

**PROPOSAL:
CERTIFICATE PROGRAM IN INDUSTRIAL ECOLOGY (P.I.E.)**

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List of Acronyms Used in Text

CEMP	Corporate Environmental Management Program
CSS	Center for Sustainable Systems
EIH	Environmental and Industrial Health Department, School of Public Health
EHS	Environmental Health and Safety
IESET	Institute for Environmental Science and Engineering Technology
IGERT	Integrative Graduate Educational and Research Training
NGO	Non-governmental organization
NPPC	National Pollution Prevention Center for Higher Education
NSF	National Science Foundation
PIE	Program in Industrial Ecology
SNRE	School of Natural Resources and Environment
SPH	School of Public Health
U.S. EPA	United States Environmental Protection Agency

List of Acronyms Used in Curriculum and Internship Descriptions

AOSS	Atmospheric, Oceanic, and Space Sciences
BA	Business Administration
BIOSTAT	Biostatistics
BUS	Business
CEE	Civil and Environmental Engineering
CHE	Chemical Engineering
CS	Corporate Strategy
ECON	Economics
EIH	Environmental and Industrial Health
EPID	Epidemiology
GIS	Geographical Information Systems
GVSU	Grand Valley State University
IOE	Industrial and Operations Engineering
ME	Mechanical Engineering
MSU	Michigan State University
MTU	Michigan Technological University
NRE	Natural Resources and Environment
REM	Resource Ecology and Management
RPB	Resource Policy and Behavior
SPP	School of Public Policy
UP	Urban Planning
WMU	Western Michigan University

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I. Program Conception and Objectives

A. DEFINITION

The phrase "industrial ecology" appeared in a 1989 *Scientific American* in article (Robert Frosch¹ and Nicholas Gallopoulos, "Strategies of Manufacturing," September 1989: 144–152). In part, it said:

The industrial ecosystem would function as an analog of biological ecosystems. . . . An ideal industrial ecosystem may never be attained in practice, but both manufacturers and consumers must change their habits to approach it more closely if the industrialized world is to maintain its standard of living — and the developing nations are to raise theirs to a similar level — without adversely affecting the environment.

Since 1997, the *Journal of Industrial Ecology* has defined industrial ecology in the following way:

[Industrial ecology] systematically examines local, regional, and global material and energy uses and flows in products, processes, industrial sectors and economies. It focuses on the potential role of industry in reducing environmental burdens throughout the product life cycle through the extraction of raw materials, to the production of goods, to the use of these goods and to the management of the resulting wastes.

This "material and energy balance" approach and the ecosystem analogy above provide a foundation for the proposed Certificate Program in Industrial Ecology (known as PIE or "The Program"). To achieve a viable education program, we will build upon this foundation by integrating multi-disciplinary perspectives. **This unique integration incorporates technological and industrial innovation, consumer behavior and consumption patterns, policy and regulatory issues, and economic factors and market forces to achieve more sustainable systems.**

B. CHALLENGE

It is critical that the University of Michigan accept and undertake the leadership responsibility to educate and train future leaders to implement and institutionalize "sustainable systems." In the context of university education and research, this challenge means to organize and lead interdisciplinary research and teaching to support the design, assessment, and management of systems that meet societal needs in a sustainable manner. These systems include products, processes, services, communities, and other large-scale complex systems. Industrial ecology is a foundation upon which to build the educational structures to meet this challenge.

C. OBJECTIVE

The primary objective of this Certificate Program in Industrial Ecology is to enhance the education of graduate students in a range of relevant disciplines at the University of Michigan by providing them fundamental skills and knowledge of industrial ecology methods and applications. These specialized students will be better prepared to design and manage natural and industrial systems to meet human needs in an environmentally, economically, and socially sustainable manner.

D. BACKGROUND

One indicator that underscores the imperative for industrial ecology as a needed educational activity is energy production and consumption. In 1996, the United States had roughly 5% of the world's population but consumed 25% of the world's energy production (93.9 Quads/375.1 Quads); of that, only 8% (7.39 Quads/93.9 Quads) came from renewable energy sources (hydro, solar, wind, biomass).² As other areas of the world seek to enhance their living standards, energy production and consumption will increase. Production of greenhouse gases, especially carbon dioxide from fossil fuel, will increase, as will the potential for global warming. Another indicator of unsustainable resource consumption is municipal solid waste (MSW). In 1960, each person in the U.S. generated an average of 2.7 pounds of MSW each day; by 1996, this figure had nearly doubled, reaching 4.3 pounds per person per day.³

¹Former vice president of research at General Motors.

²Energy Information Administration, *Annual Energy Review* (Washington: EIA, 1997)

³U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the U.S.* (Washington: 1997).

Students must be educated and trained to incorporate concepts of sustainability into their mind-sets and into their problem-solving approaches. The U.S. and the rest of the world need to be much more efficient in producing and consuming energy and other material resources. Industrial ecology provides a viable and effective educational experience that addresses such basic societal issues as efficient-energy production and consumption. The concepts of industrial ecology and sustainability are needed both now and certainly in the 21st century.

1. Why a Certificate Program?

A certificate in industrial ecology is a most appropriate way to initiate this new educational activity here at the University of Michigan. First of all, it enables graduate students already at the University of Michigan to complement and extend their present graduate degree work. Second, the presence of the Certificate program will enhance recruitment of outstanding students to established graduate programs since it will be possible for them to incorporate the PIE Certificate as an addendum to their disciplinary focus. Third, it will encourage effective cooperation among the participating educational units here at the University. In this way, the necessary interdisciplinary connections and interactions will have the opportunity to be established and potentially flourish.

2. Relevance at the University of Michigan

The importance of the Program in Industrial Ecology is framed by the following section drawn from the "Final Report of the Provost's Advisory Group on Teaching and Research on the Environment—the PACE Report:"

The Challenge

There are enormous pressures being created by human activity on the natural and physical environment, many of which today are reaching global proportions. The problems arising from air, water and industrial pollution, resource and species depletion, and the effect of human settlement patterns are not new per se but are growing in pervasiveness, causing irreparable change, and are unparalleled in the threats they pose to the habitability of the earth. . . .

There is urgent need for a more sophisticated and encompassing scientific knowledge on which to base effective action. Scientists and scholars are now expected to understand and explain to the broader society the complex and often subtle interrelationships between physical, natural, and human systems. They are being challenged to discern how to redesign economic and social institutions in ways that can best ameliorate the most destructive aspects of human activity

The growing scale of the scientific challenge and the imperative for action are more widely understood than ever before around the world by business and industry, communities, universities, and individual citizens. Nothing short of a revolution in human understanding and behavior is underway in many sectors.

