Integration of Industrial Ecology Concepts into Industrial Engineering Curriculum

Julie Ann Stuart

The Ohio State University

Abstract

In this paper, the author describes how industrial engineering faculty can integrate industrial ecology concepts into industrial engineering curriculum. This paper begins with the motivation for industrial ecology and its life cycle perspective. Next, the integration of industrial ecology concepts into engineering curricula is discussed. References to integration efforts for industrial ecology and industrial engineering are summarized. Two integration approaches that the author has used at her university are described: an elective course in industrial ecology for industrial engineers and integration with existing core industrial engineering courses. The core course integration example focuses on facilities planning. The description of the elective course in industrial ecology for industrial engineers includes course topics as well as an active learning module to demonstrate important course concepts.

1. Motivation for Industrial Ecology Integration with Industrial Engineering Curriculum

Industrial engineers analyze industrial metabolism, the linkages between suppliers, manufacturers, consumers, refurbishers, and recyclers. Because industrial engineers are actively involved in the design of industrial systems, their design decisions effect the environmental impacts of those systems.

Environmental impacts are resource depletion, pollutants and waste, and energy consumption [1]. Resource depletion includes materials extraction, loss of soil productivity, landfill exhaustion, and loss of species diversity. Pollutants and wastes include contamination of groundwater and air quality. Due to the increasing level of environmental impacts caused by industrial systems, environmental legislation has increased in many countries [2 3 4].

While industrial engineers focus on industrial metabolism, environmental engineers, on the other hand, study environmental metabolism which includes analysis of biota, land, freshwater, seawater, and atmosphere. Industrial ecology requires the study of the interactions between

industrial metabolism and environmental metabolism [5]. The new quarterly *Journal of Industrial Ecology* published by MIT Press contains research and applications for industrial ecology.

It is important that industrial engineers understand the life cycle impacts of their system designs. The life cycle of a product includes the materials extraction, manufacturing, assembly, distribution, use, reuse, and materials recovery stages. Traditionally, industrial engineers analyze the economic impacts of selected stages of the life cycle of a product or system. A natural extension is the multidisciplinary consideration of environmental cost impacts and ecological impacts of the total product life cycle. Because many industrial engineers have no background in ecology, their consideration of environmental impacts may be made in cooperation with environmental engineers. For example, the author was first exposed to industrial environmental concerns as an industrial engineer working on a multidisciplinary waste minimization team in industry.

To prepare industrial engineers to contribute to multidisciplinary pollution prevention solutions, this paper presents introductory material on industrial ecology that may be integrated into industrial engineering curriculum. In the next section, resources for industrial ecology and its integration into industrial engineering curriculum are summarized. In section 3, an example of an industrial ecology course with an industrial engineering perspective is presented. In section 4, an example of industrial ecology integration into a facilities planning course is given. Section 5 concludes with challenges for future industrial engineering curriculum.

2. Resources for Industrial Ecology Integration with Industrial Engineering Curriculum

In recent years, some engineering educators have begun to integrate industrial ecology into their courses. For example, several educators have proposed approaches for integrating industrial ecology and design for environment into engineering curricula [6 7 8 9 10 11]. The Society of Manufacturing Engineers Education on Target Program specifies integration of design for recycling into engineering curricula [12]. Several educators have provided documentation of inclusion of pollution prevention in engineering curricula outside a traditional environmental engineering program [13 14 15 16 17 18].

Examples of inclusion of industrial ecology in industrial engineering curriculum are summarized on the National Pollution Prevention Center (NPPC) for Higher Education Website [19]. Articles, exercises, or case studies are available from NPPC in the areas of capital budgeting, decision analysis, facilities planning, operations research, organizational design, production control, and total quality management. Case studies from Harvard Business School Publications and World Resources Institute are also available [20 21]. Several new textbooks devoted to topics related to industrial ecology have recently been published [22 23 24 5 17]. Despite these resources, most engineering programs contain little or no industrial ecology content in the undergraduate or graduate core courses, especially in the discipline of industrial engineering. In addition, most

textbooks used in industrial engineering classes contain no references to industrial ecology concepts.

