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Improving the Multi-Media Assessment Capabilities of the U.S. EPA: Recommending the Use of Input/Output Life-Cycle-Analysis

Lewis D. McCulloch

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IMPROVING THE MULTI-MEDIA ASSESSMENT CAPABILITIES OF THE U.S. EPA: RECOMMENDING THE USE OF INPUT/OUTPUT LIFE-CYCLE-ANALYSIS

by

Lewis D. McCulloch

B.Sc. Environmental Science

Western Washington University, 1998

Submitted to the Engineering Systems Division
And the Department of Civil and Environmental Engineering
in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Technology and Policy
And
Master of Science in Civil and Environmental Engineering

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Signature of Author…………………………………………………………………………………………………
Technology and Policy Program and the Department of Civil and Environmental Engineering
May 9th, 2003

Certified by………………………………………………………………………………………………………
Joanne Kauffman
Principle Research Scientist, Laboratory For Energy and the Environment
Thesis Supervisor

Certified by………………………………………………………………………………………………………
David Marks
Morton and Claire Goulder Family Professor
Director, Laboratory For Energy and the Environment
Thesis Supervisor

Accepted by………………………………………………………………………………………………………
Oral Buyukozturk
Professor of Civil and Environmental Engineering
Chairman, Committee for Graduate Students

Accepted by………………………………………………………………………………………………………
Daniel Hastings
Professor of Aeronautics and Astronautics and Engineering Systems
Director, Technology and Policy Program
Chairman, Committee for Graduate Students

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ABSTRACT

The purpose of this research is to evaluate how the United States Environmental Protection Agency (U.S. EPA) can improve its multi-media assessment capabilities. It is increasingly evident that environmental problems are complex and often impact more than a single media (air, water, land). New analytic methods are therefore required to understand and analyze these problems in a holistic way.

To assess the most effective way to improve this capability, the mission of the U.S. EPA and the current methods used to support this mission are reviewed, including both the development of new regulations and emerging voluntary initiatives. Some limitations with the current methods are discussed. In response to these limitations, the field of industrial ecology and specific life-cycle-assessment methodologies are explored. Weaknesses of traditional life-cycle-assessment methodologies, from the point of view of an environmental regulatory agency, are examined.

Input/output life-cycle-assessment is presented as an appropriate tool to overcome these weaknesses. Details of input/output life-cycle-assessment are described and a brief demonstration of how the U.S. EPA could use this tool to evaluate some of the industries currently working with the U.S. EPA is presented. Finally some recommendations on how the U.S. EPA could incorporate the use of input/output life-cycle-assessment into its regulatory process and voluntary initiatives are offered.

Thesis Supervisor: Joanne Kauffman
Title: Principle Research Scientist, Laboratory For Energy and the Environment

Thesis Supervisor: David Marks
Title: Morton and Claire Goulder Family Professor
Director, Laboratory For Energy and the Environment

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CHAPTER 1: INTRODUCTION

To protect human health and safeguard the natural environment is the deceptively simple mission of the United States Protection Agency (U.S. EPA). The U.S. EPA was created to be an agency that could address the emerging complex environmental problems facing this nation. The agency has evolved around a myriad of media-specific mandates from Congress and has struggled with how to evaluate environmental issues in a holistic manner.

Effective environmental protection requires information. Without information on the state of the environment (the quality of the air, water, and land) and what is being polluted and where the pollution is occurring, it is impossible to design and implement policies to improve the environment. The U.S. EPA maintains several large databases created to maintain and track a variety of environmental information. Most of the systems address information about a specific media (i.e. water, air, waste.) This information is then used by the U.S. EPA to, among other things, assess the state of the environment and to design policies to protect the environment.

Industrial ecology is emerging as an alternative means of evaluating the "health" of the environment. This field focuses on a multi-media view of all aspects of an industry's processes and business. One of the leading tools used in industrial ecology for assessing all the environmental impacts of a particular industry is Life-Cycle-Assessment (LCA). LCA is a methodology that tracks material and chemical flows from extraction to disposal (cradle to grave.) The United Nations Environment Program defines life-cycle-assessment as "the process of evaluating the effects that a product has on the environment over the entire period of its life cycle." (UNEP, 1996) LCAs include information on the release of substances into the environment as well as incorporating additional environmentally significant information, such as the environmental impacts of a product during the usage and disposal phases.

The U.S. EPA has long been aware of the benefits of taking a multi-media approach to environmental policy and assessment but has been struggling with implementing measures to foster this type of approach. The evolution of environmental regulations has created a stove-piped system where integration across media and over time is difficult if not impossible to accomplish. "Ecologists are steadfast in suggesting the need for a comprehensive, as distinct from a fragmented, approach to environmental problems." (Guruswamy, 2001)

Purpose of this Research

The purpose of this research was to evaluate how the U.S. EPA can improve its multi-media assessment capabilities. The goal was to determine whether it is feasible for the U.S. EPA to utilize life-cycle-assessment (LCA) as an analytic tool. LCA has been proposed as an effective means to address environmental problems in a holistic way. In order to accomplish this purpose the various means that the U.S. EPA uses currently to accomplish its mission were studied to determine whether specific LCA methodologies could be effectively employed. The field of industrial ecology, from which LCA has emerged, and a variety of LCA methodologies are explored to determine which specific methodologies are appropriate for use by the U.S. EPA.

Organization of this Thesis

Chapter 2: Presents the mission and goals of the U.S. EPA. This chapter describes the history of the agency including the original design of the agency and the Congressional mandates that have shaped the ways in which the U.S. EPA operates.

Chapter 3: Describes how the U.S. EPA works today to achieve its mission and goals. This chapter explores both the regulatory activities and the voluntary initiatives that the agency is using to protect the environment.

Chapter 4: Reviews some limitations with the current approach employed by the U.S. EPA.

Chapter 5: Is a literature review on the field of Industrial Ecology and Life-Cycle-Assessment. It describes the field of industrial ecology and presents some of the details about various LCA methodologies. The chapter ends with some limitations of the traditional LCA methodologies with particular reference to environmental protection..

Chapter 6: Describes Environmental Input/Output Life-Cycle-Assessment (I/O LCA). I/O LCA is a specific LCA methodology that addresses the limitations of traditional LCA tools.

Chapter 7: Presents the results of a small study of how environmental input/output life-cycle-analysis could be used by the U.S. EPA.

Chapter 8: Concludes this thesis with a set of policy recommendations for the U.S. EPA on how to incorporate environmental input/output life-cycle-analysis into its day-to-day work.

CHAPTER 2: MISSION AND GOALS OF THE U.S. EPA

The purpose of this chapter is to outline the overall mission of the U.S. EPA and to describe the specific goals that have been identified and which constantly evolve for the U.S. EPA to achieve this mission. In order to set the stage for the current iteration of the mission and goals defined in the latest agency strategic document it is important to understand the historical beginnings of the agency. This chapter is not intended to provide a comprehensive overview of the rise of environmentalism or the complete history of the creation and evolution of the U.S. EPA. The purpose is to point out that from the very beginning the agency was charged with examining environmental problems from a multi-media perspective and for a variety of reasons the agency has been hampered in its ability to do just that. The rationale for making this point clear is to show the relevance of the research presented in the remainder of this thesis to improving the multi-media assessment capabilities of the agency.

1960's – The Emergence of Environmentalism

The environmental movement began during the 1960s. This movement was based on holistic and ecological thinking. (Ackerman and Hassler, 1980) This type of thinking was tempered, on the other hand, by the doubts of the general population that independent administrative agencies were capable of creatively regulating a complex social problem in the public interest. (Ackerman and Hassler, 1980) These two competing view points contributed to the way in which the U.S. EPA was created in 1970.

1970's – Federal Reorganization and the Creation of the U.S. EPA

It is interesting to note that from the very beginning, the vision for the U.S. EPA was one that allowed for the multi-media assessment of environmental problems. "In his message accompanying the reorganization plan creating the U.S. EPA, President Nixon stated his desire that the Agency would merge pollution control functions that had been scattered across the federal bureaucracy into an organizational structure capable of perceiving the environment 'as a single interrelated system' and of regulating pollution after 'determining the total exposure of man and his environment.'" (Hornstein, 1984, pg. 580) The specific language used by President Nixon in his address to Congress on July 9th 1970 is quite explicit in the need to look at environmental problems in a holistic way:

> "Many agency missions, for example, are designed primarily along media lines--air, water, and land. Yet the sources of air, water, and land pollution are interrelated and often interchangeable. A single source may pollute the air with smoke and chemicals, the land with solid wastes, and a river or lake with chemical and other wastes. Control of the air pollution may produce more solid wastes, which then pollute the land or water. Control of the water-polluting effluent may convert it into solid wastes, which must be disposed of on land. Similarly, some pollutants--chemicals, radiation, pesticides--appear in all media. Successful control of them at present requires the coordinated efforts of a variety of separate agencies and departments. The results are not always successful. A far more effective approach to pollution control would:
>
> - Identify pollutants.
>
> - Trace them through the entire ecological chain, observing and recording changes in form as they occur.
>
> - Determine the total exposure of man and his environment.
>
> - Examine interactions among forms of pollution.
>
> - Identify where in the ecological chain interdiction would be most appropriate."

This theme was reiterated by President Nixon's first report to Congress on the state of the environment. It stressed that the U.S. EPA would consolidate the fragmented responsibilities of various pollution control agencies and that "air pollution, water pollution, and solid wastes are different forms of a single problem," and that it was evident that a new approach was necessary. (Guruswamy, 2001)

Despite this vision, the legislation that was enacted in the 1970's, such as the Clean Air and Clean Water Acts, reflected the mistrust of executive agencies ability to effectively make decisions, by requiring the agency to address very specific problems. Agencies were directed to comply with legislatively ordained mandates and specific deadlines.

One of the outcomes of this style of legislation was that the U.S. EPA was prevented from taking a more integrated and comprehensive approach to addressing environmental problems. (Guruswamy, 2001)

The nature of these Congressional mandates dictating the structure and activities of the U.S. EPA has meant that media offices were created and rules were put in place largely along media lines. Table 1 below lists the major environmental Congressional Acts that have been passed since the creation of the EPA.

Table 1: Major Federal Environmental Statutes Passed Since the Creation of the U.S. EPA[1]

Year Passed	Name of Act	Media/Substance
1970	Clean Air Act	Air
1972	Federal Environmental Pesticide Control Act	Food
	Ocean Dumping Act	Oceans
1974	Safe Drinking Water Act	Drinking Water
1976	Toxic Substances Control Act	Toxic Waste
	Resource Conservation and Recovery Act	Solid Waste
1977	Clean Water Act	Water
1980	Comprehensive Environmental Response Compensation and Liability Act	Toxic Waste Sites
1982	Asbestos School Hazard Abatement Act	Asbestos
1986	Asbestos Hazard Emergency Response Act	Asbestos
1988	Indoor Radon Abatement Act	Radon
1990	Pollution Prevention Act	**Multi-media**

It should be noted that the first act to address an environmental issues in a multi-media way was passed 20 years after the creation of the agency intended to look at all environmental problems in this way.

Attempted Integration at the U.S. EPA

The U.S. EPA was created with the specific objective of integrating the various legislative mandates entrusted to it. "President Nixon envisioned an agency that would end much of the fragmentation of environmental policy." (Guruswamy, 2001) A White House task force was charged with handling the transition from Congressional approval

[1] This list is not a comprehensive list of all federally mandated actions required by the U.S. EPA. This is a list of the major environmental acts passed by Congress (not including amendments) and is intended to demonstrate the fragmentation of the enabling legislation governing the activities of the U.S. EPA.

and enabling statutes to the actual start of the agency's operations. This task force was headed by Douglas Costle, who would later become the U.S. EPA's Administrator. Costle concluded that in the short term an incremental strategy of integration would be preferable to a complete reorganization along functional lines. (Guruswamy, 2001) A three-stage integration plan was recommended. To start with, the five programs dealing with air, water, pesticides, solids waste and radiation, and noise would be preserved. After a period of time, three new offices would be created along functional lines. These offices would deal with Planning and Management, Standards and Compliance, and Research and Monitoring. The five individual programs would initially be allowed to retain their separate identity in the remaining administrative offices. Finally, the program distinctions were to be eliminated entirely. (Guruswamy, 2001) For a variety of political and operational reasons this integration was never fully accomplished and today the U.S. EPA has a combination of media and functional offices.

Mission and Goals of the U.S. EPA Today

The latest iteration of the mission statement of the U.S. EPA is clearly stated on the agency's website: To protect human health and to safeguard the natural environment—air, water, and land—upon which life depends. To aid in the achievement of this mission the latest U.S. EPA strategic plan (U.S. EPA, 2003) outlines five goals which the agency will work towards:

1. *Clean Air* – Protect and improve the air so it is healthy to breathe and free of levels of pollutants that harm human health or the environment.

2. *Clean and Safe Water* – Ensure drinking water is safe. Restore and maintain oceans, watersheds, and their aquatic ecosystems to protect human health, support economic and recreational activities, and provide healthy habitat for fish, plants, and wildlife.

3. *Preserve and Restore the Land* – Preserve and restore the land by reducing and controlling risks posed by releases of harmful substances; promoting waste diversion, recycling, and innovative waste management practices; and cleaning up contaminated properties to levels appropriate for their beneficial reuse.

4. *Healthy Communities and Ecosystems* – Protect, sustain or restore the health of people, communities, and ecosystems using integrated and comprehensive approaches and partnerships.

5. *Compliance and Environmental Stewardship* – Improve environmental performance through compliance with environmental requirements, preventing pollution, and promoting environmental stewardship. Protect human health and the environment by encouraging innovation, and providing incentives for governments, businesses, and the public that promote environmental stewardship.

