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Journal of Cleaner Production 13 (2005) 1–17
Journal of Cleaner Production
www.elsevier.com/locate/jclepro

Environmentally benign manufacturing: Observations from Japan, Europe and the United States

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Received 14 August 2002; accepted 12 October 2003

Abstract

A recent international panel study (Gutowski T, Murphy C, Allen D, Bauer D, Bras B, Piwonka T, Sheng P, Sutherland J, Thurston D, Wolff E. WTEC Panel Report on: Environmentally Benign Manufacturing (EBM), 2000 on the web at; http://itri.loyola.edu/ebm/ and http://www.wtec.org/ebm/) finds Environmentally Benign Manufacturing (EBM) emerging as a significant competitive dimension between companies. With differing views on future developments, companies, especially large international companies, are positioning themselves to take advantage of emerging environmental trends. Among Japanese companies visited, the panel observed an acute interest in using the environmental advantages of their products and processes to enhance their competitive position in the market. In the northern European countries visited, the panel saw what could be interpreted as primarily a protectionist posture; that is, the development of practices and policies to enhance the well-being of EU countries, that could act as barriers to outsiders. In the U.S., the panel found a high degree of environmental awareness among the large international companies, most recently in response to offshore initiatives, mixed with skepticism. In this article, we survey EBM practices at leading firms, rate the competitiveness of the three regions visited, and close with observations of change since the study. Based upon these results, major research questions are then posed. In sum, the study found evidence that U.S. firms may be at a disadvantage due in part to a lack of coherent national goals in such areas as waste management, global warming, energy efficiency and product take back.

1. Introduction

In this paper, the findings of a recent report [1] based on a global benchmarking study of Environmentally Benign Manufacturing are summarized. This panel study was funded by the U.S. National Science Foundation and the U.S. Department of Energy, and in part, was motivated by the desire to understand the competitiveness of the U.S. with respect to environmental issues. While the environment is not often associated with market competitiveness, in fact, as globalization increases, it is emerging as a significant factor. Other goals for the study were; 1) to advance the understanding of environmentally benign manufacturing, 2) to establish a baseline and to document best practices in environmentally benign manufacturing, 3)

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doi:10.1016/j.jclepro.2003.10.004

to promote international cooperation, and 4) to identify research opportunities.

The focus products and technologies for this study were in the automotive and electronics sectors with an emphasis on metal and polymer processing. Over 50 sites were selected for visits in Japan, (northern) Europe and the United States which are listed below in Table 1(A)–(C). The methodology, site selection and reporting procedures are given in Section 2 of this paper. The study took place from July 1999 to April 2001. The results presented here are given in three subsections: Motivation, Regional differences, and Systems level problem solving. This last section is subdivided into 4 sub-subsections entitled: Cooperation and the Dutch model, Take-back systems, Strategic planning, and Analytic tools. Specific technology examples are embedded in each of these sections as appropriate. In section 4 Epilogue and Research Questions, changes since the study are noted and unanswered research questions are posed.

Table 1
Sites visited

(A) Japan	
Fuji Xerox	NIRE
Hitachi PERL	New Earth Conference & Exhibition
HORIBA LTD.	NRIM
Kubota	PVC Industrial Association
MITI/Mechanical Engineering Lab.	Sony Corporation
MITI/AIST/NOMC	Toyo Seikan Kaisha
Nagoya University	Toyota Motor Corporation
NEC Corporation	University of Tokyo
Nippon Steel Corporation	Institute for Industrial Science
(B) Europe (Belgium, Denmark, Netherlands, Germany, Sweden, and Switzerland)	
Corus Holland	ICAST
DaimlerChrysler	IVF
Denmark Tech. U.	MIREC
EC Environmental Directorate	Siemens
EC Research & Technical Development	TU Aachen
Excello	TU Berlin
Fraunhofer, Aachen	TU Delft (Ministry of Environment, Lucent Tech., Phillips)
Fraunhofer, Berlin	University of Stuttgart
Fraunhofer, Stuttgart	Volvo
(C) US	
Applied Materials	GM
Caterpillar	IBM
CERP	Interface
Chaparral Steel/Cement	Johnson Controls
DaimlerChrysler	MBA Polymers
Corus, Tuscaloosa	Metrics Workshop
DuPont	Micro Metallics
Federal Mogul	NCMS
Ford	

2. Research questions and methodology

The first question this study sought to answer was; "Why are firms engaging in pro-active environmental behavior?" The conflicts and dilemmas that green actions and fiscal responsibility pose [2,3,4] make this perhaps the central issue. The second question was; "If pro-active, in what kinds of green behaviors are the companies engaged?" To study these questions, the panel was assisted in this investigation by the World Technology (WTEC) Division[1] of the International Technology Research Institute [5]. WTEC has administered numerous studies of this type, listed on their website, and has developed a systematic approach to the evaluation of new technologies. The WTEC methodology can be found in detail in references [6,7].

The process starts (after the study area and funding are identified) with panel selection and briefings, followed by site selection and travel logistics. For this study, ten panelists were selected from Massachusetts Institute of Technology, University of Texas at Austin, University of California-Berkeley, Georgia Institute of Technology, University of Alabama, Michigan Technological University, University of Illinois, and Caterpillar.[2] The study started with briefings on the technology roadmaps for the aluminum, steel, polymers, composites, castings, electronics and automotive industries. Inputs were also received from the U.S. NSF, U.S. DOE and U.S. EPA [8].

One of the goals was to benchmark best available technologies and practices; therefore, site selection for overseas visits was based upon identifying leading organizations that espouse significant environmental initiatives. Since the bulk of these appeared to be located in Japan and northern Europe and since there was a logistical need to limit the geographical areas covered, the study was restricted to these regions. Visits were spread between; 1) government labs and agencies, 2) companies and 3) universities. In the United States visits focused on companies as the panel had access to government agencies through their sponsors, and universities were broadly represented by the panel members. These sites were further distributed over the technology focus areas including; 1) polymer processing, 2) metals processing, and 3) the automotive and electronics sectors. In many cases, examples of 1 & 2 were found at the automotive and electronics firms. Not all organizations invited to participate accepted the invitation,[3] and not all organi-

[1] Formerly at Loyola College in Baltimore and now as a private institute; World Technology Evaluation Center, Inc. 2809 Boston St., Suite 441, Baltimore, MD 21224, phone; 410.276.7797, web; http://www.wtec.org/.

[2] Egon Wolff, currently with Bradley University, was with Caterpillar at the time of this study.

[3] These were few, and generally due to scheduling difficulties.

zations willing to host the panel could be seen due to logistical difficulties. Generally four sites were visited a day by splitting the panel into two groups. Using this approach, more than 50 site visits took place between July 1999 and July 2000. Table 1 lists the sites that were visited in Japan, Europe, and the U.S.

