Int. J. Engng Ed. Vol. 23, No. 6, pp. 1081–1089, 2007
Printed in Great Britain.
0949-149X/91 $3.00+0.00

Course Content for Life Cycle Engineering and EcoDesign*

J. JESWIET
Queen's University, Mechanical Engineering, Kingston, ON, Canada. E-mail: jeswiet@me.queensu.ca

J. DUFLOU AND W. DEWULF
KU Leuven, Production Engineering, Leuven, Belgium

C. LUTTROP
KTH, Machine Design, Stockholm, Sweden

M. HAUSCHILD
Danish Technical University, Lyngby, Denmark

There is a need to create an awareness of Life Cycle Engineering and EcoDesign in Engineering students. Topics covered in an LCE/EcoDesign course will create an awareness of environmental impacts, especially in other design course projects. This paper suggests that an awareness of product impact upon the environment must be created at an early stage in undergraduate education. Deciding what to include in an LCE/EcoDesign Course can be difficult because there are many different views on the subject. However, there are more similarities than differences. All LCE/EcoDesign Engineering courses have the ultimate objective of decreasing the environmental impact of a design. It has been observed that 70% of product costs are decided at the design stage. This can be extended to environmental impact, where it can be observed that, the design is correct, at the beginning, the environmental impact can be reduced by an estimated 70%. An LCE course does not need a high mathematical content and can give undergraduate students exposure to information that can be used in product design courses as they progress through university. The general content of such a course is suggested in this paper.

Keywords: life cycle; sustainable engineering; course content

INTRODUCTION

THERE IS A NEED to arrive at a tentative agreement, internationally, on what should be included in a Life Cycle Engineering/EcoDesign course. The formation of a CIRP Working Group that will work on an Environmental curriculum for Manufacturing Engineers was recently proposed at a CIRP LCE conference [1]. The idea is to negotiate, at an international level among engineers doing work in LCE, what course content is necessary when educating undergraduate engineers about environmental concerns. CIRP, the Collège International pour la Recherche en Productique, is an international organization that has about 300 members from academia and industry. They do both theoretical and practical research in Design and Manufacturing Engineering. A CIRP Life Cycle Working group was formed in 1993. In 2003 it combined with the CIRP Scientific Technical Committee (STC) on Assembly to become one STC, dealing with both environmental and assembly issues.

The need for an undergraduate LCE course stems from an increasing awareness by society of the role played by Engineers in designing and manufacturing products that are contributing to non-sustainability. This awareness started with milestones, such as the report by the Bruntland Commission [2]. It included the well-known definition for Environmental Sustainability, "Development which meets the needs of the present without compromising the ability of future generations to meet their own needs".

In one recent, non-refereed, article by Rotor [3], 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". In this paper we suggest that society must also design in a different way, with the environment being a principal factor. This recognizes the contribution of Product Design to Environmental Impacts. It includes the need for engineering students to be exposed to LCE/EcoDesign concepts at an early stage of their education.

The early stages of design are important. Boothroyd *et al.* [4] observed that 70% of product costs are decided at the design stage. However, product costs are not the only important factor. With respect to the design of products and their impact upon the environment, Graedel and Allenby [5] make the observation that if we get

* Accepted 17 December 2006.

the design right, at the beginning, then environmental impacts can be reduced by an estimated 70%.

Rotor [3] observes that “as a profession, Engineers had to fight their way into international negotiations such as the Rio Earth Summit in 1992”. In addition to this observation, 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 subjects of EcoDesign and Life Cycle Engineering are simply not on the agenda of policymakers, and they should be. The place to start is with young engineering students who are just beginning their engineering education. They will add to the chorus of Engineers telling policy makers to include LCE/EcoDesign at the early stages of design

Thrown into this mix is the fast changing nature of products. Products are becoming more complex as a result of to fast changing technologies. Micro- and nano-technology are examples. In this case, Jeswiet and Hauschild predict an increase in complexity of products with potential, concomitant environmental complications [6]; see Fig. 1.

