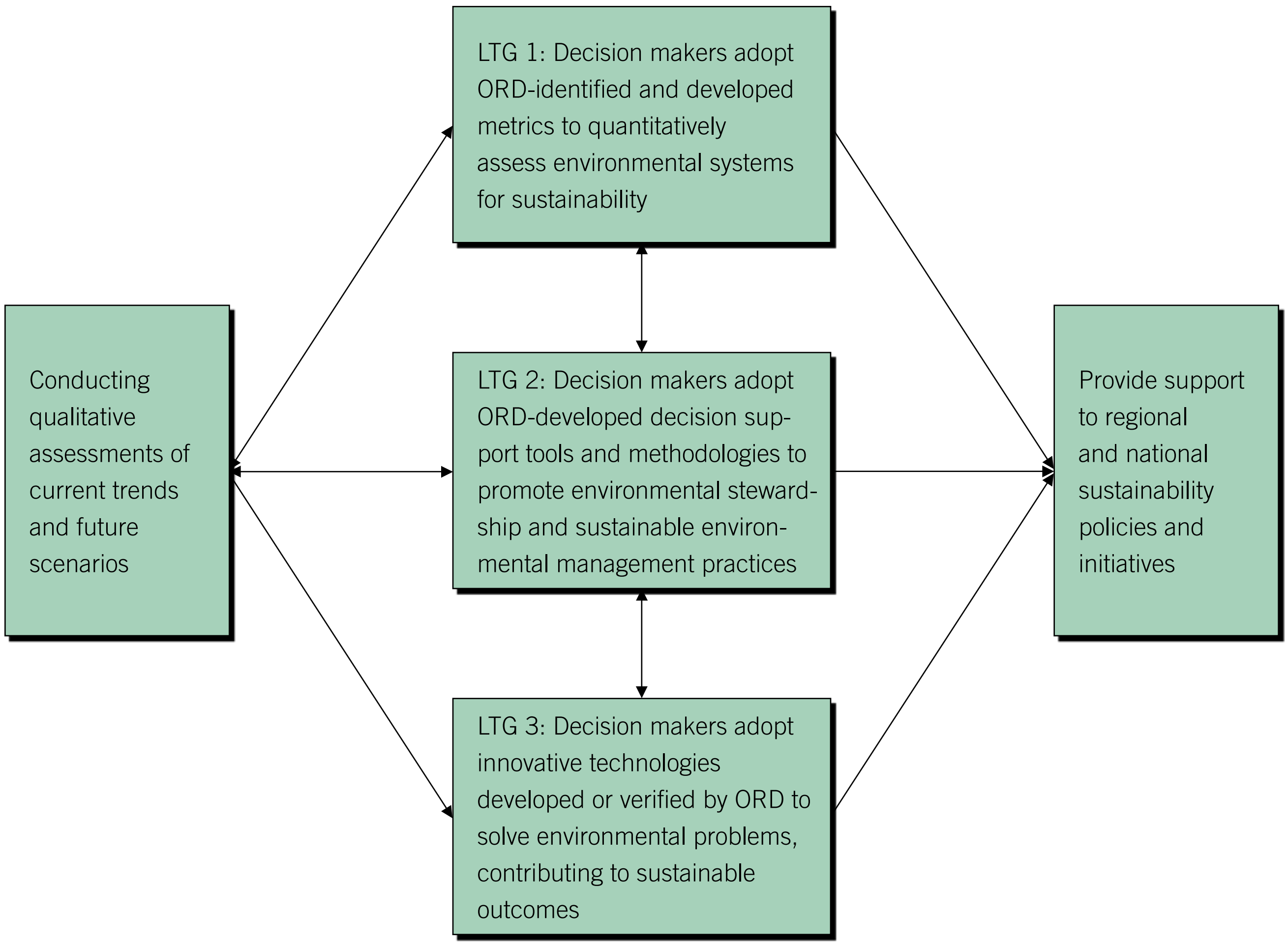
The Sustainability Research Roadmap

1. TRANSITION FROM POLLUTION PREVENTION TO SUSTAINABILITY

The first element in ORD's roadmap toward sustainability is the transition of the existing Pollution Prevention and New Technology MYP to a new Science and Technology for Sustainability (STS) MYP. The restructured program gives greater emphasis to key elements of sustainability research, including green chemistry and green engineering, systems studies, life cycle assessment, and technology verification.

