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Sustainability: Affirming Engineering Values*

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This paper encompasses and extends opening remarks made at a workshop on sustainability and design education by the chair of the workshop's organizing committee. Held at Harvey Mudd College in May 2009, and supported by Mudd's Center for Design Education, Mudd Design Workshop VII provided a forum for engineers and designers—in their roles as educators, researchers, and practitioners interested in learning and in design—to identify and articulate important aspects of sustainability in design and engineering education. The remarks detailed below are intended to remind us, as engineering and design educators, that issues of sustainability are inherent in and central to our professional obligations as engineers.

Keywords: environmental drivers; resource utilization; engineering values

1. INTRODUCTION

THE SIXTH MUDD design workshop (MDW VI) of May 2007 was intended to extend the reach of prior workshops [1–5] to explore the impacts of globalization and the 'flattening of the world' on engineering and design education [6]. In that 2007 workshop a global focus meant a focus on the consequences of global trade and economics. This seventh Mudd Design Workshop is set within the context of increasing global recognition of an increasing global threat to the very existence of the environment within which human civilization has developed [7].

We will highlight just a few of the signs that indicate how rapidly and thoroughly our environment is changing in the next section, after which we outline some of the responses of the engineering enterprise to these environmental changes. Then we will talk briefly about sustaining traditions in the local context of the MDW design community and then we close by offering some concluding suggestions.

2. THE DRIVERS: THE ENVIRONMENT WRIT LARGE

We begin by recycling (from MDW VI) and harking back to a warning provided by the late John H. McMasters. He identified a *perfect storm* of forces that reflect major changes in the environment. McMasters' perfect storm identifies the following four major components that are also depicted in Fig. 1 [8].

- *global warming (and the role that human activity plays in fostering it)*, which is now, apparently (and finally?) accepted and understood as the major—and in some sense perhaps *the*—environmental challenge facing the world;
- our increasing awareness of the *finite supply of natural resources* such as oil, water (especially potable water) and a variety of minerals (including soil);
- a *rapidly growing world population* and its concomitant demographics, as a result of which many countries and regions are faced with disproportionately large populations of young people who need not only food and shelter, but also education, and for whom jobs must be provided in economies that are not growing nearly fast enough; and
- that *many of our institutions and cultures are either unable or unwilling to change* or to otherwise respond positively to the other three converging trends of this perfect storm.

Now, there are many indicators that point to changes in the environments in which we engineers (in particular) live, are educated, and practice. Some indicators reflect the vast growth of knowledge, which as with so many other matters these days itself often seems to easily outstrip Gordon Moore's famous heuristic about the doubling of computer processing capability. Sustainable design inexorably involves all four of the trends in McMasters' perfect storm (deteriorating climate, scarce resources, increasing population and cultural inertia), and there are vast amounts of data available on each. For the present, however, it seemed interesting to simply take a snapshot of a few news items that touched only on the first two aspects of the perfect storm (i.e., deteriorating climate and scarce resources) and that crossed the author's desk and screen over the course of a few days. After all, this is part of the information overload to which we are all subjected, even when

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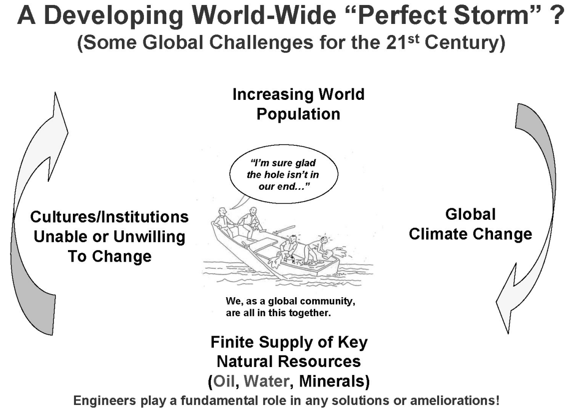

Fig. 1. McMasters' depiction of the perfect storm [8].

we are not really paying attention because of our own everyday concerns.