In addition to the changing nature of products, it is recognized that companies that are managed in a more environmentally responsible way are also more likely to be financially better managed [7]. Many companies, for whom engineering students eventually will work, are concerned about their environmental image and how this will have an impact upon sales of their brand. A recent article by Macalister [8] shows that an oil company held secret meetings with environmental groups worldwide in an effort to change its hard-nosed public image. Critics claim the company has played a major role in the fight against the Kyoto treaty on climate change. According to the article, competitors who are more compliant to the Kyoto agreement have a better public relations image. For instance, another energy company, formerly a large producer of greenhouse gases, was shown to have dealt with the Kyoto accord requirements for reduction of greenhouse gases. Their balance sheets eventually showed a net gain of 650 million dollars, after greenhouse emissions had been reduced throughout the company [7].

Engineers design both products and processes.

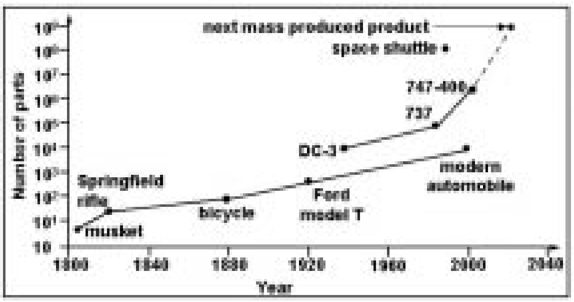

Fig 1. The increase of the number of parts used in a product as manufacturing methods have increased in sophistication [6].

Engineering students usually become fully aware of this in their Capstone Year. However, an awareness of the potential environmental impact of a product on the environment, and the need for proper Product Design and EcoDesign, must be created at an early stage in undergraduate education, well before the final year and graduation. Introducing students to an LCE/EcoDesign course in their first year will give undergraduate students exposure to information that can be used in all Product Design courses, as they progress through to their final year. The content of such a course is suggested in this paper.

LIFE CYCLE ENGINEERING

Life Cycle Engineering, LCE, is a label used to describe the areas where environmental concerns coincide with Design and Production Engineering. This can be as interpreted in different ways. A definition for LCE was first presented in 2002 [9, 10] and the content needed in LCE courses has been discussed on several previous occasions [11, 12, 13]. LCE has been described as an aegis for all issues surrounding environment-engineering concerns [10]. It is useful to show this graphically; see Fig. 2.

Because LCE is all-encompassing, deciding what to include in an LCE/EcoDesign Course can be difficult. However, is there a divergence of views with respect to the final goal? Lagerstedt [14] observed that there are more similarities than differences between the different approaches to Environmental Engineering; indeed there is a convergence of goals, with the common objective of decreasing the environmental impact of all designs.

The need to create awareness, in both Engineers and Engineering students, of the topics covered by LCE, has been discussed in several papers [15, 16]. Part of the need to address Environmental issues is being met at a recently established Website where CIRP members working in Life Cycle Engineering and education can discuss their views [17].

Fig 2. The many facets of Life Cycle Engineering [10].

COURSE OBJECTIVES

A tenet of LCE is that Design and Manufacturing Engineers play a critical, central role in deciding the environmental impact of a product and, regardless of the product, there is always an environmental impact. Hence, the Engineer, when designing a product, must consider the environment, in addition to the many other factors that are considered, such as function, strength and cost.

Since 1993, a list of course objectives has been put together at a series of CIRP Seminar,. These have been collected and published [13]. They include:

- understanding how major stressors impact the environment;
- learning the rudiments of environmental impact assessment;
- gaining a basic understanding of environmental management systems, ISO 14000 is an example;
- learning about tools that can be used in design for the environment;
- understanding how risk assessment affects management decisions and public perception;
- an appreciation of the importance of the environment in human and long-term economic welfare; and
- a recognition of the importance of the environment in social welfare.

In the foregoing, emphasis is placed upon the ultimate goal of Product Life Cycle Assessment, which is to produce a series of recommendations for a product design team, which will lead a reduction in the environmental impact of the product, at all Life Cycle stages of the product. These are called DFE, Design for Environment recommendations. They should be used to improve the design of a product, so that all environmental impacts of the product are minimized across all stages.