The long-term goals (LTGs) of the new STS MYP are outcome-oriented, providing technical support to broader regional and national sustainability policies and initiatives (Figure 6.1).

Figure 6.1. Long-Term Goals of Science and Technology for Sustainability MYP



To accomplish these goals, regular and continuous assessment of environmental trends is needed, as well as thoughtful consideration of likely alternative future scenarios. Together, these considerations will inform the development of sustainability metrics (LTG 1) that will not only provide baseline information on the sustainability of systems, but will also allow the measurement and tracking of progress in achieving sustainable outcomes. Information gathered during the assessment of conditions and the development of metrics will provide researchers with information critical for developing and implementing decision-support tools (LTG 2) and innovative technologies (LTG 3) that will promote sustainable outcomes.

Supporting the central theme of helping decision makers make better and more sustainable decisions, the STS includes two grant programs aimed at stimulating technology development and putting existing sustainability ideas into practice.

The *People, Prosperity, and Planet (P3)* student sustainability design competition inspires and educates the next generation to research, design, and develop solutions to sustainability challenges in areas such as agriculture, materials and chemicals, energy, information technology, water, and the built environment. P3 students and their faculty advisors quantify the benefits of their projects in the environmental, economic, and social dimensions and advisors integrate the projects into their educational syllabi. Through the P3 program, students learn to work in a multidisciplinary environment and to make collaborative, interdisciplinary decisions. By integrating sustainability concepts into higher education, P3 is helping to create a future work force with an awareness of the impact of its work on the environment, economy, and society.

The *Collaborative Science and Technology Network for Sustainability (CNS)* program supports consortia of government and non-government organizations on high-impact regional projects that explore and provide learning opportunities for new approaches to environmental protection that are systems-oriented, forward-looking, and preventive. The CNS program is described in more detail later in this section.

2. COORDINATING AND INTEGRATING PRIORITY RESEARCH ACROSS ORD AND EPA

The next element of the Sustainability Research Roadmap is coordinating and connecting existing ORD research programs. The resulting research portfolio is more integrated, will inform policy and decision making, and will illuminate further research priorities across ORD and the rest of EPA. The first step in this process is identifying the synergies and potential coordination among the other research strategies and MYPs (shown in Table 4.2) that will enhance EPA's research contribution to sustainability. A model of synergies between the Sustainability Research Strategy (SRS) and the Environmental Economics Research Strategy (EERS) is shown in Figure 6.2.

The EERS presents a focused analysis of Agency research priorities in economics and decision sciences, which are supported through the Economics and Decision Sciences (EDS) extramural research program. As shown, the identified EERS research priorities dovetail nicely with the SRS integrated framework as outlined in Chapter 4.

The general intersection of behavioral science research and sustainability gives rise to the last two of the six SRS themes described in Chapter 4: Economics and Human Behavior and Information and Decision Making. These themes include five high-priority EDS research topics presented in the EERS consultation process: Health Benefits Valuation, Ecological Benefits Valuation, Market Mechanisms and Incentives, Environmental Behavior and Decision Making, and Benefits of Information Disclosure.

These five EERS topics will in turn provide critical input into the SRS research objectives described in Chapter 5. The penultimate goal of this research coordination is to provide the behavioral science research necessary for developing environmental policies that support sustainability outcomes and are cost-efficient over the long term.