There are still those who make the (sometimes interesting) case that the threat of global warming and environmental deterioration is exaggerated [9], with perhaps the most persuasive argument (to this author, at least) being that the scientific consensus has been woefully wrong in the very recent past. That is, in the 1970s it was predicted that a major cooling of the planet was inevitable, and in the 1980s a shortage of renewable natural resources was predicted because of anticipated population increases. Neither of these events has occurred, the argument goes, so we should not believe today's scientific consensus. Yet as we acquire more information it is hard to simply ignore that information and dismiss the consensus about what the best available science is telling us right now [7, 10].

Now, all engineering practices—whether traditional or sustainable—must account for the fact that inputs to engineering processes and manufacturing are increasingly expensive because of the increasing scarcity of key natural resources. For example, during the time period 2004–08, the prices of oil and natural gas *doubled*, while the price of industrial electricity *tripled* [11]. And the future is not likely to be any more forgiving than the recent past.

Consider the data displayed in Table 1 wherein current US sources of electrical power and their anticipated 2016 costs are displayed. The data show that we are highly dependent on coal, and markedly less so on nuclear power and natural gas. The data also clearly show that so-called alternative sources of energy are not likely to be very cheap nor are some of them widely acceptable. For example, nuclear power generation is the cheapest, yet it still remains controversial and a source of fear for many. Further, there have already been widely publicized instances of NIMBYism with regard to various wind generation projects, and ecological and aesthetic concerns are also being expressed about large-scale solar projects.

It is also interesting that the above US-centered view is rendered almost meaningless if even just a few global aspects are included. For example, the Department of Homeland Security's representative on the national Science and Technology Council recently said that ([11], emphasis added), 'There are *six* cars for every 1,000 people in China and more than *300* cars for every 1,000 people in the United states. When the Chinese increase that to *eight* cars per 1,000, *they will consume as much gasoline as the United States today*.' Imagine what that means for the economies of the US and the rest of the world. Still further, it is hardly a secret that China has worked very hard over the last decade to lock up mineral resources, from copper to oil, in long-term contracts.

Figure 2 displays a recent article in the *Los Angeles Times* [13] that described a brand new commercial greenhouse used to grow tomatoes. Among its attributes, the greenhouse 'generates its own renewable power . . . hoards rainwater . . . hosts its own bumblebees for pollination . . . and requires a fraction of the chemicals used in neighboring fields to coax plants to produce like champions.' The greenhouse achieves this by bounding a 'closed, sustainable environment' that less than one-fifth of the water than conventional field irrigation and cultivation would dictate. The greenhouse was built near Camarillo, California, by Houweling Nurseries, a Canadian farming company. The company's president, Casey Houweling, said that, 'We believe this is the first greenhouse in the world that is energy neutral.' It may be more than coincidence that Houweling is himself of Dutch extraction.

Why more than coincidence? A 1995 article in the *Harvard Business Review* [14] argued that there is an inherent logic that couples environmental and

Table 1. Future electricity costs (adapted from [12])

Energy Source	**Current Use (electrical production, trillion BTU; (%))**	**2016 Cost (per megawatt hour, 2007$)**
Nuclear	8,415 (20)	$104.80
Hydroelectric	2,463 (6)	$112.80
Biomass	824 (2)	$113.00
Natural gas	7,716 (19)	$114.80
Wind	319 (1)	$115.50
Coal	20,990 (51)	$120.40
Oil	715 (2)	NA
Solar (photovoltaic)	6	$385.40
Solar (thermal)	6	$257.50

Los Angeles Times B

BUSINESS

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DOW 8,284.89 ▼184.22 | S&P 500 883.92 ▼24.43 | NASDAQ 1,664.19 ▼51.73 | GOLD $925.50 ▲2.00 | OIL $58.02 ▼0.83 | EURO $1.361 ▼0.003 | U.S. T-BILL (6-mo.) 0.29% ▼0.01 | U.S. T-NOTE (10-yr.) 3.10% ▼0.07

Photographs by Anne Cusack Los Angeles Times

OLD AND NEW: A Houweling Nurseries representative photographs a traditional hothouse, left, next to the more efficient design, near Camarillo.