The Program is designed to lay the basis for graduate students at the University of Michigan to tailor a Certificate Program which complements their major field of study. Accordingly, the PIE Certificate is designed to provide each student with state-of-the-art education in the theory and practice of the application of life-cycle design and analysis techniques to sustainability issues in the students' field of professional interest. The important and unique contribution of the Program is its commitment to educating and training students and faculty to address the Challenges identified in the PACE Report.

3. Connection to U-M Schools and Colleges

a. College of Engineering: IESET

PIE has been endorsed by the Curriculum Committee of the Institute for Environmental Science and Engineering Technology (IESET). The overarching mission of this Institute is to shape, facilitate, and support cooperative education and research activities in the College of Engineering in all areas of environmental sciences, engineering, and technology. The PIE curriculum provides engineering graduate students the opportunity to enhance their discipline-specific education with an industrial ecology specialization. A new MSE Program in Engineering and Environmental Sustainability is currently being developed by IESET; PIE complements this new CoE initiative. Both of these education and training opportunities enable students to address complex environmental and resource challenges facing industry and municipalities with a broader set of technical tools and skills.

b. School of Natural Resources and Environment: Sustainability Theme

As a consequence of strategic planning activity during 1996-97, SNRE has developed a major theme for its teaching and research activities: sustainability. And, thanks to SNRE's National Pollution Prevention Center for Higher Education (NPPC), which is now known as the Center for Sustainable Systems (CSS), the School has an established record of life-cycle research and application. SNRE is also one of the co-managers of the CEMP joint degree [described below in Section I.3.d] and is organizing and implementing the winter 1999 "Sustainability Lecture Series" [described in Section II.E]. Because of the School's leadership in sustainability education and research, it is appropriate to have SNRE faculty and researchers take the lead in developing the Certificate Program in Industrial Ecology.

c. School of Public Health: EIH Department

The Program compliments the existing curriculum in the Environmental and Industrial Health Department of the School of Public Health. Specifically, the Program addresses resource productivity, environmental economics, and resource policy and law which is not emphasized in the Environmental Health Sciences curriculum. When combined with the environmental impact assessment and human health risk assessment/management curriculum of the Environmental Health Sciences department, the PIE curriculum provides students with the comprehensive knowledge base required for meeting environmental health challenges, particularly in large urban areas.

d. Business School: CEMP

The Michigan Business School is a recognized leader in the field of environmental management through the Corporate Environmental Management Program, which the School jointly manages with SNRE. Through CEMP, a student may earn joint masters degrees in business (M.B.A.) and natural resources (M.S.). Since CEMP's inception in 1993, many of its students have undertaken industrial ecology master's research projects. The PIE curriculum provides essential technical training and measurement technique that complement the CEMP joint degree. CEMP/PIE students will be ideal candidates for positions in technology-based companies such as 3M, Xerox, Lucent Technologies, Hewlett-Packard, and IBM as well as in the automobile industry.

4. Professional Activities in Industrial Ecology

a. Market Demand: The Need for Graduates With This Knowledge

Since Dr. Keoleian began offering NRE 557: Industrial Ecology (4 credits) in 1993, a number of students who have taken his course and also worked as NPPC/CSS research staff have been hired into research firms, government agencies, and private companies because of their skill, knowledge, and expertise in concepts of industrial ecology and sustainability. In discussion with representatives of leading companies with whom the NPPC has worked closely for more than seven years, the message is clear that companies are becoming increasingly concerned with the life-cycle implications of their products and processes. At the March 1998 meeting of the NPPC External Advisory Committee (now the CSS External Advisory Board), members fully endorsed the development of this proposal. [Members are listed in **Appendix 1.**]

A select set of companies that have begun to implement life-cycle tools and programs include the following: Alcoa, BASF, Daimler-Chrysler, Dow, Ford, General Motors, Hewlett-Packard, IBM, Kodak, 3M, and Xerox. These companies want and need for their employees to have strong disciplinary foundations, and this is how the Certificate Program is an extremely attractive complement to graduate degrees in Natural Resources, Engineering, Business, Public Health, and Public Policy. [Letters of support from industry members, including a former student, are provided in **Appendix 2.**]

b. Professional societies and organizations

The following organizations are actively supporting the development and application of life-cycle methodologies through workshops, conferences, and publications.

- i. Society of Automotive Engineers(SAE)
- ii. Institute of Electrical and Electronics Engineers (IEEE)
- iii. Society for Environmental Toxicology and Chemistry (SETAC)
- iv. International Standards Organization (ISO)

5. Existing Academic Resources in Industrial Ecology

a. Programs at other universities:

The proposed PIE Certificate is unique and can be distinguished from other university programs listed below on the basis of its interdisciplinary scope in both education and research. (Note: The following list is representative of programs being offered—it is not an exhaustive description of all of the programs currently available.)

- i. Carnegie Mellon

The *Green Design Initiative* began campus-wide in 1992 to promote environmentally conscious engineering, product and process design, manufacturing, and architecture. Partnerships are formed with industrial corporations, foundations, and government to develop joint research and education programs which improve environmental quality while encouraging sustainable economic development. Director: Dr. Lester Lave

- ii. Georgia Institute of Technology

The *Systems Realization Laboratory* began in Fall 1992. It focuses on the decision-based design and realization of open and sustainable engineering systems. Research activities are directed towards the development of (computer-based) methods and tools for designing, producing, deploying, maintaining, and retiring engineering systems in a technically, economically, ecologically and ethically sound way.

- iii. Michigan Technological University:

The *National Center for Clean Industrial and Treatment Technologies* (CenCITT) is a research consortium founded in 1992 to address clean technology needs of industry and environmental interests of government and the public. CenCITT's goal is to help create industrial facilities in which waste is minimized through the application of economically sound technologies and a combination of optimized manufacturing processes, treatment operations and reuse of materials. One research area, Environmentally Conscious Manufacturing, concentrates on the principles of disassembly simulation and environmental assessment of assembly and materials processing practices used in discrete product manufacturing industry. Director: John C. Crittenden

- iv. Massachusetts Institute of Technology

The *Technology, Business and the Environment Program* (TBE) is one of 12 research programs which operate under the umbrella of the Center for Technology, Policy, and Industrial Development (CTPID). The focus of CTPID is to foster teaching and research on policy issues related to science and technology. The TBE Program is directed by Dr. John Ehrenfeld and it was founded to help companies meet the challenge of achieving both environmental excellence and business success.