Figure 6.2. Integrating the Environmental Economics Research Strategy (EERS) and Sustainability Research Strategy (SRS)

Behavioral Sciences Research and Sustainability

How individual, firm and institutional behavior enables and/or prevents sustainable outcomes

SRS Themes	**Economics and Human Behavior**	**Information and Decision-Making**
EERS Topics	**Health Benefits Valuation:** Value of mortality and morbidity risks associated with pollution **Ecological Benfits Valuation:** Ecosystem services value **Market Mechanisms and Incentives:** Effectiveness and potential of trading programs	**Environmental Behavior and Decision-Making:** How consumers and producers meet their environmental obligations under mandatory and voluntary initiatives **Benefits of Environmental Information Disclosure:** How information disclosure improves efficiency of decision-making
SRS Objectives	1. **Economic Instruments:** Trading schemes and taxes 2. **Systems understanding** through integrated ecological-economic models 3. **Economic sustainability metrics** for individuals, business, policy makers to: • Make sustainable consumption decisions • Determine the business case for sustainability • Regulatory analysis (cost-benefit, cost-effectiveness analysis)	1. **Decision-support tools** to help policy maker, corporate officials, engineers, local/regional planners identify and implement sustainable options 2. **Collaborative decision-making**

Cost-efficient environmental policies and outcomes for U.S. business and consumers

The behavioral science and sustainability programs cooperated to organize a December 2005 workshop that examined economic aspects of sustainability, and plan to cooperate in developing future CNS, Market Mechanisms, and Environmental Behavior solicitations. In addition, the programs will coordinate with each other in synthesizing and communicating research results to support regional decision making as part of this collaborative element of the roadmap. Finally, the EDS program will contribute knowledge and insight on organizational behavior in the private sector that will inform EPA interaction with businesses on sustainability, part of this roadmap element.

These examples illustrate collaboration that can be applied to other research strategies as well. The coordination and integration across research strategies will enable ORD and the rest of the Agency to identify knowledge gaps and to more effectively identify emerging priorities. This process will be ongoing, proceeding from the prioritization factors discussed earlier in this chapter.

3. INITIATING AND STRENGTHENING COLLABORATIONS AND PARTNERSHIPS

The third element in ORD's roadmap toward sustainability involves teamwork with a wide range of collaborators and partners: EPA program and regional offices, states, local governments; other federal agencies, universities, the business communities, and international agencies and organizations. After some general considerations, this section will explore each of these areas for ORD collaboration.

ORD is in a unique position to lead in sustainability research and its connection to policy and decision making. As a science-based organization within a regulatory agency, ORD can provide leadership in the following ways: (1) provide integrated multimedia scientific information reflecting considerations beyond single media for more sustainable policies; (2) provide strong input into Agency indicators of environmental sustainability; and (3) collaborate with universities, nonprofit organizations, businesses, and research organizations in other countries, to better understand sustainability and to identify knowledge gaps and emerging priorities.

A draft report to assist meeting deliberations for the SAB review of this research strategy called for EPA leadership in sustainability:

> There is a need for, and EPA should provide, leadership both internal to the Agency and external among the federal agency family and other organizations. … EPA has an opportunity to coordinate and lead in the definition of environmental sustainability and in the use of related research products that will influence how other federal agencies and organizations move forward with their sustainability programs.[54]

[54] www.epa.gov/sab/pdf/sustainability_for_chartered_board_jan_18_07.pdf

In implementing this research strategy, external collaboration and partnering with stakeholders and customers will be a key element of ORD's management approaches.

As a science-based organization, ORD faces the critical challenge of finding effective ways to deliver its research products to decision makers and to work with them to translate research into practical outcomes. ORD initiated its Collaborative Science and Technology Network for Sustainability (CNS) program on the premise that sustainable outcomes would best be achieved by collaborative problem solving in which scientists and decision makers together assess and understand implications of policy choices. In achieving sustainability, ORD scientists must strive to be both good scientists and good communicators.