EXAMPLES OF CURRICULUM CONTENT

Comparison of three final year courses

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

The design of products, their manufacture and their environmental impact is addressed in several 4th, and final year Mechanical Engineering courses. Three examples are chosen because they are easily accessible on the Web, and the course instructors have discussed Life Cycle concepts among themselves at conferences over the years:

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/course];
3. Environmentally Conscious Design and 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:

- LCA, SLCA, LCI, Product Life Cycles;
- DFX's: DFMA, DFE, DFD, DFR, EOL;
- ISO 14000 Environmental Management Standards;
- Sustainable design;
- CO2, global warming, carbon trading issues;
- Toxic materials;
- Chemistry and the environment;
- FMEA;
- Energy systems and needs.

Georgia Tech:

- LCA, Product Life Cycles;
- DFE, DFR and demanufacture;
- Life Cycle Design;
- ISO 14000 Environmental Management Standards;
- Sustainable design;
- Service, reuse and remanufacturing;
- Environmental impact of engineering products and processes;
- Pollution prevention;
- Eco-labels.

U Toledo:

- LCA, LCI, Material and Energy Balances;
- Product Life Cycles (LCA);
- DFE, DFR, remanufacturing;
- ECDM (Environmentally Conscious Design and Manufacturing);
- Material acquisition and refining, materials selection;
- Manufacturing phase and use phase;
- Logistic system design for ECDM;
- Product features that create environmental impact;
- Feature, fastener and material selection for ECDM;
- Environmental Law and Regulations, national and international;
- Risk assessment and management.

Obvious commonalities occur in:

- 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 systems and needs;
- Global warming, CO2, carbon trading;
- Eco-labels;
- Risk assessment and management;
- EcoDesign.

The foregoing is open to negotiation for inclusion in the recommended core curriculum. Reasons for including them are given below.

Including energy in an LCE curriculum

Energy is at the root of many environmental problems, in both its production and use. Energy must be included in LCE/EcoDesign courses because it is the major source of greenhouse gases. Energy is a factor everywhere in the complete Life Cycle of a product, including transportation at all stages, and heating and lighting at all stages, and in product use. Product use is one of the greatest consumers of energy, hence the reason for product Eco-labels. Energy production systems, energy needs, and global warming are all tied together. Ultimately, at the lowest level of production, even the smallest fastening device requires energy in its manufacture, assembly and transportation. Energy use can often be hidden so that students, and even instructors, often are not cognizant of the need to consider it at all stages.

Energy use is not static. The demand for energy will continue to rise [17] due to increased global demand: for heating and cooling; for industrial production, especially in non-OECD manufacturing spheres such as China with its increased use of transport. One estimate claims that in the next twenty years, 20% of the increase in global energy requirements will be in China, due to the increased consumer demands.

To understand how we have reached the current state of affairs in energy production and consumption, it is important to understand how energy sources have changed over time and how sources continue to change; see Fig. 3. The major user of energy resources is the industrial sector, which is trying to meet all product Life Cycle energy demands created by increased consumer demand.

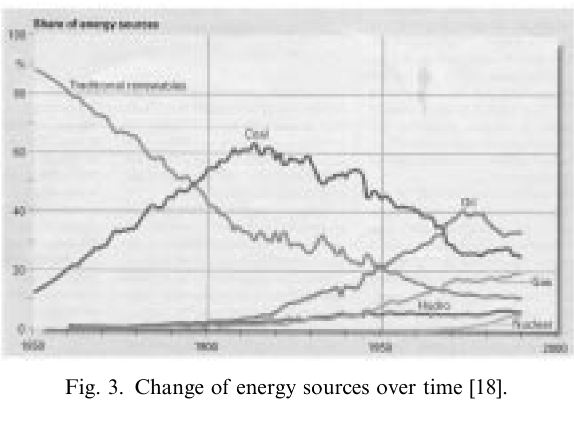

Fig. 3. Change of energy sources over time [18].

The increased use of traditional energy sources, in all sectors, can only increase CO_2 production and Global Warming.

The raw materials industry is a disproportionate user of energy. 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]. When raw materials are transformed or converted into intermediate and finished products, they account for 40 to 80% of manufacturing energy use, depending on the country concerned. Increased efficiency, due to technology improvements, can reduce energy demand in key raw material industries. This will play an important role in reducing global industrial energy demand and greenhouse-gas emissions.

The energy used during the operation of products, such as white goods, is also important. Those in marketing, selling white goods, recognize this by labeling products with the amount of energy they consume; these labels are sometimes called Eco-labels.