These five goals indicate the results that the agency hopes to achieve. Each of these goals is further broken down into objectives, sub-objectives, and where appropriate specific targets. In addition to the 5 results based goals, the strategic plan outlines a set of "Cross-Goal Strategies" that the agency will employ to help achieve these goals. These are important to mention in order to establish how the research conducted in developing this thesis would fit into and be applied in the current agency framework for working towards environmental protection. Only the relevant cross-goal strategies, for the purposes of this research, are mentioned here:

1. *Information Analytic Capacity* – Providing access to new analytical tools that facilitate data interpretation and enable users to respond to environmental problems, set priorities, make sound decisions, manage for results, and measure performance.

2. *Innovation in Solving a Set of Priority Environmental Problems* – The U.S. EPA understands the need to deal with the persistent, wide-spread problems that are

not being adequately addressed with the current tools and approaches in use today. Voluntary initiatives and agreements with specific industry sectors and new information tools that support decision making are two approaches that are mentioned in the strategic plan as ways to attack these types of problems.

3. *Innovation in Continuing to Develop Tools That Have Already Proven Effective on a Limited Scale and That Have Applicability Across Many Environmental Programs* – Currently the U.S. EPA is considering the expanded use of Environmental Management Systems (EMS) and other things that can foster a more comprehensive approach to environmental protection.

4. *Use of Sound Scientific Information to Inform Decisions* – The U.S. EPA understands the continued need to have access to sound scientific and technical information to support the setting of environmental priorities and the making of effective environmental decisions.

The next chapter explores the ways in which the U.S. EPA is working to achieve the above stated goals today.

CHAPTER 3: HOW THE U.S. EPA WORKS TO ACHIEVE ITS MISSION AND GOALS TODAY

This chapter explores the ways in which the U.S. EPA currently works to accomplish its mission and meet its goals. There are two main sections of this chapter: the first examines how the U.S. EPA designs regulations, the second looks at emerging ways that the agency is using voluntary initiatives and innovative approaches to working with industry to achieve better environmental results. The design of environmental regulations is the more traditional way in which the U.S. EPA works to protect the environment while the voluntary initiatives are an emerging mechanism the agency is exploring for continuing to improve and enhance environmental protection.

The U.S. EPAs Regulatory Design Process

There are five main stages the U.S. EPA follows for developing new regulations[2], the first is the categorization, into one of three tiers, of the proposed action, the second is the development of the draft rule by agency staff, the third stage is requesting and gaining the review of any proposed action by the Office of Management and Budget (OMB), the forth is developing the final action, which includes, public involvement, and the fifth and final stage involves requesting the Administrator's signature, publishing the action, and ensuring congressional review. The following sections provide additional details about each of these stages.

Step 1: Categorization of Proposed Action

The first step in the regulatory design process is to categorize the proposed action into one of three tiers. This responsibility falls to the U.S. EPA Office responsible for the rule. The most controversial and visible rules are classified as Tier 1. These include any rules that are designated by the Administrator as a priority or are deemed economically

[2] For the purposes of this thesis the enabling statutes passed by Congress which provided the legal basis for any new regulations established by the U.S. EPA are not discussed. As was mentioned in the introduction of this thesis, the purpose is to evaluate how the U.S. EPA can more effectively use multi-media assessment capabilities in the current administrative framework, therefore a discussion about altering the enabling statute is inappropriate.

significant under the conditions specified in Executive Order 12866 (these conditions are discussed in more detail in the section covering review by the Office of Management and Budget.) Rules that involve cross-media impacts or have significant issues are classified as Tier 2. All rules that are not considered Tier 1 or Tier 2 are classified as Tier 3. The proposed classification is reviewed and then approved by the Administrator's office.

Step 2: Development of the Draft Action

Step 2 of the process constitutes the development of the draft action. This process occurs in three parts:

1. *Analytic Blueprint* – A cross-agency workgroup develops an analytic blueprint for the proposed action. This plan serves as the outline for the various analyses, consultation, and other activities that will be completed to collect the necessary information required to support the development of the regulation. This plan details how information (economic, scientific, and intergovernmental) will be obtained. This is not a blueprint or outline for the regulation itself, it is simply a description of what research will be done to put together the relevant background material that will be used to develop the rule. Once completed the analytic blueprint is circulated for approval within the agency.

2. *Options Development* – The lead program office consults with a wide range of stakeholders (industry, state, local, and tribal governments, public interest groups, etc.) The workgroup conducts the analyses specified in the blueprint (such as cost/benefit analysis, risk assessment, etc.) and develops a variety of options for the regulation.

3. *Options Selection* – Once options are developed, senior management reviews the scientific findings, benefits and costs, and policy issues. If a rulemaking option is selected, the cross-agency workgroup then drafts the preamble to the rule, the proposed regulatory text, and any supporting documents.

It should be noted that the steps mentioned above are only required for proposed actions that have been classified as Tier 1 or Tier 2. The steps taken for the development of Tier 3 rules are similar to those mentioned for Tier 1 and Tier 2; however, they are much less formal. Once the above three steps have been completed the draft rule is ready for the next phase of regulatory development, the review of the proposed rule and its alternatives by the Office of Management and Budget.

Step 3: Requesting and Obtaining OMB Review

All Federal agencies must complete a Regulatory Impact Analysis (RIA) for proposed actions classified as "significant regulatory actions." A "significant regulatory action" is any proposed action that falls into one of the following categories as specified in Executive Order 12866:

1. The proposed rule will have an annual effect of the economy of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local, or tribal governments or communities.

2. The proposed rule will create a serious inconsistency or otherwise interfere with an action taken or planned by another agency.

3. The proposed rule will materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligations of recipients thereof.

4. The proposed rule will raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in this Executive Order.

5. The proposed rule is designated as major by OMB.

The RIA must describe the costs and benefits of the proposed rule and alternative approaches, and justify the approach chosen. The specific language of this requirement is laid out in Executive Order 12866 and states:

> "For those matters identified as, or determined by the Administrator of OIRA (the Office of Information and Regulatory Affairs) to be, a significant regulatory action within the scope of section 3(f)(1), the agency shall also provide to OIRA the following additional information developed as part of the agency's decision-making process (unless prohibited by law):
>
> 1. An assessment, including the underlying analysis, of benefits anticipated from the regulatory action (such as, but not limited to, the promotion of the efficient functioning of the economy and private markets, the enhancement of health and safety, the protection of the natural environment, and the elimination or reduction of discrimination or bias) together with, to the extent feasible, a quantification of those benefits;
> 2. An assessment, including the underlying analysis, of costs anticipated from the regulatory action (such as, but not limited to, the direct cost both to the government in administering the regulation and to businesses and others in complying with the regulation, and any adverse effects on the efficient functioning of the economy, private markets (including productivity, employment, and competitiveness), health, safety, and the natural environment), together with, to the extent feasible, a quantification of those costs; and
> 3. An assessment, including the underlying analysis, of costs and benefits of potentially effective and reasonably feasible alternatives to the planned regulation, identified by the agencies or the public (including improving the current regulation and reasonably viable nonregulatory actions), and an explanation why the planned regulatory action is preferable to the identified potential alternatives."

All proposed rules must be submitted to OMB before the Notice of Proposed Rulemaking is published in the Federal Register. In addition no proposed rule can be published until OMB has completed its review. Once this review is complete, the rule can move on to the next stage of the regulatory development process.

Step 4: Development of the Final Action

Once the U.S. EPA has drafted a proposed rule and is ready to engage in the final "rulemaking" process, section 4 of the Administrative Procedure Act (APA) requires that the agency publish a "general notice of proposed rulemaking" in the Federal Register (Ashford and Caldart, 1996). This notice must specify the following: 1) a statement of the time, place, and nature of the public rulemaking proceedings, 2) a reference to the legal authority under which the rule is proposed, and 3) either the terms or substance of the proposed rule or a description of the subjects and issues involved. Once this has been accomplished there are two general procedures that agencies can follow for completing this portion of the regulatory development process:

1. *Formal rulemaking*: Formal rulemaking is defined in sections 7 and 8 of the APA and is only required if Congress has specified it in the originating statute. This is the most lengthy and burdensome process of the three and is rarely required in today's regulatory statutes. Formal rulemaking is much like a legal trial and includes a hearing before an impartial presiding officer, an opportunity to present evidence and to cross-examine witnesses, a final decision on the record, an opportunity to submit proposed findings, exceptions, and supporting reasons, and a statement of findings and conclusions.

2. *Informal rulemaking*: Informal rulemaking is defined in section 4 of the APA and is the most common form of rulemaking used by the U.S. EPA. This form of rulemaking is often called "notice and comment" rulemaking. After the required notice is published in the Federal Resister, the U.S. EPA is required to give interested parties an opportunity to participate in the rulemaking process through submission of written data, views, or arguments with or without opportunity for oral presentation. This method of rulemaking does not require a formal hearing and allows the agency to consider any material as opposed to only material which is part of the hearing record.

In addition to formal and informal rulemaking a third option, called negotiated rulemaking, is available to all Federal agencies. The rationale for the development of the negotiated rulemaking option was to have a rulemaking process that would provide the opportunity to obtain input and buy-in from external stakeholders much earlier in the process and to attempt to reach consensus on the final rule. In 1990, Congress added to the APA a subchapter on Negotiated Rulemaking. This section details the procedures that an agency may follow if it chooses to use negotiated rulemaking as part of the informal rulemaking process. This form of rulemaking, unlike formal and informal rulemaking, takes place prior to the drafting of a proposed rule and involves participation from people outside the agency at a much earlier stage. The first step in the negotiated rulemaking process is to identify the interested parties that would be significantly affected by a proposed rule and to determine whether those interests could be represented in a negotiated rulemaking committee. This committee is made up of persons representing the various interests and must include at least one representative of the agency. The goal of the committee is to come to consensus on the proposed rule. If consensus is reached the rule may still be subject to the notice and comment procedures of informal rulemaking. It is important to note that because administrative regulations can be challenged in court agencies are encouraged and work hard to include provisions that will satisfy potential legal adversaries. (Kagan, 1999)

Step 5: Requesting the Administrator's Signature, Publishing the Action, and Ensuring Congressional Review

Once the above four steps have been completed the final rule is sent to the Administrator's office for final review and signature. Once signed the rule is published in the Federal Register and is submitted to congress for a final review.

In addition to the setting of formal rules and regulations, the U.S. EPA is engaging in more and more voluntary initiatives to address environmental protection. Important aspects of this program are described in the following section.

The U.S. EPAs Voluntary Initiatives

In addition to the official rules and regulations that the U.S. EPA develops and enforces, there is a growing number of voluntary initiatives and approaches being pursued to achieve environmental protection. There are several benefits that can be achieved by following this course of action: "From both government and industry perspectives voluntary regulation can have a number of advantages. For government, effective voluntary action might deliver benefits which reduce the need for mandatory regulation and therefore the requirement for costly regulatory agencies. For industry, reductions in the level of government intervention may allow scare resources to be channeled toward environmental improvement rather than bureaucratic compliance." (Gouldson and Murphy, 1998) There are a variety of reasons that the U.S. EPA is utilizing voluntary initiatives to supplement the traditional regulatory approach to protecting the environment. Two of the most important issues defined in the U.S. EPA's 2003 innovating for better environmental results document are described below (U.S. EPAa, 2003):

1. *An increased focus on environmental results*: The U.S. EPA continues to move its focus towards the achieved environmental results rather than how environmental results are achieved. There is an increased awareness that non-regulatory approaches and new partnerships are required to make this transition.

2. *The integration of environmental management across facilities, industries, and media*: This has been noted before in this thesis and has long been a problem recognized by the U.S. EPA. Current regulations are typically single-media based and do not address environmental problems from a holistic perspective. The use of voluntary initiatives can help alleviate this problem by looking at environmental burden from an industry-wide perspective.

To address these issues, the U.S. EPA is utilizing a variety of mechanisms. For the purpose of this thesis only a few of these are considered.[3] There are two main categories of activities that are applicable for discussion in the framework of this thesis. These categories are outlined below:

1. *The Partners for the Environment*[4]: In this program, the U.S. EPA works with organizations that willingly set voluntary environmental goals and commitments such as conserving water and energy or reducing greenhouse gases, toxic emissions, solid waste, indoor air pollution, and pesticide risks. These efforts not only help the environment, but have often proven to be highly cost effective as participants make processes more efficient and make better use of their resources. Participants include small and large businesses, citizens groups, state and local governments, universities, and trade associations. To date the U.S. EPA has worked with more than 11,000 organizations in this program. A specific part of this program works with industry sectors to find ways to reduce overall environmental burden. The five industry sectors currently working with the U.S. EPA are: ship building, meat processing, metal casting, metal foundry, and metal finishing.

2. *Environmental Management Systems*[5]: The U.S. EPA is working to promote the use of Environmental Management Systems (EMS) in numerous industries. An EMS is a set of processes and practices that enable an organization to reduce its environmental impacts and increase its operating efficiency. They must include procedures for assessing the company's own procedures for identifying and resolving environmental problems and for engaging the company's workforce in a commitment to the company's improved environmental performance. EMS's are seen as a way to promote an evolutionary change away from command and

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[3] A more detailed account of the range of activities that the U.S. EPA is engaging in can be found on the web at: http://www.epa.gov/opei/innovation.htm.
[4] More information can be found on the partners for the environment program on the U.S. EPAs website at: http://www.epa.gov/partners/index.htm.
[5] More information can be found on the environmental management systems program on the U.S. EPAs website at: http://www.epa.gov/ems/.

control regulations and toward more cooperative environmental enforcement efforts. (Stenzel, 2000)

The above programs provide only a small glimpse at the variety of voluntary initiatives that the U.S. EPA is exploring today. These two broad programs were mentioned specifically because of their industry-wide nature and the fact that they are looking at environmental problems from a multi-media perspective. The next chapter focuses on some of the limitations with the current approach, both regulatory and non-regulatory.