AGRICULTURE

Planting a farming revolution

High-tech facilities sip water, generate power and bear more fruit per acre

Jerry Hirsch

On a coastal plain near Camarillo not far from a U.S. Navy base and an outlet mall, the future of California farming is taking shape.

Rising out of verdant acres of strawberries and artichokes between Highway 101 and the Pacific Ocean in Ventura County are two mammoth, high-tech greenhouses.

Climate change is a serious threat to California's $36-billion agricultural economy. The farming company behind this $50-million complex sees it as insurance against perpetual drought, volatile fossil fuel prices and resilient pests.

The facility generates its own renewable power. It hoards rainwater. It hosts its own bumblebees for pollination. And it requires a fraction of the chemicals used in neighboring fields to coax plants to produce like champions.

This fledgling movement to grow food crops in closed, sustainable environments could become as revolutionary to farming in the 21st century as California's development of massive farms was in the 20th, agriculture experts say.

"We are doing all of this not only because it will be good for our business but because it will be good for everyone else," said Casey Houweling, president of Houweling Nurseries, the Canadian farming

[See **Greenhouse,** Page B2]

INNOVATOR: President Casey Houweling stands high above the crop in one of his new greenhouses, where pickers climb instead of stooping.

Fig. 2. A Dutch-Canadian-American farming revolution [13].

resource concerns to innovation and good design and engineering in a very positive way. Early in the days of the environmental movement it was routinely argued that ecological concerns were in an adversarial trade-off with economic growth because the environmental benefits were seen to be *social* (or society's) benefits, whereas the costs of cleaning up or preventing pollution were *private* costs that would be borne by industry. However, the argument goes, it should be recognized that pollution represents an inefficient use of resources that typically results from excess or wasted manufacturing by-products. Good design and innovation that is aimed at reducing these polluting by-products results in *resource productivity* that enhances profits [14].

And what does this have to do with Casey Houweling being Dutch? Well, perhaps nothing, but it is also the case that, as the *Harvard Business Review* article also points out [14], it was the Dutch who long ago recognized that it had severe environmental problems in cultivating its renown tulips: 'Intense cultivation of flowers in small areas was contaminating the soil and groundwater with pesticides, herbicides, and fertilizers. Facing increasingly strict regulation . . . The Dutch understood that the only effective way . . . develop a closed-loop system . . . flowers now grow in water and rock wool . . . reducing fertilizer . . . delivered in water that circulates and is reused.' That is, the Dutch developed tightly monitored closed-loop systems that dramatically reduced the costs and the environmental impact. These closed-loop systems also increased the quality of the flowers grown and enhanced Holland's global competitiveness in the international flower market.

It is important to point out here that while some key resources are clearly irreplaceable and expensive in terms beyond simple financial reckoning, that is less the case for the potential shortages of minerals. In fact, the consequences of mineral shortages have typically been sorted out in the marketplace by demand-driven pricing (e.g., people drive less and/or buy more efficient autos when gas prices go up) and by technical innovation (e.g., wireless communication is clearly supplanting our extensive grid of telephone land lines made of copper). (See [9] for an entertaining description of a world-famous bet made by a renowned biologist who drove much of our concern about a population explosion.) By way of contrast, when we lose water and soil, we are absolutely losing very scarce resources, a situation that also applies to global biodiversity, tropical rain forests, and many types of fish across the oceans [15, 16].

As noted above, on any given day there are dozens of news stories about environmental (and, these days particularly) economic degradation and increasing numbers of stories about design and engineering efforts aimed at substantially mitigating, if not virtually eliminating, pollution and waste. Indeed, a few more examples will be cited in the next section as we discuss the response of the engineering profession. It seems safe enough to say that the need for better design and better engineering is real, notwithstanding the doubting Thomases [9]. In fact, even if one were to embrace the doubters' skepticism, it would seem like good engineering practice to design for sustainability in the spirit of Pascal's famous wager. That is, in its starkest terms, can we afford not to design for sustainability? Even if current models of how much sea levels would rise if Antarctica's massive western ice sheets fully disintegrated as a result of global warming are imperfect models, can we put their (varying) predictions aside? What if the predictors of global catastrophe are right?

