"Green Engineering: Defining the Principles"— Results from the Sandestin Conference

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During the week of May 19, 2003, approximately 65 engineers and scientists convened at the Sandestin Resort in Florida for the first conference on "Green Engineering: Defining the Principles," sponsored by Engineering Conferences International. Over four days, a series of oral and poster presentations inspired discussion of green engineering principles. Each day attendees met during breakout sessions to discuss specific elements of green engineering principles. By the end of the conference, a set of nine collectively agreed upon principles that summarized all breakout session discussions had been compiled. These represent a majority view of green engineering principles as determined during the Sandestin deliberations, and should not be construed as individual opinions of any of the participants or sponsors. The Environmental Protection Agency, National Science Foundation, Department of Energy (Los Alamos National Laboratory), and the Green Chemistry Institute, all provided funds to support the meeting.

HISTORY OF THE CONFERENCE

The genesis of the Sandestin conference was a green engineering conference held in July 2001 ("Green Engineering: Sustainable and Environmentally Conscious Engineering," Virginia Polytechnic Institute and State University, College of Engineering, July 29 to 31, 2001, Hotel Roanoke and Conference Center, Roanoke, Virginia). Following discussion by several of the participants, it was determined that a more focused and in-depth workshop-oriented conference was required to define the scope and tone of green engineering, relative to all engineering disciplines. An organizing committee was established to create the conference, and included participants from government, industry, and academia, and from various engineering disciplines (chemical, mechanical, civil, and environmental). This organizing committee identified as the focus of the conference the task of defining green engineering principles, and identified speakers to participate in the discussion. Engineering Foundation Conferences (EFC, which later become the Engineering Conferences International) was asked to sponsor the conference, since they are an umbrella organization serving all engineering disciplines, and they agreed to do so.

PRE-CONFERENCE DEVELOPMENT

As stated above, the organizing committee determined early on that there was a need to develop a set of principles for green engineering. While numerous definitions of green engineering already existed, and several principles statements for sustainability have been produced, no one was aware of a concise statement of principles for green engineering. Thus, this was chosen as the theme of the conference.

Next, the committee identified three "themes" to serve as the organizational structure for the conference. Each theme was a central focus for the oral presentations scheduled for that specific day. The themes selected were:

- Theme 1 (Drivers): What are the drivers for green engineering and how consistent are they across various engineering disciplines?
- Theme 2 (Metrics and Tools): How do we measure progress and evaluate performance? What are the metrics to determine the "greenness" of a product or process? What are the tools that are unique to green engineering? How can they be applied across various disciplines? What are their limitations?
- Theme 3 (Connecting Process to Product): The connection between the process/product design and improvements to the environment (i.e., "systems approaches").

Prior to the conference, the organizers compiled an analysis of existing principles sorted into categories to determine if there was any duplication. The principle statements included in the analysis were:

- Hannover Principles [1].
- Twelve Principles of Green Chemistry [2].
- CERES (Coalition for Environmentally Responsible Economies) Principles, [3].
- Ahwahnee Principles, produced by the Local Government Commission [4].
- DfE Key Strategies produced by the National Resource Council of Canada [5].
- Earth Charter Principles [6].

These statements were collected into common thematic areas to identify overarching principles that the organizing committee determined appropriate for discussion during the conference. These themes could also serve as a basis for the development of green engineering principles, and were related to material included in the textbook of Allen and Shonnard [7] that is geared towards chemical engineers. After its release in March 2003, Anastas and Zimmerman's article describing the "Twelve Principles of Green Engineering" [8] was also included in the preliminary information list of principles distributed at the conference. These categories included:

Embody a holistic, systems approach to risk reduction. This concept resonated in several of the principles statements, suggesting its importance as a principle in sustainable design, and as such, became the first category included in the compilation of existing green engineering principles. Anastas & Zimmerman discuss the use of inherently non-hazardous materials; the CERES principles discuss the concept of risk reduction and the use of safe products and services, while the Design for the Environment (DfE) key strategies suggest that one must examine the function(s) of a product in terms of both development assumptions and the needs of the end-user. The Earth Charter simply states that prevention of harm is the best method of environmental protection. Put in simple terms, all of these concepts discuss the need to evaluate and reduce the environmental, health, and safety impacts of designs, products, technologies, processes, and systems on ecosystems, workers, and communities, continually and holistically. These concepts, including environmental risk, holistic, and systems approaches, are addressed at length in the green engineering textbook, through its discussion of approaches and tools for evaluating the environmental performance of chemical processes and their adaptation for use in other non-chemical systems. Because of its significance, this category was embodied in the first principle statement raised by several of the breakout groups at the end of the conference.