CHAPTER 4: LIMITATIONS OF THE CURRENT APPROACH

This chapter examines some of the limitations of the current approach that the U.S. EPA is taking toward achieving its mission and goals. The chapter is divided into two sections, similar to the previous chapter, and discusses first some limitations with the current regulatory approach and second some limitations with the voluntary activities that are underway. It should be noted that the following critique of the current mechanisms used by the U.S. EPA to protect the natural environment and human health is not intended to diminish the significant role that the agency and these rules and programs have played in protecting human health and safeguarding the natural environment to date. The critique is merely intended to point out some weakness of the current approach to environmental protection and to set the stage for the following two chapters which attempt to outline the use of a new tool to help alleviate some of these issues.

Regulatory Activities

There are two categories of limitations to the regulatory activities that the U.S. EPA is pursuing, the first is in the regulatory design and development process and the second is the current set of regulations in place and being enforced. These two categories are treated separately below:

Regulatory Design Limitations: On April 10, 2001, Administrator Whitman directed a Task Force, composed of the Assistant Administrators at the time, to reexamine the agency's regulatory development process and identify ways to strengthen it and improve the quality of supporting scientific, economic, and policy analysis. While the task force found that, in general, the existing system for developing regulations is well designed, there were several areas that could use improvement. One of the areas that the task force recommended looking at in more detail was the enhancement of the quality of the information that is used to support agency decisions. Two of these problems are discussed below: (U.S. EPA, 2001)

1. Use of Information to Support Design of Regulations

The task force stated that: "We (the U.S. EPA) can do more to enhance the quality of information supporting our decisions and to ensure that science and economic issues are adequately addressed at the right stages in regulatory development." (U.S. EPA Task Force, 2001, pg. 3) The need to have high-quality information to support decision-making is not a new or profound idea. Providing consistency in the type of information used and the methods of analyses conducted is complicated however. While the task force report made these issues clear, little guidance was provided on how to effectively address this concern.

2. Use of Cost/Benefit in Regulatory Design

Governmental actions are increasingly required to be justified in terms of economic analysis. This is largely done through the use of cost/benefit analysis. As described earlier all "significant" agency rules and regulations are subject to review by OMB. This review includes presenting the "justification" of a new rule in terms of the costs and benefits of the proposed action and all alternative actions considered. Although the need for an economic justification of federal environmental regulation can be debated, a large body of literature exists and the debate is outside the scope of this thesis, nonetheless, several points raised by others are directly relevant to the present analysis and are included here. There are some practical limitations and some inherent flaws with the use of cost/benefit analysis in the design of environmental and human health regulation which need to be considered:

- In general costs are easier to express than benefits but are still largely uncertain. Additionally, there is a tendency, to overestimate the costs of regulations in advance of their implementation. This happens in part because the lower costs that will result due to the development of new technologies that will be developed as a direct effect of more stringent regulations are not considered in these analyses. (Ackerman and Heinzerling, 2002)

- Many of the benefits of environmental protection (improved quality of life, better human health) are difficult (if not impossible) to estimate. This is critical because, "Absent a credible monetary metric for calculating the benefits of regulation, cost-benefit analysis is inherently unreliable." (Ackerman and Heinzerling, 2002)

- Cost/benefit analysis does not adequately account for the future, long-term benefits of environmental protection. One of the most important aspects of environmental law is the focus on the future. Environmental protection seeks to avoid harm to people and to natural resources in the future, not only within this generation, but within future generations as well. This goal has been explicitly stated in the National Environmental Policy Act, which has been called the fundamental charter of environmental protection in this nation. The goal is to promote the nation into "fulfilling the responsibilities of each generation as trustee of the environment for succeeding generations." (U.S.C., 42, 55, 4331(b)(1)) "Cost-benefit analysis systematically downgrades the importance of the future in two ways: through the technique of discounting and through predictive methodologies that take inadequate account of the possibility of catastrophic and irreversible events." (Ackerman and Heinzerling, 2002)

- Cost/benefit analysis does not convey how the costs (and benefits) will be distributed over time and over different populations. Concerns about equity should, and frequently do, enter into debates over public policy. "If decisions are based strictly on cost-benefit analysis and willingness to pay, most environmental burdens will end up being imposed on the countries, communities, and individuals with the least resources." (Ackerman and Heinzerling, 2002)

- Cost/benefit analysis proponents claim that the method provides benefit from the additional objectivity and transparency obtained by completing the process. This claim is largely unfounded. "Cost-benefit analysis … is unable to deliver on the promise of more objective and more transparent decision making. In fact, in most cases the use of cost-benefit analysis is likely to deliver less objectivity and less transparency. Furthermore, as we have seen, cost-benefit analysis relies on a byzantine array of approximations, simplifications, and counterfactual hypotheses." (Ackerman and Heinzerling, 2002)

Regulations Currently In-Use: The following limitations are widely recognized and are intended to help guide and inform future environmental protection efforts. It should also be noted that the limitations noted below do not apply to all U.S. EPA rules and regulations.

1. *Command and Control*

A majority of the regulations in use today are focused on a "command and control" approach to environmental protection. This means that the U.S. EPA will set a standard in terms of a limit to a particular pollutant and require industry to meet this limit. There is little regulatory flexibility built into this approach and the regulated industry has reported that this style of regulation is burdensome and does not allow them to explore creative or cost-effective solutions to environmental problems. "Command and control … focus(es) on crisis-by-crisis, reactive enforcement of statutes and regulations. (Stenzel, 2000) These regulations can be considered "top down" regulation, and, generally they operate using one of the two following types of mechanisms. First is the use of permits. A set of performance standards for businesses are established and these standards are then enforced through a system of permits allowing pollutants to be emitted at regulated rates. A second mechanism is one in which government requires technology-based controls for specific activities that cause pollution. "Violations of either type of regulation (permit-based or technology-based) can result in civil fines or even criminal prosecution of business managers." (Stenzel, 2000) The biggest problem with command and control regulation is that it is piecemeal and fails to address problems in a holistic manner. (Stenzel, 2000) "A command and control approach to regulation leads to fragmented environmental management and focuses on dealing with environmental problems after they are created rather than on preventing them." (Reiley, 1997)

2. Media Specific

As was noted earlier the initial vision of the U.S. EPA was that of an agency that could respond to and address environmental concerns in a holistic and multi-media way. This has not been how the agency has evolved, however, and many of the dominant regulations in use are focused on a specific environmental media. The U.S. EPA Task Force noted in their report that: "Today we are working on far more complex environmental problems, often involving multi-media impacts from multiple sources of pollution." (EPA Task Force, 2001, pg. 4) This desire to approach issues from a cross-media perspective has long been a goal of the agency but little has successfully been implemented in formal regulations to make this a reality. "The major environmental statutes (CAA, RCRA, and the CWA) are uncoordinated and media-specific." (Reiley, 1997) Single media regulations result in businesses managing environmental aspects in isolation from each other rather than in a holistic way. Industrial facilities typically generate more than one pollutant, and few pollutants exist in isolation from other emissions. "The result (of this regulatory approach) is more regulatory rigidity and bureaucratic red tape, less creative environmental management, and less efficient technology." (Reiley, 1997)

Figure 1 shows a simplified version of the information available to the U.S. EPA today where one facility that has multiple sources of pollution will be submitting information to four or more separate database systems being maintained by the agency. The figure depicts a facility with four separate sources of emissions. Existing regulations would require a facility of this type to submit information to the U.S. EPA to (at least) four national systems: the Toxics Release Inventory (TRI), the Resource Conservation and Recovery Act system, (RCRA), the Permit Compliance System (PCS), and the Aerometric Information Retrieval System (AIRS.) Integrating this information and using it to assess the state of the environment is a very complicated and time consuming task.

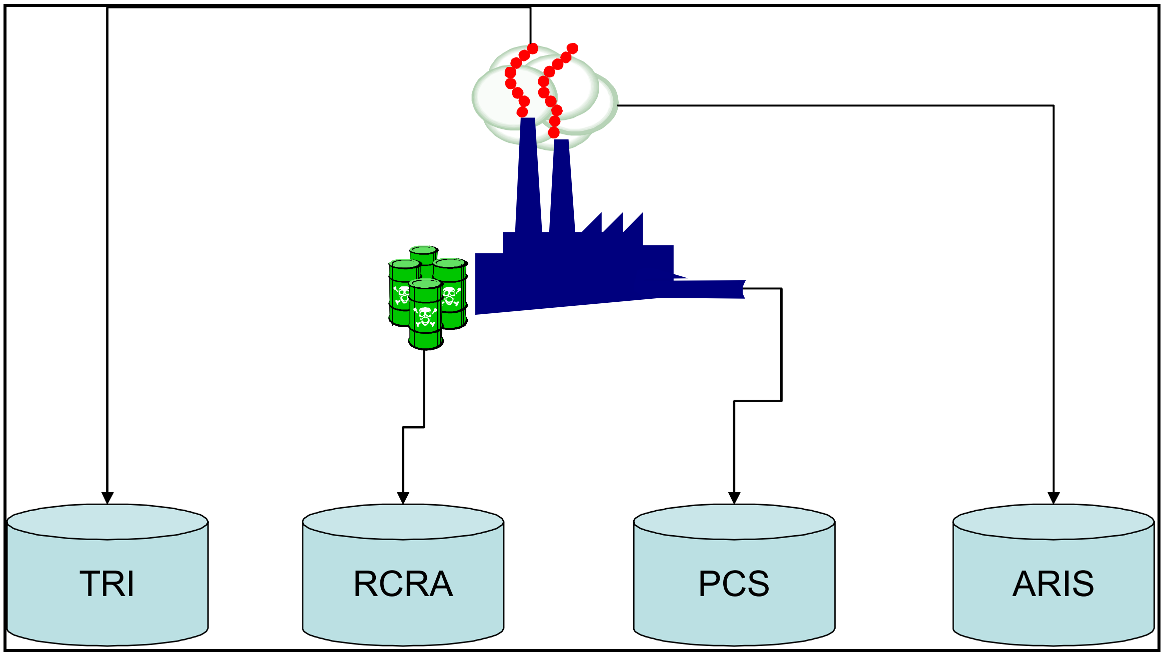

Figure 1: Stove-pipe Information Currently Being Reported to the U.S. EPA

3. End of Pipe

Another concern with the regulations being enforced today is that they largely deal with pollution and other environmental burdens at the "end-of-pipe" or where the substances of concern leave the individual facility. While these end-of-pipe solutions have done a significant amount to reduce pollution (especially in the air and water) there are some who feel that more could be done if the entire process was evaluated for ways in which to lower the environmental burden.

4. Problem of Risk Shifting

The importance of risk identification and avoidance of risk shifting has long been recognized. Risk shifting can be summarized as the shifting of pollution (or any environmental burden) from one media or source to an alternate media or source to take advantage of less stringent regulations. In 1990 the U.S. EPA Science Advisory Board issued a report titled "Reducing Risk: Setting Priorities and Strategies for Environmental Protection" which looked at this problem in great detail. The problem of risk shifting is basically a combination of the fact that the current regulatory framework is fragmented by media, command and control based, and only focuses on the problem at the end-of-pipe. “The last thirty years witnessed mounting criticism of the failings of the existing fragmented approach to pollution control. Commentators argue that the present fragmented regime concentrates on moving the pollution generated by polluting activities from one place to another.” (Guruswamy, 2001)

The problem of risk shifting has emerged in legal cases as the following examples demonstrate. In Essex Chemical Corp. v. Ruckelshaus, which was consolidated with Appalachian Power Co. v. EPA, the petitioner corporation maintained, that in promulgating standards for sulfuric acid, the U.S. EPA failed to consider the adverse impact on water caused by tail gas scrubbers that would have to be installed if the new source performance standards were to be met. The petitioner argued that the U.S. EPA should have complied with National Environmental Protection Act (NEPA). The agency, while admitting that the setting of standards might involve other environmental impacts, cast NEPA in general terms, in contrast to the specific provisions of the Clean Air Act. The U.S. EPA further argued that the Clean Air Act was based on the premise that air pollution levels were at crisis levels demanding strict time limits for compliance. The application of NEPA would be inconsistent with the time constraints central to the Clean Air Act. The court found no reason to divert or expand from the logic of an earlier decision, and it held that NEPA impact statements were not a condition to making Section 111 determinations, in effect upholding the right of the U.S. EPA to consider pollutants in a single-media manner. Thus, increasing the likelihood of risk shifting. (Essex Chemical Corporation v. Ruckelshaus, 486 F.2d 427 (D.C. Cir. 1973))

5. Tracking Effectiveness of Regulations

Another area that has long been recognized as an area of concern for the U.S. EPA is the ability to monitor and track the effectiveness of the regulations in use. The U.S. EPA Task Force noted that increased discipline and structure is required in the rule-making process, especially after the rules have been issued and are in-use. This encompasses the need for a more effective means of assessing whether regulations are achieving their stated goals as well as the need to periodically evaluate the effectiveness of regulatory programs.

In part to address the above limitations the U.S. EPA has embarked on a series of voluntary activities designed to take environmental protection further.

Voluntary Activities

The two limitations listed below are quite broad and are based on comments received by U.S. EPA staff, a review of the information made available by the agency on its website and through a variety of strategy documents.

