1st Annual CDIO Conference
Queen's University
Kingston, Ontario, Canada
June 7 to 8, 2005

A Curriculum for Life Cycle Engineering Design for the Environment

J. Jeswiet[1], J. Duflou[2], W. Dewulf[2], C. Luttrop[3], M. Hauschild[4]

[1] Queen's University, Mechanical Engineering, Kingston, ON, Canada
[2] KU Leuven, Production Engineering, Leuven, Belgium
[3] KTH, Machine Design, Stockholm, Sweden
[4] Danish Technical University, Lyngby, Denmark

ABSTRACT

There is a need to create awareness, in Engineering students, of the topics covered by Life Cycle Engineering, LCE. Topics covered in an LCE course should be included as background information in any design situation. LCE is concerned with the Environment and an awareness of environmental considerations is needed in future engineers.

Deciding what to include in an Environmental Course can be difficult due to the many techniques and apparent differences of views on the subject. However, there are more similarities than differences between the different approaches to Environmental Engineering. They all have the objective to decrease the impact of a design upon the environment.

It has been observed that 70 percent of product costs are decided at the design stage. With respect to the design of products and their impact upon the environment, it can be observed that if we get the design right, at the beginning, then environmental impacts can be reduced by an estimated 70%. Therefore, an awareness of product impact upon the environment, must be created at an early stage in undergraduate education. Such a course does not need to have a high mathematical content and can give undergraduate students exposure to information which can be used, in product design courses, as they progress through university. The content of such a course is suggested in this paper.

Keywords: Life Cycle, Curriculum

1 INTRODUCTION

There is a need to arrive at a tentative agreement, internationally, on what should be included in a Life Cycle Engineering and EcoDesign curriculum. The formation of a CIRP Working Group that will work on an Environmental curriculum for Manufacturing Engineers was proposed recently at an LCE conference [1]. The idea is to negotiate, at an international level, among engineers doing work in LCE, what is necessary for educating undergraduate engineers about environmental concerns.

This need stems from an increasing awareness, by society, of the role played by Engineers in producing products, which are contributing to non-sustainability. In one recent, non-refereed, article by Rotor [2], the reader is urged to think: "Produce Differently. Consume differently. Think differently. These critical actions, required for sustainable development, demonstrate how integral engineering and technology are to the process". One major point, often omitted, is the contribution of Design to Environmental Impacts, as it is in the foregoing.

The early stages of design are important for a variety of reasons. Boothroyd et al [3] observed that 70% of product costs are decided at the design stage. With respect to the design of products and their impact upon the environment, Graedel and Allenby [4] make the observation that if we get the design right, at the beginning, then environmental impacts can be reduced by an estimated 70%. Rotor [2] observes that "as a profession, Engineers had to fight their way into international negotiations such as the Rio Earth Summit in 1992". This paper argues that the lack of cognizance by policymakers of the contribution of Product Design to environmental impacts, is a case of "déjà vu all over again". The subject of EcoDesign, and Life Cycle Engineering is simply not on the agenda of policymakers.

Engineer's design most products, therefore an awareness of product design, product impact upon the environment, and EcoDesign, must be created at an early stage in undergraduate education. Such a course can give undergraduate students exposure to information that can be used in product design courses, as they progress through university. The content of such a course is suggested in this paper.

2 LIFE CYCLE ENGINEERING

Life Cycle Engineering, LCE, is the label used to describe the areas where the environmental concerns coincide with Design Engineering and Production Engineering. The definition of LCE was first presented in 2002 [5, 6] and the content needed in LCE courses has been discussed on several previous occasions [7,8, 9]. Deciding what to include in an LCE/EcoDesign Course can be difficult due to the many techniques and apparent differences of views on the subject. However, is there such a divergence of views? Lagerstedt [10] observed that there are more similarities than differences between the different approaches to Environmental Engineering. She observed that they all have the objective to decrease the impact of a product design upon the environment, and hence have a convergent view.

The need to create awareness, in Engineers and Engineering students, of the topics covered by LCE, has been discussed in several papers [10, 11]. Part of the need to address Environmental issues is being addressed at a recently established website where CIRP members working in Life Cycle Engineering and education can discuss their views [13].

3 COURSE OBJECTIVES

A tenet of LCE, and the proposed course, is that Design and Manufacturing Engineers play a critical, central role in deciding the environmental impact of a product, hence the Environment must be a concern to the Engineer when designing a product, in addition to the many other factors that must be considered, such as costs, strength, function, etc.