In terms of the company sites that were visited, the panel met with anywhere from 3–20 or more representatives who generally represented the environmental effort, product engineering, manufacturing operations, research and development, and in some cases, public relations. The panel was well aware that every organization desired to show its best side. A few companies were almost stunned by the panel's interest in the environment because within their organization it was not recognized as a significant issue. At the other end of the spectrum, several companies were almost evangelical in their approach (justifying, for example, certain "green" capital expenditures with a 65-year payback). The overwhelming majority of the companies (> 90%), however, were in the middle, struggling to balance business goals and environmental goals and were very eager to discuss these issues with us. The meetings usually included presentations on both sides followed by discussion and in some cases tours. Every visit was documented in a site visit report, which was reviewed by the host for factual content. The interviews were structured to cover certain basic themes; motivations, metrics, tools, technology, integration and systems, but the specifics varied depending upon the expertise of both the organization and the representatives. Additional organizational data were obtained from brochures, websites, and the panelists' personal experience and contacts. These were used to verify and expand on our impressions from these visits. The detailed site reports can be found in the appendices of the final report [1]. Following the completion of the site visits, a public workshop was held in Washington, DC on July 13, 2000, to present the findings and to receive comments and criticisms. The workshop was attended by a mix of individuals from U.S. and international government agencies, companies, and universities. These comments were then used to modify the final report released in April 2001 [1].

3. Study findings

3.1. Motivation

Assigning a motivation for an action can be a complicated process. At the individual level, subconscious factors can make the interpretation a research project in itself. At the organizational level however, since goals must be conveyed to the workers, motivating factors should be more accessible. The report [1] describes the motivating factors recounted by the organizations, so long as they are consistent with other indicators. Of course, the motivating factors could be more complex than reported or change with time. The factors may also depend upon which part of the organization was interviewed, or be influenced by "gaming". Regardless of whether the reported motivating factors are real or not, naming the reasons for adopting "green behavior" can be constructive and act as a means of diffusing the factors throughout the organization.

Perhaps the key finding of the panel was the clear trend towards the internalization of environmental concerns by manufacturing companies, particularly large international companies. For a variety of reasons large companies like Sony, Toyota, Hitachi, Volvo, Daimler-Chrysler (Europe), IBM, Motorola, Ford, DuPont, and others professed to behave in environmentally responsible ways and provided reports and data from self audits to demonstrate this commitment. The motivations for this behavior are many, but at the core, the panel was convinced that many companies really do understand the problem; any long-term sustainable business plan must address its relationship to the environment.

The motivating factors expressed by the companies varied, ranging from compliance with regulations, to the advantages of voluntary proactive behavior. Table 2 lists the motivating factors and actions most cited by companies when explaining their behavior. Several examples indicated that as voluntary proactive behaviors became common practices, the pressure on non-

Table 2
Motivating factors and actions for EBM

Regulatory Mandates
Emissions standards (air, water, solid waste)
Worker exposure standards
Product take-back requirements (EU, Japan)
Banned materials and reporting requirements e.g. EPA Toxic Release Inventory (TRI)
Competitive Economic Advantage
Reduced waste treatment and disposal costs ($170 billion/year in US)
Conservation of energy, water, materials
Reduced liability
Reduced compliance costs
First to achieve cost-effective product take-back system
First to achieve product compliance
Supply chain requirements
Proactive Green Behavior
Corporate image (including avoiding embarrassment by NGO's and others)
Regulatory flexibility
Employee satisfaction
ISO 14001 Certification
Market value of company
Dow Jones Sustainability Group Index
Investor Responsibility Research Center
Green purchasing, Eco-labeling

participants mounted. For example, while ISO 14001 certification is voluntary, once it is adopted by an OEM (original equipment manufacturer), suppliers often must adopt it. Secondly, as EBM behaviors and strategies become clearer and to some extent, standardized, they become easier to adopt. The panelists observed that the leading companies saw clear business advantages in environmentally benign behaviors and worked to integrate these behaviors into a well thought out business plan. In general, these companies evolved from reactionary "end-of-the-pipe" treatment approaches to far more inclusive/proactive approaches. (e.g. pollution prevention, design for the environment, and sustainable development). Table 2 gives specific examples of motivations and actions for the companies that were visited.

These observations compare favorably with the arguments and data presented in the environmental and business literature. For example, Florida [9] has pointed out that both the opportunities and skill sets of large international firms favor them as early adopters of EBM practices. Furthermore, the results of his survey of "key factors in corporate environmental strategy" correspond closely with the "motivating factors and actions for EBM" in Table 2. Florida's eight factors taken from an industry survey of 256 firms are (from most important to least); 1) regulations, 2) corporate citizenship, 3) improving technologies, 4) serving key customers, 5) improving productivity, 6) competition, 7) market for green products, and 8) pressure from environmental organizations. And in a more recent publication Hall [10] also sheds light on this issue by listing primary non-regulatory pressure exerted upon firms such as; consumer pressure, customer pressure, share holders, pension/mutual fund investors, credit rating agencies, environmental advocacy pressure, accountability/disclosure requirements, employee/unions, green voters, corporate citizenship and improving technologies.

In all cases, proactive EBM behaviors are essentially a bet on the future. For example, Reinhardt [11] finds justification in "beyond compliance" behaviors based upon: 1) increasing expected value, and/or 2) appropriately managing business risks. The "optimists" the panel interviewed saw clear competitive advantages, while the few "pessimists" visited saw mostly disadvantages and added costs.[4]

Of all the motivating factors and actions for pursuing environmentally benign manufacturing, conservation was the factor that led the list in terms of providing financially calculable gains. Reductions in waste, materials used, toxins, and energy consumed all can translate directly to savings at the bottom line. The panel heard of many successful conservation practices. For example, when visiting Toyota, the panel saw the same dedication and attention to detail that has become famous in their "lean" manufacturing system, [12,13] but now applied to "green". In one factory, the energy consumption of the production equipment was measured at different rates of production and then the equipment was redesigned to reduce energy, particularly when there was no production. One example of the energy measurements for machining operations at Toyota is shown in Fig. 1. Notice that most of the energy is consumed even while the machine is "idling". Much of this energy is related to the pumping of coolants, lubricants, and hydraulic fluids that are later treated as wastes. A minimization of coolants could then save twice. Similar data are also available for injection molding. New electric injection molding machines developed in Japan, and now available elsewhere, can reduce the energy requirement by one-half to one-third.

Toyota also focuses significant attention on the reduction of wasted materials during the assembly process. At its Tsutsumi assembly site even the floor sweepings are sorted for recycling. The plant reportedly now produces only 18 kg of landfill waste per vehicle. This improvement was driven by the philosophy; "when combined it is waste, but when sorted it is a resource". This philosophy was also used to focus the

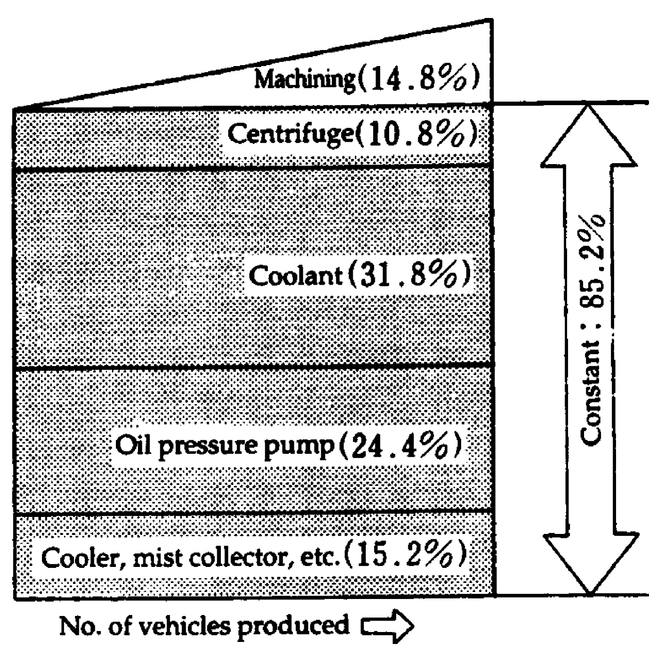

Fig. 1. Energy use breakdown for machining. [Courtesy Toyota Motor Corporation].