3. ENGINEERING VALUES

What should we—as designers, engineers and educators—be doing in the face of this continuing avalanche of news and data about environmental deterioration? After all, there's no doubt that the US engineering enterprise, and particularly its education effort, have been both affected by and are players in many of the major issues of our times. For example, once operations research and applied physics had demonstrated their utility in fighting World War II, engineering education and research was markedly influenced—if not steered—by defense considerations. Similarly, both the space race (starting in the 1960s) and environmental concerns (beginning in the 1970s) became major players in engineering academia. So, will climate and sustainability issues become similarly significant? And will that significant presence be felt only in the educational establishment, or will it become so in practice as well?

It seems pretty clear—at least to this observer—that sustainability has become a matter of importance, although some of its influences may not be readily observable or easily identified or ascribed. In academia, for example, it is already very clear that college and universities are taken on the issues of sustainability in the ways that they operate, both short term with such innovations as 'trayless cafeterias,' and long term with LEED certification now being a prominent part of facility planning and design.

What is truly interesting about these developments is that they seem to be very much student driven, as opposed to being driven by faculty or academic administrators. By way of contrast, the environmental movement that emerged in the 1970s and which led to many great changes in academic offerings—just think of how commonplace it has become for departments of civil engineering to become departments of civil *and environmental* engineering—was as much driven by younger faculty as it was by student interests. Now, however, it seems that the motivation is more often comes from students who evince concern about ecological fragility, the scarcity of precious resources such as clean air and water, and the general health of the planet.

The attitudes of engineers in industry are rather similar to those of their student counterparts, according to a recent survey of mechanical engineers on sustainability [17]. Although by slightly different margins, both professionals and students considered that the most important sustainable technologies are (in decreasing order of importance): designs that use less energy or reduce emissions, manufacturing processes that use less energy and natural resources, designs that use materials that are renewable/recyclable/recycled, and manufacturing processes that produce less pollution or greenhouse gases. On the other hand, working engineers felt that their organizations are most likely to use sustainable methods to make cost-competitive new products or to reduce the costs of existing products, that is, cost appears to be the driving factor. At the same time, these working engineers felt that the factors most likely to affect their organization's use are (again in decreasing order) regulatory requirements, rising energy costs, clients' demands, with the ability to gain a market advantage and long-tern investment return being tied for fourth/fifth place.

One widespread area of concern about design for sustainability is a dearth of information about many of the issues involved, with their seeming to be a clear need for more codes and more standardized methodologies for design and evaluation. One engineer cited in the survey [17] noted that, 'Perhaps the biggest hurdle is the lack of a clear 'road map' to effective sustainable practices. As there is no single technique or practice, each industry or even location must figure out on its own what sustainable practices it can effectively implement.'

Notwithstanding this expressed concern for codes and practices and other sorts of engineering information, engineers are in fact achieving significant sustainability success stories. Some of these stories seem like nothing more than (uncommon!) common sense, as in the desire to reduce or even eliminate waste. (Recall the earlier discussion of waste and consequent pollution as a sign of inefficiency that ought be addressed by improving resource productivity.) For example, the parent company of Subaru of Indiana Automotive Inc., Fuji Heavy Industry Ltd., told Subaru in 2002 that it wanted them to generate no landfill waste by 2006 [18]. In fact, Subaru achieved this goal by May 2004 by initially recycling soda cans, using recycled paper and disposing of plastics in color-coded recycling bins. Over time—and not much time at that—this recycling mentality was extended to include steel, wooden shipping pallets, cardboard, plastics of all sorts, and Styrofoam. Thus, while Subaru generated 459 lb of waste for each assembled automobile in 2000, it got down to 251 lb per car by 2007, of which 190 lb was steel that was easily recycled. Some of their unused packing materials are returned to Japan in otherwise unfilled shipping containers for re-use, while other waste materials are either sold (e.g., plastics, steel) or used for power generation (unrecyclable paper).