- v. Rochester Institute of Technology

The *National Center for Remanufacturing and Resource Recovery* provides technical assistance and applied research and development to the remanufacturing industry and manufacturers interested in manufacturing and resource recovery techniques. The technical staff at the center is complemented by faculty and students from the following

disciplines: industrial and manufacturing engineering, mechanical engineering, electrical engineering, packaging science, economics, and business. This year the Center sponsored a national conference on environmentally conscious manufacturing.

vi. Stanford University

The *Design for Environment* program is part of the Manufacturing Modelling Lab. Its principle research interests focus on Product Retirement Planning, Design for End-of-Life, and Disassembly Analysis Methods and Metrics. One of the current research products is a new Design for the Environment software package, "ELDA."

vii. University of California–Berkeley

The *Consortium of Green Design and Manufacturing, Engineering Systems Research Center* was established in 1993 to encourage multidisciplinary research and education on environmental management and pollution prevention issues in critical industries. Faculty and students in Mechanical Engineering, Industrial Engineering, Architecture, the Public Health, and Business work with their industrial and public sector colleagues to achieve objectives such as forming multidisciplinary research teams to address issues of environmental management and pollution prevention, integrating green design and manufacturing into the curriculum, establishing collaborative research with industry partners, establishing channels of support and information exchange with government agencies at all levels, and disseminating information on green design and manufacturing.

viii. University of Tennessee

The *Energy, Environment, and Resources Center* (EERC) at the University of Tennessee has been in existence for 26 years. Its primary mission is to conduct analytical, unbiased, and multidisciplinary research designed to promote real-world solutions to problems in the fields of energy, environment, technology, and economic development. The EERC also serves as an umbrella administrative organization for seven active programs including the Center for Clean Products and Clean Technologies (CCPCT). Established in 1992, CCPCT focuses on pollution prevention through design and manufacturing processes with the environment in mind. Staff develop, evaluate, and promote cleaner products through inter disciplinary research aimed at sustainable development. CCPCT's goals are to assist federal, state, and private institutions in their efforts to prevent and reduce pollution, to assess performance and economic feasibility, identify environmental benefits resulting from cleaner products and technologies, and to provide students with opportunities to gain experience in the emerging field of pollution prevention.

ix. Yale University

The *Industrial Environmental Management Program* is part of the Industrial Environmental Management, which is in the School of Forestry and Environmental Studies. This Program, together with Industrial Ecology, deals with industrial operations and their impact on the global environment. Pioneering ways to manage this impact are developed, taught, and applied at Yale. The *Journal of Industrial Ecology* is published by M.I.T. Press for Yale University and is part of this Program.

b. Selected textbooks

Allenby, Braden R., and Deanna J. Richards. *The Greening of Industrial Ecosystems*. Washington: National Academy Press, 1994.

Graedel, T. E., and B. R. Allenby. *Industrial Ecology*. Englewood Cliffs, N.J.: Prentice Hall, 1995.

———. *Industrial Ecology and the Automobile*. Englewood Cliffs, N.J.: Prentice Hall, 1998.

Keoleian, G. A., K. Kar, M. M. Manion, and J. W. Bulkley. *Industrial Ecology of the Automobile: A Life Cycle Perspective*. Warrendale, Pa.: Society of Automotive Engineers, 1997.

Socolow, R., C. Andrews, F., Berkhout, , and V. Thomas, eds. *Industrial Ecology and Global Change*. Cambridge, England: Cambridge University Press, 1994.

c. Selected journals

Environmental Conscious Design and Manufacturing

International Journal of Life Cycle Assessment

Journal of Cleaner Production

Journal of Industrial Ecology (MIT Press)

Journal of Sustainable Product Design

II. Program Description

A. REQUIRED COURSES

1. Core PIE Curriculum

[Syllabi appear in **Appendix 3.**]

a. Five courses totalling 16 credit hours

- i. NRE 557 / CEE 586 Industrial Ecology(4)
This includes a one (1) credit hour on-site field component
- ii. EIH 572 / NRE 514 Environmental Impact Assessment (3) *or*
AOSS 408 Environmental Problem Solving with Computers (3) *or*
AOSS 467 Biogeochemical Cycles (3)
- iii. Physics 419 Energy Demand (3) *or*
ME 499 Energy Engineering (3)
- iv. NRE 475 Environmental Law (3)
[Cross-listed as EIH 588 in the School of Public Health] or
NRE 532 Natural Resources and Environmental Conflict Management (3) *or*
EIH 554 Risk Management in Occupational and Environmental Areas (3)
- v. SPP 573 Cost-Benefit Analysis (3) *or*
CEE 589 Risk-Benefit Analysis (3) *or*
IOE 451 Engineering Economy (3)

B. RELEVANT OPTIONAL COURSES

1. School of Natural Resources and Environment

a. Policy, Behavior, and Law

NRE 475: Environmental Law (3)

NRE 501 (Section 002): Intergovernmental Relations in Environmental Policy (3)

NRE 501 (Section 014): Seminar on the Economics of Pollution Control (2)

NRE 530: Management of Environmental NGOs in Developing Countries (3)

NRE 532: Natural Resources Conflict Management Theory (3)

NRE 533: Negotiations Skills (2)

NRE 550: Resource Policy Analysis (3)

NRE 557 / CEE 586: Industrial Ecology (4)

- NRE 558: Water Resources Policy (3)
- NRE 515: Risk Communication (3)
- NRE 560: Behavior & Environment (3)
- NRE 561: Conservation Behavior: Source Reduction and Recycling (3)
- NRE 562: Resource Policy and Administration (3)
- b. Resource and Environmental Economics**
 - NRE 470: Natural Resources Economics (3)
 - NRE 570: Microeconomics With Natural Resource Applications (3)
 - NRE 585: Water Resource Economics (3)
 - NRE 571: Environmental Economics (3)
- c. Remote Sensing**
 - NRE 441: Remote Sensing of Environment (2)
 - NRE 442: Interpretation of Remote Sensor Data (2)
 - NRE 541: Energy Flow Processes in Remote Sensing (3)
- d. Resource Ecosystems**
 - NRE 411: Fluvial Ecosystems (4)
[Offered in odd-numbered years]
 - NRE 418: Biology and Management of Insects (2–4)
 - NRE 419: Agricultural/Forest Pest Management (1-4)
[Offered in odd-numbered years]
 - NRE 425: Applied Population Biology (4)
[Cross-listed in LSA as Biology 496]
 - NRE 427: Aquaculture (3–4)
 - NRE 432: Forest Hydrology and Watershed Management (2–3)
 - NRE 452: Multiple Use Forest Management (4)
 - NRE 453: Tropical Conservation and Resource Management (3)
 - NRE 460: Fishery Science (4)
[Offered in odd-numbered years]
 - NRE 505: Human Resource Ecology (2 or 4)
 - NRE 511: Introduction to Aquatic Ecosystems (4)
 - NRE 530: Geography: Spatial Analysis, Theory and Practice (3)
 - NRE 540: GIS and Natural Resource Applications (3)
 - NRE 553: Agroforestry (3)
[Offered in even-numbered years]
 - NRE 589: Ecological restoration (3)
- e. Directed Studies**
 - NRE 600: Directed Research and Special Problems (1–8 arr.)
- f. CEMP: see 6.a**