1. *Lack of Coordinated Approach*

   There is no discernable overall strategy in terms of the voluntary initiatives that the U.S. EPA is exploring. The approach seems to resemble a patch work of individual initiatives and efforts based in a variety of offices and without much oversight and coordination. On one hand it can be argued that more is better in terms of these new innovative approaches. On the other hand, however, it can be argued that without coordination it is impossible to determine what if anything is being missed, whether or not the current initiatives are the most cost-effective, or if there is significant overlap in the efforts underway.

2. *Lack of Performance Review Metrics*

   Much like one of the limitations noted with the current regulatory framework there is a similar lack of monitoring and tracking of the performance and effectiveness of the voluntary initiatives and industry-partnerships that are being developed. While it can be argued that the promoting the use of EMS's by industry is beneficial to the work of environmental protection there are two key limitations with the approach:

- The use of an EMS, and subsequent certification, is based on goals that are set by the company being certified. "Some consider this to be desirable because management has the flexibility to choose technologies and programs based on costs and its own needs. However, others consider it to be ISO 14001's greatest flaw, because companies may set very lenient goals for themselves." (Calkins, 1997).

- EMS's deal only with processes, and not with environmental outcomes. "Goals and priorities articulated by the company are self-chosen, and there is no minimum standard beyond compliance with applicable law." (Murray, 1999).

Table 2 below summarizes the limitations described above:

Table 2: Summary of Limitations with the Current Approach to Environmental Protection

Limitation	*Description of Limitation*
Limitations with the Current Regulatory Design Process	
1. Use of Information in Design	• There is no consistent approach to generating/gathering the information used in designing regulations.
2. Use of Cost/Benefit in Design	• Cost/Benefit fails to adequately capture the long-term benefits of protecting the environment. • Cost/Benefit fails to convey which groups of people would bear the costs of various activities.
Limitations with the Current Regulations In-Use	
1. Command and Control	• The setting of rules, limits, and standards that industry must meet or follow is largely inflexible.
2. Media Specific	• A majority of regulations only address a single media. It is increasingly recognized that environmental problems are often multi-media in nature.
3. End-of-Pipe	• Regulations focus on pollution as it leaves a facility. • There is limited evaluation of how to improve environmental performance at other stages in the process.
4. Risk Shifting	• Pollution is shifted from one media/source to another media/source.
5. Tracking Effectiveness	• There are limited means to track the effectiveness of current regulations.
Limitations with the Current Voluntary Activities	
1. Lack of Coordination	• Voluntary activities at the U.S. EPA are currently being pursued on an ad-hoc basis.
2. Lack of Performance Review Metrics	• There are limited means to track the effectiveness of current voluntary activities.

The following chapter begins to lay out a relatively recently developed ideological approach to addressing environmental problems that, at least in part, solves some of the limitations raised above.

Chapter 5: Background on Life-Cycle-Assessment

This chapter presents background on the field of industrial ecology and details specifics about traditional life cycle assessment methodologies in the form of a literature review. The purpose for this review is to present an area of research that at least in part addresses a means to look at environmental problems from a holistic and multi-media perspective.

Literature Review – Industrial Ecology and Life-Cycle-Assessment

The following literature review presents research in the field of industrial ecology and specifically details the analysis tool life-cycle-assessment. The framework used in defining and presenting this review is the applicability of life cycle assessment to the work of the U.S. EPA. The goal of the review is to outline important research that has already been accomplished and to identify key research questions that remain to be answered.

This literature review is organized by the major themes (or areas) that emerged while performing the review. The following areas are included 1) an overview of industrial ecology and life cycle assessments, 2) uses and users of life cycle assessments and their applicability to the U.S. EPA, 3) information required to perform life cycle assessments, 4) benefits with life cycle assessments, and 5) problems and limitations with life cycle assessments. Each area includes information about the key findings and a discussion about the shortcomings of the research. A brief discussion of the sources used in this literature review precedes the sections on the five major themes.

Discussion of the Sources Found

A majority of the articles I found focused on only one component of life-cycle-assessments or presented the results of a particular life cycle assessment effort. In order to supplement the peer-reviewed literature I included in this review government documents, which were helpful in defining work that the U.S. EPA has accomplished to date and also areas that the U.S. EPA is hoping to incorporate into its future work. For basic background information on life-cycle-assessments the United Nations Environment Program report and the Feldman and Tibor's book on implementing ISO 14000 were consulted.

Overview of Industrial Ecology and Life-Cycle-Assessments

The literature is quite extensive in describing the general field of industrial ecology and life-cycle-assessment (LCA) as the primary analysis tool in the field. Both industrial ecology and life-cycle-assessment have evolved since the 1970's and as can be expected the literature expands significantly over this time period. It is interesting to note that there are wide variations in the definition of the term industrial ecology, in fact the Ehrenfeld report (Ehrenfeld, 1994) and the Seager and Theis article (Seager and Theis, 2001) deal primarily with the issue of definition of the term industrial ecology and how best to apply it in today's world.

Ehrenfeld suggests four different paradigms for thinking about the world and humans place in it. The first is the current paradigm of modern life, which Ehrenfeld argues has led us to the environmental problems we are facing today. The three subsequent paradigms presented as alternatives to the current state, they are: economic/environmental, industrial ecology, and deep ecology. The economic/environmental paradigm is a variation on the current state except for the way that the environment is valued and social strategies are designed. The industrial ecology paradigm introduces a new way of thinking about humans role in the environment. The major shift is that human systems are considered an integral part of the world rather than controlling the environment around them. The final paradigm presented is deep ecology, which is the most radical system of thought (compared with the current state) and introduces the notion that humans, as the only conscious, thinking beings, must act as stewards of the world as a whole. What is interesting to note is the he suggests that the only way to change our ability to improve the environment is to switch paradigms and create policies under the new paradigms. For Ehrenfeld the only option that includes elements to acheive sustainable development is one that is governed by industrial ecology. Ehrenfeld defines industrial ecology as a framework for thinking about and organizing human social production/consumption systems in ways that resemble natural, dynamically stable ecosystems. Ehrenfeld argues for product policies that are fundamentally different from most traditional end-of-pipe pollution control systems. Product, rather then process, policies shift the producers of products to address all aspects of design across the entire supply chain, rather then just what emissions could out of a plant or facility. He feels that these types of policies are required to make significant improvements to the environment and that these policies are the only ones that address the whole life cycle and have a strong flavor of technological innovation.

The Seager and Theis paper initially describes the historic terminology evolution of industrial ecology. The paper then goes on to describe the two primary analytical approaches for industrial ecology: life cycle assessment and systems analysis. The authors argue that LCA is more applicable to industrial metabolism, wherein the emphasis is on examining specific materials, flows and processes, whereas system analysis is more applicable to industrial ecology, wherein the emphasis is on examining interrelationships.

A comprehensive and appropriate definition of Industrial Ecology is provided by Graedel and Allenby:

> "Industrial Ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital." (Allenby, 1999, pg. 40)

This definition provides a good segue into a specific analysis tool that has evolved out of the industrial ecology philosophy, life-cycle-assessment.

The two primary references used for describing the international development and characterization of LCA are the Feldman and Tibor book (Feldman and Tibor, 1997) and the United Nations Environment Program (UNEP) Report (UNEP, 1996).

Feldman and Tibor's book presents a description of what the International Organization for Standardization (ISO) is, what international standards are, and why we need them. The focus of the book is on ISO's development of an international standard for life-cycle-assessment. A significant shift in ISO's work occurred in 1979 when for the first time, ISO convened a technical committee (the group chartered with developing a standard) to develop global standards for quality management and assurance systems. This was the first standard that focused on a process, rather then a product. ISO 9000 was a result of this effort and was the precursor to ISO 14000. In response to the proliferation of various environmental standards worldwide, ISO began to look at the environmental management field. It is important to note that specifically left out of ISO 14000 are the following: 1) test methods for pollutants (these are included in other standards), 2) setting caps regarding pollutants or effluents, 3) setting environmental performance levels, and 4) the standardization of products. Only one of the standards (14001) in the series is used for third party verification, the rest are for guidance purposes only. The basic steps in 14001 follow a plan-do-check-act cycle (much like a total quality management system) where the organization defines an environmental policy, designs a plan to fulfill its policy, implements and operates its policy, monitors and measures and evaluates the environmental performance, and finally continually reviews and improves its environmental management system. The ISO 14000 standards are process, not performance standards. They focus on setting up a system to achieve internally set policies, objectives, and targets. The overall goal of ISO 14000 implementation and certification is to increase confidence among all stakeholders that an organization has a system in place that is likely to lead to better environmental performance. There is little practical information in the standard to facilitate the implementation and use of a tool, such as LCA, by an organization to effectively improve and monitor their environmental performance over time. This is the biggest weakness pointed out by critics of the ISO standard.

The UNEP report describes the basics of what a life-cycle-assessment is and how to perform one. The report presents some key differences of life-cycle-assessment over other environmental tools: 1) they can be used to study the environmental impact of either a product or the function a product is designed to perform, 2) it provides objective data, which are not dependent on any ideology, and 3) it is much more complex than other environmental tools. The report describes the three basic stages of performing an LCA: first, identify and quantify the environmental loads involved, second, assess and evaluate the environmental impacts of these loads, and third, assess the opportunities to bring about environmental improvements. The report summarizes the history and future of LCA work.

I would argue that work in this particular area, although constantly evolving, is basically complete. The field of industrial ecology has been defined, granted in a variety of ways for a variety of purposes, but each is well explained. The analysis tool life-cycle-assessment is well studied and described.

Uses and Users of Life-Cycle-Assessment and the Applicability to the U.S. EPA

This area provided information on quite a variety of uses of LCAs. In addition to highlighting the many uses of LCAs it was also interesting to note the variety of potential users of LCAs. One difficult thing to determine was the appropriate role of the U.S. EPA (and the federal government in general) in using LCAs. This area provided most of the interesting questions for further work.

The UNEP report includes a nice section which summarizes the various users of LCAs and this includes a discussion about governmental users.

Sorensen's paper (Sorensen, 1996) walks through the role of life-cycle-assessment in risk analysis. The various elements in analysis are presented. One conclusion drawn by the author is that there still is an urgent need to be able to present qualitative and quantitative impacts to a decision-maker in such a way that the weight and importance of each impact become clear. Sorensen also argues that life-cycle-assessment and the embedded risk assessments will hardly ever become a routine method of computerized assessment, but they may continue to serve a useful purpose by focusing and sharpening the debate involved in any decision-making process. They can help to increase the quality of the basic information upon which a final decision is made about whether to start to manufacture a new product, or to arrange a sector of society in one way or another.

Metry and Wallin's paper (Metry and Wallin, 1992) looks at the critical issues related to the application of LCA as a tool for working towards meeting the goals of sustainability, specifically in the manufacturing sector. The authors suggest that effective use of LCA can bring about the following: 1) the integration of staff from research and development, marketing, manufacturing, packaging, and other areas to creatively work as a unit towards product improvement while protecting the environment, 2) the identification of key areas for improvement so that environmental dollars can achieve maximum results, 3) an increase in environmental awareness and sense of responsibility throughout the company, encouraging the development of products with higher environmental quality, and 4) the creation of the potential for less expensive product costs, and often lower total life-cycle cost for the product. The authors argue that the fact that the public is willing to pay more to protect the environment indicates that the manufacturing industry has to look carefully at the impact of its operations and products on the environment if the industry is to maintain market share and, in some extreme cases, stay in business.

The U.S. EPA Industrial Ecology Workgroup (US EPA, 2001) report presents several themes that were discussed at a U.S. EPA Industrial Ecology workshop and probably provides the most insight into how LCAs should be used by the agency. Five recommendations are given on how the U.S. EPA could get started. The U.S. EPA should: 1) work to familiarize key groups with the concept of industrial ecology, 2) provide the data/information foundation for industrial ecology, 3) ask each headquarters and regional office to make appropriate commitments to pursue industrial ecological approaches, 4) work with other agencies of federal, state, and local government, as well as foreign governments and organizations outside of governments, and 5) set specific goals and expectations to measure progress. The paper lays out some general goals and principles that the U.S. EPA would like to use to guide policy and programmatic changes. The paper mentions a U.S. EPA industrial ecology workgroup, an ad hoc group at the agency "monitoring" work on industrial ecology initiatives being done within the agency. The report makes it clear that U.S. EPA staff firmly envision that industrial ecology approaches should guide and supplement but not replace the current regulatory structure and programs. A specific role for the agency may be to provide incentives, information, and regulatory flexibility for system changes and product stewardship more than to focus primarily on regulating "end-of-pipe" emissions from individual sources. Industrial ecology approaches can help the U.S. EPA determine where to build flexibility into its regulations and they can help the regulated community to meet regulations more efficiently. Another characteristic of the emerging approach that the U.S. EPA would like to take is that most of them are non-regulatory, relying on the tools of incentives, information and regulatory flexibility.

