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Executive Summary

The growing population of this planet depends on the continued development of agricultural and industrial endeavors. These advancements have enabled many around the globe to achieve significant improvement in their social and economic well-being over the past two centuries. This progress, however, has come at a well-documented price in the form of global warming, ozone depletion, soil sterilization, air contamination, pollution of water resources, and other environmental concerns. In addition, the natural resources that are the lifeblood of industrialization are, in many cases, not being managed sustainably—Stocks are dwindling.

Issues of resource depletion and environmental stress are not limited to industrialized societies. Throughout the world in developing nations, many people live in desperate poverty and lack adequate supplies of fresh water, food, and energy. Such situations place their own pressures on the ecosystem and societal infrastructure, while also contributing to widespread human suffering.

The solutions to any of these problems cannot be found in isolation. The challenges are too broad, complex, and interconnected, with decisions made in one part of the world often having unintended consequences on another. Strategies for sustainable resource management need to be global in scope, rather than focused within local or national boundaries. The same holds true

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for the disciplines and technologies that can be brought to bear in resolving these issues. An advancement or new approach may address one pressing need, only to create a host of new questions with regards to resource allocation, environmental impact, and economic equity. In particular, any action plans developed within one engineering discipline to support its particular priorities without an appreciation of the impact on others would be extremely short-sighted—Interdependencies of energy and transport or transport and housing, as well as decisions impacting water, food, and health, can be ignored only at our peril. Sustainable engineering concepts are likewise dependent on the collective actions of industry, national governments, local authorities, Non-Governmental Organizations (NGOs), and civil society for their effective deployment, and in some instances, their very existence.

Effectively launching a coordinated approach within the engineering community to delineate, manage, and preserve materials and resources critical to social sustenance first requires consensus on what comprises "sustainable engineering." Such a definition must do more than take into account the diverse perspectives of the array of engineering disciplines. It must also present common principles of practice that can enable engineering decisions to rise beyond immediate problem-solving to take the long view of addressing larger issues of environmental and economic stability.

To lay the groundwork for these foundational concepts, the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) organized *Engineering Solutions for Sustainability: Materials and Resources,* an international workshop held at the École Polytechnique Fédérale de Lausanne, Switzerland, from July 22–24, 2009. Co-sponsored by the American Society for Civil Engineers (ASCE) and the American Institute of Chemical Engineers (AIChE), the workshop convened thought leaders from an array of engineering backgrounds to begin forging a common understanding of the role and responsibility of engineering in achieving global sustainability in the following sectors: transportation, energy, recycling, housing, food, water, and health. A cross-cutting topic area—human resources—was also developed to highlight strategies for unlocking the fullest potential of scientists and engineers to achieve sustainable development. The common thread weaving these sectors together—as well as the various engineering disciplines that impact upon them—was identification of potential ways that the engineering profession could aid in advancing societal sustainability through technological, educational, and public policy solutions. This workshop report distills these findings and offers a blueprint for future action.

DEFINING SUSTAINABILITY

A key workshop outcome was the development of a consensus definition of sustainability as it applies to engineering to provide a common basis for deliberation and action among various disciplines.

Framing this definition is the assumption that demand for energy and resources, a clean environment, and prosperity and equity will remain persistent, even though societal understanding, perceptions, and values regarding sustainability may evolve over time. In addition, irrespective of the relative importance placed on these demands, the path toward sustainability must be a continuous process, fueled by innovative and disruptive technological advances and engineering solutions. Within this context, the workshop delegates identified the following key principles underlying the concept of "sustainable engineering":

- ***Economic:*** The engineered system is affordable.
- ***Environmental:*** The external environment is not degraded by the system.
- ***Functional:*** The system meets users' needs—including functionality, health and safety—over its life cycle.
- ***Physical:*** The system endures the forces associated with its use and accidental, willful, and natural hazards over its intended service life.
- ***Political:*** The creation and existence of the system is consistent with public policies.
- ***Social:*** The system is and continues to be acceptable to those affected by its existence.

UNIFYING THEMES

The complexity of any single sector examined in this project—transportation, energy, recycling, housing, food, water, and health—requires synergistic efforts, not only on behalf of the technical and scientific community, but by many other aspects of society as well, if any meaningful progress is to be made. With a focus on defining common priorities and linkages, six critical overarching themes were identified that could provide a unifying framework in formulating strategy and implementing solutions within this diversity of challenges, issues, and stakeholders. In fact, because these themes account for the array of interdisciplinary factors required to successfully develop and implement sustainable solutions, it is suggested that they be adopted as the preferred validity test for engineering strategies, rather than the current "triple bottom line" approach that only broadly considers social, environmental, and financial elements.