2. College of Engineering

a. Atmospheric, Oceanic, and Space Sciences

AOSS 408: Environmental Problems Solving with Computers (3)

AOSS 467: Biogeochemical Cycles (3)

AOSS 475: Earth-Ocean-Atmosphere Interactions (3)

AOSS 479: Atmospheric Chemistry (3)

AOSS 563: Air Pollution Dispersion Modelling (3)

AOSS 578: Air Pollution Chemistry (3)

b. Chemical Engineering

CHE 447: Waste Management in Chemical Engineering (3)

CHE 507: Mathematical Modelling in Chemical Engineering (3)

CHE 517: Biochemical Science and Technology (3)*

Cross-listed as MFG 517 (3)

CHE 548: Electrochemical Engineering (3)

c. Civil and Environmental Engineering

CEE 480: Dynamics of Environmental Systems (3)

CEE 485: Water Supply and Waste-water Engineering (3)

CEE 580: Physiochemical Processes in Environmental Engineering (3)

CEE 584: Hazardous Waste Processes (3)

CEE 585: Solid Waste Management (3)

CEE 586 /NRE 557: Industrial Ecology (4)

CEE 587/NRE 558: Water Policy (3)

CEE 589/NRE 595: Risk and Benefit Analysis in Environmental Engineering (3)

CEE 599: Hazardous Wastes: Regulation, Remediation, and Worker Protection (3)

CEE 692: Biological and Chemical Degradation of Pollutants (3)

d. Industrial and Operations Engineering

IOE 451: Engineering Economy (3)

e. Mechanical Engineering

ME 499: Energy Engineering (3)

ME 599: Management for Sustainable Manufacturing (3)

3. College of Literature, Science, and the Arts

a. Economics

ECON 471: Environmental Economics (3)

ECON 472: Intermediate Natural Resource Economics (3)

ECON 668: Advanced Natural Resource Economics (3)

b. Mathematics

MATH 462: Mathematical Models (3)

c. Physics

[See required courses in Section II.A.1.a.iii]

4. School of Public Health

a. Environmental and Industrial Health

EIH 528: Ecological Toxicology (3)

EIH 550: Industrial Hygiene (3)

EIH 551: International Environmental Management (2)

EIH 554: Risk Management in Environmental and Occupational Areas (3)

EIH 574: Environmental Chemistry (3)

EIH 576: Evaluating, Managing, and Communication Risk Assessments (3)

EIH 584: Hazardous Waste (3)

EIH 680: Environmental Management & Hazardous Waste (3)

5. College of Art and Architecture

a. Urban Planning

UP 573: Urban and Regional Theory (3)

UP 670/HMP 674/NRE 670: Transportation and Society (1)

6. Business School

a. Corporate Environmental Management Program

BUS 512/NRE 512: Ethics of Corporate Management (2)

CS 564/NRE 513: Strategies for Environmental Management (3)

BA 745/NRE 501 (Section 024): Lecture Series on Sustainable Development, Community and Business (3)

7. School of Public Policy

SPP 573: Cost-Benefit Analysis (3)

C. SAMPLE PROGRAMS WITH THREE U-M SCHOOLS/COLLEGES: BASIC REQUIREMENTS [see II.A for required PIE courses]

1. Engineering: Chemical Engineering M.S.E.: thirty (30) credit hours

All of the required courses (13 credit hours); plus CHE 517 (3 credits) and CHE 695 (6 credits; may be fulfilled by research internship project). These courses will satisfy the Chemical Engineering MSE requirements. In addition, the PIE Core Courses (16 credit hours) shown below will satisfy the cognate graduate credit requirement in Chemical Engineering, which, in this example, is 8 credit hours. The rules for double counting allows 1/6 of the 30 credit hour MSE to be double counted. This means that five (5) credit hours of the PIE Core courses can be double-counted for both the MSE and the PIE Certificate. The student takes a total of 41 credit hours to satisfy both MSE Chemical Engineering and the PIE Certificate requirements.

a. Thirteen (13) credits must be the following ChE courses:

- i. CHE 595: Research Survey (1 credit)
- ii. CHE 527: Fluid Flow (3 credits)
- iii. CHE 528: Reactor Analysis (3 credits)
- iv. CHE 526/529/541/542: Heat and Mass Transport (3 credits)
- v. CHE 507/508//509/510/607/608: Math/Modelling elective (3 credits)

- b. Nine (9) credits must be ChE courses; we suggest:**
 - i. CHE 695: Research Problems in Chemical Engineering (6 credits)
 - ii. CHE 517: Biochemical Science and Technology (3 credits)
- c. Three (3) credit hours must be chosen from the listing of relevant PIE courses [see II.A]**
- d. Five (5) credit hours from core PIE courses are counted for both the standard Chemical Engineering M.S.E. and the PIE certificate**
- e. Eleven (11) additional credit hours must be from PIE core courses [see Figure 1].**

A	B	C	D	E
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Figure 1: Credits required in each area:

- A = 13 credits of ChE core courses
- B = 9 credits (ChE 695 + ChE 517)
- C = 3 credits cognate (PIE optional courses—see section II.B)
- D = 5 credits cognate (PIE core courses—see section II.A)
- E = 11 credits PIE core courses (see section II.A)

$A + B + C + D = 30$ credits required by Chemical Engineering M.S.E.

D = five double-counted credits

$A + B + C + D + E = 41$ total credit hours

2. Natural Resources and Environment: Resource Policy and Behavior M.S.: thirty-six (36) credit hours

This sample program requires a total of forty-six (46) hours. The normal RPB program requires a minimum of thirty-six (36) hours; the PIE certificate requires sixteen (16) hours; six (6) hours are shared (double-counted) between these programs. Modifications to this sample curricula may be made based on a student's preparation and goal, subject to approval of the student's advisor and program coordinator. (Note: The sample curriculum shows only one option.)

a. SNRE requirements: six (6) credit hours

- i. NRE 570: Microeconomics With Natural Resources Application (3 credits)
- ii. NRE 562: Resource Policy and Administration (3 credits)

b. Analytics requirement: a minimum of seven (7) credit hours; we suggest:

- i. STAT 402: Statistics (4 credits)
- ii. NRE 540: Natural Resource Applications of GIS (3 credits)

c. REM requirement: a minimum of three (3) credit hours; we suggest:

- i. NRE 517/EIH 580: Biological Conservation: The Assessment Process (4)

d. Opus requirement of three to six (3–6) credit hours can be met with a master's project, practicum, thesis, or integrative seminar; our sample uses six (6) credits.