Utilize life cycle concepts. It is essential that one consider the environmental impacts throughout the product or process life cycle, from extraction, through manufacturing, use, and finally disposal. Thus, one must evaluate and optimize materials used in all relevant life cycle stages of products, processes, technologies, and systems to minimize waste. The Hannover principles [1] discuss the concept of evaluation and optimization over the full life cycle of products and processes, to approach the state of natural systems, in which there is no waste. This is similarly expressed in the Anastas and Warner principles [2], which emphasize prevention rather than treatment, the Earth Charter principles which emphasizes closing the loop and reducing, reusing, and recycling wherever feasible and Allen and Shonnard's green engineering textbook which dedicates several chapters to life cycle methods.

Minimize the use of non-renewable resources. Most principles statements include an element that focuses on renewable resources. For example, the DfE strategies declare that one should select the most environmentally appropriate materials, while the CERES principles [3] state that one should make sustainable use of renewable natural resources. This is echoed in Anastas and Zimmerman's 12th principle, which states "Material and energy inputs should be renewable rather than depleting." Many other principles discuss the use of renewable energy sources, such as the Hannover principles recommendation to rely on natural energy flows, or the CERES principles statement to conserve energy and improve energy efficiency. A number of approaches and techniques for conserving materials and energy and improving energy efficiency of processes and systems are also presented throughout Allen and Shonnard's green engineering textbook.

Minimize complexity. In general, complexity in products limits the opportunities for recycling and recovery due to the difficulties in separating the various materials used during the manufacturing process. The DfE strategies suggest numerous strategies to minimize complexity, including design for disassembly, using less packaging, dematerialization, and ease of maintenance and repair. These concepts are echoed in Anastas and Zimmerman's principles and suggest that one should promote disassembly and value retention. There are also concepts of flexible design, durability, and recyclability (Augsburg Materials Declaration) and an understanding of the limits of design (Hannover principles).

Account for all wastes and dispose of them appropriately. This is again a common idea that describes the importance of treating wastes appropriately when they cannot be eliminated. The CERES principles provide a concise statement of this concept, "All waste will be handled and disposed of through safe and responsible method." The Augsburg Materials Declaration suggests the use of traceable and accountable waste management strategies, and the Earth Charter discusses the concept of avoiding environmental harm. Many of these principles apply the precautionary principle, i.e., the concept that waste should be avoided when its impacts on the ecosystem are not known. Allen and Shonnard's green engineering textbook describes approaches and methods for estimating release of waste streams from chemical operations and the importance of accounting for these releases as a critical step in assessing the environmental performance and improving chemical processes.

CONFERENCE ACTIVITIES

Sixty-five engineers and scientists attended the meeting. Approximately 35 attendees came from academia, with the remainder coming from government (12), nongovernmental organizations (7), and industry (8). Most of the attendees had engineering backgrounds, with the largest number being chemical engineers, followed by civil, and mechanical engineers.

Both oral and poster presentations were given during the conference, allowing leading engineers, scientists, and "green thinkers" to discuss their views of green engineering and sustainability. Each presenter focused on one of the three themes listed above. Presentations that focused more on philosophical issues were held in morning sessions, with those more attuned to application reserved for the evening sessions.

A keynote presentation by Arnulf Gruebler (IIASA, Laxenburg, Austria, and Yale University) provided context for the conference. Dr. Gruebler raised a number of challenging issues, and presented several engineering paradoxes that set the stage for extensive deliberations by the participants. The first of these, "We need green engineers to solve the problems created by the success of engineering," was presented through data demonstrating that all engineers have contributed to our improved way of life and the gross domestic product of industrialized nations, but at the expense of substantial environmental impacts.

The main work of the conference was conducted during lunchtime and afternoon discussions in which participants were tasked with developing a set of green engineering principles. Groups were established so participants from various disciplines were interspersed. Also, attendees were rotated to different groups each day. Each group was assigned a specific task or draft principle that could lead to a set of green engineering principles.