Providing industrial ecology instruction for engineering students will aid future efforts in pollution prevention. The format for this instruction may take one of two forms: an industrial ecology course and integration of industrial ecology into existing core curriculum. In the next two sections, both of these two approaches are discussed.

3. An Industrial Ecology Course with an Industrial Engineering Perspective

The author developed a new engineering course in industrial ecology with an industrial engineering focus. The course introduces students to analysis of environmental metrics and labels, life cycle assessment, design for environment, material selection, production planning with environmental considerations, reverse logistics, service industry impacts, disassembly planning, recycling technologies, and environmental cost accounting. The course is designed as a sequence of modules. Each module may be integrated individually into other courses or the entire set of modules may be taught as an industrial ecology course.

Most of the modules contain active learning exercises that require students to participate in discussion and analyze environmental implications of product and/or service cases. For example, in the second module, students are given two different answering machines of different ages (eg: 1980s vintage and 1990s vintage). They are instructed to answer the following questions and fill out the worksheet shown in Table 1.

- What is the purpose of the product?
- Are there alternative means to accomplish this purpose?
- What are the environmental impacts of these alternatives?
- Compare your "guess-estimates" of the life cycle impacts of the product and its alternatives in the table below.

Table 1. Class Worksheet for Comparison of Life Cycle Environmental Impacts

	Product	Alternative 1	Alternative 2
Materials?			
Manufacturing and assembly impacts?			
Distribution? Packaging?			
Consumer use impacts?			
Repair? Refurbish? Upgrade?			
Recycle? Incinerate? Disposal?			

Often the students list voice mail, personnel, and email as alternatives. They may even propose a leased long life answering machine that may be refurbished as an alternative. The exercise encourages them to analyze the impacts of aggregate product functions (voice mail) as well as information technology (world wide web). It also facilitates their learning of life cycle impacts

and focuses their attention on issues such as energy consumption, resource depletion, functional product life, product design, materials selection, and resource recovery.

Students are also introduced to the use of operations research for environmental planning. For example, a mixed integer programming model for product selection is presented which includes considerations for energy consumption, waste emissions, and material consumption over the product life cycle [25]. In addition, students are introduced to a fast heuristic for disassembly planning [26].

In addition, to class discussion exercises, the course includes several assignments that introduce students to industrial ecology. The first assignment is for students to browse through the Environmental Guidelines Document published on the web by the Department of the Navy's Best Manufacturing Practices Program [27 28]. In this document, there are over a hundred examples of environmental problems and solutions. The students must select a problem and critique it by answering the following questions:

- What is the problem statement? (Include constraints, assumptions, and boundaries)
- What is the solution presented? Comment on this solution.
- Present and discuss an alternative solution or extension and discuss.

This assignment exposes students to a variety of problems and approaches early in the course. It introduces them to a helpful manufacturing resource that has helped many government agencies and industries. It also challenges the students to be creative and think of alternative solutions.

The second assignment that students complete is a case study analysis. Case studies from industries as diverse as pharmaceuticals and automotive provide students with further study of industrial ecology issues [20 21]. The students study engineering problems in the case studies as well as compare the total costs (including environmental impact costs) of the alternatives using the P2/Finance spreadsheet software tool [29].

The third assignment is for the students to select an industrial ecology project topic to explore an area of interest to them. Students have analyzed paint versus appliques for aircraft, powder coating versus traditional paint, plastics recycling methodologies, improved packaging for detergents and a soda machine that accepts bottle returns.

After the focused lecture discussions, industry interaction provides an opportunity for students to discuss and observe industrial ecology applications. Students have taken class tours of local Mettler-Toledo and Lucent Technologies plants and discussed industrial ecology applications with EH&S engineers and managers. Telemeetings with non-local engineers and managers at Motorola, MCC, Eastman Chemical Company, and Delco provide dialogue of industrial ecology applications. In addition, a panel of local engineers and managers from General Electric, Advantage Enterprise, Inc., and Recyclights has facilitated a discussion of the life cycle of fluorescent lamps.