- i. NRE 700: Master's Project Planning (3 credits)
- ii. NRE 701: (varies with section) (3 credits)

e. Additional open credits fulfilled through NRE courses: seven (7) credit hours plus six (6) credit hours of core PIE courses:

- i. NRE 560: Behavior and Environment (3 credits)
- ii. NRE 670/UP 670: Transportation and Society (1 credit)
- iii. NRE 558/CEE 587: Water Resource Policy (3 credits)
- iv. NRE 574/PHY 419: Energy Demand (3 credits)
- v. NRE 475: Environmental Law (3 credits)

f. PIE program requirements: ten (10) credit hours plus the six (6) shared in Section e above:

- i. NRE 557/CEE 586: Industrial Ecology (4 credits)
- ii. SPP 573: Cost-Benefit Analysis (3 credits)
- iii. EIH 572/NRE 514: Environmental Impact Assessment (3 credits)

3. Public Health: Environmental Health Sciences M.S.: thirty-six (36) credit hours

This sample program requires a total of 46 hours. The normal EHS program requires a minimum of thirty-six (36) hours; the PIE certificate requires sixteen (16) hours; six (6) hours are shared (double-counted) between these programs. Modifications to this sample curricula may be made based on a student's preparation and goal, subject to approval of the student's advisor and program coordinator. A particular strength of the EHS program is the ability to meet specialized needs via the wide range of program electives. (Note: The sample curriculum shows only one option.)

a. SPH requirements: seven (7) credits

- i. BIOSTAT 503: Intro Biostatistics (4 credits)
- ii. EPID 503: Strategies and Use of Epidemiology (3 credits)

b. EHS program requirements: fourteen (14) credits

- i. EIH 501: Toxic Exposures in Work and Home (3 credits)
- ii. EIH 574: Environmental Chemistry (3 credits)
- iii. EIH 572/SNRE 514: Environmental Impact Assessment (3 credits)
- iv. EIH 688: Topics in Environmental Health (1 credit)
- v. EIH 698: Research (3 credits)
- vi. EIH 699: Masters Thesis (1 credit)

c. EHS program electives: fifteen (15) credits

- i. EIH 582: Principles of Community Air Pollution (3 credits)
- ii. EIH 528: Ecological Toxicology (3 credits)
- iii. EIH 554: Risk Management in Occupational & Environmental Areas (3 credits)

- iv. EIH 576: Evaluation of Risk Assessment (3 credits)
- v. EIH 680: Environmental Management in Hazardous Substances (3 credits)

d. PIE program requirements: ten (10) plus six (6) shared above:

- i. NRE 557/CEE 586: Industrial Ecology (4 credits)
- ii. EIH 572/SNRE 514: Environmental Impact Assessment (3 credits)
- iii. Physics 419: Energy Demand (3 credits)
- iv. EIH 554: Risk Management in Occupational & Environmental Areas (3 credits)
- v. CEE 589: Risk-Benefit Analysis (3 credits)

4. Ph.D.

Doctoral students enrolled at the University of Michigan would apply for admission to PIE in consultation with their primary advisors. It is envisioned that the PIE curriculum of five (5) core courses would provide a foundation for doctoral research utilizing industrial ecology tools. The sequence of the PIE courses would be dependent upon the research focus of the individual doctoral student.

D. PROVISION FOR WORK EXPERIENCE, FIELDWORK, AND INTERNSHIPS

The Program will provide each PIE student with an approved field experience during their graduate work here at Michigan. The experience of students working as paid pollution prevention interns under the auspices of the NPPC demonstrates the great value and benefit that can occur as a consequence of a well structured and well supported field/intern experience. Attached as **Appendix 4** is a listing of the Pollution Prevention Internships undertaken by both graduate and undergraduate students through the NPPC from 1992 to 1998. It is our intent to develop and extend off-campus opportunities for all students in the Program to have a field/intern experience to fulfill the academic requirements for the PIE Certificate. It is recognized that there will need to be flexibility in meeting this requirement given the potential diversity of students in the Program. It is our intent that wherever possible, the field/intern experience will take place in an appropriate external setting with a faculty advisor here at the University and a mentor on-site to enable the student to have access to both university and site-specific resources as they carryout the field/intern experience. In appropriate cases, this field/intern work would be done as part of a sponsored research effort in the general field of industrial ecology and sustainable systems.

E. PLANS FOR VISITING SCHOLARS AND SEMINARS

The Program is designed to have a very close and continuing relationship with the research initiatives are fostered through CSS. Accordingly, the Program will benefit from the presence of visiting scholars who are at U-M as a consequence of ongoing research work in sustainable systems.

Two visiting scholars have been in residence during the fall 1998 and winter 1999 terms: One is with the American Council for an Energy Efficient Economy in Washington; the other is from the Royal Institute of Technology in Sweden.

During the current academic term, students and faculty associated with CSS are participating in the Fuel Cell Seminar program, which is jointly sponsored by CSS, the Department of Physics, and the College of Engineering's Institute of Environmental Sciences Engineering and Technology (IESET).

In the Winter 1999 term, CSS faculty, students and researchers are involved with the "Sustainability Lecture Series," being organized and implemented by SNRE; this lecture series is an affiliated event of the National Town Meeting for Sustainable America to be held in Detroit, May 2-5, 1999.

In addition, NPPC/CSS is the organizer of three workshops. The first, *Sustainable Agriculture*, was held February 26-27, 1999, here at the university—leading experts in sustainable agriculture worked with us to identify "Indicators of Sustainable Agriculture" using a life-cycle framework. A second workshop,

Sustainable Architecture and Green Buildings for Universities and Commercial Institutions, is planned for fall 1999. (Both are supported with major funding from U.S. EPA Region V.) A third workshop, *International Environmental Systems Analysis*, is scheduled for fall 1999. It is supported in part by DuPont; participating universities include the Royal Institute of Technology (Sweden), the Swiss Federal Institute of Technology, the Vienna University of Technology, and University of California-Berkeley.