The focus of the foregoing example appears, at a superficial level, to be simply about reducing waste. However, it is also about examining the processes by which waste materials are produced and the by which they are wasted. Indeed, many of the advances in sustainability will be made by the detailed examination of processes using sophisticated technical understanding and achievement. For example, some 2 billion gallons of metalworking fluids were used to cool and lubricate metals in the US in 2000, and it costs about $1/gal to buy, maintain, recycle and dispose of such metalworking fluids [18]. It turned out that a mechanical engineer deconstructed the lubrication process and developed a new process that eliminated the real problem, the water required for conventional metalworking lubrication. This new process uses supercritical carbon dioxide (in place of water) to provide the minute amount of oil used to provide machining lubricity and to then dissolve and eliminate the oil. With this new process water is no longer a problem because oil is now used at a rate of only 5 ml/hr, at which rate one would have to machine metals for 30–60 24-hour days to produce the same waste with conventional techniques. And there is no shortage of further instances of sustainable process design [18].

It should be that the examples cited above involved corporate desires to reduce costs and to provide management leadership on sustainable design. Of course, both of these elements were cited as important in the survey of mechanical engineers mentioned above [17]. Cost issues are inherent in so many ways. For example, the installation of a new metalworking technology such as that just outlined most likely requires capital investment, in which case decisions are required about the requisite investment and about its allocation on the company's books and its distribution among its cost centers. In addition, of course, there is the longstanding concern about balancing costs that are easily identified as private with benefits that may be social, private, or a mixture, depending on who is assigning or apportioning those benefits. Of course, if codes or regulations require certain compliances, then the benefits must then be accounted for as the those resulting from being able to market and sell an appropriately compliant product—and there is mounting evidence that there are certain demographics that are more willing to spend more to buy products that are not environmentally damaging.

Leadership at sufficiently high levels is especially important to ensure that problems—and potential solutions—not be confined to silos within a company. For example, soy-based inks are renewable, biodegradable, and less toxic than conventional inks, yet they also can make shop floors slippery. Thus, safety compliance (and perhaps the human resources) issues have to be addressed, as well those of printing efficacy, which means that a broad spectrum of people within the company need to be involved. Similarly, in some instances corporate leadership may be required to ensure that sustainability concerns are properly addressed by companies or organizations outside of the company, such as its suppliers. For example, claims that a complex product has been produced with an optimized carbon footprint can only be supported if the various suppliers of materials and components (to the manufacturer) also adhere to corresponding sustainability goals, which is likely to happen only if there are appropriate relationships between the manufacturer and the members of its supply chain. Interestingly enough, in addition to appropriate relationships with suppliers, such approaches require standardized methodologies and measures for assessing performance and compliance, which is one instance of a generic point made earlier.

Now, while sustainability is increasingly seen as a desirable and 'hot' topic in engineering design, practice, research and education, it is also worth noting that sustainability concerns are entirely consistent with longstanding obligations laid out in the codes of ethics laid out by some professional societies. For example, the American Society of Civil Engineers (ASCE) has since 1996 explicitly recognized sustainability as central tenet of its first fundamental canon (viz., Fig. 3). It is interesting to note that the American Society of Mechanical Engineers (ASME) has within its code of ethics the same fundamental principle and the same fundamental canon as does the ASCE, it does not specifically address (or even mention) sustainability here. The Institute of Electrical and Electronic Engineers (IEEE) does not mention sustainability and, by way of contrast with the ASCE and the ASME, rather than 'hold paramount the safety, health and welfare of the public,' it instead insists only that engineers should make 'to accept responsibility in making decisions consistent with the safety, health and welfare of the public.' Perhaps this difference in wording is unimportant, but perhaps it is.

In fact, it seems a fairly good argument that engineers and designers do have a special burden to work toward sustainability because their very methodology enables them to ascertain costs and benefits, both public and private. It is true that this position may require some 'readjustment' of the frameworks and limits within which engineers do their work. But in the same way that industry learned to turn environmental challenges into eco-

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ASCE CODE OF ETHICS (Excerpts)

Fundamental Principle

Engineers uphold and advance the integrity, honor and dignity of the engineering profession by:

1. using their knowledge and skill for the enhancement of human welfare and the environment;

Fundamental Canons

Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development [1] in the performance of their professional duties.

