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Teaching Environmentally Benign Manufacturing

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1. Introduction

Teaching Environmentally Benign Manufacturing (EBM) presents the general challenges of teaching an application rather than a discipline. This is not too different from the challenges of teaching manufacturing about ten years ago. In that case we could rely heavily on successful practice and then develop principles to explain those successes. The principal success at that time was the Toyota Production System. Even today people continue to observe and write about why it works and its limitations [1, 2, 3].

In the case of EBM, other than the real successes of many end of pipe solutions, many of the current ideas (LCA, DFE, Eco-efficiency, eco-industrial parks etc.) have yet to offer convincing proof that they actually work[1]. Hence, without too much exaggeration, there is neither theory nor much reliable practice to teach. (This point of view is discussed in more detail in the last section of this paper.) There is however, a real and very important problem that we face as a society. This suggests that what we really have is a research problem, and that teaching should follow a research model. This should include open discussion, critical review of ideas and the generation and testing of hypotheses. Hence the teaching of EBM is an excellent opportunity to teach about research and critical thinking in a systems setting.

2. Teaching EBM at MIT

The EBM subject at MIT (2.83 in Mechanical Engineering) is a first level graduate subject with a few advanced undergraduates. On the order of half of the graduate students are from the "Leaders for Manufacturing" (LFM) Program that offers both an MBA and a Masters in Engineering. These students are usually older with 3 to 5 years of industrial experience.

The course is centered around an individual term long mini-research project. These projects can be on almost any topic concerning manufacturing and the environment, but the student must generate and attempt to test a hypothesis. This is a challenging task that requires considerable background investigation, as well as data collection and varying amounts of supervision. Some of the

[1] That is, that they will actually improve the environment in an economically viable way.

fundamental lessons students learn during this exercise are:

1) A hypothesis requires a theory, and a theory requires considerable background work.

2) The testing of an hypothesis requires an experimental plan and data. Data gathering in this area is often a very difficult part of the problem.

3) The issues in EBM are often so complex that one needs to use the work of others. This brings up the basic issues of trust, integrity, and communication.

4) Concerning trust; what information sources can we trust, and what bias and omissions should we look for?

5) Concerning communication; given how complex these issues are, how can we expect the average citizen to understand the consequences of their actions? What can engineers do about this?

In the end the student may only reach the point of hypothesis generation. This is perfectly acceptable provided the key lessons mentioned above are learned along the way.

The student projects for the last three years are listed below. It has been only in the last year that hypothesis generation has been a project requirement.

2001 Student Projects
Understanding Carbon Dioxide
A Practical Model for Sustainable Manufacturing: Making Life Cycle Analysis (LCA) Work
Engine Technologies for the 21st Century
Re-manufacturing and Recycling of Automotive Tires
Environmentally Benign Transportation
Environmental Regulations and How They Relate to Manufacturing Plant Location within the U.S.
Worldwide Water Crisis: Is Desalination a Viable Solution?
Cathode Ray Tube Recycling

2002 Student Projects
Predicting Material Recycling Rates for a Heterogeneous Waste Stream
Flame Retardants in Electronics: Are Halogen-Free Alternatives the Future?”
Carbon Sequestration and Bio-Fuel Production from Power Plant Exhausts: A Critical Review
The Environmental Impact of Online Buying
Hoy No Circula (No-Driving Day)
PCB Contamination and the Disposal of Fluorescent Light Ballasts
Durable Container Greening Strategy
Hybrid Electric Vehicles in 2002: Products & Technology
Environmentally Benign Manufacturing Report: Recycled Plastic Lumber
Assessing the Sustainability of Hydropower
The Dynamics of Fuel Cell-Powered Vehicles in the Automotive Industry
Does Moore’s Law Govern Waste Water?

2003 Student Projects
Car Sharing as a Product Service in the US: Analysis of Potential Economic and Environmental Impacts

Improving Recycling in Massachusetts: Strategies for Reducing Landfill Waste and Increasing Diversion Rates
U.S. Cap and Trade Programs
The U.S. Housing Industry: Advances in Energy Efficiency and Trends in Overall Energy Consumption
ISO 14001: Improved Environmental Performance?
The External Costs of Gasoline for Cars and Light Trucks in the United States
Ending the NEV Debate: From Corn Kernel to Cellulose Ethanol
Is Ecological Footprint a Good Indicator for Consumption Patterns?
Economics of small-scale electrolytic hydrogen production
Accelerating Fuel Cell Vehicle Adoption-Role of Government
A Critique of Progressive Indicators in the Global Arena

Class time in 2.83 is spent motivating the project, and in providing the background materials for conducting the research projects. This is usually done through discussions on various readings and the presentations of invited guests. The more experienced students help enormously with these discussions. Many of them have already had relevant industrial experience including working at Ballard, the Rocky Mountain Institute, and Russian oil fields. The challenge is to help the less experienced students to participate.