III. Faculty Resources

A. NUMBER AND RANK OF FULL-TIME EQUIVALENT (FTE) FACULTY COMMITTED TO THE PROGRAM, ALONG WITH THEIR RELEVANT SPECIALTIES AND RESEARCH INTERESTS (see Appendix 5 for brief vitae)

1. PIE

a. Co-Directors and Co-Chair of PIE Executive Committee

- i. Jonathan W. Bulkeley (School of Natural Resources and Environment/ Civil and Environmental Engineering/CSS/ IESET Fellow):
Multi-Objective Planning and Risk Analysis
- ii. Gregory A. Keoleian (School of Natural Resources and Environment/CSS/ IESET Associate Research Scientist):
Industrial Ecology

2. Faculty Participants and Executive Committee Members

a. College of Engineering

- i. Arvind Atreya (Mechanical Engineering/IESET Fellow):
Energy Technology
- ii. Mary Anne Carroll (Atmospheric Oceanic and Space Sciences/IESET Fellow):
Atmospheric Chemistry
- iii. Henry Wang (Chemical Engineering/IESET Fellow):
Biotechnology, Sustainable Technologies

b. School of Public Health

- i. Stuart Batterman (Environmental and Industrial Health):
Environmental Impact Assessment

c. Business School

- i. Thomas Gladwin (Corporate Environmental Management Program; Erb Institute):
Sustainable Enterprise

d. College of Literature, Science, and the Arts

- i. Marc Ross (Physics):
Automotive Emissions and Energy Efficiency

e. College of Architecture and Urban Planning

- i. Jonathan Levine (Urban Planning)
Transportation Planning

B. FACULTY'S ADMINISTRATIVE, TEACHING, SUPERVISORY, AND COUNSELLING ROLES

The Program in Industrial Ecology is an educational focus within SNRE. Its companion and closely related research activity is the Center for Sustainable Systems (CSS), also located in SNRE. Both of these activities have their roots in the National Pollution Prevention Center for Higher Education (NPPC), which has been a primarily U.S. EPA-funded Center from 1991 to 1998. As the NPPC phases down its activities, the PIE initiative and CSS become the focal activities of Professor Bulkley and Dr. Keoleian. The educational component of PIE will be the primary responsibility of Professor Bulkley; the closely related research activities and the teaching of life-cycle design, analysis, and assessment will be Dr. Keoleian's responsibility. Because PIE is a certificate program, its students will have their primary administrative homes in a School or College, with assigned faculty advisors. The Executive Committee [see Section III.A.2] will provide the educational and research direction for PIE students. This Committee will serve several major functions: it will ensure that our listing of relevant courses in the several Schools/Colleges at the university is current and correct; its faculty will help identify potential students who may be encouraged to apply for the PIE Certificate; and its faculty can help advise PIE students from their discipline areas.

C. EXTERNAL SUPPORT

The Center for Sustainable Systems has established a five-year budget for core operations including leadership and administrative support for PIE. This budget includes endowment support from the Ford Motor Company and funding from the Charles S. Mott Foundation, DaimlerChrysler, General Motors, the Wege Foundation, the Environmental Protection Agency, and 3M.

A major donor has recently committed to the establishment of a new endowed Chair in the School of Natural Resources and Environment in the field of sustainable Systems. It is anticipated that this endowed Chair will be a major catalyst for subsequent external funding. Accordingly, it is our belief that we have funds in hand to enable PIE to be initiated and implemented for a period of at least five years. It is our intent to seek additional funding from a variety of internal and external sources to enable us to ensure the long term-viability of this initiative. We believe that our record of excellent education and research over the past 11 years demonstrates the capabilities being brought to this new activity.

IV. Students and Student Funding

A. ENROLLMENT BY GENDER AND CITIZENSHIP

It is anticipated that PIE will attract both men and women from a range of graduate programs here at the University. The experience of the NPPC is that graduate students from SNRE, Engineering, Public Health, and Business have come to work with us as researchers on educational projects as well as research in life-cycle design, analysis, and assessment. It is anticipated that the PIE Certificate will only increase the number of students who wish to become involved in these activities.

B. PUBLICITY AND RECRUITING MECHANISMS

As a consequence of our research and educational work to date, undergraduate students from colleges and universities have contacted us regarding the potential to undertake graduate studies in life-cycle design, analysis, and assessment here at the University of Michigan. We shall advertise the PIE Certificate Program on our website and also prepare a brochure that can be disseminated to colleges and universities both in this country and overseas. We shall link our website with other graduate programs' websites here at the University of Michigan. In this way, potential applicants in a wide range of graduate programs will be advised that the PIE Certificate is in place and can be combined with their primary professional graduate interest. Furthermore, the faculty Executive Committee will serve as a recruitment mechanism. Finally, through previous efforts at NPPC/CSS, we have established a directory of more than 400 faculty members at colleges and universities throughout this country and abroad. We shall link with these individuals, using our existing e-mail network, to provide information on the availability of the PIE Certificate.

C. ADMISSION CRITERIA

First, each applicant for PIE needs to have been admitted to a graduate degree program here at Michigan. Second, demonstrated analytical and problem-solving skills are necessary for admission to PIE. Third, in addition to having graduate admission, applicants to PIE would submit copies of their graduate application, including letters of reference; this package would be supplemented by a brief additional statement of intent as to why the applicant wants to undertake PIE. Finally, if the applicant is from a program or department where one of the Executive Committee faculty is located, the application would need to be endorsed with an appropriate letter from this faculty member. Admission decisions will be based upon a review of all information in the student's application package.

D. APPROXIMATE NUMBER OF APPLICANTS AND ENROLLEES EXPECTED ANNUALLY

It is anticipated that PIE will begin with a modest number of applicants and enrollees. For example, it may begin with 7–10 applicants drawn from ongoing graduate students here at the University; perhaps 5–8 of these would actually enroll in the program. Over the next five years, it is estimated that we may process 20–25 applicants/year; the actual enrollment under the present structure may level off between 15 and 20 students/year. As we gain experience with the actual administration of the program and receive feedback from students and employers on coursework and field/intern experiences, we will be able to more accurately predict the growth potential of the program.

E. PROVISIONS FOR ACADEMIC ADVISING AND CAREER COUNSELLING

As a Certificate Program, PIE is seen to be an add-on to the student's primary field of study and interest. Academic advising will be handled primarily by Professor Bulkley. Career counselling again will be primarily in the individual student's home unit. When PIE students' field/intern experiences and research work leads to recruitment by the companies for whom they worked, Professor Bulkley and Dr. Keoleian will provide career counselling.

F. SNRE FUNDS, TRAINING GRANTS, FELLOWSHIPS, FACULTY GRANTS AND CONTRACTS AVAILABLE FOR GRADUATE SUPPORT

Graduate student support will be provided through a vigorous and vital research program of the Center for Sustainable Systems in combination with research support from the Executive Committee and other participating faculty. The CSS has provided financial support for six students on an annual basis through federal grants (EPA and NSF), industrial contracts, and foundation grants. PIE students will be strong candidates to work on these research projects.