1. In November 1996, the ASCE Board of Direction adopted the following definition of Sustainable Development: 'Sustainable Development is the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development.'

Fig. 3. Excerpts of the code of ethics of the American Society of Civil Engineers (ASCE), as modified July 2006.

IEEE CODE OF ETHICS (Excerpts)

We, the members of the IEEE, in recognition of the importance of our technologies in affecting the quality of life throughout the world, and in accepting a personal obligation to our profession, its members and the communities we serve, do hereby commit ourselves to the highest ethical and professional conduct and agree:

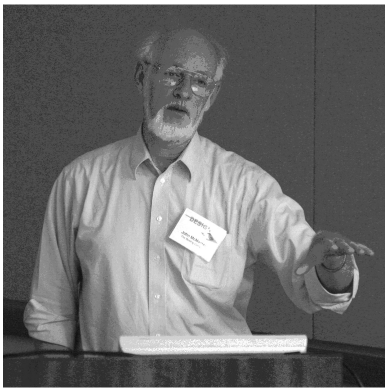
1. to accept responsibility in making decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

Fig. 4. Excerpts of the code of ethics of the Institute of Electronics and Electrical Engineers (IEEE), dated February 2006.

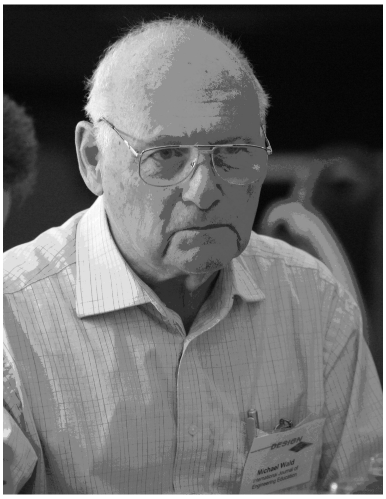
nomic opportunities—as did DuPont and imperial chemical Industries with their development of chlorofluorocarbon (CFC) substitutes [18]—engineers can and should routinely view their cost and benefit calculations within the broadest possible parameters. Thus, they should routinely work to avoid waste and pollution inefficiencies, while at the same time working to improve resource productivity by minimizing the use of scarce, irreplaceable, expensive resources.

4. SUSTAINING TRADITION

Since our last meeting, at MDW VI in May 2007, we have lost two very good friends—friends to this series of workshops, friends to the community of those interested in design and in engineering education, and personal friends to many of us gathered here today. Both John. H. McMasters and Michael Wald were very conscious of the need for elders to impart—with humility—their accumulated wisdom and to provide intellectual and moral sustenance to those who aspired to follow along their paths.



John. H. McMasters (1939–2008)
@ MDW V (2005)



Michael Wald (1932–2008)
@ MDW VI (2007)

We will remember and celebrate John's and Michael's many contributions at our traditional workshop banquet, in a session titled *Sustaining Tradition.*

5. CONCLUDING THOUGHTS

In the words of one well-known heuristic [19], engineers should, 'Always give an answer.' And in this context, any and all answers should be cast in the broadest possible terms. That is, in the context of unsustainable ecological damage and irretrievable loss of essential resources, engineering educators should perhaps follow the lead of their students and erase—or at least work energetically to minimize—the distinction between private benefits and social benefits. Further, while some of the present remarks may be in the vein of preaching to the choir about issues of teaching design, it is also true that the many benefits associated with emphasizing sustainability in teaching design also address many of the primary goals of engineering education. Thus, as is clearly indicated by the breadth and depth of the workshop's presentations and discussions, the importance of both design and sustainability to engineering education cannot be overemphasized.

Perhaps, as a colleague of mine recently suggested [20], the emergence of sustainability as a major driver of engineering education and research perhaps represents the mainstreaming on environmentalism. It would be nice to think that is uniformly true across all engineering disciplines, as well as across the practice of engineering and design. To the extent that it is not, as design and engineering educators we should also work energetically to make it so.

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