[4] In retrospect, it is now clear that the period for this study (July 1999–April 2001) was a relatively optimistic time. For example the Dow Jones Industrial Average stood near 11,000 for this entire period compared to its recent position, hovering around, or below 9000 over the last 9 months. This perspective will be further addressed in the Epilogue and Research Questions at the end of this paper.

redesign of various components for ease of separation. For example, rubber insert molded vacuum cups used in materials handling were redesigned to facilitate separation of the rubber from the metal for recycling. Note that Mercedes Benz claims to recycle 97% (material plus thermal) of their production waste resulting in only 21 kg of landfill waste per vehicle.

One of the most successful applications of conservation was seen at the Toyo Seikan Saitama plant where steel beverage cans are produced. The heart of the innovation at Toyo Seikan was a new stretch drawing—ironing process for forming the cans (called the TULC process for "Toyo Ultimate Lightweight Can"). The process, which uses tin-free steel laminated on both sides with a 20 micron polyester film has several advantages; it reduces the tin in the steel waste stream, it eliminates the need for lubricants and coolants, and it eliminates the need for organic coatings and drying with attendant volatile organic compound emissions (VOCs). These improvements not only reduced the energy, waste, wastewater, VOCs, and CO_2 from the plant, but also reduced the size of the factory by 50% and the operating costs by 42%.

In many cases, corporate actions came from longer-term thinking. As the number and complexity of environmental regulations mount, the shortcomings both in terms of cost and effectiveness also become increasingly apparent, leading both corporations and regulators to seek new formats for interaction. These new models generally seek agreement on larger overarching goals, while leaving the details of implementation to the companies. Perhaps one of the best examples of this kind of cooperative behavior between industry and regulatory agencies comes from the Netherlands, where a very successful model (described later) has led to a significant decoupling between economic growth and environmental impacts. The usual underlying premise for these approaches is that the judicious application of free market tools can lead to more efficient environmental protection. Such behavior has not been absent in the United States either. For example, Presidents Reagan and Clinton issued executive orders requiring cost benefit analysis in all major rule making and Congress codified these orders in the Unfunded Mandates Reform Act of 1995 [14]. Specific free market examples applied in the U.S. to the environment include the SO_2 (sulfur dioxide) cap and trade provision of the 1990 Clean Air Act Amendment (CAAA), and similar provisions for SO_2, NO_x (oxides of nitrogen), and Hg (mercury) emissions in the Clear Skies Initiative of President Bush.

Nevertheless, the almost exponential rise in environmental regulations in the U.S. as well as other factors, has prompted many companies and industries to consider pro-active environmental behavior. For example, almost all major international manufacturing companies now publish an annual environmental performance report. Usually available on the Internet these documents report on goals, values and performance, often in the form of resources used or pollutants emitted per unit of goods and services produced. Several prominent examples of pro-active behavior exist in the electronics industry,[5] the chemical industry,[6] and the automotive industry.[7]

Addressing Customer's Concerns

Motorola's Goals:	Consumer	Government Regulation	Industry to Industry
Improve Recyclability		●	●
Increase Recycled Contents	●		●
Minimize Packaging		●	●
Label Plastics/Metals		•	●
Reduce Hazardous Materials	◒ →	◓	●
Reduce Energy	●	•	●

R.C.Pfahl

Fig. 2. Environmental concerns versus drivers [courtesy, Motorola, ref [48]].

Much of the motivation for "green" behavior can also come through the supply chain and from other companies [1,10,15,16]. A particularly clear example of this comes from Motorola. In Fig. 2, a matrix is displayed that illustrates the customers that benefit from specific company environmental goals. The important point here is that "industry-to-industry" customers are driving many of Motorola's goals. Business-to-business pressure is likely to grow, particularly for those who do business overseas. Increasingly, countries in the EU and Japan are putting in place "take-back" laws that require that the manufacturer take-back the used product at its "end-of-life". Currently most attention is focused on computers, electronics, automobiles, and white goods. Similar legislation is also being considered at the State level in the United States particularly in California and Massachusetts [50].

It is likely that much of the supply chain pressure a company will feel will come in the form of business practices. Some companies are trying to implement uniform practices throughout their various geographical

[5] For example Intel's 1996 Project XL [17], and HP's and IBM's recycling efforts [1].

[6] For example, Dow's WRAP program, and 3M's 3P program [18], and DuPont's methanolysis pilot plant at Cape Fear [1].

[7] For example Ford's ill fated announcement that they would voluntarily improve the fuel economy of their sport utility vehicle (SUV) fleet 25% by 2005 was a demonstration of pro-active behavior [19,20].

regions. These practices can range from lists of banned materials to uniform design for recycle methodologies, all the way up to detailed Environmental Management Systems (EMS). One form of this is in terms of ISO 14000 certification. This family of voluntary regulations (with some similarities to ISO 9000 quality standards) outlines the steps to put into place an EMS. Large international companies are taking this very seriously and in many cases are requiring that their suppliers do so also. The panel observed that all of the automakers and suppliers that were visited and most electronics firms are pursuing ISO 14000 or are developing their own environmental management system to be compatible with ISO 14000. For example all Chrysler group facilities were slated to be certified according to their EEMS (Enhanced Environmental Management System), which is more stringent than ISO 14001, by 2002. Similar goals were stated by Johnson Controls. Federal Mogul's EHS (environmental, health, and safety) policy mandated that all plants should be ISO 14000 certified no later than 2002. All Ford manufacturing sites were certified by 1998. Siemen's goal is to structure their environmental management system to be compatible with ISO 14001, and while they did not yet have a company wide policy on ISO 14000 certification at the time of the interview (April 7, 2000) that has since changed. Now Siemens reports that thirty of their manufacturing locations in Europe have been validated in accordance with the EU's Eco-Management and Audit Scheme (EMAS), and that all of their production sites worldwide are audited by internal regulations which are "more stringent than the requirements laid out in the ISO 14001 standard" [21].

The panel did see regional differences in attitudes towards ISO 14000 certification. While the European-based organizations appear to view this pursuit as consonant with their overall environmental strategies, attitudes in Japan and the U.S. seem to be more focused on certification as a hurdle to achieve market entry. The expectation is that this ISO certification requirement will be passed through the supply chain. In the case of GM, a list of restricted materials has been distributed to all suppliers and the tier-one suppliers were notified that they needed to be ISO 14001 certified by the end of 2002. Ford made a similar announcement and has been helpful with ISO training seminars for suppliers. Toyota has developed environmental purchasing guidelines for 450 suppliers and is encouraging suppliers to meet ISO 14001 by 2003.

Notable for its absence from the discussions was direct mention of the effects of Non-Governmental Organizations (NGOs) on the motivation of firms. However, NGOs were indirectly acknowledged several times when companies, wishing to emphasize their change in attitude, would point out that they were now "in the same organization as GreenPeace", or "working with the Sierra Club", etc. or that they were no longer a member of certain industry groups, such as the Global Climate Coalition, which contrary to its name has greatly resisted efforts to reduce global carbon emissions [22,23].