V. Interdepartmental Activities

A. RESEARCH AND TEACHING AGENDA

At present, industrial ecology research and education activities are centered in SNRE and draw upon contacts and informal relations with faculty and students in SNRE and other units, including Engineering, Business, and the School of Public Health. Since 1991, the NPPC worked collaboratively with faculty and students in the Business School, the College of Engineering, and the School of Public Health to develop educational resources on the topic of pollution prevention and sustainable development. The AT&T Education Foundation Grant (1993–94) provided for the initial development of the Industrial Ecology curriculum. The second AT&T Education Foundation Grant (1994–95) supported the "Industrial Ecology of the Automobile" series: this brought faculty from cross-campus disciplines together with key representatives from the auto industry, material suppliers, regulatory agencies, and environmental non-governmental organizations (NGOs). A current research initiative through the National Science Foundation (NSF) supports CSS research with faculty in environmental economics, energy policy, and architecture.

As the PIE Certificate is established, it is anticipated that there will be additional avenues for collaborative research in a number of key areas including transportation, sustainable energy, green buildings, sustainable communities, and other critical topic areas as we move into the 21st century.

B. PROPOSED FACULTY COLLABORATIONS

1. Executive Committee

This will be an Executive Committee of key faculty drawn from programs and units with close connections to the PIE Certificate. [Members are listed in Section III.]

2. Faculty Resources

The research mission of CSS is to organize and lead interdisciplinary research focused on industrial ecology and related topics. This provides another mechanism for cross-campus faculty collaborations. Participating faculty also will serve as mentors for PIE students undertaking off-campus internships.

C. LETTERS OF SUPPORT

Initial letters of support are sought from the following Deans since it is believed that these Schools and Colleges will have graduate students most likely to want to take advantage of the PIE Certificate:

School of Natural Resources and Environment (Dan Mazmanian)

College of Engineering (Stephen Director)

School of Public Health (Noreen Clark)

Business School (Joe White)

[Existing letters of support from deans are found in **Appendix 6**.]

D. EVALUATION AND RECOGNITION OF FACULTY BY PARENT DEPARTMENTS

The teaching evaluation will be handled through the regular course evaluation processes, which are well-established at the University. Faculty who serve as members of the Executive Committee for PIE will be performing critical interdisciplinary functions, and this will be noted on their annual review reports to their own units.

E. NEED FOR ADDITIONAL SPACE, LABORATORIES, EQUIPMENT, AND/OR SUPPORTING PERSONNEL

Basic administrative support will be provided by SNRE. This includes essential recordkeeping capabilities associated with admitting students into the PIE Certificate, monitoring their progress, placing them in off-campus internships, providing administrative support to the faculty Executive Committee, and reviewing fulfillment of the Certificate Requirements.

F. DESCRIPTION OF CORE COURSES

See **Appendix 3** for syllabi.

G. ENROLLMENT AND BUSINESS PLANS

A number of activities need to be accomplished in order for this certificate program to be initiated and for it to be effective. Our immediate objective is to seek approval by the Rackham Executive Board at its April meeting. If the proposal is approved, the following activities will be carried out.

a. Publicity

Build initial website to advertise the PIE Certificate: June 1, 1999

b. Recruitment

Undertake active recruitment activities through faculty and graduate students presently working with us: June 1, 1999

c. Executive Committee

Formally establish faculty Executive Committee: July 1, 1999.

d. Selection

Review initial applications/select initial PIE Certificate students: August 31, 1999

e. Enrollment

Enroll first students in PIE Certificate Program: September 1999.
[Note that the courses are already in place; the PIE Certificate Program provides a pathway for graduate students to enhance their graduate education by gaining a Certificate in Industrial Ecology.]

f. Internal Review

Establish a periodic process to comprehensively review PIE and its curricula: June 2000.
[This will be repeated every five years.]

f. Internship

Establish PIE Internship Program: Summer 2000
[Note that this means working with off-campus locations to identify sites/funding/topics, all of which would need to be chosen by early Fall 1999.]

h. External Review

The existing CSS External Advisory Board will provide periodic external review of PIE. Board members represent industry, government, and non-governmental organizations:

3M	National Academy of Engineering
Daimler Chrysler	National Wildlife Federation
Dow Chemical Co.	Proctor and Gamble
Ford Motor Company	Steelcase
General Motors	U.S. Department of Energy
Guardian Industry	U.S. Environmental Protection Agency
Lucent Technology	Xerox
Michigan Department of Environmental Quality	

i. Core Leadership

The core leadership and day-to-day administration of PIE Certificate activity will be handled through SNRE.

Appendix 1: CSS External Advisory Board

Patty Calkins
Manager of Health & Safety
Xerox Corporation

Terry Cullum
Manager, Corporate Affairs
General Motors

Pat Hayes
Senior Environmental Engineer,
The Procter & Gamble Company

Rebecca Head, Ph.D.
Director of Environmental & Infrastructure
Services, Washtenaw County

Marcia Horan
Unit Chief, Pollution Prevention Division,
Michigan Department of Environmental
Quality

Barbara Karn, Ph.D. (invited)
National Center for Environmental Research &
Quality Assurance

Howard Klee, Ph.D.
Amoco Corporation

David Kling, Ph.D.
Director, Pollution Prevention Division,
U.S. Environmental Protection Agency

Gerald Kotas
Senior Environmental Scientist,
U.S. Department of Energy / Golden Field Office

Markus Lehni, Ph.D. (invited)
Operations Manager,
World Business Council for Sust. Development

Joseph M. Morabito, Ph.D.
Director, Environmental Health & Safety
Center, AT&T Bell Laboratories

Scott Noesen
Manager, Business Development,
The Dow Chemical Company

Doug Orf
Pollution Prevention Specialist,
DaimlerChrysler

Deanna J. Richards
Director of Technology and Environment,
National Academy of Engineering

Susan M. Rokosz
Principal Facility Control Engineer,
Ford Motor Company Environmental Quality

Dolly Tong
Environmental Scientist,
U.S. EPA Region V

Mike Turnbull
Environmental Manager,
Guardian Industries Corporation

Henry Wang, Ph.D.
Prof. of ChemE & Biomedical Engin., U-M;
American Society for Engineering Education

Peter Wege
Vice-Chairman,
Steelcase, Inc.