Fung and O'Rourke (Fung and O'Rourke, 2000) present arguments and analysis that the Toxic Release Inventory (TRI) is one of the U.S. EPA's most successful regulations. The main argument is that the TRI created a mechanism of "populist maxi-min regulation." This mechanism is based on the government creating an information rich state in which the general public can apply pressure to firms to fix environmental problems. The authors argue that by properly understanding the mechanisms by which TRI was successful, more intentional public policy designs can be implemented to expand this success. The authors argue that the major role of public agencies is not to set and enforce standards, but to establish an information-rich context for private citizens, interest groups, and firms to solve environmental problems. They also argue that by properly understanding the mechanisms that drive TRI's accomplishments, more intentional public policy designs can expand the system of populist maxi-min regulation and achieve even more rapid toxics reduction. Rather then testing new programs and policies, which the authors argue is extremely time consuming and costly, the U.S. EPA should spend more time learning from existing ones. It is surprising and significant to note that the TRI, which has no permitting, no standard setting, a weak monitoring and enforcement component, very little litigation, and no economic instruments, seems to have achieved so much. The TRI catalyzes the involvement of ordinary people in the determination of toxics emissions standards by changing the effective limit that is publicly acceptable rather than legally allowable, whereas command-and-control policies leave discussions of toxics to 'experts' in environmental agencies, industry, and sometimes environmental groups. The voluntarist view argues that TRI data support voluntary pollution reduction efforts by revealing to them opportunities for operational changes that reduce both releases of toxics and the cost of doing business.

The UNEP report also recommends several uses of LCAs by governments. The main government applications of LCAs listed are: eco-labeling, deposit-refund schemes, subsidies and taxation, and general policies. This list seems at the same time too specific and too broad, as well as being inadequate. The first two items mentioned are specific approaches to product marketing and reduction of waste, while the last two items are so general they provide little help in moving forward with a governmental approach to using LCAs. The report states that LCA generated information can be used in making decisions with environmental consequences: decisions about how to develop, improve, and produce products; how to develop government policies affecting both manufacturers and consumers; and how non-governmental organizations can produce environmentally-sensitive guidelines. The report argues that governments have a responsibility to help develop LCAs because of LCAs potential uses in achieving sustainable forms of development. What is lacking is a clear description of how this should be implemented.

The Program in Science Technology and Environmental Policy (PSTEP) White Paper (Foster, Larson, and McCulloch, 2002) describes an emerging research program at the Massachusetts Institute of Technology that is evolving to address issues of environmental regulation in a more cooperative way. Two interesting points raised by the white paper are 1) the need for the U.S. EPA to look across the entire supply chain to examine where the most improvement can be made and 2) that traditional environmental regulations have the perverse effect of shifting risk (pollution) from one media to another. A more holistic systems based approach is needed to address both of these issues. The paper recommends a shift in general approach that regulators should take to addressing environmental problems from one that focuses on identifying what is optimum to one that focuses on developing new information about the problem.

> "A final and important element in the PSTEP program involves the holistic framework within which environmental issues must be addressed in the future. The inefficiencies associated with regulations directed at single sources of emissions and narrow technology 'fixes' have been noted. The next generation of regulations and industrial performance improvements will be most effective only if whole production processes are considered, from product design and raw material extraction through waste management and recycling. (Foster et al, 2002)"

Baumann and Rydberg's paper (Baumann and Rydberg, 1994) provides a comparison of three different methods for using LCA to categorize the impacts of a particular product. The three methods studied are: 1) the ecological scarcity method, 2) the environmental theme method, and 3) the environmental priority strategies in product design method. The article examined these three different methods from the point of view of a specific company or governmental authority in using the approaches to make product policy decisions. "These evaluation methods are attempts to rationalize decision-making concerning the environment (Baumann and Rydberg, 1994, pg. 19)". The analysis looked at what was needed in order to determine which product (out of a set of choices) had the least environmental impact. In order to do this resource use and discharged substances are transformed into a single comparable parameter. All three of the methods were similar in that the stated goal of each method is to set a one-dimensional value on resource use and emissions in order to calculate the total impact of a process. The article does a nice job of describing the differences in the assessment methods and describes the flexibility that is available in choosing standards to be evaluated depending on the purpose of the study. One important note in the discussion of the article was that having several evaluation methods available to decision-makers allows for the selection of an appropriate assessment methodology for the problem to be studied.

The Hertwich et al (Hertwich et al, 1997) paper provides a comparison of six different methods for evaluating the environmental impacts of products and processes. The six different methods evaluated are: 1) health hazard scoring, 2) material intensity per service-unit, 3) Swiss ecopoints, 4) sustainable process index, 5) the Society of Environmental Toxicology and Chemistry's life-cycle impact assessment, and 6) the environmental priority system. There is an excellent table in the paper (table 1) that summarizes the six different methods and describes the goals and metrics of each. One of the key concerns raised by the paper is that some of the LCA methods are so data intensive that they are not practical for use when evaluating sophisticated or complex products or processes. Another concern raised in this paper, which is true of any analytic method which attempts to aggregate information on diverse impacts into a single index, is that ethical judgments and values will be assumptions that end up embedded in the output of the analysis. This can have a significant impact on the resulting policy for specific populations of people as well as on the distribution of problems over time.

Efforts by private firms to embrace and use industrial ecology tools (such as LCA) are not enough to address sustainability (Allenby, 1999). A much broader systems based approach is needed. There is a missing government role that needs to be played in order to break down some of the barriers to using these tools in moving towards sustainability. Four areas of activity required for an industrial ecology infrastructure and effective use of LCAs:

1. Establishing policies designed to encourage appropriate behavior on the part of producers and consumers

2. Establishing means to define and prioritize environmental risks both among themselves and in conjunction with other risks and costs raised by policy decisions

3. Defining and prioritizing the values that private firms and individuals can use to make trade-offs in their operations

4. Supporting research and development and providing industrial ecology tools, such as LCAs

Information Required to Perform Life-Cycle-Assessments

This area is quite well documented and seems to be expanding over time as the complexity of LCAs and their use in different sectors increase. One interesting issue which builds upon the previous area is the information required or collected by the U.S. EPA which could feed into LCAs, this is a key area for further work and analysis.

Merty and Wallin's paper presents a framework that could help to identify the information gaps in the current U.S. EPA information systems to show how LCA brings information together from multiple media to make assessments.

The UNEP report provides an extensive review of what is needed to make (or perform) a LCA, including: deciding upon a methodology, information requirements, and the use of software.

The Clark et al article (Clark et al, 2001) explored the use of LCA to analyze whole "fleets" of products rather than single products. This is a completely different approach to inputting and using the information provided by a LCA. Ideally decision makers would be able to use this approach in evaluating the benefits and costs of a product decision over the lifetime of production and use. No conclusion was reached about what "hard" rules existed for when this approach should be used, rather it was stated that using fleet-wide LCA should be determined on a case by case basis. The authors also argue that an important role of the LCA research community is to identify and classify the circumstances under which the forms of LCA must be adapted to meet the evolving demands of decision makers. Although many life-cycle-assessments focus on products as the functionally equivalent unit, the actual emissions burdens arising from the production, use, and disposal of these products are a consequence of all the units in service. In particular, the fact that products are produced in large quantities over long periods of time and may also be used over long periods of time suggests that the entire set of products in use, instead of a single product, should be the appropriate unit of analysis.

Boguski's report (U.S. EPA, 2000) evaluates the EPA's publicly available data sources for their use in constructing generic LCA data sets. The report goes on to identify the usefulness of these sources in a LCA context and demonstrates methods for using the data in LCA studies. Limitations to using public sources of data are also studied. 12 data sources were evaluated in the report. One big weakness is that energy use and emissions are not tied to production, this is because of the lack of information on process. The author states that the availability of data has always been a serious problem for those who attempt to perform life cycle assessment studies.

Norris (Norris, 2001a) explores the need for traditional LCAs to incorporate economic consequences of alternate product or process choices into account in private sector decisions. The paper presents two mechanisms for integrating the economic and environmental tradeoffs into product/process design decision making. The author also points out another hole in the ISO 14000 standards in the fact that they have not addressed the integration of economic analysis with LCA. A key difference is that the "life-cycles" being addressed by each methodology are vastly different. Life cycle cost (LCC) considers the economic life of a product, which may in some cases be even shorter then the usage phase in an LCA. LCC focuses on cost flows whereas LCA focuses on physical flows.

The consequences of leaving the LCC out of a LCA are: 1) that there is limited influence and relevance of the LCA for decision making without the economic information built in, 2) the inability to capture relationships among environmental and cost consequences, which also inhibits the search for the most cost-effective means to environmental improvement, and 3) the potential to miss economically important or in some cases even economically pivotal environmental-related consequences to the company of alternative decisions. LCAs evaluate the relative environmental performance of alternative product systems for providing the same function. LCC studies compare the cost-effectiveness of alternative investments or business decisions from the perspective of an economic decision maker such as a manufacturing firm or a consumer. The author states that properly and fully integrating meaningful economic analysis into a LCA requires going well beyond simply treating economic cost as 'just another flow', or as another property of flows, within traditional LCA software. It requires the addition of a time dimension to the modeling; the ability to introduce and work with variables that have no causal dependence upon inventory flows; and the ability to create and work with probabilistic scenarios in order to capture risks.

The U.S. EPA industrial ecology workgroup report states that LCA approaches must be information based. Without the proper information base we will not know where our best opportunities lie and we will not be able to measure our progress later.

Seager and Theis point out a significant problem in collecting the necessary information to perform an adequate life cycle inventory. They contended that such an inventory requires compilation of chemical information for intermediary or by-products for which manufacturers or suppliers maintain little quantitative account. Even when such data do exist, it is often regarded as proprietary, and therefore unverifiable or unpublishable.

Benefits with Life-Cycle-Assessment

The benefits with LCA are largely documented in the literature and background material available on LCA. A brief overview of some of these benefits is presented below.

The UNEP report details the benefits of LCA and includes the prevention of shifting of problems to other areas or stages in the life-cycle. This is an important benefit as one significant way in which the regulated community deals with reporting pollution information today is to shift it to the media with the least reporting requirements. Requiring industry to report data across the life cycle would significantly alleviate this problem.

There is also some literature on quantitatively calculating the value of performing LCAs. Norris' paper (Norris, 2001b) presents a method for estimating the cost (and value) of performing a LCA. Two different characterizations of value are presented – the private and the public. From a private (or client) perspective, LCA can be used in marketing claims and can also lead to product redesign which better positions the product in the market. LCAs also may uncover opportunities for efficiency improvements or cost reductions. A systems dynamics model of the potential benefits of doing a LCA for the manufacturing industry is presented. Norris explains that the costs and benefits due to a LCA will be either market or non-market in type. He then goes on to characterize these costs and to explain the specific benefits associated with certain stakeholder groups.

Problems and Limitations with Life-Cycle-Assessment

While most analytical articles on LCA deal with and assess limitations to the methodology, there is a lack of academic research on how to overcome the identified weaknesses. This thesis is intended to contribute to the next generation of LCA literature by analyzing the limitations in light of current tools and assessing means to overcome them. The following describes the primary limitations with traditional LCA methodologies identified in the literature.

Merty and Wallin describe several limitations of LCA include the following: 1) LCA should not be used as a tool for determining if one product is "good" or "bad," but rather to determine a product's comparative advantage to substitutes, 2) qualitative approaches tend to become subjective and less reproducible, 3) quantitative approaches require a large volume of information and data that either many not be available or may be expensive to collect, and 4) some danger exists if such techniques are seen as a panacea to quantifying and judging products. The authors suggest that a LCA should be considered one tool, of many, used in the decision-making process.

Seager and Theis identify additional limitations to LCA use: 1) the lack of inventory data, 2) difficulties in identifying the boundaries of a system, 3) disparate underlying assumptions, and 4) impact assessments in terms that are not directly comparable.

The UNEP report also provides an overview of the problems with LCA: they take a long time to perform, often times they result in contradictory results, they may hinder technical improvements which later turn out to be environmental improvements as well.

Arnold (Arnold, 1993) suggests the use of traditional point source regulations to address environmental problems over LCA. He argues that the price system cannot be trusted to inform people about the true ecological costs of alternative products or processes. So consumers, businesses, and governments instead want some sort of environmental report card to guide their choices. The main problem as he sees it, is that it is impossible, practically speaking, to identify and measure all of the indirect sources of environmental problems for a given product or process. In addition, all of the sources of environmental harms can change over time and vary across the country, which is a level of complexity far beyond the scope of real work LCAs. In all real world LCAs, the list of caveats is long, as is the list of omissions and shortcomings. As a result, whatever "answer" an LCA reaches is not necessarily applicable to any specific person or any real-world setting whose circumstances differ from those assumed in the study. And in comparing actual environmental harms, how can one tally up these proxies – a gallon of fuel against a pound of pollution – and then weight them against each other? The main problem is that this backtracking through inputs to inputs that fan out through the entire economy quickly gets out of hand unless one can confidently decide just how much detail is sufficient and how far away from the product an input can be before it is safe to exclude it from the analysis. The issue of scope is inherently hard to set and define. Arnold argues that predicting what will actually happen to the levels of economic activities remotely connected to the decision under study, much less any changes in the environmental problems of concern they cause, it a tricky business that is largely ignored in the LCA literature. LCA does not provide conclusive results of any use in guiding consumer and producer choices to greener alternatives. More confidence that environmental problems are being addressed and that the consequences of doing so will be incorporated into prices ultimately eliminates the original motivation for conducting LCAs.

Table 3 below summarizes the limitations with traditional LCA methodologies, focusing on the applicability of the methodologies from the point of view of a regulatory agency like the U.S. EPA:

Table 3: Limitations of Traditional LCA Methodolgies

Limitation with Traditional LCA	Description of Limitation from EPA Perspective
1. Do not provide an 'absolute' answer	• At best LCA provides only a relative comparison of two or more products or processes • Only provides analysis of products/processes that are entered into the analysis
2. Large volume of information required	• Large amount of inventory (input and output) information is required to study relatively small number of potential outcomes
3. Difficult to define system boundaries	• Defining where a product or process starts and ends is difficult and increases the complexity of the analysis
4. Take a long time to perform	• Large amount of time is required to perform analysis of a small number of potential outcomes
5. Are focused on a single product/process	• It is not efficient for the U.S. EPA to regulate on a process by process or product by product basis

The next chapter describes a modified LCA approach that attempts to solve some of the problems mentioned in the above table.