3.2. *Regional differences*

The panel observed different environmental concerns and responses in the three regions visited. Although many of these themes run throughout the report and this paper, here in summary form are the chief differences that were observed.

3.2.1. *Europe*

In Europe there is a very high level of public awareness of environmental issues that has propagated up into the government often through elected "Green Party" officials. Current environmental concerns are focused primarily on product end-of-life (EOL) and the elimination of materials of concern such as lead in printed wiring boards and brominated flame-retardants in plastics. Related to these, considerable concern for infrastructure development was expressed, including both supply chain and reverse logistics, and systems level modeling. These concerns are driven and supported, in large part, by the insular nature of the EU, with the majority of imports and exports being between Member States. Furthermore, the high level of attention to systems level issues is related to the recent development of the EU itself. For example, the EC Directorate funds Virtual Research Institutes and other industry/academia networks that suggest strategic directions and provide technical insights for research [24]. Approximately 100 of these networks exist.

Take-back infrastructure is especially well developed in the Netherlands, and other countries are expected to develop similar programs in the near future. These efforts are being driven in large part by the WEEE (Waste Electrical and Electronic Equipment) Directive and by the ELV (End-of-Life Vehicle) Directive.

The EU is also a world leader in the area of life cycle assessment (LCA), and the integration of LCA into business practices. Arguably, design for environment (DFE) and LCA software tools were first introduced in the United Kingdom and France [25,26]. (A good reference to LCA can be found at the European Environment Agency (EEA) web site: http://org.eea.eu.int.).

In general, the panel saw evidence of more collaborative relationships between government, industry, and universities in the EU countries visited, than in either Japan or the United States. For example, new environmental directives were not met with the same level of skepticism that one would see in the U.S., and major regional projects exhibited the equal participation of all three groups: government, industry and academia. In both Japan and the U.S. cooperation between these three groups seemed less. In general, the panel felt they saw more attempts at using "carrots" rather than "sticks" in the EU. In addition, while some of the policies are met with skepticism, and sometimes even downright refusal to cooperate, the governments appear to offer more room for post-policy negotiation than in the U.S.

One interesting trend is the introduction of environmental taxes by Member States on environmentally harmful products and activities [27]. While the shifts have been small and the bulk of the revenue is from energy taxes, there are clear indications that this is an increasing trend. The tax base is also being broadened from "polluter pays" to the more comprehensive "user pays". For example, there are taxes on groundwater extraction in France, Germany, and the Netherlands. In contrast, North America tends to view ground water as a resource that can be owned and managed through free-market enterprise (price dictated by supply and demand). While price structures in the U.S. are most commonly managed through State and local governments, in some instances this control may fall to the private sector. This is particularly notable in the case of Texas groundwater extraction where based upon one's "mineral rights" it can be pumped and sold as a free enterprise activity [28].

3.2.2. Japan

As a country that relies heavily on marketing high value-added consumer products to countries all over the world, Japanese industry must be highly responsive to global policies. The most striking example of this is the strong emphasis on ISO 14000, which was observed advertised in public areas, including mass transit systems. Japanese electronics companies were the first to develop lead-free solders and offer bromine-free printed wiring boards in response to the EU's WEEE Directive (now broken out as ROHS[8]). There is also evidence of early adoption of emerging (including non-Japanese) technologies in new products; Honda, and Toyota were the first to introduce hybrid cars and Sony and Hitachi manufacture a significant volume of printed wiring boards that use micro-via interconnect and bromine-free flame retardants. Japan's limited amount of natural resources and limited landfill space evoke a strong awareness of the relationship between conservation and economics. Of the three regions studied, Japan appears to have the greatest concern with CO_2 emissions and global warming. Since CO_2 emissions are directly related to fossil fuel energy consumption, and since Japan has extremely high-energy costs, there is a clear economic incentive as well as environmental incentive to be concerned with this issue. However, given that most of Japan's population lives at or near sea level, there may be concern over rising sea levels as well.

Japan demonstrates a strong alignment of internal resources not seen in the other two regions. This manifests itself as a unified response to EBM and is evident in the areas of public education, environmental leadership, and consensus building. In fact, since our report, and in spite of a prolonged economic down turn, Japan has recently enacted extensive "Green Purchasing" guidelines for all government agencies [29]. There is also a commitment to public development of data and software tools such as their national LCA (life cycle assessment) project. In this effort, the Japanese government is working to develop a large LCA database that is specific to Japan and which is viewed as a national project.

Although very concerned about waste reduction, the emphasis on recycling in Japan at the time of our visit appeared to be between that of the U.S. and the EU. Yet the panel saw strong indications of the government's investment in the development of the recycling infrastructure, particularly for recycling of polyvinyl chloride plastic (PVC). In addition, industry is beginning to establish standards for recycled materials, such as PVC for non-pressurized waste water pipes. Since our visit Japan has enacted a number of pieces of legislation aimed at collection and recycling of post-consumer products. This has resulted in increased interest, in particular, in technologies for sortation and reclamation of engineering thermoplastics used for appliance housings.

3.2.3. United States

Most of the EBM focus in the U.S. is on materials and processes within the traditional manufacturing environment. This may be viewed as a logical response to media-based regulations and policy, since these areas and activities most directly affect air, water, and solid waste. The automotive industry has concentrated on the materials and processes used in structural metals and for paint application; the electronics industry has concerns over a number of materials and processes. However, where there are market drivers that encourage consideration of products and end-of-life solutions, there are activities in U.S. industries within these areas as well. For example, large international firms such as Ford and IBM are responding aggressively to EU directives (specifically the Waste Electrical and Electronic Equipment (WEEE) and End-of-Life Vehicle (ELV) Directive). Ford has designed a car expressly for European take-back. IBM and Hewlett-Packard (HP) have strong electronics products recycling histories and IBM has produced a computer with a 100% recycled plastic housing.

[8] ROHS stands for "Restriction Of the use of certain Hazardous Substances".

Metrics and supply chain management are of concern in the U.S. but not nearly to the degree that was observed in Europe. In addition, the motivation appears to be different. Often it can be linked to concern over potential future liability (especially with large chemical and electronics companies) or in response to a customer (such as Johnson Controls responding to the automakers). However, there are some exceptions. Within large companies, e.g., DuPont, Ford, IBM, AT&T, General Motors, and HP, there are typically small groups that are very focused on systems level environmental issues. In addition, some smaller companies have adopted a systems level approach to managing environmental issues as a key strategy, e.g., Interface.

As a country though, the U.S.'s response to environmental issues is often fragmented and contentious, which creates an uncertain environment for business development. For example, the almost exclusive U.S. reliance on free market drivers can put the recycling system at risk compared to the other regions visited [30]. The panel felt that there is a strong need for environmental leadership in the United States that can shape unifying themes and provide constancy of mission.

To summarize the collective findings of the panel, a "competitiveness" rating of the three regions visited was determined. In this context, competitiveness is primarily a rating of the intensity and the leadership shown by the region for the particular issue noted. Table 3 lists the panel ratings for a wide range of environment-related activities; (more competitive = more stars).