Course objectives include [9]:

- to recognize the importance of the environment in social welfare.
- to appreciate the importance of the environment in human and long term economic welfare.
- to recognize the type and major stressors upon the environment.
- to learn the rudiments of environment impact assessment.
- to gain a basic understanding of environmental management systems.
- to understand how risk assessment affects management decisions and public perception.
- to learn about tools, for the EcoDesigner, which can be used in Design for the Environment.

Emphasis is placed upon the fact that the ultimate goal of a Product Life Cycle assessment is to produce a series of recommendations for a product design team, which will lead a reduction in environmental impact of the product. It is stressed that these are called DFE, Design for Environment, recommendations and that the recommendations should be designed to improve the product design and thereby to minimize the product’s environmental impact.

1 EXAMPLES OF CURRICULUM CONTENT

A good way to assess what course content should be is to look at courses being given now. The premise is these courses are attuned to what is needed.

The design of products, their manufacture and their environmental impact is addressed in several Mechanical Engineering courses. Three examples are:

1. Environmentally Conscious Design and Manufacture-ME 4171, Georgia Tech [http://www.srl.gatech.edu/ education/ME4171/index.html];
2. Life Cycle Engineering, MECH 424, Queen’s University [http://me.queensu.ca/undergraduate];
3. Environmentally Conscious Design & Manufacturing-MIME4980/5980,U. Toledo.[http://www.eng.utoledo.edu/~wolson/ecdm].

Each of these courses can be broken down into subject areas as shown in the following:

Queen’s:

- CO_2, global warming, carbon trading issues
- Toxic materials
- Chemistry and the Environment
- LCA, SLCA, LCI, Product Life Cycles
- DFX’s: DFMA, DFE, DFD, DFR, EOL
- FMEA
- Sustainable Design
- ISO 14000 Environmental Management Standards

- Energy

Georgia Tech:
- Environmental impact of engineering products and processes
- Life Cycle Design
- Pollution Prevention
- LCA, Product Life Cycles
- DFE, DFR and Demanufacture
- Service, Reuse and Remanufacturing
- Eco-Labels
- ISO 14000 Environmental Management Standards
- Sustainable Design

U Toledo:
- ECDM (Environmentally Conscious Design and Manufacturing)
- LCA, LCI, Material and Energy Balances
- Product Life Cycles (LCA)
- Material Acquisition and Refining, Materials Selection
- Manufacturing Phase and use phase
- Logistic System Design for ECDM
- DFE, DFR, Remanufacturing
- Product Features that create environmental impact
- Feature, Fastener and Material Selection for ECDM
- Environmental Law and Regulations, International Environmental Law and Regulations
- Risk assessment & management

Obvious commonalities occur as follows:
- LCA, LCI
- Product Life Cycles
- DFE, DFR
- Remanufacturing
- ISO 14000 Environmental Management standards
- Sustainable Design

These can form a basis for discussion of what should be included in a standard LCE course.

Obvious differences occur in:
- Energy
- Risk Assessment and management
- Eco-labels
- Global Warming, CO_2, Carbon Trading

These would be open to negotiation for inclusion in the recommended core curriculum. Details for including some of these have supporting data such as in the following.

4.1 Including Energy in an LCE curriculum

Why should energy sources, production and use be included in all LCE, EcoDesign courses? Because these are the major sources of GHG's. Ultimately, at the lowest level of production, even the smallest fastening device will consume energy when being made and assembled.

The demand for energy will continue to rise [18]. This will be due to increased demand: for heating and cooling; for industrial production, especially in non-OECD manufacturing spheres such as China; increased transportation activity.

To understand how we reached the present state of affairs for energy supply and consumption, it is important to understand how energy sources have changed over time, as seen in figure 1. The major user of these resources is the industrial sector. Increased use of traditional sources, in all sectors, can only increase **CO_2 production** and **Global Warming**.

Within the manufacturing sector, a subset of industries exists in which the energy required to produce a unit of economic output is three to five times greater than the average energy required for industry overall [18]. In this subset of energy-intensive industries, raw materials are transformed or converted into intermediate and finished products, accounting for 40 to 80% of manufacturing energy use depending on the country. Efficiency or technology improvements that can reduce energy demand in these key raw-materials industries will play an important role in reducing global industrial energy demand and greenhouse-gas emissions. For the foregoing reasons energy production and alternative methods of production should be looked at on in any course.

How both traditional energy sources and new sources are converted into usable energy for society become important considerations to the designer. Hence discussion is needed within the framework of an LCE course. Figure 2, gives an idea of the different methods available to generate energy.