CHAPTER 6: INPUT/OUTPUT LIFE-CYCLE-ASSESSMENT

As the previous chapter noted, traditional life-cycle-assessment methodologies have focused on specific products or processes. It has long been noted that there is a "need for environmental policy to take into account the full chain of pollution and resource consumption consequences associated with production and consumption decisions." (Spengler et al, 1999, pg. 7) This chapter presents a modified version of an economic analysis tool that can be used to look at the environmental impacts of entire industry sectors. This tool is called environmental input/output life-cycle-assessment (I/O LCA). Before getting into the details of how this tool can be used by an environmental regulatory agency it is important to understand how the tool has been developed and some of the mathematics powering the assessment capabilities.

Background on Input/Output Life-Cycle-Assessment

Input/Output analysis (I/O A) was first introduced by economist Wassily Leontief in approximately 1930 (Heijungs and Suh, 2002). The tool was originally designed and developed to study the structure of economies and the flow of money throughout the economy. I/O A breaks the economy into distinct sectors and tracks how the outputs from one industry are used as the inputs to other industries. The tool uses a matrix to create this model. Figure 2 shows a hypothetical and very simplified inter-industry matrix. The entries in this matrix are based on producing $100 worth of shoes. Each column in the matrix represents the inputs required from the other industry sectors to create the output from the shoe manufacturing industry. For example, $100 of shoe production requires $5 of electricity, $7 worth of rubber, and $6 worth of laces. Because the I/O A model is a linear model, $200 of shoe production would double all of the required inputs.

Inputs	Electricity Industry	Rubber Manufacturing	Laces Manufacturing	Shoe Manufacturing
Electricity Industry	$0	$4	$3	$5
Rubber Manufacturing	$0	$0	$0	$7
Laces Manufacturing	$0	$0	$0	$6
Shoe Manufacturing	$0	$0	$0	$0

Figure 2: Sample Input/Output Industry by Industry Matrix For Shoe Production

An input/output model has been created for the United States economy by the Department of Commerce, which separates all the U.S. industries into over 500 distinct sectors. This comprehensive model is based on annual data collected and maintained by the United States Department of Commerce.

The Extension of Input/Output Analysis

I/O A was extended into the arena of the environment by looking at the flows of pollution and resource use across industry sectors in the 1960's. I/O LCA combines economic databases on intersectional flows with environmental/resource databases on industry specific pollution and resource flows (Spengler et al, 1999).

There are three main categories of environmental I/O LCA (Miller and Blair, 1985):

1. Generalized Input-Output Models – formed by supplementing the technical coefficients matrix with additional rows and columns to reflect the pollution generated and resources used for each unit process.

2. Economic-Ecologic Models – formed by extending the interindustry model to include "ecosystem" sectors, where flows will be recorded between economic and ecosystem sectors along the lines of an interregional input/output model.

3. Commodity-by-Industry Model – formed by expressing environmental factors as "commodities" in an input/output table.

The focus of this research is on the use and extension of generalized input/output economic models into (category 1 above) an environmental input/output life-cycle-assessment tool. This category of input/output assessments is the most straightforward to extend because the underlying industry by industry matrix already exists and it is simply a matter of adding environmental data to this existing model. For a detailed description of the mathematics behind this extension please see Miller and Blair (1995) and Joshi (1999).

What is Environmental Input/Output Life-Cycle-Assessment

Environmental I/O LCA offers a high-level view across all economic sectors that are entered into the tool. This high level view is especially useful at identifying industries with the highest pollution or resource consumption and thus prioritizing areas to focus on to make the most improvements.

Environmental I/O LCA also provides users the ability to examine more closely a specific industrial sector to look across the supply chain for that sector and to determine where the largest environmental burdens are occurring.

Sources of Environmental Input/Output Life-Cycle-Assessment Data

As stated previously it is relatively easy to add environmental information to an existing input/output model. This begs the question, what are the sources of environmental data that can be added to this model? There are a variety of publicly available data sources to draw on. Table 4 below indicates some of the data sources used in the Carnegie Mellon University Green Design Initiative's web-based environmental input/output life-cycle-assessment tool for calculating various environmental impacts. (http://www.eiolca.net/methods.html)

Table 4: Data Sources Used by CMU web-based Input/Output LCA Tool for Calculating Environmental Impacts

Environmental Impact	Data Sources Used in CMU On-line Tool
Toxics Releases	U.S. EPA's 1995 Toxic Release Inventory
Global Warming Potential	U.S. EPA AP-42 emissions factors
Electricity Use	1992 Census of Manufactures
Conventional Pollutant Emissions	U.S. EPA AIRS database

This table provides only a small percentage of the total environmental information that is available for use in this type of tool.

Advantages of Input/Output Life-Cycle-Assessment

There are several major advantages of environmental I/O LCA over traditional product/process LCA. Some of these are presented below:

1. It is possible to protect proprietary information (e.g. trade secrets) in environmental I/O LCA. This is a concern that is often voiced by the regulated community when dealing with the U.S. EPA's information collection requirements. This is less of a concern with I/O LCA in that the analysis combines all the firms from a specific industry thereby hiding company-specific information.

2. Environmental I/O LCA provides the ability to identify where among the supply chain the largest environmental burdens exist for an entire industry. This allows for the identification of the largest environmental problems.

3. Some of the difficulties associated with product-specific LCAs are alleviated by using industry-wide or even an economy-wide LCA. For example, average values for energy costs and use are more reliable (Graedel, 1998.) Traditional product-specific LCAs attempt to calculate exactly where the energy comes from whereas environmental I/O LCA generalizes across the entire industry.

4. The problem of where to draw the system boundaries are alleviated because environmental I/O LCA examines the entire economy. It is much less likely that any inputs will be missed using this approach. Depth of tiers and breadth of inputs are major advantages of I/O LCA. There is no need to draw arbitrary boundaries around the system as there is with a product or process specific LCA (Hendrickson et. al, 1998).

5. There is no need to spend time defining the functional unit, which can be problematic in a traditional LCA. The functional unit is the unit of study in a traditional LCA. The exact definition of the function unit can have a significant impact on the final results of the LCA. The functional unit can be thought of as the measure of a product or process which sets the scale for comparison of two or more products or processes. For example a can of paint could be the functional unit, but one could also define the functional unit as square feet of painted surface. For a discussion about the importance of and the mechanism for defining a functional unit in a traditional LCA see: http://www.dk-teknik.dk/ydelser/miljo/LCA%20guide/3rd_ed/kap333.htm.

   In environmental I/O LCA the unit is goods produced from a specific industry expressed in dollar amount.

6. The data collection and analysis are much less time-consuming and costly with environmental I/O LCA. Because a large part of the data is already being collected, it is simply a matter of inputting the data into the environmental I/O LCA analytic tool and generating results. This means that there is a relatively low cost associated with using environmental I/O LCA is (Hendrickson et. al., 1998). Baseline data linking the industrial sectors is available from the Department of Commerce. Some data on emissions is already available and has been integrated into I/O LCA tools. Quick and easy comparisons are possible. Adding additional levels of detail in terms of environmental burdens to the matrix is straightforward.

7. Environmental I/O LCA allows users the ability to link information about socio-economic and environmental impacts which is beneficial for integrated policy analysis.

Limitations of Input/Output Life-Cycle-Assessment

As others have noted, there are several limitations with I/O LCA that need to be addressed in order for the tool to be effectively used. In particular, additional quality control of the accuracy, completeness, and timeliness of the data used for the assessment of environmental burdens must be assured (Hendrickson et. al., 1998).

Work should be done to study the accuracy of the regional linkages in the economic input/output models to ensure consistency across the nation. This will be increasingly important if international imports and exports are to be properly accounted for (Hendrickson et. al. 1998).

The level of disaggregation may not be sufficient to account for all of the detail in certain industrial sectors. Moreover, there may be variation within an industry on the processes used and products generated to accurately account for the impacts in a single row in the I/O matrix (Hendrickson et. al., 1998).

Another limitation with I/O LCA is that the end-of-life product stages are not as easily considered as they are in traditional LCAs. (Hendrickson et. al., 1998)

These limitations will be further addressed in the recommendations section of this thesis.

Chapter 7: Example of How Input/Output Life-Cycle-Assessment Could be Used by the U.S. EPA

The purpose of this chapter is to demonstrate how environmental input/output life-cycle-assessment can be used to evaluate environmental impacts across the economy and within specific industrial sectors. The analysis presented here is a very short introduction to the breadth and depth of information that I/O LCA can provide. This chapter is divided into two sections: the first presents evidence of how I/O LCA can be used to look across the economy to evaluate which industries and where within the supply chain of those industries environmental protection efforts should be focused and the second section shows how I/O LCA can be used to complete a more extensive evaluation of specific industry sectors.

Prioritization of Industries

Figure 3 below contains data on the air pollution burden, over the supply chain, for over 500 industries in the United States economy (Spengler et. al., 1999). The chart shows the percentage of the total air pollution burden, by industry, that occurs upstream rather than on-site. It is important to note that for approximately 80% of the industries represented by the data, 80% of their total air pollution burden occurs upstream in the supply chain. What this indicates is that the best way to reduce air pollution, for 80% of US industries, would be to attempt to reduce the air pollution upstream in the supply chain rather than regulating direct emissions (Spengler et. al., 1999).

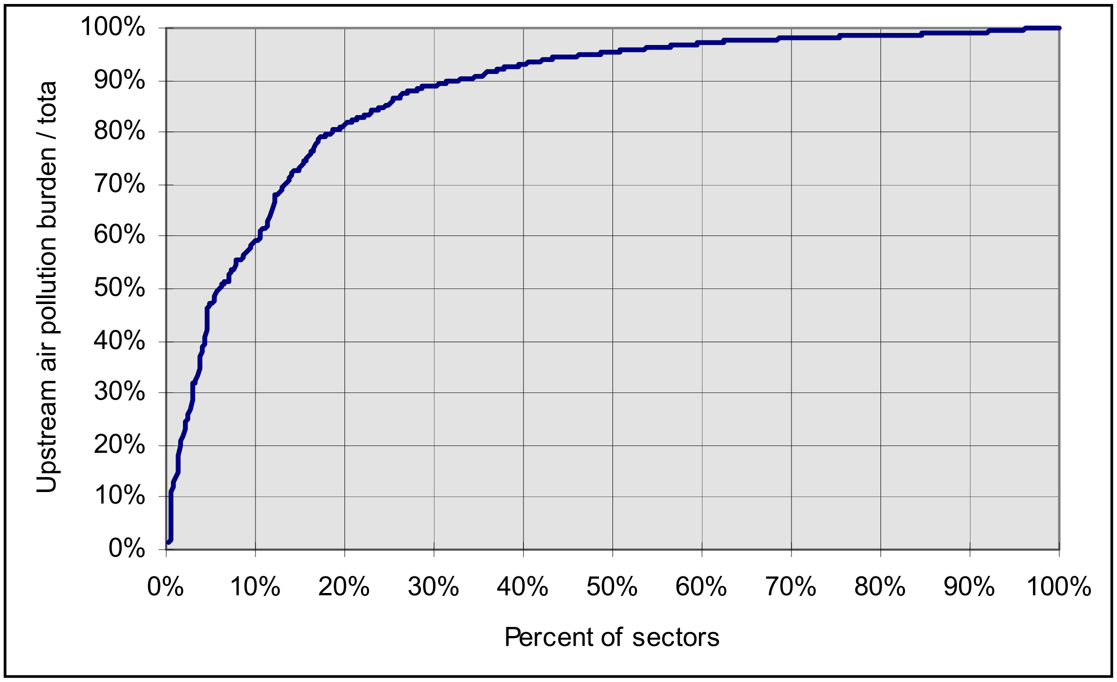

Figure 3: Upstream Air Pollution Burden as a Percentage of the Total Air Pollution Burden of 500 United States Industrial Sectors. (Spengler et al., 1999)

Figure 4 below contains data for the 30 U.S. industrial sectors that have the largest direct air pollution burden (Spengler et. al., 1999). For this chart, the emissions of nitrous oxides (NOx), volatile organic compounds (VOCs), sulfur dioxide (SO2), carbon monoxide (CO), particulate matter (PM), and carbon dioxide (CO2) were combined to give an overall air pollution burden figure. The upstream air pollution burden for these 30 sectors was added to the chart, using I/O LCA, to demonstrate that direct environmental burden is not a good indicator of total environmental burden. Note that the sectors ranked 12th and 22nd based on direct burden only would jump to 5th and 2nd respectively if both direct and upstream burdens were considered together. It is clear that to effectively address the environmental impacts of industries it is important to ensure that all of the impacts are known. What the example shows clearly is that I/O LCA is one mechanism to obtain this more complete set of information.