3.a. Collaboration with EPA Program and Regional Offices, States, and Local Governments

Program Offices: ORD research has traditionally served to address specific issues raised by EPA program offices. ORD NPDs are responsible for coordinating with program offices to identify critical research gaps. EPA program offices have identified a number of sustainability-related research questions that are reflected in existing MYPs and in the new Science and Technology for Sustainability MYP. Many of these program office activities reflect applications of sustainability research supported by ORD and defined in this strategy. These activities include a focus on systems or multimedia approaches, sustainable design, system resilience, and collaborative and community-based problem solving.

The challenge ahead is to coordinate research that may involve several program offices and NPDs. One example illustrates how the common goal of sustainability is reflected in program offices and MYPs around the research theme of urban sustainability (human-built systems and land use). Table 6.2 identifies a number of key Agency programs related to the common goal of a sustainable built environment.

Table 6.2. EPA Programs Related to the Built Environment

Media, EPA Programs, and Program Offices[55]	Program Objectives
Land: Smart Growth (OPEI)	Help design low-impact and green communities through sharing best practices and promoting 10 development principles.
Land: SMARTe (ORD)	With Web-based decision-support tool, help developers evaluate future reuse options for a site or area.
Land: Brownfield Revitalization (OSWER)	Revitalize contaminated sites to be economically productive.
Land: Environmentally Responsible Redevelopment and Reuse (ER3) (OECA)	Use enforcement and incentives to promote sustainable development of contaminated sites.
Water: Sustainable Water Infrastructure (OW)	Better manage utilities, full-cost pricing, efficient water use, and watershed approaches.
Water: WaterSense (OW)	Help conserve water for future generations by providing information on products and programs that save water without sacrificing performance.
Water: National Pollution Discharge Elimination System (OW)	Control water pollution by green infrastructure and regulating point sources that discharge pollutants into waters of the United States.
Energy Use: Energy Star (OAR)	Evaluate and test energy efficiency of products in more than 50 categories; provide information on green building design and energy efficiency.
Air: Air Toxics Strategy (OAR)	Identify and monitor urban air toxics from stationary, mobile, and indoor sources.
Air: Community-Based Air Quality Programs (OAR)	Support air toxics projects in about 30 communities across the nation, helping inform and empower citizens to make local decisions concerning the health of their communities.
Indoor Air: Indoor Environment Management Research (ORD)	Develop better understanding of the relationship among indoor air quality and emissions sources, heating, ventilating, and air-conditioning systems, and air-cleaning devices.
Climate: Climate Impact Assessment Research (ORD)	Integrate remote and ground-based data and dozens of models to assess potential impacts of climate change.

[55] OPEI: Office of Policy, Economics, and Innovation; ORD: Office of Research and Development; OSWER: Office of Solid Waste and Emergency Response; OECA: Office of Enforcement and Compliance Assistance; OW: Office of Water; OAR: Office of Air and Radiation.

Achieving sustainability in the built environment is clearly a national challenge that is being addressed by many EPA programs that cut across program offices and strategic goals. These programs include building design and energy efficiency, urban land revitalization, smart growth, management of urban systems and water infrastructure, and improving air quality. ORD's challenge is to help define the underlying research needed to support these programs and work to provide the integration across program offices and MYPs.

ORD has also begun working with program and regional offices to identify indicators that define and measure trends related to the sustainability outcomes identified in Chapter 2. The emergence of the focus on sustainability outcomes reflects the evolution of thought in EPA on how best to address mission responsibilities. This new effort is linked to EPA's *Report on the Environment and its Draft Strategic Plan 2007-2012*.

Regional Offices: Because ORD is committed to working closely with EPA regional offices, ORD has created the positions of regional science liaisons in each region. Many regional offices have identified sustainability-related issues as major priorities. The existing Regional Applied Research Effort (RARE) program provides the regions with near-term research on priority region-specific science needs, and improves collaboration among regions and ORD laboratories and centers. Each year, ORD provides funding for each region to develop a research topic, which is then submitted to a specific ORD laboratory or center as an extramural research proposal. Once approved, the research is conducted as a joint effort, with ORD researchers and regional staff working together to meet region-specific needs.