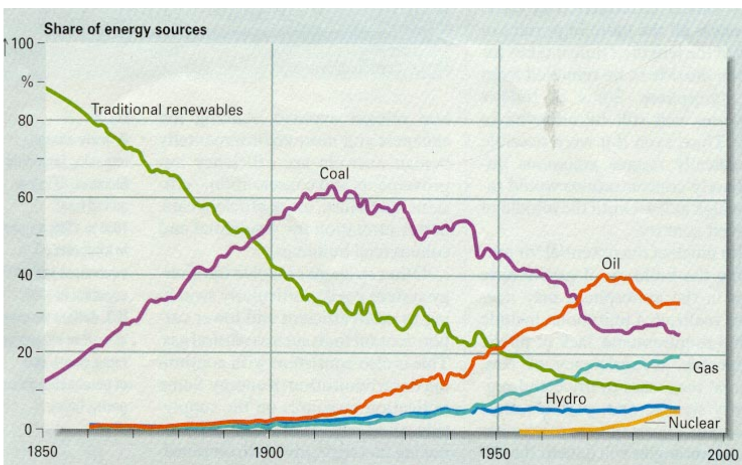

Figure 1. How use of energy sources has changed with time [Siemens Review, 1998].

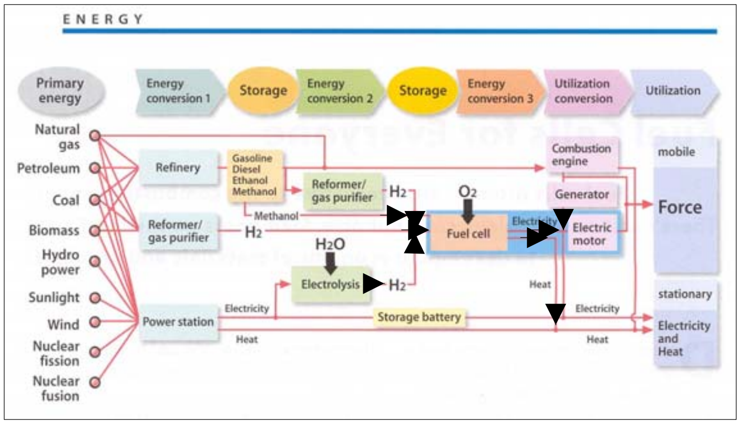

Figure 2. Methods available to generate energy [Siemens Review, 1998].

Electricity generation is expected to nearly double between 2001 and 2025 [19], from 13,290 billion kilowatthours to 23,702 billion kilowatthours. Strongest growth is projected for the countries of the developing world, where net electricity consumption is expected to rise by 3.5 percent per year, compared with a projected average increase of 2.3 percent per year worldwide. Robust economic growth in many of the developing nations is expected to boost demand for electricity to run newly purchased home appliances for air conditioning, cooking, space and water heating, and refrigeration. For the industrialized world where electricity markets are more mature, more modest annual growth rates of 1.5 and 2.0 percent, respectively, are projected.

Finally, Product Design and Production is a commercial enterprise and it is useful to see how commercial energy consumption is distributed around the world in relation to population distribution, as shown in figure 4.

4.2 Inclusion of Risk Analysis

Risk Analysis is becoming increasingly important. Financial Institutions are finding that companies which act environmentally responsibly are often better managed financially and hence have a lower financial as well as environmental risk [14]. Companies have also become concerned with their environmental image and how this will affect their brand and sales. One example is given, in an internationally read paper, where critics claim a company has played a major role in the fight against the Kyoto accord [15]. Jeswiet and Hauschild [16] state that “it can be predicted, that companies not only need to change their image in many cases, but there is a need for tools which can be used to assess both their old and new product lines, and whether a new area of endeavor can be both profitable and environmentally responsible. Part of that assessment will require an Environmental Risk Analysis, which will probably be included in the tools used by the EcoDesigner” [16, 17]. Hence there is a need to include Risk Analysis in any LCE/EcoDesign course outline.

Annual commercial energy consumption in the regions of the world				
Region	Energy consumption		Population (millions)	Annual commercial energy consumption per capita
	EJ y^{-1}	% of total		GJ pc y^{-1}
Africa	9.8	3	731	13
Asia Pacific	89	27	3300	27
Mid-East	13	4	160	81
USSR (f)	36	11	293	122
Europe	70	21	507	138
Latin America	13	4	488	27
North America	96	29	295	325
World	327	100	4500	67

1996 energy consumption data from *BP Statistical Review of World Energy*, 1997. The British Petroleum Company p.l.c.; 1997.
USSR (f) refers to the countries that made up the former Soviet Union.