The ratings provided in Table 3 represent the collective, subjective judgments of the panel based upon the information gathered during this study as well as other professional experiences. The column labeled "Europe" refers to the countries visited. The observed trends indicate that the northern EU countries are ahead in governmental and educational activities, while Japan[9] appears to be focused on industrial activities. In the area of general research and development both Japan, which had a strong showing in applied research, and Europe, which was particularly strong in the areas of automotive and systems development, demonstrated roughly equal amounts of activity that exceeded that observed in the U.S. However, the United States remains strong in polymer and long-term electronics research and is particularly adept at risk mitigation to avoid financial and legal liability. U.S. protection of media, particularly air and water, appears to be equal to or better than Japan and Europe. In general, however, it was the consensus of the panel that the U.S. lags in all four categories covered in the tables.

It is useful to compare the ratings in Table 3(A) and (B) with environmental statistics collected for Japan, Germany, and the U.S. (Table 4). In a general sense, there is agreement in such areas as "landfill bans" and "recycling infrastructure" (Table 3(A) and (B)), with "glass and paper recycling" and "% land filled" (Table 4). One can also see agreement between "energy conservation" (Table 3(B)), and "energy usage per capita (Table 4). In one area however, there appears to be a marked disagreement between "water conservation" (Table 3(B)), and "industrial water usage" (Table 4). One explanation of this difference is that in the former cases (agreement between panel rating and statistics) the results of established behavior and programs may be evident, while in the latter case (disagreement between panel rating and statistics with regard to industrial water usage) relatively recent attention to the problem may be reflected. In fact, Table 4 may be indicating precisely why the panel saw significant new attention to the water usage issue in the United States.

3.3. Systems level problem solving

There are few systems as complex as the environment. Because of the intricate interplay between regulatory, technical, economic, societal, biological, and other factors, environmentally benign manufacturing requires a systems level approach. This was expressed on numerous occasions by the site hosts, who through experience have found that technological competence and good intentions alone do not assure success. A systems level approach starts with a strategic plan, which identifies goals, sets targets, and monitors progress. The use of strategic planning for EBM is in itself a statement that the process has moved from regulatory compliance to a management system. Many aspects of this process can be aided by analytical tools that use quantifiable metrics. This helps set objective goals to which all parties can agree. Finding shared values and goals among the many parties involved is generally the most difficult part of EBM. In the area of systems level problem solving, the panelists saw striking differences between the regions visited. Summarized below are the findings of the panel in four areas: 1) cooperation and the Dutch model, 2) take-back systems, 3) strategic planning, and 4) analytic tools.

3.3.1. Cooperation and the Dutch model

The most striking and distinguishing feature of the European approach is the way in which environmental

[9] It should be noted that Japan has moved quickly since this report to enact takeback regulations for household appliances and computers [62,63], and has instituted "green purchasing" requirements for over 100 items [64]. In addition the state of California has also enacted takeback legislation for computers[65] and legislation is pending in 22 other states in the U.S. [66].

Table 3
Relative competitiveness

Activity	Japan	US	Europe
(A) Government activities			
Take-back legislation	**	—	****
Landfill bans	**	*	***
Material bans	*	*	**
LCA tool and database development	***	**	****
Recycling infrastructure	**	*	***
Economic incentives	**	*	***
Regulate by medium	*	**	*
Cooperative/joint efforts with industry	**	*	****
Financial and legal liability	*	****	*
(B) Industrial activities			
ISO 14000 Certification	****	*	***
Water conservation	**	***	*
Energy conservation/CO_2 emissions	****	**	**
Decreased releases to air and water	*	***	**
Decreased solid waste/post-industrial recycling	****	**	***
Post-consumer recycling	***	*	****
Material and energy inventories	***	*	**
Alternative material development	**	*	***
Supply chain involvement	**	*	**
EBM as a business strategy	****	**	***
Life-cycle activities	**	**	**
(C) Research and development activities			
Relevant Basic Research (>5 years out)			
Polymers	**	***	**
Electronics	**	***	*
Metals	***	*	**
Automotive/Transportation	**	*	***
Systems	**	*	***
Applied R&D (≤5 years out)			
Polymers	*	***	**
Electronics	***	**	**
Metals	***	*	**
Automotive/transportation	***	*	***
Systems	**	*	***
(D) Educational activities			
Courses	**	**	***
Programs	*	*	**
Focused degree program	—	—	*
Industry sponsorship	*	**	***
Government sponsorship	*	*	**

protection legislation is formulated. In Japan and the European countries that were visited, it appeared that regulators, citizens, academia, industry, and consultants interact in a more cooperative, less adversarial manner than in the United States. In general, the panel experienced a greater sense of shared values concerning the environment in both Japan and Europe compared to the United States.

The Dutch are often cited as having the best cooperation, and cooperative policies between industry and government, followed by the Scandinavians. Credited with this shift in environmental policy is the 1989 decision by the Dutch Ministry of Housing and Spatial Planning (the equivalent of the U.S. Environmental Protection Agency) to switch from the classical media (air, water, land) based approach to an industry sector based approach. This change was embodied in a series of National Environmental Policy Plans (NEPP 1, 2, and 3). Under these plans, the Ministry of Economic Affairs began to cooperate directly with the Ministry of Housing and Spatial Planning. The NEPP policies that guided this transition embody the very essence of good strategic planning. The policies helped in establishing themes and goals, identifying and soliciting the cooperation of target groups, developing a range of policy instruments from incentives to taxes, forming voluntary agreements termed "covenants", providing for continuous monitoring and critique, supporting public education, allowing for flexibility in response, and planning for the life cycle of the policies them-

Table 4
Environmental statistics for Japan, Germany, and the US

	Japan	US	Germany	Units	Reference
Commercial Energy; use per capita (1997)	4084	8076	4231	Kg oil equivalent per capita	World Bank, 2000 [31]
GDP/energy (1997)	6.0	3.6	5.2	$US per Kg oil equivalent	World Bank, 2000 [31]
Mfg. Energy Usage per capita (1990)	–	53	37	GJ per capita	NAE, 1997a [32]
CO_2 per capita (1996)	9.3	20.0	10.5	metric tons per capita	World Bank 2000 [31]
Industrial water usage per capita (1998)	578	5959	1865	M^3 per capita	World Bank, 2000 [31]
Organic water pollutants (1997)	0.14	0.15	0.12	Kg per worker per day	World Bank, 2000 [31]
Total domestic output[a]/GDP (1996)	0.49	3.15	1.43	metric tons per $K	World Resource Institute, 2000 [33]
Domestic processed output[b]/GDP (1996)	0.26	0.92	0.44	metric tons per $K	World Resource Institute, 2000 [33]
Glass recycling 1992–1995	56%	22%	75%	Percentage of total consumption	AAAS, 2000 [34]
Paper recycling (1997)	53%	46%	72%	Percentage of total consumption	World Watch Institute, 2000 [35]
Municipal waste per capita	400	720	400	Kg. Per capita	AAAS, 2000 [34]
% Recycled, municipal waste treatment (mid 1990's)	4	27	29	Percent of total	AAAS, 2000 [34]
% Incinerated, municipal waste treatment (mid 1990's)	69	16	17	Percent of total	AAAS, 2000 [34]
% Land filled, municipal waste treatment (mid 1990's)	27	57	51	Percent of total	AAAS, 2000 [34]

[a] Total domestic output (TDO) is the aggregate measure of domestic processed output (material outflows from the economy) plus domestic hidden flows (which do not enter the economy). It represents the total quantity of material outputs and material displacement within national borders and is the best proxy indicator of overall potential output-related environmental impacts in each country.