RARE provides a means to address a number of sustainability issues. Past RARE research topics have touched upon all aspects of environmental sciences, from human health concerns to ecological effects of various pollutants. The RARE program also supports *Regional Science Topic Workshops*, which aim to improve cross-Agency understanding of science issues and develop a network of EPA scientists working on selected topics. These programs provide sound foundations for those who will continue to exchange information on science topics as the Agency moves forward in planning education, research, and risk management programs.

Several national issues relevant to all EPA regions offer special potential for ORD cooperation with regional offices. Two of the most often cited national issues that affect regions in different ways are energy generation and use, and ecosystem management. National attention to issues like geochemical life cycles (e.g., nitrates) involves complex interactions across regions. ORD's implementation of the Sustainability Research Strategy points to a need for stronger coordination across EPA regions on key national issues.

State and Local Governments: ORD recognizes that many critical decisions on sustainability—such as urban growth and development, ecosystem protection, water and energy use, and human health—are made at state and local levels. In addressing these areas, decision makers must anticipate potential social and environmental conditions (future scenarios) and work to integrate media (air, water, and land) impacts through a systems approach.

To better understand such high-priority regional sustainability issues, ORD and the Office of Policy, Economics, and Innovation (OPEI) have initiated outreach to state, local, and tribal governments. This interaction will enable ORD to contribute to the identification and scientific understanding of the longer-term societal issues that will likely affect EPA's mission responsibilities at regional and national levels. ORD will also be able to contribute possible solutions and management options in the form of technologies, decision-making tools, and collaborative problem solving.

The CNS program is a significant part of ORD's strategy to support the application of science to local and regional decision making in pursuit of sustainability. Table 6.3 shows the projects and collaborators funded through the first CNS solicitation.

Table 6.3. Projects and Partners of the Collaborative Science and Technology Network for Sustainability

Project	Grantee	Partners and Collaborators
Moving Toward Sustainable Manufacturing Through Efficient Materials and Energy Use	Northeast Waste Management Officials' Association	Commonwealth of Massachusetts
Multi-Objective Decision Model for Urban Water Use: Planning for a Regional Water Reuse Ordinance	Illinois Institute of Technology	State of Illinois, City of Chicago, Fox Metro Water Reclamation District
Ecological Sustainability in Rapidly Urbanizing Watersheds: Evaluating Strategies Designed to Mitigate Impacts on Stream Ecosystems	University of Maryland - College Park	Montgomery County, U.S. Geologic Survey
Using Market Forces to Implement Sustainable Stormwater Management	City of Portland, Energy Office	Portland State University, University of Oregon, Willamette Partnership
Sustainable Sandhills: Development a Plan for Regional Sustainability	Sustainable Sandhills	State of North Carolina, Sandhills Area Land Trust, Base Closure and Realignment Regional Task Force, Southeast Regional Partnership for Planning and Sustainability, National Association of Counties
Sustainability of Land Use in Puerto Rico	Universidad Metropolitana	Commonwealth of Puerto Rico, US Forest Service, Puerto Rico Planning Society
Transforming Office Parks Into Transit Villages	The San Francisco Foundation Community Initiative Funds	Hacienda Business Parks Owners Association, Cambridge Systematics, Inc., Oracle
Industrial Ecology, Pollution Prevention and the New York/New Jersey Harbor	New York Academy of Sciences	Rutgers University, Manhattan College, General Electric, State of New Jersey, State of New York, Columbia University, Port Authority of New York and New Jersey, New York City, Natural Resources Defense Council, Hudson River Foundation
Harnessing the Hydrologic Disturbance Regime: Sustaining Multiple Benefits in Large River Floodplains in the Pacific Northwest	Oregon State University	University of Oregon, Willamette Partnership, State of Oregon, City of Eugene, City of Corvallis, City of Albany, U.S. Dept. of Agriculture, U.S. Fish and Wildlife Service, National Marine Fisheries Service
Bringing Global Thinking to Local Sustainability Efforts: A Collaborative Project for the Boston Metropolitan Region	Tellus Institute	(Boston) Metropolitan Area Planning Council, The Boston Foundation, Commonwealth of Massachusetts
Integrating Water Supply Management and Ecological Flow Water Requirements	The Nature Conservancy	Tellus Institute, Tufts University, State of Connecticut
Cuyahoga Sustainability Network	University of Maryland Baltimore County	Cleveland State University, University of Iowa, Kent State University, Chagrin River Watershed Partners, Euclid Creek Watershed Council, West Creek Preservation Committee
Framework for Sustainable Watershed Management	Delaware River Basin Commission	Monroe County, State of Pennsylvania, U.S. Geological Survey, Brodhead Watershed Association