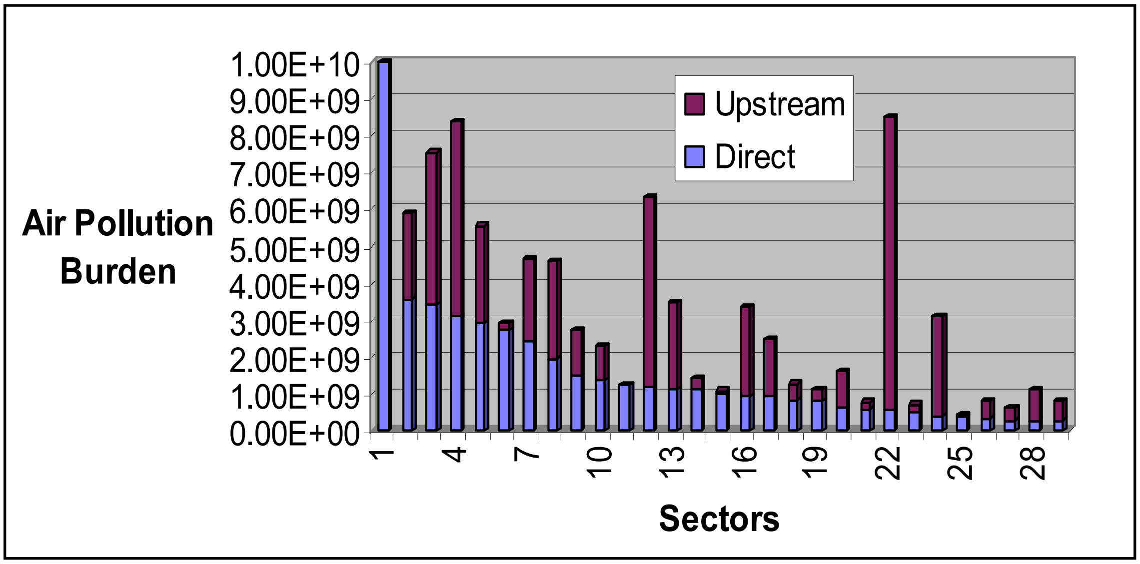

Figure 4: Direct and Upstream Air Pollution Burdens for the 30 U.S. Sectors with the Largest Direct Air Pollution Burdens. (Spengler et. al., 1999)

Evaluation of Specific Industries

The following evaluation compares two industries currently working with the U.S. EPA on developing voluntary partnerships. The industries being considered are: ship building and meat processing. While these industries were chosen simply because they are two of the industries that the U.S. EPA is beginning to work with, in reality, the I/O LCA analysis shown above in figures 1 and 2 could be used to determine which industries to concentrate on. This evaluation is meant to serve as a demonstration of how the U.S. EPA could use I/O LCA in assessing the various environmental impacts of specific industries and how efforts could be tailored to address the most significant impacts in the most cost-effective ways.

For the purposes of this simple study it was necessary to match up the industries with specific Standardized Industrial Classification and Commerce Sector codes to generate data using the I/O LCA tool. Ship building was matched most closely with "Ship Building and Repairing" (SIC code – 3731/Commerce Sector – 61.0100) and meat processing was matched most closely with "Meat Packing" (SIC code – 2011/Commerce Sector – 14.0101).

The data for this study were generated using an on-line environmental input/output life-cycle-analysis tool developed by Carnegie Mellon University's Green Design Initiative.[6]

One of the most important aspects of environmental I/O LCA is that it can provide detailed information on where pollution is occurring. "As LCA researchers increasingly recognize and attempt to incorporate fate/transport/damage models in Life Cycle Impact Assessment, the location of pollutant emissions can significantly influence their environmental consequences." (Spengler et al., 1999, pg. 10) Table 5 below contains the toxic releases by media (air, water, and land) for the 10 most polluting industries in the supply chain for the ship building and repairing industry. The pollution is expressed per $1 million worth of output produced by that industry. The data are presented by megatons (mt) emitted and percentage of total emissions released into the specific media. For example, the ship building and repairing industry itself contributes 0.13 megatons of toxic pollutants into the air and this accounts for 53.07% of the total toxic pollutants emitted into the air for the production of $1 million worth of output from the shipbuilding and repairing industry. Table 6 presents similar information for the other industry sectors within the supply chain for the production of $1 million worth of output from the meat packing industry.

[6] The on-line tool can be accessed on the web at: http://www.eiolca.net/

Table 5: Toxic Releases by Media for Industry Sectors in the Supply Chain for the Ship Building and Repair Industry

Toxic Releases by Media	*Air Releases*		*Water Releases*		*Land Releases*	
Industry Sectors	**mt**	**%**	**mt**	**%**	**mt**	**%**
Ship building and repairing	0.13	52.07%	0.0012	12.88%	0.000051	0.05%
Blast furnaces and steel mills	0.012	4.81%	0.0046	47.45%	0.027	28.39%
Electrometallurgical products, except steel	0.0033	1.36%	0.00046	4.82%	0.0082	8.58%
Fabricated structural metal	0.0028	1.17%	0.000001	0.01%	0.00015	0.16%
Primary nonferrous metals, n.e.c.	0.045	18.32%	0.00024	2.53%	0.034	35.53%
Industrial inorganic and organic chemicals	0.0057	2.35%	0.0017	17.43%	0.0013	1.45%
Paints and allied products	0.0024	0.99%	0	0.00%	0.000005	0.01%
Iron and steel foundries	0.0020	0.81%	0.000011	0.11%	0.0055	5.72%
Petroleum refining	0.0017	0.69%	0.00014	1.47%	0.000021	0.02%
Plastics materials and resins	0.0021	0.85%	0.00008	0.83%	0.000058	0.06%
All Other Sectors	0.041	16.58%	0.0012	12.47%	0.019	20.02%
Total Releases (mt)	0.24		0.0096		0.096	

Table 6: Toxic Releases by Media for the Industry Sectors in the Supply Chain for the Meat Packing Industry

Toxic Releases by Media	*Air Releases*		*Water Releases*		*Land Releases*	
Industry Sectors	**mt**	**%**	**mt**	**%**	**mt**	**%**
Meat packing plants	0.017	7.00%	0.079	65.74%	0.016	20.11%
Nitrogenous and phosphatic fertilizers	0.085	35.32%	0.033	27.36%	0.046	56.90%
Soybean oil mills	0.037	15.51%	0.000006	0.00%	0.000013	0.02%
Industrial inorganic and organic chemicals	0.014	5.73%	0.004	3.36%	0.0033	4.17%
Cottonseed oil mills	0.0066	2.72%	0.000022	0.02%	0	0.00%
Petroleum refining	0.0047	1.95%	0.00039	0.33%	0.000058	0.07%
Pesticides and agricultural chemicals, n.e.c.	0.0057	2.38%	0.00066	0.54%	0.000047	0.06%
Miscellaneous plastics products, n.e.c.	0.0091	3.78%	0.000006	0.00%	0.000014	0.02%
Prepared feeds, n.e.c.	0.0073	3.04%	0.00057	0.47%	0.00020	0.25%
Plastics materials and resins	0.0029	1.19%	0.00011	0.09%	0.00008	0.10%
All Other Sectors	0.052	21.37%	0.0025	2.08%	0.015	18.30%
Total Releases (mt)	0.24		0.12		0.08	

These two industries work well for demonstration purposes because they have similar total amounts of toxic emissions but very different media and supply chain distributions of these emissions. For example, both industries emit a total of approximately 0.24 megatons of toxic pollutants into the air. However, the ship building and repairing sector accounts for 52.07% of the air pollution in the production of its outputs while the meat packing sector only accounts for 7.00% of the air pollution in the production of its outputs. This demonstrates that direct regulation of air emissions could do a significant amount to reduce air pollution in the ship building and repairing sector, but would do little in the meat packing sector.

A reverse situation occurs if only water releases are considered. The meat packing sector accounts for 65.74% of the toxic releases into water in the production of its outputs while the ship building and repairing sector only accounts for 12.88% of the toxic releases into water in the production of its outputs.

A third situation occurs if only land releases are considered. In the production of outputs for these two industry sectors neither is the primary emitter of toxic pollutants onto land. In the production of $1 million worth of output from the ship building and repairing industry, the primary nonferrous metals, n.e.c. sector is the largest emitter of toxics to land, with 35.53% of the total emissions to this media while in the meat packing industry, the nitrogenous and phosphatic fertilizers industry contributes 56.90% of the total emissions to land.

Figures 5 and 6 show the percentage breakdown of toxic releases by media for the top 10 polluting industries in the supply chains for the meat packing industry and the ship building and repairing industry respectively. These figures present a graphical representation of the descriptions given above.

Figure 5: Toxic Releases by Media for all Sectors in the Supply Chain for the Meat Packing Industry

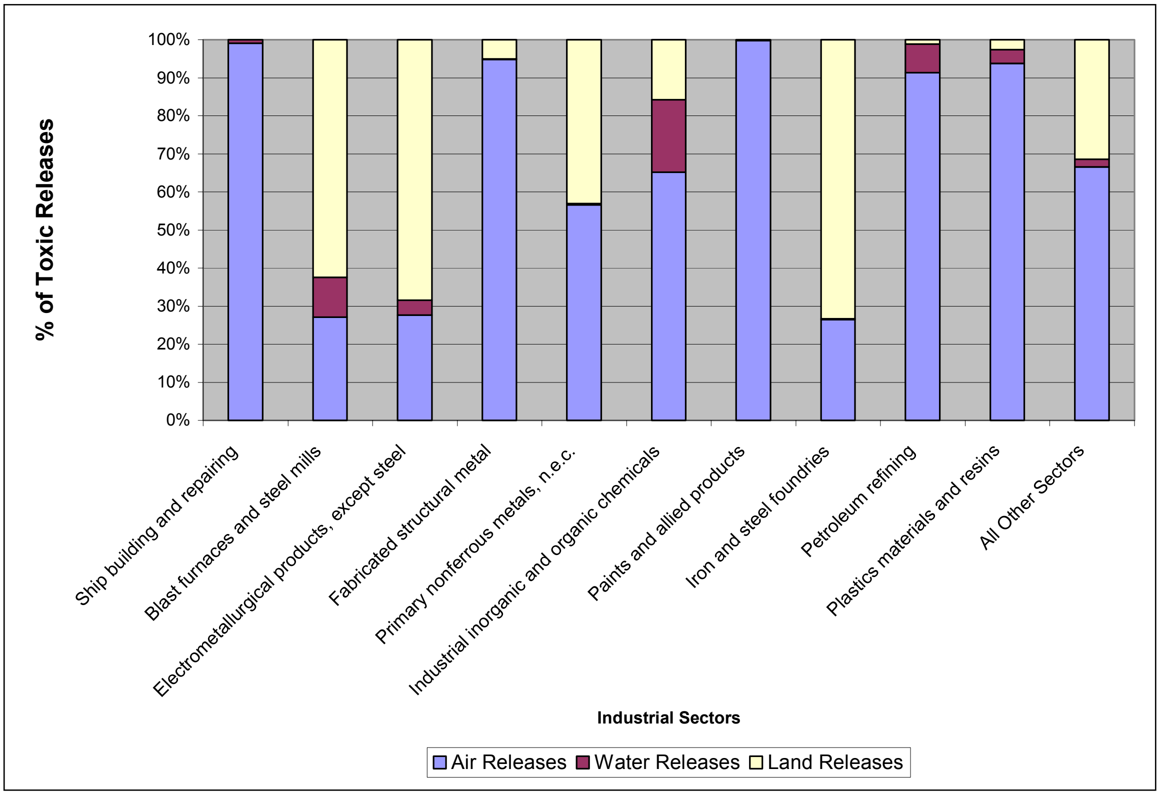

Figure 6:Toxic Releases by Media for All Sectors in the Ship Building and Repairing Supply Chain

In addition to evaluating toxic releases, global warming potential (GWP) can also be examined throughout an industry's supply chain. Figures 7 and 8 present data for the ten most contributing industries, in terms of GWP, in the supply chains for the ship building and repairing sector and the meat packing sector respectively. Again, these emissions are based on the production of $1 million worth of output produced for the ship building and repairing and meat packing industries. The GWP data are calculated by converting the estimated releases of the following greenhouse causing gasses: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and chloroflurocarbons (CFCs) into equivalent releases of CO2. This conversion follows the standards set by the Intergovernmental Panel on Climate Change.[7]

It is interesting to note that for both of these sectors the largest contributor to GWP is the electric services industry, which accounts for 43% of the total GWP in the ship building and repairing industry and 36% of the total GWP in the meat packing industry. What this

[7] Fuel Usage, AP42 emissions factors, IPCC 1995 weightings

indicates is that the best way to reduce the GWP of these two industries would be to focus on ways to reduce electricity use.