[b] Domestic Processed Output (DPO); the total weight of materials, extracted from the domestic environment and imported from other countries, which have been used in the domestic economy, then flow to the domestic environment. These flows occur at the processing, manufacturing, use, and final disposal stages of the economic production-consumption chain. Exported materials are excluded because their wastes occur in other countries. Included in DPO are emissions to air from commercial energy combustion (including bunker fuels) and other industrial processes, industrial and household wastes deposited in landfills, material loads in wastewater, materials dispersed into the environment as a result of product use, and emissions from incineration plants. Recycled material flows in the economy (e.g. metals, paper, and glass) are subtracted from DPO.

selves. Through this process, the Dutch have set challenging goals and timetables, and have achieved simultaneous improvements in economic growth and environmental protection [36,37].

The Dutch success stands as a role model and it has been widely studied and adopted both by individual European countries and by the EU. While there is interest in the Dutch model in the United States, there are at least two serious limitations to employing this approach in the U.S.; one is the traditionally adversarial relationship between U.S. government regulators and industry, and the other is the litigious nature of the U.S. society. It should also be noted that achieving cooperative interaction in a small country with a rather homogeneous population is much easier than doing so in a country as large and diverse as the United States.

3.3.2. *Take-back systems*

One example of the Dutch "systems approach" is their initiative to require product take-back and recycling in order to reduce landfill. The Netherlands is the first country in Europe that has adopted and fully implemented take-back legislation. Their efforts focus on two categories of products; 1) "information and communication technology products" including CPU's, monitors, telephones and printers, and 2) "metal and electro-producers products" including TVs, toys, tools, and refrigerators. The Dutch take-back system has a scheme for assigning costs, relies on a national system of collection points, and employs for-profit organizations such as MIREC (which was visited as part of the study [1]) to disassemble and reprocess end-of-life products. These efforts serve as examples to study and use. The European Commission legislation on electronics take-back will most likely follow the Dutch model and include medical equipment. With the success of the Dutch and other efforts in Belgium and Germany, and new EU directives for product take-back, it was observed that European manufacturers no longer question the issue of product take-back, but rather are focusing their energies on how to achieve the best results. Japanese manufacturers are similarly focused on cost-effective compliance with European, as well as Japanese, take-back legislation.

In some cases, recycling infrastructures are set up to capture particular target materials because they are either valuable or troublesome. For example, among thermoplastics, PVC (polyvinyl chloride) usually requires special handling because it can produce toxins during incineration, and it is a contaminant for most other plastics during recycling. During the visit to Japan, the panel learned of a sophisticated infrastructure to collect and recycle PVC back into pipe and window frames. The significant features of the Japanese infrastructure are:

1. Careful collection and sortation of construction waste by a licensed technician on site (this is paid for by the site owner),
2. Reprocessing of the PVC to established industrial standards,
3. Financial support in terms of a subsidy provided by the government to allow the recycled material to compete with the virgin material, and
4. Technical development of an application for the recycled material. In the case of the PVC window frame mentioned earlier, processing involves the use of a 3 material co-extrusion process originally developed in Germany and then modified to produce a frame cross-section with a PMMA (polymethyl methacrylate or acrylic) exterior, virgin PVC interior, and recycled PVC core.

Applications are also developed with potential markets in mind. Vinyl window frames, with their superior thermal insulation properties, are in great demand in northern Japan where the current frames are predominately aluminum. Thoughtful and effective infrastructure developments can payoff by cleaning up feed streams for other plastics and by preventing pollution from improper disposal of PVC. Furthermore, as volumes and efficiencies increase, these kinds of "model" efforts have the potential to become stable and sustainable. Similar recycling schemes, in which 3-layer PVC pipe is manufactured, have been supported in the EU. An equivalent PVC pipe enterprise in the U.S. does not exist, in part, due to shortcomings in the infrastructure [38].

Properly designed recycling systems should also create strong incentives for manufacturers to redesign their products. One scheme implemented by the Dutch, charges manufacturers for recycling based upon the weight and a percentage share of the recycling cost attributed to the company's products. Hence lighter-weight, longer-lasting, and easier-to-disassemble products should all result in lower fees for the manufacturer.

In spite of these successes, there are many challenges to achieving successful product recycling. At present, many methods of product disassembly are quite labor intensive, and while this may be seen as an opportunity to create new jobs in some countries, it represents a major cost barrier for others, particularly in the U.S. Key areas for further development are reverse logistics, reprocessing technology, materials selection, and new product design.

3.3.3. *Strategic planning*

In order to identify critical research needs in environmentally benign manufacturing at the corporate level, it is first necessary to define the objectives of EBM and to identify the forces driving its implementation. If this strategic framing of goals is not done, then EBM becomes just a collection of loosely connected technologies. The panel observed, worldwide, that many companies are struggling with the challenges of defining and implementing key facets of EBM. Several hosts shared examples of implementation failures due to incomplete planning. Yet, common issues and approaches emerged. The panel found five common environmental themes:

1. reducing energy and material consumption,
2. waste reduction and reduced use of materials of concern,
3. reducing the magnitude and impacts of product packaging,
4. managing products that are returned to manufacturers at the end of their designed use, and
5. customer demands for documented Environmental Management Systems (EMS).

The emphasis and the importance of these five themes varied in different parts of the world and from company to company. For example, Fig. 2 showed how Motorola's themes are customer driven. This first step of identifying themes and drivers is critically important for developing the strategic plan of a company. In the case of Motorola, "industry-to-industry" connections were an important driver. All tier-one suppliers that were visited mentioned this same theme. Even still, companies varied greatly in their corporate strategies. Siemens, offers two lines for many of their products: the "green" version (often more expensive) and the conventional version (typically at lower cost). Others strongly believed that "green" and "low cost" were synonymous for their products (e.g., Interface and low-mass floor coverings, DuPont and "rent a chemical").

Further development of the strategic plan requires stakeholder involvement, cooperation, and technology awareness. Technology awareness can be gained from benchmarking and "industry roadmaps", which are prepared by trade groups and governmental organizations. The U.S. Department of Energy's Office of Industrial Technologies has been developing a variety of research roadmaps (including steel, aluminum, and metals casting) through the Vision 2020 program [39]. Also, USCAR has many excellent references available for automotive technologies on their web site [40]. Many other examples are given in the panel's report [1].

In order to translate a strategic plan into a program of action it is necessary to develop the means by which targets can be set and progress monitored. Using quantitative metrics stakeholders can agree upon objective goals and monitor their progress in achieving them. For example, at a workshop hosted by MCC, "Making Design-For-Environment and Life-Cycle Assessment Work" [41], a list of 29 metrics was agreed upon by a large group of electronics OEMs and suppliers.

However, in many cases it is best to begin with just a few metrics that can be tracked and understood throughout the organization. An excellent illustration of this was seen at Interface Americas, where a very simple set of metrics were used; 1) mass, 2) energy, and 3) cost. These three metrics give clear visibility to performance and allow for communication of priorities. Using commonly understood metrics, one can then move to an EBM implementation plan. The essential features of this plan would include 1) the setting and communication of targets throughout the supply chain, 2) monitoring and visibility of performance compared to targets, 3) incorporation of environmental performance into the business plan, which will provide the means for obtaining the stated goals, and 4) leadership and constancy of purpose throughout the organization.