Figure 4. Annual commercial energy consumption in the regions of the world [20].

4.3 EcoDesign

EcoDesign plays an important role in the product design, including use and final disposition. Whether or not it belongs under aegis of LCE [5] or it is a separate area of design is a moot point. It is important to the designer who wants to design in an environmentally friendly way, with the least amount of impact. EcoDesign includes rules such as those called the 10 Golden Rules for EcoDesigners.

The 10 Golden Rules for EcoDesigners, as defined by Luttropp [21] are:

1. Do not use toxic substances, and used closed loops when necessary to do so.
2. Minimize energy and resource consumption in production and transportation through striving for efficiency.
3. Minimize energy and resource consumption in the use phase, especially for products with their most significant environmental aspects in the use phase.
4. Promote repair and upgrading, especially for system dependent products.
5. Promote long life, especially for products with their most significant environmental aspects outside the use phase.
6. Use structural features and high quality materials, to minimize weight, however these should not interfere with necessary flexibility, impact strength or functional properties.
7. Use better materials, surface treatments or structural arrangements to protect products from dirt, corrosion and wear.
8. Arrange in advance for upgrading, repair and recycling, through good access, labeling, modules and breakpoints, and provide good manuals.
9. Promote upgrading, repair and recycling by using few, simple, recycled, not blended materials and do not use alloys.
10. Use the minimum joining elements possible using screws, adhesives, welding, snap fits, geometric locking, etc. according to Life Cycle guidelines.

4.4 Other Design Rules

There are many other design rules that can be added to the list. For instance, “The rules for EcoDesign”, set out by Luttropp, can be expanded to include additional rules such as shown in table 1 [22].

5 RECOMMENDED COURSE REQUIREMENTS

A possible set of core requirements could include the following:

- LCA, LCI
- Product Life Cycles
- DFE, DFR
- Remanufacturing
- ISO 14000 Environmental Management standards
- Sustainable Design
- Energy
- Risk Assessment and management
- Eco-labels
- Global Warming, CO_2, Carbon Trading

Details of these could be located at website such as the one provided by KU Leuven specifically for this purpose [23].

6 SUMMARY

In the future there will be a need to have a recommended set of guidelines for core content in LCE/EcoDesign courses.

The drivers for this will likely be awareness that if designs are done properly, at the beginning, then environmental impacts can be reduced by an estimated 70%. Engineers make product designs, and the best place to start educating them is at the beginning of the undergraduate level, with a course which adheres to a recommended set of guidelines.

Having to follow a set of recommended guidelines will not be legally enforceable, however, they will provide a reference for due diligence purposes when presenting a course.

7 REFERENCES

[1] Jeswiet, J. “A Curriculum for Life Cycle Engineering: leading the way”. *12th CIRP LCE Seminar* proceedings 3-5 april 2005, Grenoble. Cdrom.

[2] G. Rotor. “Agents of Global Change”. *Engineering Dimensions*, Sept/Oct 2003; p 29.

[3] G. Boothroyd, P. Dewhurst and W. Knight. Product *Design and Manufacture for Assembly*. © 1994 Marcel Dekker.

[4] Graedel, T.E., and Allenby, B.R. *Industrial Ecology*. © 1995 Prentice-Hall, New Jersey.

[5] J. Jeswiet. *Keynote Speaker*. “What is Life Cycle Engineering?” *8th International Seminar on Life Cycle Engineering*. June 18, 2001. Varna Bulgaria; pp 9 - 16.

[6] J. Jeswiet. *Plenary Speech*. “A Definition for Life Cycle Engineering”. *36th International seminar on Manufacturing Systems*. June 3, 2003. Saarbrucken Germany; pp 17 - 20.

[7] J. Jeswiet and C.A. van Luttervelt."Teaching Environmentally Conscious Design". 1998. *SME Technical Paper No. ER98-320*.

[8] J. Jeswiet."An Approach to Life Cycle Engineering Education". *8th International Conference on Manufacturing Engineering* , August 2000, Sydney, Australia; on CD-ROM.

[9] J. Jeswiet. *Keynote Speaker*. "Teaching Mechanical Engineering Courses Relating to the Environment". *Design and Manufacture for Sustainable Development.* Sept 2003, Cambridge University; pp 23-35.

[10] J. Lagerstedt, Doctoral thesis, Department of Machine Design, KTH, Stockholm, Sweden, Functional and Environmental factors in early phases of product development – Eco Functional Matrix. p 23, chapter 2, Concepts and Methods.