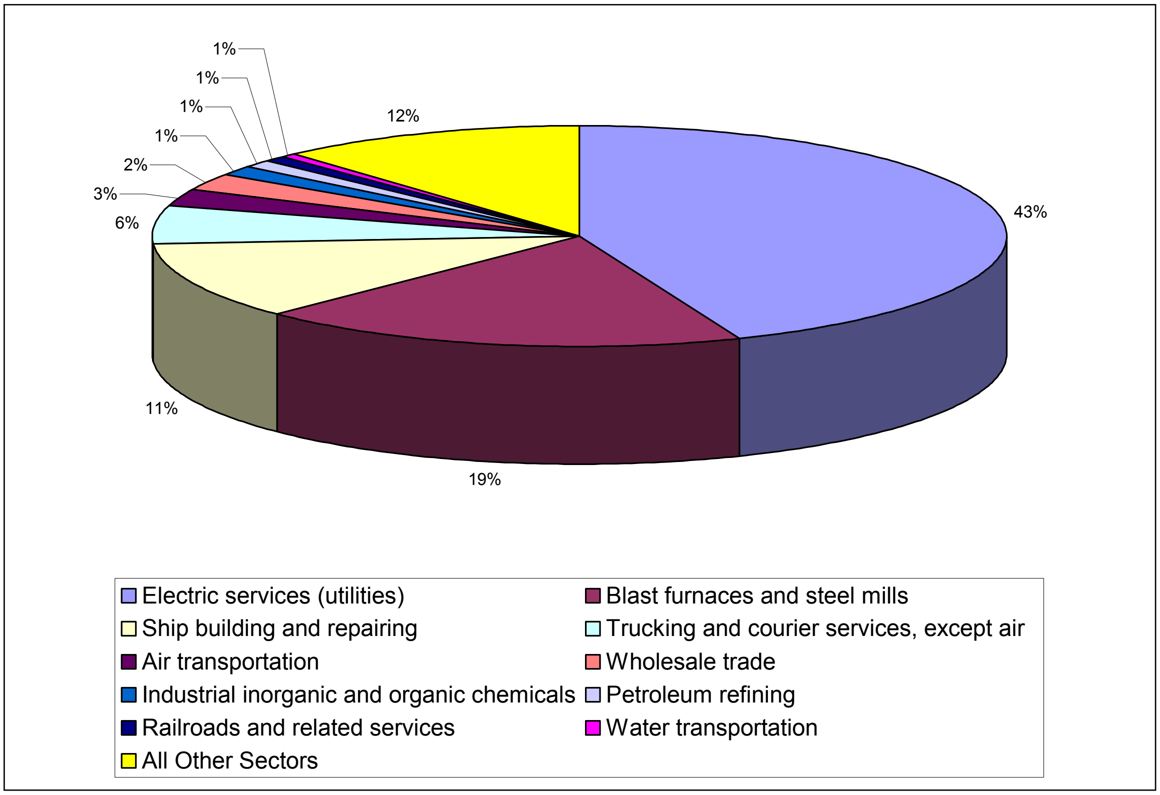

Figure 7: Global Warming Potential for All Sectors in the Supply Chain for the Ship Building and Repairing Industry

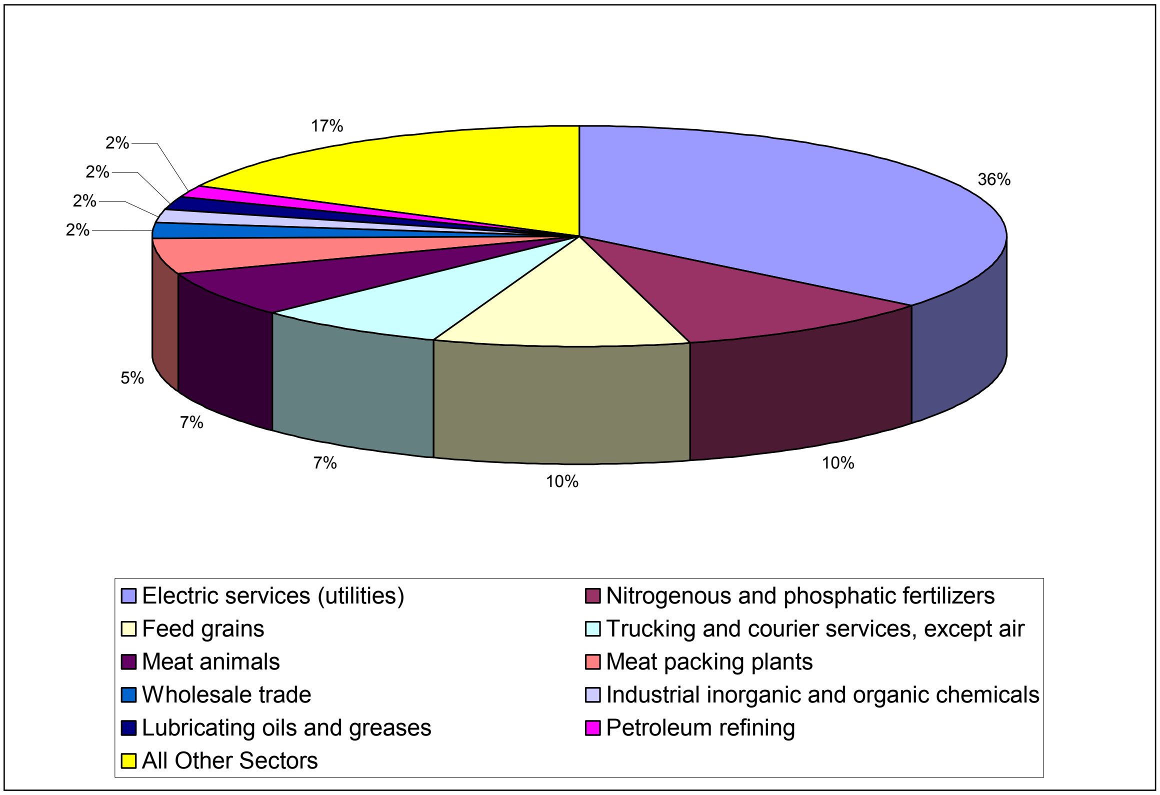

Figure 8: Global Warming Potential for All Sectors in the Supply Chain for the Meat Packing Industry

Conclusion

What this brief study illustrates is that I/O LCA can be used at two critical levels. First, the tool can be used to look at an entire economy to determine which industries have the largest environmental burdens. This high-level view of the economy looks at direct environmental impact as well as upstream impacts to assess the total impacts of particular industries. Second, I/O LCA can be used to do a more detailed analysis of specific industrial sectors. This more detailed evaluation can break down where emissions are occurring in the environment (air, water, land) as well as where they occur in the supply chain.

Chapter 8: Recommendations to the U.S. EPA on how to Incorporate and Improve the Effectiveness of Environmental Input/Output Life-Cycle-Assessment

This chapter presents specific recommendations to the U.S. EPA on how to incorporate the use of environmental input/output life-cycle-assessment to achieve the mission and goals of the agency. These recommendations are divided into two categories. The first category focuses on how the U.S. EPA could best use environmental input/output life-cycle-assessment. The second category focuses on how the U.S. EPA can enhance and improve the information available to include in environmental I/O LCA.

Recommendations on How the U.S. EPA Could Best Use Environmental I/O LCA

***Recommendation 1*: Environmental input/output life-cycle-assessment should be included as part of the Analytic Blueprint when designing new regulations.**

As mentioned in chapter 3 rules that are classified as Tier 1 and Tier 2 require the development of an analytic blueprint as part of the regulatory development process. It is recommended that an environmental I/O LCA be included as part of this blueprint. Tier 2 rules are those that explicitly deal with cross-media issues and it therefore is feasible that an analytic method that addresses burdens to all media, such as environmental I/O LCA, be used to collect the appropriate background material before the development of a new rule.

Environmental I/O LCAs are relatively easy to complete once information has been collected and entered into an appropriate tool. Therefore, this recommendation will not unnecessarily lengthen the regulatory development process. Additionally environmental I/O LCAs will provide increased information that can be used as part of the required cost/benefit assessment. Environmental I/O LCAs provide valuable information that can be used to justify actions based on cost-effectiveness.

Recommendation 2: **Environmental input/output life-cycle-assessment should be used to prioritize which voluntary industry partnerships are pursued by the U.S. EPA.**

As the study presented in chapter 7 showed, environmetnal I/O LCA can be used to evaluate environmental burdens across the entire economy. This analysis can assist with the prioritization of which industries the U.S. EPA works with to establish voluntary partnerships. Additionally, environmental I/O LCA can be helpful in doing a more thorough evaluation of where within specific industries environmental protection efforts should be focused.

Recommendation 3: **Environmental input/output life-cycle-assessment should be used to track the effectiveness of environmental protection activities.**

The use of environmental I/O LCA over time would facilitate the tracking of specific environmental protection efforts in order to assess their effectiveness. Because most of the information used in environmental I/O LCAs are collected annually it would be possible to track the emissions of various pollutants into the different media from one year to the next.

Recommendation 5: **Environmental input/output life-cycle-assessment should be used to prioritize research and development efforts.**

As stated previously, environmental I/O LCA can be used to identify where the most significant environmental burdens exist within both the economy and a specific supply chain. In addition to focusing on voluntary partnerships and regulatory development efforts, this information could also be used to determine the areas in greatest need of technological innovation, and hence where research and development dollars should be spent. Work on this recommendation could increase the engagement between the private and public sector in addressing complex environmental problems and could be an important component of future government/industry partnerships.

Recommendations on how the U.S. EPA Could Enhance the Information Available for Environmental I/O LCA

Recommendation 6: **Cross-office workgroup should be formed within the U.S. EPA to evaluate the information resources currently maintained by the agency for use in environmental input/output life-cycle-assessment.**

The U.S. EPA has a variety of resources that are already used in many environmental I/O LCA tools. A workgroup could quickly evaluate whether all of the information that the agency maintains is being used in the most effective way.

Recommendation 7: **The U.S. EPA should work with the academic and industrial community to expand current information and integrate existing information to improve the effectiveness of an environmental input/output life-cycle-assessment tool.**

There are a wide variety of resources available to pull into a comprehensive environmental I/O LCA tool. The U.S. EPA could gain a lot by continuing to work with the academic community to pull this information into a usable format. This would facilitate better use of environmental I/O LCA by the agency on addressing environmental problems and could also aid future academic research into this methodology. Additionally, the U.S. EPA should work with the industrial sectors to improve the accuracy of the information used in environmental I/O LCA, especially in industries where there is a lot of variation in the processes used and products developed.

How Recommendations Address Identified Limitations

The following three tables describe how the above recommendations address the limitations with the current U.S. EPA approach to environmental protection, traditional LCAs, and environmental I/O LCAs identified earlier in this thesis.

Table 7: How Recommendations Address the Limitations with Current U.S. EPA Activities

Limitation of Current U.S. EPA Activities	***Description of How Recommendations Address Limitation***
Limitations with the Current Regulatory Design Process	
1. Use of Information in Design	• Use of I/O LCA in the regulatory design process will help ensure consistency.
2. Use of Cost/Benefit in Design	• I/O LCA can be used to supplement traditional Cost/Benefit analysis and can provide critical information for cost-effectiveness considerations..
Limitations with the Current Regulations In-Use	
1. Command and Control	• Continued use of I/O LCA can help the U.S. EPA determine which regulations are important and where flexibility could be built in to make additional environmental improvements.
2. Media Specific	• I/O LCA addresses environmental burdens to all media.
3. End-of-Pipe	• I/O LCA evaluates environmental problems throughout the supply chain.
4. Risk Shifting	• I/O LCA allows users to determine which media are being impacted. This will ensure that risks are not being shifted from one media to another.
5. Tracking Effectiveness	• Annual use of I/O LCA will provide a mechanism to track the performance of specific regulations/actions over time.
Limitations with the Current Voluntary Activities	
1. Lack of Coordination	• E I/O LCA will assist the U.S. EPA in prioritizing which industries to focus on.
2. Lack of Performance Review Metrics	• Annual use of E I/O LCA will provide a mechanism to track the performance of specific environmental protection activities over time.

Table 8: How Recommendations Address the Limitations with Traditional LCAs

Limitations with Traditional LCA	*Description of How Recommendations Addresses Limitation*
1. Does not provide an 'absolute' answer	• I/O LCA provides the ability to determine where the largest environmental burdens are occurring and therefore provides the means to prioritize environmental protection efforts.
2. Large volume of information required	• Large volume of information already exists for use in I/O LCA. This information, once entered into a tool, can be used for a wide variety of assessments.
3. Difficult to define system boundaries	• Because I/O LCA includes information on the entire economy all inputs are included for analysis. There is no need to define an arbitrary system boundary.
4. Take a long time to perform	• Once information is entered into the I/O LCA tool, specific assessments can be completed rapidly.
5. Are focused on a single product/process	• I/O LCA looks across the entire economy and provides a high level overview of where the most significant environmental problems exist.

Table 9: How Recommendations Address the Limitations with Environmental I/O LCAs

Limitations with I/O LCA	*Description of How Recommendations Address Limitation*
1. The accuracy, completeness, and timeliness of the data used for the assessment of environmental burdens needs to be improved	• Will be partially addressed by U.S. EPA workgroup, which is recommended to evaluate current information resources maintained by the agency. • Critical issue to be addressed by governmental/industry/academic partnerships.
2. Regional linkages in the economic input/output models are unknown	• Critical issue to be addressed by governmental/industry/academic partnerships.
3. Disaggregation may not be sufficient to account for all of the detail in certain industrial sectors	• Critical issue to be addressed by governmental/industry/academic partnerships.
4. End-of-life product stages are not considered	• Critical issue to be addressed by governmental/industry/academic partnerships.

How Recommendations Align with U.S. EPA Strategies

Table 10 below shows how the recommendations listed above align with the four cross-goal strategies mentioned earlier in this thesis:

Table 10: How Recommendations Align with U.S. EPA Cross-Goal Strategies

Cross-goal Strategies	How Recommendations Align with Strategy

1. Information Analytic Capacity	• I/O LCA represents a new analytic tool that can facilitate data interpretation.
	• I/O LCA can help users:
	  ○ Respond to environmental problems
	  ○ Set priorities
	  ○ Make sound decisions
	  ○ Manage for results
	  ○ Measure performance

2. Innovation in Solving a Set of Priority Environmental Problems	• I/O LCA will help enable and inform the voluntary industry initiatives currently under way. • I/O LCA represents a new information tool that can support decision making
3. Innovation in Continuing to Develop Tools That Have Already Proven Effective on a Limited Scale and That Have Applicability Across Many Environmental Programs	• I/O LCA has been used in a limited capacity in previous U.S. EPA studies. • I/O LCA is a tool that has applicability across many environmental programs. • I/O LCA can expand upon the success of the agencies voluntary efforts to promote the use of Environmental Managements Systems by industry.
4. Use of Sound Scientific Information to Inform Decisions	• I/O LCA integrates a large portion of the information already being collected and used by the U.S. EPA into a form that is easy to use and can facilitate the setting of environmental priorities.

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