Ultimately, how both traditional energy sources and new energy sources are converted into usable energy, for both manufacturing use and societies use, are important considerations to the designer. Figure 4, gives an idea of the different methods available for generating energy and can provide a basis for discussion.

Electricity generation is expected to nearly double between 2001 and 2025 [19], from 13,290 billion kilowatt-hours to 23,702 billion kilowatt-hours. Strongest growth is projected for the countries of the developing world, where net electricity consumption is expected to rise by 3.5% per year, compared with a projected average increase of 2.3% per year worldwide. Robust economic growth in many developing nations, driven by increased consumer demand, is expected to boost demand for electricity to run newly purchased home appliances for air conditioning, cooking, space, water heating and refrigeration. In short, demand for products will increase the need to consider energy use at all product life stages. For the industrialized world where electricity markets are more mature, more modest annual growth rates of 1.5% and 2.0%, respectively, are projected. Finally, both Product Design and Production are commercial enterprises and it is useful to see how commercial energy consumption is distributed around the world in relation to population distribution, as shown in Fig. 5. In the final analysis, energy production and alternative methods of energy production should be looked at in any course.

A direct result of excess CO_2 production and of global warming is the concept of Carbon Trading. Although Carbon Trading is not yet an important factor, it has the potential to become one. Discussion of Carbon trading leads to an understanding of CO_2 emissions and greenhouse gas accumulation, hence the need to include discussion of these in an LCE course.

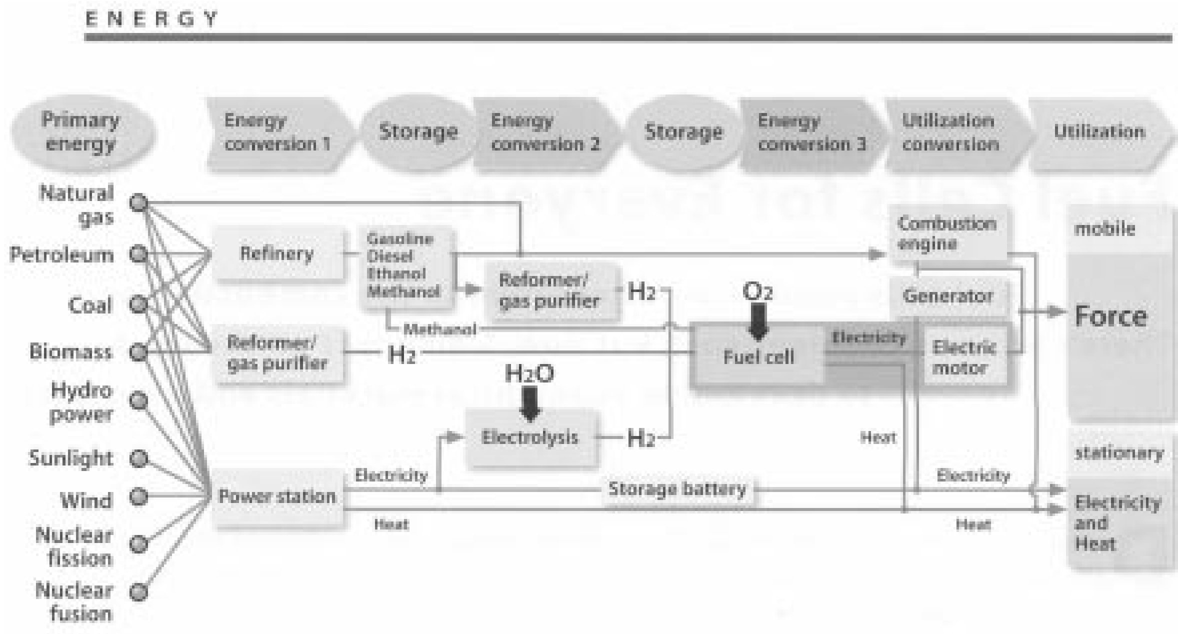

Fig. 4. Methods available for generating energy [18].

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.

Fig. 5. Annual commercial energy consumption in the regions of the world [20].