Guy Williams
Pollution Prevention Specialist,
National Wildlife Federation

Appendix 2: Letters of Support From Industry Members

Appendix 3: Syllabi of Core PIE Courses

Appendix 4: NPPC Internships, 1992 –1998

Intern	Project	Company	Year	Intern's Dept.	Faculty Mentor (U-M unless otherwise noted)
Leith Harmon	<i>Total Quality Management: Pollution Prevention as Continuous Improvement at Ford Motor Company</i>	Ford Motor Company	1992	IOE	S. Pollock
Adam Larky	<i>Degreaser Replacement at Ford Motor Company's Climate Control Division</i>	Ford Motor Company	1992	CEE	J. Bulkley and G. Keoleian
Lori Barnard	<i>Determining Mass Balances in Ford-Wixom's Phosphate Coating System.</i>	Ford Motor Company	1993	ChemE	S. Montgomery
James E. Hensley	<i>Waste Minimization Audit Guide</i>	Steelcase	1993	Industrial Engineering, GVSU	J. Vail, GVSU
Krista Johnsen	<i>EPA's Comprehensive Pollution Prevention Orientation Slide Show</i>	U.S. EPA	1993	SNRE	J. Bulkley and G. Keoleian
Holly Lynch	<i>EPA's Comprehensive Pollution Prevention Orientation Slide Show</i>	U.S. EPA	1993	SNRE	J. Bulkley and G. Keoleian
Robert G. Landers	<i>Achieving Environmental Excellence</i>	National Center for Manufacturing Sciences	1993	ME	J. Ettlle
Jonathan Koch	<i>Optical Imaging Systems: Pollution Prevention Opportunities in Flat-Panel Display Industry</i>	Optical Imaging Systems	1994	CEMP	J. Bulkley and G. Keoleian
Tricia Ferrell	<i>3M: Waste Minimization</i>	3M	1994	ChemE, Washington University	W. Lanen
Becky Vander Eyk	<i>Auto Body Solvent Wipe Process</i>	Chrysler Corporation	1995	ChemE	S. Montgomery
Jason Ferns	<i>Auto Body Solvent Wipe Process</i>	General Motors	1995	ChemE	S. Montgomery
Michael Valentine	<i>Auto Body Solvent Wipe Process</i>	Ford Motor Company	1995	ChemE	S. Montgomery
Carl Ferguson	<i>Guardian Industries Audit Software</i>	Guardian Industries	1994	CEMP	S. Hart
Nicole Chardoul	<i>Best Management Practices in Spray Booth Cleaning</i>	Ford Motor Company	1995	CEE	J. Birge

Intern	Project	Company	Year	Intern's Dept.	Faculty Mentor (U-M unless otherwise noted)
Chris Davis	<i>Best Management Practices in Spray Booth Cleaning</i>	Chrysler Corporation	1995	ChemE	J. Birge
Scott Grasman	<i>Analysis of Auto Project</i>	AAMA	1997	IOE	J. Birge
Colleen West	<i>Identifying the Opportunities to Reduce the Use of Great Lakes Persistent Toxic Substances at U.S. Automotive Plants</i>	General Motors Corporation	1996	SNRE	S. Montgomery & J. Birge
Laura Diepenhorst	<i>Identifying the Opportunities to Reduce the Use of Great Lakes Persistent Toxic Substances at U.S. Automotive Plants</i>	AAMA	1996	CEE	S. Montgomery
Michael Colarossi	<i>Identifying the Opportunities to Reduce the Use of Great Lakes Persistent Toxic Substances at U.S. Automotive Plants</i>	Chrysler Corporation	1996	ChemE	S. Montgomery
Kristopher Wiljanen	<i>Identifying the Opportunities to Reduce the Use of Great Lakes Persistent Toxic Substances at U.S. Automotive Plants</i>	Ford Motor Company	1996	ChemE	S. Montgomery
Thomas H. Savage	<i>Analytical Assistance & Technical Support for the Hazardous Waste & Recyclability Assessments of Xerox-Marketed Product Parts</i>	Xerox Corporation	1996	CEMP	G. Keoleian
Krista Hoversten	<i>Research Assistance and Case Study Development in Pollution Prevention in the Auto Industry</i>	AAMA	1997	Engineering, MTU	K. Paterson, MTU
Scott Ratz	<i>Research Assistance and Case Study Development in Pollution Prevention in the Auto Industry</i>	GM	1997	ChemE	P. Savage
Michael J. Colarossi	<i>Research Assistance and Case Study Development in Pollution Prevention in the Auto Industry.</i>	Chrysler Corporation	1997	ChemE	P. Savage
Ellen Schwab	<i>Research Assistance and Case Study Development in Pollution Prevention in the Auto Industry</i>	Ford Motor Company	1997	ChemE	J. Schwank

Intern	Project	Company	Year	Intern's Dept.	Faculty Mentor (U-M unless otherwise noted)
Stephanie Schultz	<i>Research Assistance in Pollution Prevention in the Paper Industry</i>	E. B. Eddy	1997	ChemE	S. Montgomery
Peter Reppe	<i>Life Cycle Analysis on Magnesium vs. Aluminum for Transmission Case Design</i>	Ford Motor Company, Facilities Engineering	1997	SNRE	G. Keoleian
Jeremy Chapman	<i>MDEQ-Recognized Environmental Management System</i>	Stone Container Corporation	1997	Chemical Engineering, MTU	J. Richardson and D. Chesney, MTU
Christopher Edlin	<i>Pollution Prevention Opportunities at a Large Pulp and Paper Mill</i>	Mead Publishing Paper Division	1997	Civil & Environmental Engineering, MTU	K. Paterson, MTU
Nicole J. Grossen	<i>Sewer Loss Monitoring and Minimization</i>	Champion International Corporation	1997	Chemical Engineering, MTU	D. Hand, MTU
SaraCox	<i>Water/Sewer System P2 at Waldorf Corporation</i>	Waldorf/Rock-Tenn	1997	Environmental Engineering, WMU	IV. Maltby, WMU.
Colleen West	<i>Best Management Practices in Spray Booth Cleaning</i>	General Motors Corporation	1995	ChemE and SNRE	S. Montgomery & J. Birge
Scott Grasman	<i>Best Management Practices in Spray Booth Cleaning</i>	AAMA	1995	IOE	J. Birge
Steven Booth	<i>Environmental Eval. of Hydraulic Fluids, Oils, & Greases Used in Manufact. & Maintenance Operations</i>	Chrysler	1998	Engineering	S. Montgomery
Bryon Lawrence	<i>Environmental Eval. of Hydraulic Fluids, Oils, & Greases Used in Manufact. & Maintenance Operations</i>	GM	1998	SNRE	Jonathan W. Bulkley
Todd Schebor	<i>Environmental Eval. of Hydraulic Fluids, Oils, & Greases Used in Manufact. & Maintenance Operations</i>	AAMA	1998	Engineering	G. Helfand
Rebecca Fitzgerald	<i>Environmental Eval. of Hydraulic Fluids, Oils, & Greases Used in Manufact. & Maintenance Operations</i>	AAMA	1998	Chemical Engineering, MTU	M. Mullins, MTU

Appendix 5: Vitae of PIE Faculty

Appendix 6: Letters of Support from U-M Deans