4. Integration of Industrial Ecology into Core Courses such as Facilities Design

In the previous section, a course composed of modules for industrial ecology with an industrial engineering focus was summarized. Another option for using these modules is to integrate them into existing core courses in industrial and systems engineering. One industrial engineering course in which the author has integrated industrial ecology concepts is facilities design.

Facilities design requires consideration of the environmental impacts of the processes and services of a Greenfield solution, an extension to an existing facility, or remodeling of an existing facility. Several examples of facilities planning and consideration of effluents, emissions, energy conservation, and materials conservation follow. If the example is described in a facilities planning textbook, then that text reference is included.

Examples of Industrial Ecology Considerations for Facilities Planning

- When locating a facility, the facilities planner must take into account disruption to the ecology of the proposed site's surrounding environment as well as local environmental regulations[30,31].
- The facilities designer should include waste treatment equipment to meet or exceed environmental regulations and account for its space requirements[30].
- When estimating capacity, the facilities designer must consider scrap rates as well as space requirements for processes to repair, recycle or dispose of scrap.
- The facilities designer may need to consider worker exposure to harmful emissions when designing the material handling system.
- It is important for the facilities designer to be cognizant of the environmental engineers' progress in obtaining proper permitting to avoid permitting start-up delays.
- The facilities designer may partition off equipment that emits significant amounts of heat in order to conserve energy for cooling surrounding areas.
- The facilities designer may consider energy consumption when selecting insulation[32,31], HVAC equipment, lighting[31], and processing equipment.
- The facilities designer may include an area and equipment for material collection for baling for recycling rather than disposal[31].
- The facilities designer may consider reusable packaging for the material handling system design to consolidate packages to reduce handling and one-use packaging waste.

It is important to integrate the idea that facilities planners can proactively work with environmental, product, and process engineers to prevent pollution costs and impacts. In addition to lecture discussions of this concept, students should also include a section in their facilities design project reports on the environmental concerns that they have addressed. This report section challenges students to consider the environmental impacts of their facilities design.

Another approach that the author has used to integrate industrial ecology into facilities planning is to discuss the facilities planning of a product take-back center. The author shows two short videos of two different demanufacturing plants which receive discarded products for repair or materials recovery. The plant layouts, material handling systems, capital and operating costs, and automation advantages and disadvantages are contrasted for the two demanufacturing plants. This example not only challenges students to analyze facilities planning, but also to think about end-of-life stages of the product life cycle.

Thus, integration may take several forms. Facilities planning questions that involve industrial ecology issues may be incorporated into course material. Facilities planning projects should require students to analyze the environmental impacts of their proposed design. Facilities planning examples analyzed in the course may include consideration of space, material handling, cycle time impacts, and costs for reusable containers, equipment insulation, in-process recycling, or product take-back for refurbishment.

5. Conclusions

Industrial ecology integration into industrial engineering curriculum may include new engineering courses in industrial ecology. However, most important is the integration of industrial ecology into core industrial engineering classes. In addition to the facilities planning examples in Section 4, engineering educators may include industrial ecology concepts in engineering economics, operations research, manufacturing processes, and product design courses. An example of the profession of industrial engineering recognizing this need is the inclusion of a new chapter that focuses on industrial ecology and industrial engineering in the forthcoming third edition of the Handbook of Industrial Engineering [33].

In conclusion, industrial engineering curriculum needs industrial ecology integration so that industrial engineering students learn to consider the broader impacts and implications of their product, process, and system designs. Teaching industrial engineering students to consider life cycle environmental impacts will enable them to design and manage more environmentally friendly systems.

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JULIE ANN STUART

Julie Ann Stuart is an Assistant Professor of Industrial and Systems Engineering at The Ohio State University. She is a registered Professional Industrial Engineer in the state of Ohio. She has received both a CAREER grant and an Industrial Ecology grant from the National Science Foundation. She was awarded a SLOAN Foundation grant to attend the ASEE/IEEE Frontiers in Engineering Education Conference in 1997 as a New Faculty Fellow. Dr. Stuart received her B.S. in Industrial Engineering from North Carolina State University in 1992 and her Ph.D. from the Department of Industrial and Systems Engineering at the Georgia Institute of Technology in 1996.