Inclusion of risk assessment

Risk assessment is becoming increasingly important, everywhere. This includes not only financial risk, but also environmental risk. ISO 14000 was originally an Environmental Management System and it ties in directly to management of a company. One of the common topics of discussion listed in the three courses in the section above, 'Comparison of three final year courses', is ISO 14000. Hence it is a logical extension to include risk assessment in course needs.

Risk assessment is well developed in both the Chemical and Materials industries. Both these industries play an important role in producing toxic elements. It is also important to industries in the Biomedical and Biomechanical fields. However, in the area of Product Development, other than in the application of materials, and medical devices, there does not appear to be much information on Risk Assessment in either Product Development or EcoDesign.

At the beginning of this paper, it was stated that financial Institutions are finding that companies that act environmentally responsibly are often better managed financially and hence have a lower financial risk as well as a lower environmental risk [6]. The coincidence of financial and environmental risks becomes obvious in a risk analysis. The influence of management systems such as ISO 14000 can be seen to play a role in this. ISO 14000 is all about due diligence with respect to environmental impact.

Companies are also concerned with their environmental image and how this will affect their brand and sales [7]. Jeswiet and Hauschild [5] predict that companies not only need to change their image in many cases, but there is a need for tools that can be used to assess both their old and new product lines, and whether a new area of endeavor could 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. Hence there is a need to include Risk Analysis in any LCE/EcoDesign course.

EcoDesign

EcoDesign plays an important role in product design, including use, which ties into energy, and final disposition or the End-of-Life of a product (EOL). It is a moot point whether or not EcoDesign belongs under the aegis of LCE [9] or if it is a separate area of design. The point is that EcoDesign is important to the designer who wants to design in an environmentally friendly way, with the least amount of impact.

Recently, lists of Design Rules for Green Engineering were published [22]. However, these are more applicable to Chemical Engineering. In the case of Product Design there are simple EcoDesign rules that can be followed. An excellent example of a set of applicable design rules, are the 10 Golden

Table 1. Guidelines for material use, fasteners and product structure, bras [24]

Guideline	Reason for Guideline
A. Materials	
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 that 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 in 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.

Rules for EcoDesigners. These can provide students with a checklist and are defined by Luttropp [23] as follows.

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

It can be seen that many of the topics listed as discussion items needed in an LCE/EcoDesign course are contained in the foregoing rules.

Obviously the foregoing list is not definitive, but it does provide the Designer with an excellent set of rules from which to start.

There are many other design rules that can be added to the list. For instance, the list can be expanded to include additional rules such as shown in Table 1 [24].

RECOMMENDED COURSE CONTENT

LCE should not only be taught in the 4th year, but it should be taught at a 1st-year level, so that students can use the concepts learned in the 1st year and apply them to designs they see in other courses, as they progress through their university education. A possible set of core content requirements for a 1st-year Engineering course in LCE should include the following:

- LCA, LCI;
- Product life cycles;
- DFE, DFR;
- Remanufacturing;
- ISO 14000 Environmental Management standards;
- Sustainable design and EcoDesign;
- Energy;
- Risk assessment and management;
- Eco-labels;
- Global Warming, CO2, carbon trading.

Details of these can be located at Websites such as the one provided by KU Leuven specifically for this purpose [17] (http://www.mech.kuleuven.be/eco/home.php).

SUMMARY

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

It has been shown that Energy, CO2 production, and greenhouse gases are related and should be included in course content. In addition energy consumption is growing and needs to be included as a topic. Also, Eco-labels will become more important in future Product Design and these need to be discussed. Included in this mix is a need to discuss ISO 14000, due diligence requirements and Risk Assessment. EcoDesign is a meld of Green Engineering and Design, hence the name EcoDesign. It is another name for a set of Product Design guidelines that should be applied when taking environmental impacts into consideration. As stated by Lagerstedt [14], in the end all the different techniques have a bottom line, to reduce the impact on the environment.

The drivers for this will likely be increased awareness that if products are designed properly, at the beginning, then the environmental impacts can be reduced by an estimated 70%.

Engineers design and make products, and the best place to start to educate them about the environmental impact of a product, at all stages, is at the beginning of their undergraduate studies with a course that adheres to a recommended set of guidelines.