The readings are chosen to cover basic material, provide alternative points of view, to provide tools, and to stimulate. Unfortunately there is no textbook on EBM, but there are several basic references, which are listed in the readings below. We also include classics, such as “The Tragedy of the Commons” by Gareth Hardin, and foils such a “The Skeptical Environmentalist” by Bjorn Lomborg. Because this area is changing, the reading list changes too. The topics covered are:

1) **The human impact on the environment,** with an emphasis on sources and sinks and natural and anthropogenic cycles [4, 5, 6, 7].

2) **The connection between these impacts and manufacturing,** narrows our focus primarily to material flow related impacts [8, 9, 10, 11].

3) **How to measure progress,** raises many issues including alternatives to GDP, the difference between progress at a company and progress at the environment, the need to convey complex information to the public etc. [12, 13, 14, 15].

4) **Materials flows and life cycles,** gets into the details of the life cycle of materials and products [8, 9, 16, 17].

5) **Life cycle analysis of products and processes**, presents LCA. [18, 19, 20, 21, 22, 23].

6) **New industrial paradigms**, compares visions, business practices, and environment results [24, 25, 26, 27, 28].

7) **Consumption,** looks at our material life styles, our needs and motivations to consume, and the material intensity of various economic sectors [29, 30, 31, 31].

8) **Recycling, remanufacturing and reuse,** looks at various sustainable paradigms, the incentives and barriers, recycling technologies, and tools to make products more sustainable [33, 34, 35, 36].

9) **Energy**, looks at our current sources and the alternatives and outlines what is needed [7, 37, 38, 44, 45].

3. EBM as a Research Topic

The view presented in this class is that EBM is a discipline in the making. The idea that previously developed tools such as DFA, DFM, Lean Manufacturing, supply chain management, inventory control, quality control, and cost analysis, etc could be modified and applied to Green Manufacturing is explored, and the appropriate counterparts are presented. However, the essential differences between EBM and current manufacturing are also highlighted. The most important difference is that the system boundaries are not the same. EBM seeks to address a much wider range of stakeholders whose interests are not only economic. These differences alone bring up a host of issues which challenge our conventional decision making scheme. At the heart of the matter is the absence of the "invisible hand". The "invisible hand" as proclaimed by Adam Smith, ensures that an individual acting in her own self interest, will contribute to a system that improves everyone's well-being [43]. Unfortunately, this dynamic may now be replaced with the "tragedy of the commons" dynamic that places personal interests and commons interests in opposition [10]. This situation can be changed by policy, economic incentives and other means, but it raises the specter of a conflict that was not perceived in the conventional manufacturing system, and for which our engineers are poorly trained. Hence, there is a social responsibility aspect to the problem.

Secondly, the larger system boundaries make the connection between engineering actions and systems response less obvious. In fact, many of the engineering actions which are encouraged by well meaning "green principles" can result in at best no improvement and worse, unintended environmental degradation. Specifically, eco-efficiency may in fact drive more consumption[2], recycling targets can produce system chaos[3], and lead bans in electronic solders could actually result in unearthing more lead, not less[4]. These examples of unexpected consequences are all system effects that challenge conventional engineering thinking. This means that well intended actions at the enterprise level may not produce the expected results. This problem is particularly true in the area of sustainability. Until we develop better insight into these issues, with attendant concepts, principles and tools, EBM should be treated as an application rather than a discipline.

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[2] That efficiency can lead to higher demand is known as the "rebound" effect in economics, see [31, 39, 40]

[3] European paper recycling goals, mandated by well intended regulations, have caused chaotic system behavior, see [31, 41]

[4] European bans on lead (Pb) solders have lead to the development of new alloys, which use metals mined with Pb. This could lead to the exposure of humans to more Pb and the undermining of a relatively closed recycling system, see [8, 42]

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