CNS grantees draw on decision-making tools derived from analytical models and on collaborative approaches to practical problem solving that support progress at a regional scale toward the sustainability outcomes identified in Chapter 2.

The CNS-supported Sustainable Sandhills project in North Carolina is a model of such integrated decision making for sustainable outcomes. A non-profit institution (Sustainable Sandhills) is serving as a convener for the U.S. Army, the state of North Carolina, and dozens of local and state communities. EPA's Region 4 is collaborating with ORD ecologists and state of North Carolina scientists to develop a set of analytical decision support tools derived from geographic information linked to ecological models and future scenarios. The goal is an effective regional plan that meets long-term community goals and is cost-effective, environmentally sound, and sustainable.

The Sustainable Sandhills example reflects a general strategy of integrating and synthesizing knowledge generated across various research programs inside and outside of EPA to more effectively address sustainability-related questions at the regional level. This example illustrates how regional projects can serve as integrating mechanisms for ORD research strategies. Sustainable Sandhills and other regional projects may assist ORD in identifying additional important core research questions and prioritizing needs in the development of fundamental research methods.

Lessons learned from the CNS program will be shared with regions and communities that work with EPA through other programs, such as Community Action for a Renewed Environment (CARE), Environmental Justice Collaborative Grants, Targeted Watershed Grants, and Brownfields Technical Assistance.

3.b. Interagency Collaboration

While EPA is the lead federal agency in environmental compliance and enforcement, its overall and environmental research budgets are small relative to the federal government as a whole. In energy, transportation, agricultural management, and other areas, EPA supports and complements other federal lead agencies. A national goal of sustainable development can only be achieved through integrated and coherent polices across federal agencies.

In implementing this research strategy, ORD will build on existing partnerships and seek new collaborations with other federal agencies.[56] In 2004, ORD partnered with the Office of the Federal Environmental Executive (OFEE) to organize a sustainability workshop among federal agencies. The workshop revealed a wealth of federal activities but a paucity of coordination and policy coherence among the activities. This led to the creation of a Stewardship and Sustainability Council organized by OFEE and EPA. ORD intends to continue working with OFEE to coordinate and integrate sustainability efforts with other federal agencies and to pursue interagency collaboration that links research and application. Areas of mission focus and supported research among federal agencies corresponding to the six sustainability outcomes from Chapter 2 are shown in Table 6.4, which highlights opportunities for interagency collaboration and coordination.

[56] The Office of Science and Technology Policy (OSTP), which coordinates science and technology in federal agencies, has focused on a number of macro research and technology issues including industrial innovation, competitiveness, and nanotechnology. Extensive interagency coordination also focuses on climate change assessment and research, earth observations and GOESS, and ocean sciences. Water availability and quality and ecosystem services are emerging issues under interagency discussion.