3.3.4. Analytic tools

Manufacturing firms that wish to improve the environmental performance of their products, processes, and systems are faced with a complex task. Products move around the world and can spend much of their life outside the direct control of the manufacturer. Design and material selection must be influenced by process capability as well as end of life disposition requirements and preferences. Furthermore, "systems" come in many forms and life expectancies. Clearly the dimensions of the challenge are enormous in terms of both spatial and temporal extent, as well as in terms of interconnections and dependencies. Tools, metrics and models to help sort out these complex issues, to point directions, and to measure progress are badly needed. For example, as the emphasis in Europe and Japan is shifting toward the environmental consequences of products, there is a clear need for analytic methods to assist in this assessment. To this end, researchers have developed various approaches to track material resource use and emissions, and the implied environmental impacts of products throughout their entire life cycle including; materials extraction, materials processing, product manufacturing, distribution, use, and end of life. The first step is to produce a life cycle inventory (LCI) that accounts for the type and amount of materials, energy, and natural resources used and the emissions produced (i.e., a mass and energy balance). This list, which can include hundreds of items, must be further processed in order to be useful in decision making. Ultimately, value judgments are needed in order to prioritize the results. The entire process, referred to as life cycle assessment (or alternatively, analysis) or LCA, is defined in ISO 14040 as a "compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life." LCA tools have been found to be useful in assessing product designs, processes and systems.

The panel observed that LCA is widely used in Europe. In Japan it is less commonly employed, although there is a national effort to develop LCA tools, and in the U.S. it is typically applied much less frequently than in either Europe or Japan, and then typically only by large multi-national corporations. A key motivator to use LCA is ISO 14000 certification. To support LCA, there are a wide variety of software packages available again, mostly from Europe. Volvo has developed the Environmental Priority System, the Dutch developed the Eco-Indicator (embodied in Simapro software), and the University of Stuttgart in Germany has developed several extensive databases plus software tools (e.g., Gabi). However, LCA is very data intensive, is mostly done by experts, either internal (e.g., corporate R&D) or (hired) external consultants, and can take months to accomplish. Hence, LCA tools are typically not yet integrated with other design analyses. These shortcomings, characteristic of all currently available tools, were pointed out to us during the site visits.

One of the biggest concerns with LCA, however, is the lack of consensus on a "standard" metric or even a set of metrics for measuring environmental impact. This issue was the topic of particular discussion during the TU Delft visit. Due to the subjective nature of the impact portion of an LCA, a wide variety of interpretations are possible. In Europe, some companies have been promoting a "universal" single impact measure as provided by the Dutch Eco-Indicator. While this has the advantage of simplicity, it is met with strong opposition because many feel that this would result in using LCA more as a competitive tool than as a tool for true environmental impact improvement. Additional common criticisms regarding LCA are that it is not tied to business perspectives, it does not measure value, it is too academic, too vague, too difficult to perform, etc. While these criticisms are well known and not easily remedied [42,43,44], issues of data collection and modeling should improve with time and standardization. Issues of values are the most troublesome, requiring agreement by large numbers of stakeholders. This problem has several facets including clear communication of potential threats based upon the best available science, as well as the localized preferences of the participants. However, there are examples of regional agreement, particularly in Europe. The Japanese Ministry of International Trade and Industry (MITI) has an ¥850 million project to develop a highly reliable LCA database and methodology, within which there is an Impact Assessment Study Committee that is focused on science based damage functions [1]. Even in the United States, agencies such as the EPA and movements such as the industrial ecology community are setting environmental priorities that represent the first steps in addressing this thorny issue [45,46].

At the visit to the IVF (Swedish Institute of Production Engineering Research) in Sweden, a long-term strategy for LCA development within individual companies was offered. In this analysis, the first phase focuses on individual cases and lasts about 1–3 years. In the second phase, data are aggregated and a company-wide database is built. This phase also lasts about 1–3 years. Finally, in the third phase, acquired skills are incorporated into product and process design methods. IVF believes that if these steps are adhered to, there is potential for the full integration of LCA into the design process. In Sweden, LCA is actively used; in fact, several Scandinavian governments now require that an LCA study be performed as part of a bid on a contract.

While LCA is intended to determine material and energy flows (inventory data) and to assess the resulting environmental impacts, DFE or "Design for the Environment" is a set of methodologies for designing or redesigning a product in order to reduce its environmental footprint within a particular stage of product's life cycle. Obviously, the two methods are closely related; the typical view is that LCA provides the information to facilitate DFE and ultimately improve the life cycle impact of a product. DFE includes a broad category of tools: product and process design (including material selection), design for use, and design for end-of life (including reuse, disassembly, and recycling). Most commonly in use today are checklists rather than interactive decision-making tools and the emphasis tends to be design for end-of-life.

In Japan, the acceptance of DFE principles/methods benefits from a culturally ingrained sense of avoiding waste and conserving limited resources. While visiting Hitachi and several governmental laboratories, presentations were made of recently developed DFE tools that focused on design for disassembly and design for recycling. NEC indicated that the key design concepts behind environmentally friendly products included modifiability for longer usage, simplicity for greater recyclability, and use-flexibility such as their "SHARE" concept. This concept combines common functional units such as speakers and monitors to produce different products such as a personal computer and TV. In order to introduce DFE and LCA tools, Japanese companies need a tool written in Japanese rather than English. In response to this, there is a large national project with government and industry working in cooperation to achieve this.

Many companies mentioned that a key problem with DFE and LCA was the lack of integration with other design and management tools and practices. The sense of priority seems still to be with cost and quality at the engineering level. Hitachi and others indicated that DFE is not completely adopted nor prevalent throughout Japanese corporations.

In northern European corporations, DFE is a commonly recognized practice. However, several industrial sites visited also emphasized that DFE should not be a stand-alone activity, but rather integrated throughout the product realization process. DaimlerChrysler (Europe) stated that having experts only at the corporate level did not work; experts also need to be present at the business unit level, close to the engineers and managers who are directly involved with the product and process design and management issues. It seemed that for most companies a primary motivator was the "success story" where environmental thinking was also beneficial to the bottom-line in some way. It was very interesting to note that until last year, NEC had never investigated the economic pay-off of its environmental research and development laboratory in its 29 years of existence. Instead, management sees environmental efforts as part of "being a good citizen".

For small companies the integration of DFE and LCA tools is even more difficult. In Europe, two studies were performed that focused on small and medium-sized enterprises (SMEs) that highlighted the importance of economic and environmental win-win situations even more [1,49]. In a Dutch study, it was stated that SMEs were often extremely eager to be helped, but as soon as the consultants left, the motivator seemed to have gone as well. The reasons cited were that SMEs tend to think short-term and do not have many resources to spare. This was confirmed by a recent Swedish study. An unresolved issue, therefore, is how to promote EBM activities in small and medium sized enterprises.

From an education perspective, European universities seemed to be further ahead in integrating DFE into their curricula. Both in Europe and Japan, there are several ongoing research efforts, major national initiatives, and conferences. However, in Japan, DFE is not yet integrated in the curricula, and is mainly driven by elective courses and individual faculty interest. A similar situation appears to exist in the United States.

4. Epilogue and research questions

In this paper, a snapshot of EBM practices as observed in Japan, (northern) Europe, and the United States has been described. The message is generally positive, describing continued advancement by the leading firms. The key trends identified are: 1) the evolution of EBM as a competitive strategy for companies and governments, 2) the need for systems level thinking, strategic planning and new business practices to capture these potential advantages, and 3) as a consequence of 1 & 2 the healthy alignment of business goals and the public good. However, even while making these observations, there was also a certain sense of fragility to these trends. Recent historical events have only served to underscore these concerns.