These themes and their supporting concepts are:

- ***Acknowledging the Human Element***
  Sustainability encompasses more than environmental performance. Basic human needs and well-being are key aspects that must be taken into account when evaluating the sustainability of a technology or engineering

alternative. Engineering solutions also need to be culturally compatible and responsive to stakeholders' desires.

- ***Resiliency, Flexibility in Design Technologies and Systems***
Engineering "performance" must evolve from function, cost, quality, and safety to encompass the environment, human health, and social well-being. Resilience will be an essential aspect in design.
- ***Need for Responsible Resource Use/Resource-Efficient Design***
Solutions need to be designed for recyclability and to close the loop of material production systems. In addition, investment and policy decisions should be based on high-quality data and a clear understanding of their meaning.
- ***Life-Cycle Assessment and Costing***
Translation of vague sustainability issues into design objectives and constraints is critical. A reasonable approach would be to use industrial ecology—with its emphasis on materials and resource conservation, life cycle approach, and systems focus—to consider the economic, environmental, social, and cultural dimensions of engineering performance.
- ***Escaping the "Silo Mentality"***
Sustainable engineering implies the need for a substantial increase in the amount of information and sophistication across disciplinary boundaries. Trans-disciplinary and interactive dialogue must be promoted.
- ***Engineers in All Disciplines Need to Achieve Sustainability***
Engineering education needs to be reconceptualized to produce sustainable engineers. Sustainable engineering requires professionals for whom engineering education is a lifelong process, not an outcome at any particular stage.

A STARTING POINT FOR ACTION

Both the consensus definition and unifying themes were developed as a bridge linking all engineering disciplines in a focused effort to articulate the role of materials and resources in societal sustenance. From there, strategies can be developed that are sensitive to the interdependencies among all the sectors examined by the workshop delegates, while still being effective in addressing a particular national, industry, business or community goal. Roadmaps detailing specific interdependencies and potential engineering solutions will need to be developed in subsequent forums. As a starting point for these deliberations, the workshop delegates recommended that the following key, cross-cutting initiatives take priority because of their potential transformative impact across all the sectors:

- Early stage development and dissemination of sound, sustainable, and resilient engineering concepts.

- Widespread adoption of a systems (or scenario) approach to engineering.
- Creation of reliable tools/models for measurement of water, energy/carbon, materials footprints, and their interactions.
- Development technologies/approaches for systemic reduction of the human footprint.

A review of sector-specific considerations and technologies salient to the materials and resources issues affecting progress in sustainable development is offered in the subsequent pages of this report. Proceedings and individual presentations from the workshop that informed these conclusions are available at http://www.aimehq.org/news.cfm. Professional societies, educators, and policy makers are urged to use these resources, framed by the principles and recommendations outlined in this executive summary, as a basis for their own topical and system-wide forums organized to further develop and promote engineering solutions for sustainability.

Each passing day brings new demands and stresses upon the world's materials and resources due to (i) economic development and urbanization, (ii) climatic change, (iii) population growth, (iv) higher living standards, and (v) more materials and resources intensive activities.[1] While a goal for *Engineering Solutions for Sustainability: Materials and Resources* was to launch a coordinated, interdisciplinary dialogue among scientific and technical communities to creatively and constructively address these issues, it is also recognized that even the most groundbreaking solutions will not come to pass without the understanding and support of key decision-makers throughout society. The role of engineers and engineering in policymaking, then, is critical. Policies that impact energy creation and use, as well as those that focus on sustainable environmental management, must be based on sound science and engineering. By the same token, any potential technical solutions must be explored in conjunction with an analysis of the policy drivers and impediments to shift to more sustainable practices. This will lay the groundwork for identifying and developing new policy directions that can propel sustainable development through leap frog technologies, while effectively addressing the environmental, economic, and social contrasts that comprise the complex mosaic of our world.

ENDNOTE

1. United Nations World Commission on Environment and Development (WCED). G. Bruntland (ed.), *Our Common Future: The World Commission on Environment and Development*. Oxford, Oxford University Press (1987).