Table 6.4. Opportunities for Research or Program Collaboration across Agencies, by Sustainability Resource Area

● - Some Opportunity ● ● - Strong Opportunity

Agency[57]	Air	Ecosystems	Energy	Land	Materials	Water
DOD		●	●	● ●	●	
DOE	●		● ●			
DOI		● ●		● ●	● ●	● ●
DOT	● ●		●	● ●		
EPA	● ●	● ●	●	● ●	●	● ●
NASA	● ●					
NOAA	● ●					● ●
NSF	●	● ●	●	●	● ●	● ●
USDA				● ●	●	●

[57] DOD: Department of Defense; DOE: Department of Energy; DOI: Department of the Interior; DOT: Department of Transportation; NASA: National Aeronautics and Space Administration; NOAA: National Oceanic and Atmospheric Administration; NSF: National Science Foundation; USDA: U.S. Department of Agriculture.

One example of federal interagency cooperation is the emergence of partnerships on sustainable land management. USDA and DOI's U.S. Geological Survey each support research related to land management and development. DOD's Department of the Army is increasingly focusing on its stewardship of land on and around military bases. DOI and USDA's Forest Service are partnering in activities related to healthy forests, ecological services, and management. New partnerships are also emerging around the issue of biofuels and energy conversion. DOE and USDA co-chair the Biomass Research and Development Board (which also includes DOI, DOT, EPA, OSTP, and OFEE) mandated by the Energy Policy Act of 2005. DOE and USDA are also leading efforts to develop a comprehensive Federal Biofuels Work Plan that will define an overall interagency biomass strategy incorporating topics such as feedstock, conversion technology, biofuel infrastructure, and communication, education and outreach. Sustainability-related objectives are emphasized in the Energy Policy Act, which directs the secretaries of Agriculture and Energy, in consultation with the EPA administrator and heads of other appropriate departments and agencies, to direct research and development toward "a diversity of sustainable domestic sources of biomass for conversion to biobased fuels and biobased products" and "to maximize the environmental, economic, and social benefits of production of biobased fuels and biobased products on a large scale through life-cycle economic and environmental analysis and other means."

3.c. University Collaboration

University communities are embracing sustainability in facility operations, community development, and academic programs. With endowments and local funds, many universities have created new academic centers for sustainability systems sciences, resilience, green design, and green chemistry. Many joint programs exist between business schools and environmental programs.

ORD has developed strong ties with the university community through its extramural STAR research grants (including CNS) and fellowship programs. ORD's P3 student sustainability design competition and its engineering curriculum benchmarking project are catalyzing leadership within academia. Going beyond these grant-related activities, ORD aims to foster closer ties among universities, ORD laboratories, and other EPA program and regional offices to boost research on current environmental problems, potential future problems, and sustainable solutions. Toward this goal, ORD began in 2006 to conduct visits to major university sustainability research centers to discuss coordination and collaboration on emerging research issues. ORD aims to partner with many more academic centers to ensure that scientific advances are translated into practical management approaches. By interacting with universities and investing in research and education, EPA can support the development and refinement of academic fields that contribute to sustainability.[58]

[58] EPA's Smart Growth Program has made the greening of universities and their surrounding communities a priority issue.

3.d. Collaboration with the Business Community

Recognizing that business leadership and decisions taken by industry have a strong influence on progress towards sustainability, ORD is pursing a two-fold strategy with private industry: (1) EPA engages in a broad conversation with the business community to collectively and strategically identify and address sustainability-related problems; and (2) Drawing on knowledge gained from the EDS research program, EPA will analyze and document the business case for sustainability, bringing a better understanding of short- and long-term business motivation to inform EPA programs.[59]

3.e. International Collaboration[60]

Five years after the 2002 World Summit on Sustainable Development (WSSD), many developed and developing nations, United Nations agencies, and non-government organizations are aggressively pursuing sustainable development objectives. The WSSD launched hundreds of Partnerships for Sustainability among governments and non-government organizations to address a broad range of sustainability issues. Significant science and technology cooperation and agreements are underway within the OECD and among the G8 nations. The G8 2003 Science and Technology for Sustainable Development Action Plan focuses on areas that are central to EPA: coordination of global observation systems through the Global Earth Observation System of Systems (GEOSS); cleaner, more efficient, and sustainable energy use; agricultural productivity and sustainability; and biodiversity conservation.