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

The provision of an appropriate understanding of environmental threats and of technological opportunities, creates the essential consciousness, knowledge and skills needed to design a sustainable future. If you are thinking one year ahead, sow seeds. If you are thinking ten years ahead, plant a tree. If you are thinking a hundred years ahead, educate people.

By dedicating 2005–2014 as the Decade of Education for Sustainable Development [25], the United Nations have emphasized their sharing this vision.

REFERENCES

1. J. Jeswiet, A Curriculum for Life Cycle Engineering: leading the way, *12th CIRP LCE Seminar Proceedings*, 3–5 April 2005, Grenoble, CD-ROM.
2. The World Commission on Environment and Development, *Our Common Future*, [Brundtland Report], Oxford University Press, New York, (1987).
3. G. Rotor, Agents of global change, *Engineering Dimensions*, Sept/Oct 2003, p. 29.
4. G. Boothroyd, P. Dewhurst and W. Knight. *Product Design and Manufacture for Assembly*, Marcel Dekker, (1994).
5. T. E. Graedel and B. R. Allenby, *Industrial Ecology*, Prentice-Hall, New Jersey, (1995).
6. J. Jeswiet and M. Hauschild, EcoDesign and future environmental impacts, *J. of Materials and Design,* **26**(7), 2005, pp 629–634.
7. Australian Broadcasting Corporation radio interview, 0815, June 1, 2004.
8. T. Macalister, Exxon seeks to clean up is image as global villain, *Guardian Weekly*, October 16–22, 2003, p. 7.
9. J. Jeswiet, What is Life Cycle Engineering? *8th International Seminar on Life Cycle Engineering*, Varna, Bulgaria, 18 June 2001, pp. 9–16.
10. J. Jeswiet, A definition for Life Cycle Engineering, *36th International Seminar on Manufacturing Systems*, Saarbrucken Germany, 3 June 2003, pp. 17–20.
11. J. Jeswiet and C.A. van Luttervelt, Teaching environmentally conscious design, SME Technical Paper No. ER98-320, (1998).
12. J. Jeswiet, An approach to Life Cycle Engineering education, *8th International Conference on Manufacturing Engineering*, Sydney, Australia, August 2000, CD-ROM.
13. J. Jeswiet, Teaching mechanical engineering courses relating to the environment, *Design and Manufacture for Sustainable Development*, Cambridge University, September 2003, pp. 23–35.
14. J. Lagerstedt, Doctoral thesis, Functional and environmental factors in early phases of product development—Eco Functional Matrix, p. 23, Chapter 2, Concepts and methods, Department of Machine Design, KTH, Stockholm, Sweden.
15. M. Hauschild, J. Jeswiet and L. Alting. Design for the environment—Do we get the focus right, *2004 Annals of CIRP*, **53**(1), 2004, pp 1–4.
16. J. Jeswiet, An approach to education in Life Cycle Engineering—2002, *CIRP International Manufacturing Education Conference*, Enschede, 2002, pp. 87–95.
17. W. Dewulf, J. Jeswiet, D. Cleymans and J. R. Duflou, The EcoDesign Cooperative: A global initiative to enhance EcoDesign education through courseware exchange, *Design and Manufacture for Sustainable Development*, Loughborough University, September 2004, pp. 167–171.
18. *Siemens Review*, 1998.
19. EETD newsletter, 1999, [http://eetd.lbl.gov/newsletter/nl2/INEDES.html]
20. International Energy Outlook 2004, World Energy and Economic Outlook, [http://www.eia.doe.gov]
21. G. W. van Loon and S. J. Duffy, *Environmental Chemistry: A Global Perspective*, Oxford University Press, (2000).
22. P. T. Anastas, J. B. Zimmerman. Design through the twelve principles of green engineering, *Environ. Sci. Technol*, 2003.
23. http://www.md.kth.se/%7Econrad/EcoDesign
24. http://www.srl.gatech.edu/education/ME4171
25. *UN Resolution 57/254*, (2002), on the United Nations Decade of Education for Sustainable Development (2005–2014).