Day 1 (Monday): Each group reviewed the compilation of existing principles prepared by Nhan Nguyen, to determine if the draft principles made sense, and were sufficiently comprehensive. Some groups used the preliminary list as starting points for discussion, while a few of the groups decided to begin the deliberations discussing philosophical issues, such as what principles are and why they are needed. There was also some discussion as to the target audience for the principles, and on educational needs. The results from each group's deliberations were summarized and presented to all attendees in the afternoon.

Day 2 (Tuesday): Based on the Day 1 discussions about the preliminary compilation and the presentations of Day 1 and 2, each group was asked to compile a preliminary draft of principles. Each group identified a set of items that they believed should be included within the green engineering principles. Some groups attempted to write a definition or vision of green engineering. For example, one group suggested "Green engineering is the creative use of the earth's resources to promote human well being without compromising the health and viability of the ecosystem." A series of statements emerged that described several key green engineering concepts, including systems thinking and a life cycle approach. Discussions were summarized in an afternoon presentation. Representatives from each group assembled after the evening presentations in an attempt to organize the concepts for better discussion during Wednesday's breakout session

Day 3 (Wednesday): The groups were asked to combine, compile, and discuss the proposed items from Tuesday night, and to identify redundant items and important elements that were missed. Education was prevalent in these discussions. Each group attempted to develop principles statements without expending substantial energy on specific language. Again, the concepts of holistic and systems analysis was often mentioned, although in different terms. One group suggested, "Consider all inputs and outputs..." while another suggested "Consider temporal and spatial dimensions..." The use of resources was another common theme, with issues such as "Give preference to environmentally benign materials..." and "Use renewable resources and only at sustainable rates." The concept of a preamble to the principles, setting down the scope and goals of green engineering, was proposed and supported. During the afternoon presentation, the comments were organized into categories of holistic/systems, technologies, culture/society, resources, communication/education, end-of-life, and miscellaneous. The organizing committee reviewed those categories and worked late through the evening to consolidate and merge the eight sets of draft principles into one.

Day 4 (Thursday): The consolidated set of draft principles and preamble language were distributed to all conference participants. Each item was discussed in detail, and the specific wording for each principle evaluated in small breakout groups. At the conclusion of the meeting, those remaining at the conference voted to accept the nine items below as an appropriate set of green engineering principles.

POST-CONFERENCE FOLLOW-UP

The draft principles were forwarded to all conference participants for further review and evaluation. Responses were received from many participants, some with minor editorial suggestions and others with large changes in the principles documents. There was also substantial discussion amongst the participants and the organizing committee as to whether these principles were final, or if additional work was required. While there was consensus that further discussion is appropriate and encouraged, the sentiment of most committee members and the conference attendees was that it was important to release the principles developed at the conference. Thus, the organizing committee reviewed all of the suggestions to the draft principles and made minor editorial changes. The principles that appear below are the results of this process.

ACKNOWLEDGMENTS

Conference attendees were fortunate to receive substantial financial support for travel and registration. Funding was received from the National Science Foundation (Grant number DMI-0303838), the Environmental Protection Agency (Grant number X8 83076001-0), the Department of Energy (Los Alamos National Laboratory), and the American Chemical Society's Green Chemistry Institute. The American Institute of Chemical Engineers, the Society of Automotive Engineers, and the American Society of Mechanical Engineers were technical cosponsors. The support of all sponsors, both technical and financial, is gratefully acknowledged and appreciated.

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Draft Principles of Green Engineering

Green Engineering transforms existing engineering disciplines and practices to those that promote sustainability. Green Engineering incorporates development and implementation of technologically and economically viable products, processes, and systems that promote human welfare while protecting human health and elevating the protection of the biosphere as a criterion in engineering solutions.

To fully implement green engineering solutions, engineers use the following principles:

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems while protecting human health and well-being.
3. Use life cycle thinking in all engineering activities.
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5. Minimize depletion of natural resources.
6. Strive to prevent waste.
7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.
8. Create engineering solutions beyond current or dominant technologies; improve, innovate and invent (technologies) to achieve sustainability.
9. Actively engage communities and stakeholders in development of engineering solutions.

There is a duty to inform society of the practice of green engineering.