The two main issues which emerge can be posed as questions: 1) "Will these trends in business behavior continue, and in fact grow"? and 2) "If so, will this behavior be sufficient to protect the environment"? The first question is the main concern of many "green business" literature articles. Arguments encouraging pro-environmental behavior are essentially about future competitive advantages. The economic downturn since this study has served to re-emphasize this point. A spot check of several of the site visit locations indicates a trend toward fewer employees working on environmental issues compared to the 1999–2001 time frame. Concurrent with this downturn, is an apparent reduction in pro-active behavior by industry. Perhaps the most spectacular example of this in the automotive industry is Ford's reversal, after their well intended and industry-leading announcement on July 27, 2000 to improve their SUV fleet fuel economy 25% by 2005 [19]. On April 17, 2003 Ford executives backed away from this pledge saying that they are "still trying to get there", but that the time table is unclear [20]. This type of behavior comes as no surprise provided one does not lose sight of the essential nature of manufacturing firms.[10] At the same time, activities at manufacturing firms to address regulations, particularly those initiated from the EU have continued and in some cases increased.[11] The reasonable conclusion of this is that sustainable green business behavior requires a pay off, and this in turn, requires an "external value proposition". This "proposition" could come in many forms, from onerous regulations to voluntary consumer behavior or anything in between, but it must represent a value system that exists outside of the firm. An ironic complication (and in fact, strategy) is that the pro-active green comportment of firms could actually solicit the external value proposition. This type of behavior seems the essence of social responsibility. At the same time, however laudable this conduct, it must be considered that these pro-environmental activities may not be sufficient to protect the environment. This second issue, which we raised in the paragraph above, is rarely addressed by the green business literature. It is usually dismissed by an argument that, if a behavior is not profitable, it will not be practiced.[12] While the intent of this argument is clear, the logic is incomplete. The additional question needs to be asked, "If it is practiced, will it result in protecting the environment"? This is not a trivial question. Often lower level actions have surprising systems level results.

In this context, there are important unanswered questions that this study raises. They are presented here as research questions.

1. Almost all EBM efforts within companies start with efficiency improvements. These provide the success stories needed to sell "green" projects within the firm. But, what is the ultimate effect of improved efficiency? If the effect is reduced price and hence increased consumption,[13] the net result may be a loss for the environment. In order to effect real improvement, what EBM metric or metrics should companies try to optimize? From a systems point of view, what policies and market incentives are needed to make this work?
2. Measuring environmental progress is difficult. Leading companies report environmental improvements but there is enormous variation in what is reported, and rarely is there an opportunity for verification. On one side there is the argument that environmental data could divulge competitive information and lead to "over regulation", but on the other hand, the public has a right to information that could affect health and welfare. In spite of significant work in this area [46,55,56], much remains to be done. New measures, which exploit the success of the EPA toxic release inventory (TRI) system [57,58], could help. Appropriate areas for attention could be gross use or consumption of raw materials such as water, coal, and oil, and gross emissions such as solid waste and CO_2. In general, new sensing technology, if used appropriately could contribute significantly to this area. In some cases the modeling of standard industrial operations could prove enormously powerful for providing standard references [42].

[10] They are financial driven institutions and must meet their cash flow requirements.

[11] For example, WEEE, ELV, and ROHS (mentioned earlier), are driving product design changes in US companies who want to compete in the EU market.

[12] A clear exception to this is Porter [47] who urges "innovation-friendly" regulations.

[13] This is called the "rebound effect" by economists, see [53,54].

3. Even the skeptics on the panel were convinced by the sincere efforts by many of the visited manufacturing firms to improve their environmental performance. Yet there is no guarantee that these attitudes will prevail. Political, market and regulatory shifts can lead to new behaviors that in some cases could discourage the environmental leaders and encourage the laggards. The only real answer to these challenges must come from an educated public. However, the challenges to presenting future, and not fully understood, impacts in clear, accurate, and engaging ways are considerable. More effort in this area ranging from solid science to public relations is needed. The ecological footprint [53] is an example of a measure that is easy to understand and has clear reference values. These are clearly desirable features for metrics designed to inform the general public. In addition, new sensing technology such as RFID tags [59,60] hold significant potential for informing consumers about his or her consumption and waste habits. In fact the availability of this information holds the specter of family, or even individual social responsibility statements similar to those now reported voluntarily by companies. Recent social science research shows that citizens often hold inappropriate "mental models" of pollution mechanisms [61]. Public education in this area presents an enormous challenge.
4. When globalization came up during panel visits, our hosts often assured us that all of their manufacturing operations would be held to similar high standards regardless of geographic location. These are well-intended claims, but local conditions (lack of infrastructure and environmental regulations, and more pressing economic needs) are likely to present huge barriers to these goals. Furthermore, the panel noted a clear trend to move "dirty" resource and labor intensive operations to less developed regions of the world. To what extent will the goals for environmental equality price low-wage countries out of the market? On the other hand, how far should local governments subsidize new industries that have the potential to do environmental harm? The solutions to these problems will likely defy uniform management systems often espoused by large international firms. New technology, which could allow poor, low wage countries to capture "clean" economic advantages, may help. For example, global communications has allowed the outsourcing of certain service jobs to poorer countries particularly where education levels are high. Planning for these trade-offs could be substantively improved by the use of Life Cycle Analysis (LCA) tools, and Materials Flow Analysis (MFA) tools. Manufacturing firms have a high stake in this debate. The question is; what will be called exploitation and what will be called competitive advantage?
5. While there is general agreement that "command and control" regulation of industry is inefficient, what new set of initiatives and incentives should replace it? How broadly can the Dutch Model (as described above) be applied to other countries and other circumstances? In fact, it may no longer be viewed as such a success story, due to a slowed economy. Furthermore, the bedrock of such initiatives, trust in large corporations, may now be at a significant low, especially in the United States. There is a need for alternative models with sufficient checks and balances to work in a "skeptical" environment. The use of "free market" tools, and "innovation friendly" regulations need further attention [14,47]. This is an excellent area for cooperative research between economics, policy and technology.
6. Interestingly, there was only occasional mention during the site visits of the well-known strategy of "servicizing", i.e., selling services rather than goods,. This may be a function of the individuals that were interviewed (environmental officers vs. executive officers), and it may also be a function of the companies that were interviewed (mostly large international firms).[14] Such a radical shift may be too extreme for large corporations that have a culture built around the current business paradigms [51]. At the same time, there is evidence that "going downstream" can have a positive impact on a manufacturing company's profits [52]. The "services" paradigm may hold potential for realizing the goal of achieving simultaneous economic well being and reduced environmental impact. On the other hand, it may also encourage excessive use of non-valued resources. With this in mind, the paper closes by encouraging new research that focuses on the decoupling of human well being from materials use and dispersion.

Acknowledgements

We would like to thank Dr. Delcie Durham (NSF), for her guidance and vision as well as, Dr. Fred Thomson and Dr. K. Rajurkar (both of NSF), who accompanied us on some of our site visits and meetings. This program was administered by WTEC at Loyola University, where Geoff Holdridge, Bob Williams and Roan Horning, provided additional assistance. The smooth running of our Japanese visits was

[14] A notable exception to this trend was the relatively small floor covering services company, Interface.

ensured by the able planning and assistance of Hiroshi Morishita.

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