[11] M. Hauschild, J. Jeswiet and L. Alting. "Design for the Environment – Do we get the focus right". 2004 *Annals of CIRP* Vol. 53/1/2004; pp 1 – 4.

[12] J. Jeswiet . "An Approach to Education in Life Cycle Engineering - 2002.. *CIRP International Manufacturing Education Conference*, 2002, Enschede; pp 87 - 95.

[13] W. Dewulf, J. Jeswiet, D. Cleymans, J. R. Duflou. "The EcoDesign Cooperative: A Global Initiative to Enhance EcoDesign Education through Courseware Exchange". *Design and Manufacture for Sustainable Development*. Sept. 2004, Loughborough University. p 167 – 171.

[14] Australian Broadcasting Corporation radio interview, 0815, June 1, 2004

[15] "Exxon seeks to clean up is image as global villain". T. Macalister. *Guardian Weekly*, October 16 – 22, 2003, page 7.

[16] "EcoDesign and Future Environmental Impacts". J. Jeswiet and M. Hauschild. Journal of Machines and Design. 2005 Vol 26/7 pp 629-634.

[17] "EcoDesign and Future Environmental Impacts". J. Jeswiet and M. Hauschild. *Design and Manufacture for Sustainable Development*. Sept. 2004, Loughborough University, pp 113 – 122.

[18] EETD newsletter, 1999, [http://eetd.lbl.gov/newsletter/nl2/INEDES.html]

[19] International Energy Outlook 2004, World Energy and Economic Outlook [http://www.eia.doe.gov/]

[20] G. W. van Loon and S.J. Duffy. *Environmental Chemistry*: a global perspective © 2000 Oxford University Press.

[21] [http://www.md.kth.se/%7Econrad/EcoDesign/]

[22] [http://www.srl.gatech.edu/education/ME4171/]

[23] "The EcoDesign Cooperative: A Global Initiative to Enhance EcoDesign Education through Courseware Exchange". W. Dewulf, J. Jeswiet, D. Cleymans, J. R. Duflou. *Design and Manufacture for Sustainable Development*. Sept. 2004, pp 167 – 171.

Table 1. Guidelines for Material use, Fasteners and Product Structure [22]

A. Materials	**Reason for Guideline**
1. Minimize the number of different types of materials.	Simplify the recycling process; especially plastics
2. Make subassemblies and inseparable parts from the same or a compatible material.	Reduce the need for disassembly and sorting.
3. Mark all plastic and similar parts for ease of identification.	Many materials' value is increased by accurate identification and sorting.
4. Use materials, which can be recycled.	Minimize waste; Increase the end of life value of the product.
5. Use recycled materials.	Stimulate the market for recyclates.
6. Ensure compatibility of ink where printing is required on plastic parts.	Avoid costly label removal or sorting operations.
7. Eliminate incompatible labels on plastic parts.	Avoid costly label removal or sorting operations.
8. Hazardous parts should be clearly marked and easily removed.	Rapidly eliminate parts of negative value.
B. Fasteners	
9. Minimize the number of fasteners.	Most disassembly time is fastener removal.
10. Minimize the number of fastener removal tools needed.	Tool changing costs time.
11. Fasteners should be easy to remove.	Save time in disassembly.
12. Fastening points should be easy to access.	Awkward movements slow down manual disassembly.
13. Snap-fits should be obviously located and able to be disassembled using standard tools.	Special tools may not be identified or available.
14. Try to use fasteners of material compatible with the parts connected.	Enables disassembly operations to be avoided.
15. If two parts cannot be compatible make them easy to separate.	
16. Eliminate adhesives unless compatible with both parts joined.	Many adhesives cause contamination of materials.
17. Minimize the number and length of interconnecting wires or cables used.	Flexible elements slow to remove copper contamination steel, etc.
18. Connections can be designed to break as an alternative to removing fasteners.	Fracture is a fast disassembly operation.
C. Product Structure	
19. Minimize the number of parts.	Reduce disassembly.
20. Make designs as modular as possible with separation of functions.	Allows options of service upgrade or recycle.
21. Locate unrecyclable parts in one area, which can be quickly removed and discarded.	Speeds disassembly – see no. 8.
22. Locate parts with the highest value in easily accessible places.	Enables partial disassembly for optimum return.
23. Design parts for stability during disassembly.	Manual disassembly is faster with a firm-working base.
24. Avoid moulded-in metal inserts or reinforcements in plastic parts.	Creates the need for shredding and separation.
25. Access and break points should be made obvious.	Logical structure speeds disassembly and training.