Dr. Jack Jeswiet is Professor of Mechanical Engineering at Queen's University, Kingston, Ontario, Canada. He is the Chair of Undergraduate Studies at Queen's. Jeswiet is a Professional Engineer in the Province of Ontario. He is a Fellow of: The Canadian Society of Mechanical Engineers, The Engineering Institute of Canada, The International Academy for Production Engineering. He is also the Chief Warden of Camp 3 of the Obligation of the Engineer, commonly known as the Iron Ring in Canada. His Research interests include: LCE (Life Cycle Engineering) and EcoDesign. Sheet metal Forming; Incremental Sheet Forming; Micro-Plastic Metal Forming. Measurement of Friction and Temperature in Metal Forming. Powder Metallurgy. Dr. Jeswiet is involved in many societies, including: Board of Directors of CSME, Manufacturing and Robotics Chair. Director, NAMRI Board of Directors. Vice-chair CIRP Scientific Committee on Life Cycle/Assembly. Chair CIRP Scientific Committee on Forming. NSERC Discovery Grant Committee.

Joost R. Duflou holds master degrees in Architectural Engineering and in Electromechanical Engineering. He obtained a PhD in Engineering from the Production Engineering, Machine Design and Automation Programme and from the Centre for Industrial Management (K.U.Leuven, Belgium). He accumulated a number of years of industrial experience as Systems Engineer and Project Leader in R&D departments of international companies. From 1991 till 1997 he worked at the Asian Institute of Technology (postgraduate programme in Industrial Systems Engineering), where he was appointed CIM Laboratories Manager and Assistant Professor. Since 1997 he has again been affiliated with the Department of Mechanical Engineering of the K.U.Leuven where he has been a tenure Professor since 2006. His principal research activities are in the field of design support methods (such as DFX, LCE, KM) and managerial aspects of product development processes. As chairholder of the LVD Chair on Sheet Metal Processing he also leads a research group focusing on sheet metal oriented CNC driven manufacturing processes as well as intelligent design and process planning systems for sheet metal working. He is a corresponding member of CIRP.

Dr. Wim Dewulf is Assistant Professor at Group T Leuven Engineering School, Belgium, and Senior Researcher at the Katholieke Universiteit Leuven, Belgium, where he coordinates research activities on EcoDesign and life cycle engineering. He is also coordinator of the Leuven Research Network on Sustainable Development LONDO. His research interests are in EcoDesign, product-oriented environmental management systems, and life cycle costing.

Dr. Luttrop is an Associate Professor in EcoDesign at The Royal Institute of Technology (KTH), Stockholm, Sweden. He is a graduate in Naval Architecture from KTH and has a PhD in Machine Design with focus on EcoDesign. For ten years he has been the research leader of an EcoDesign group at KTH. He is a member of the editorial board of *The International Journal of Cleaner Production* as well as the scientific committee of several conference series in the field of EcoDesign. He has been Program Director and Lecturer at KTH, with responsibility for establishing a new Machines Department in Järfälla at the College of Engineering, KTH. This includes developing a totally new educational program for a Bachelors' Degree.

Michael Hauschild Ph.D, M.Sc.(chem.Eng.) is associate professor in environmental assessment of products and systems at the Technical University of Denmark, in the Innovation and sustainability group of the Department of Manufacturing Engineering and Management. He has been overall responsible for the department's Life Cycle Engineering research activities, teaching and professional training for more than a decade. He was a co-receiver of the Great Environmental Prize of the Nordic Council of Ministers 1997 for his work with development and documentation of the Life Cycle Impact Assessment (LCIA) of the Danish Environmental Design of Industrial Products (EDIP) programme. He held the chair of the SETAC-Europe task force on ecotoxicity assessment in LCIA 1998–2002 and currently holds the chair of the UNEP/SETAC Life Cycle Initiative task force on Assessment of Toxic Impacts in LCIA. In the CIRP, he leads the Life Cycle Engineering group and acts as secretary of the Scientific Technical Committee on Life Cycle Engineering and Assembly. He is a member of the Management of the Danish LCA Center and has been a member of the Editorial Board of The International Journal of Life Cycle Assessment since 1998. He was elected member of the SETAC-Europe LCA Steering Committee in 2006 and appointed to the LCIA Method Developers Advisory Group to the European LCA Platform project of the EU Commission same year. Furthermore, he is founding Chair of the Nordic Life Cycle Association, NorLCA aimed at dissemination of life cycle thinking in the Nordic countries.