Several European Union member countries have also developed their own sustainability research strategies. The European Union's newly launched 7th Research Framework (2007-2013) supports basic research in several areas related to sustainable development including sustainable health care, sustainable production and management of biological resources, sustainable production and consumption patterns, sustainable transport and energy systems, sustainable greenhouse gas reductions, and technology development and verification.

ORD intends to take advantage of the increasing global interest in sustainability to pursue international partnerships to support sustainability research and the achievement of the Millennium Development Goals. ORD has begun to expand its collaboration with the European Commission in areas that support the research identified in Chapter 4. These areas include environmental and sustainability indicators, uncertainty in environmental models, development of decision-support tools and environmental technologies, nanotechnology uses, and sustainable chemistry. In October 2006, EPA signed an agreement for research collaboration with China. A February 2007 agreement signed by EPA and the European Union director general for research has launched a cooperative research and eco-informatics program that provides a new framework for cooperation between the EPA and several European Commission directorates.

---

59 These ORD activities complement EPA's traditional regulatory and voluntary programs. The Agency has more than 65 voluntary programs that encourage business to move beyond complying with environmental laws to implement sustainable operations. Programs such as Performance Track operate at the facility level while others, such as the Sectors Program, work across whole industrial sectors. EPA's Climate Leadership program aims at voluntary reduction of greenhouse gas emissions. The High Production Volume Challenge Program aims to provide the public with information on many high-volume chemicals. These and many other programs are part of EPA's efforts to advance environmental stewardship and sustainable outcomes.

60 Links to many of these international programs and research strategies are available at EPA's Sustainability Web site: www.epa.gov/sustainability/international.htm

Implementing the Sustainability Research Strategy for a Sustainable Future

Advances in science and technology form a foundation that can lead to a wide array of opportunities for advancing toward
a sustainable future:

- Science and technology can enable communities, nations, and industries to measure, monitor, and characterize pollutants and environmental conditions.
- Models and data analysis techniques—ranging from chemical design tools based on computational toxicology to material flow analysis—can help society to better understand environmental conditions, their underlying social and economic causes, and their effects on human health.
- Technological advances—such as those achieved in green chemistry and engineering—can enable society to use resources more efficiently and to prevent or reduce pollution and the associated risks to human health and the environment.
- Futures analysis can assist society in better anticipating and preparing for potential social and economic changes—such as the predicted industrial transformation growing out of the convergence of nanotechnology, biotechnology, and information technology—and resulting environmental changes.
- Finally, science and technology can help to develop tools for supporting decision making that advances the protection of human health and the natural environment now and for future generations.

In short, this Sustainability Research Strategy serves our society's environmental needs in ways that also support our economy and society. The potential long-term national benefits of pursuing the research identified in the Sustainability Research Strategy are clear and compelling:

- It will enable communities and regions to envision, plan, and manage their natural and built environments so that materials and energy are conserved and the quality of air and water is protected while economic and social needs are met.
- It will enable industry and consumers to benefit from advances in scientific understanding and technology so that resources are conserved and the environment and public health are protected while economic and social objectives are met.
- It will give EPA and the nation more options to protect human health and the environment for future generations, informed by an improved understanding of systems in the natural and built environments.

For more information on
the ORD Sustainability
Research Strategy,
please contact:

Sustainability Program
Office of Research and Development
Mail Code 8101R
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue N.W.
Washington, D.C 20460

Printed on 100% recycled/recyclable paper with a minimum 50% post-consumer fiber using vegetable-based ink.

SCIENCE

EPA
United States
Environmental Protection
Agency

PRESORTED STANDARD
POSTAGE & FEES PAID
EPA
PERMIT NO. G-35

Office of Research and Development (8101R)
Washington, DC 20460

Official Business
Penalty for Private Use
$300