INSTITUTE for ALTERNATIVE FUTURES

Six Strategic Issues Shaping the Global Future of Mechanical Engineering

A report prepared for

The Strategic Issues, Opportunities and Knowledge Committee,

Strategic Management Sector,

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Introduction: Six Strategic Issues Shaping the Global Future of Mechanical Engineering

Many trends and issues in the external environment are relevant to ASME. When key trends and issues interact with one another to create critical organizational challenges, they become *strategic issues*. Strategic issues rise to a higher level of priority and become a focal point for planning. The six strategic issues identified in the 2005 environmental scan describe a future that is more open, fluid, interconnected and challenging than any period ASME has seen in its 125-year history. These issues frame bold opportunities for ASME to transform its identity, programs and services, and contributions to society. The six strategic issues are:

1. Global Harmonization of Standards
2. Technology Innovation Networks
3. Systems Thinking
4. Attracting and Educating Tomorrow's Engineer
5. Collaborative Learning Communities
6. Bioconvergence: Biology Meets Engineering

Each of these issues is important, but together they suggest that very different futures are possible for those with the aspiration to act on the opportunities. Countries and organizations that attract enough young people and educate them to succeed in a professional environment of rapid innovation and changing social priorities will claim the future. Collaborative learning communities will give all professionals the real time opportunity for lifelong learning. Mechanical engineers who can meet the need for major advances in resource productivity and the growing importance of biotechnology will be in demand. The global marketplace increasingly rewards those who keep pace with innovation and harmonize their work and products into an integrated system.

Summaries of the Six Strategic Issues

1. Global Harmonization of Standards

The relentless requirements of global trade are pushing global harmonization of standards beyond rhetoric to marketplace necessity. Protectionism and legacy systems are acting as counter-forces, but the politics of international standards will yield to new approaches and business models. The global marketplace favors a standards system with the attributes of transparency and speed.

2. Technology Innovation Networks
Global leadership in engineering is becoming a race for brains to create technology innovation networks that are natural ecosystems for invention and application. Networks are replacing geographic clusters because collaboration technologies reduce the need for physical proximity. Human capital and research and development funding are critical success factors in innovation networks.

3. Systems Thinking
By applying systems thinking, mechanical engineering can achieve greater resource productivity to “do more with less” energy, water and materials. This is critical for meeting the grand challenges of energy and water, hunger, poverty, and environmental sustainability. Improvements by a factor of 4 or even 10 are possible over the next 50 years. Mechanical engineers can play a lead role in meeting these grand challenges with multidisciplinary teams using a whole-system multiple-benefit approach.

4. Attracting and Educating Tomorrow’s Engineer
The future of mechanical engineering in the U.S. and Europe may depend on how well the profession can appeal to young people’s idealism and desire to contribute to something truly worthwhile. Students attracted to engineering today will work in a future of rapid innovation and changing social priorities.

5. Collaborative Learning Communities
Learning is the new currency of social networks as peers use collaboration technologies to create open access to the world’s knowledge and creativity. These collaborative learning communities are creating the conditions for a 21st century renaissance. People are using knowledge technologies to collaborate in research, publishing and other forms that accelerate knowledge transfer beyond organizational and geographic boundaries.

6. Bio-Convergence: Biology Meets Engineering
The explosively growing field of *industrial biotechnology*, combined with continuing rapid developments in health care and agriculture, will create major opportunities for engineers to play a larger role in creating new processes and products. But these opportunities will also bring new challenges in areas such as engineering curriculum changes, risk assessment and ethical standards, and difficulties in establishing appropriate professional associations and credentials.

The Task before the Board of Governors

For each strategic issue, the Board of Governors must consider does this issue…

- *Affect ASME’s purpose or mission? Would ASME lose important options for its future if it fails to act?*

- *Does ASME have the ability to intervene and secure a preferred outcome—even if it takes more learning, time and effort?*

- *Does the issue speak to ASME's deepest priorities and responsibility for leadership expressed in its vision?*

The ASME Strategic Issues Committee and executive staff reviewed these strategic issues, affirmed their importance to ASME's mission, and assessed the implications for future options. Each strategic issue will affect ASME's mission and either open or close future options. What ASME must decide is how and where it has the greatest capacity to intervene to secure a preferred future for the mechanical engineering profession.

Ultimately associations cannot choose to do everything for everyone and do it all effectively. If they achieve great success in one or two strategic issues, this success will have a positive effect on other issues in an interconnected world. The Board of Governors will prioritize these strategic issues in its meeting July 21. The board must decide which strategic issues speak to the association's deepest priorities expressed in its vision. Where should ASME commit itself for the future of the profession and the contribution that its members can make to the well-being of humankind?

Important Opportunities Ahead for ASME

Strategic issues call associations to leadership for their professions and industries. Leaders make smart choices about where to invest their time and resources to secure a preferred future. Even as they select a few strategic issues to pursue, they will find that certain strategies serve them well across a range of future challenges. During the analysis of these six strategic issues, certain themes emerged more than once:

- Systems thinking is not just about engineering; it is also a better way for ASME to understand its world and its opportunities for influencing a preferred future.
- Innovation is the economic driver for nations and associations.
- ASME can leverage a core competency as a third-party convener to learn faster and influence outcomes that will benefit mechanical engineers in everything from codes and standards to grand challenges to collaborative learning.

How the 2005 Environmental Scan Was Done

The ASME Strategic Issues, Opportunities and Knowledge Committee commissioned the Institute for Alternative Futures (IAF), a nonprofit futures think tank in Alexandria, VA, to assist it in this 2005 environmental scan. IAF used key phrases from the ASME vision and mission statements as a starting point for scanning and conducting an internal brainstorm on key issues with its staff of seven professional futurists. IAF selected eight potential strategic issues that could become critically important over the next five to ten years. Through further scanning and reflection, the project team narrowed the list to six. These six issues were researched and further explored through interviews with thought leaders and consultation with three additional futurists with corporate and global perspectives. This report represents IAF's learning about these issues.

This report is an introduction to these strategic issues with an analysis of the implications for ASME. IAF also evaluated the impact of these strategic issues on ASME's balanced scorecard objectives. (This assessment appears in the appendix.) Once ASME has identified which strategic issues are its highest priorities, more in-depth research and ongoing monitoring will be in order. ASME has many options for addressing each of these strategic issues. In some cases it will be possible to give work that is already underway even greater priority and resources. In other cases ASME may need to creatively restructure existing programs or create new ones with the attributes a preferred future will require.

Strategic Issues Overview: Key Issues and Driving Forces

1. Global Harmonization of Standards

The relentless requirements of global trade are pushing global harmonization of standards beyond rhetoric to marketplace necessity. Protectionism and legacy systems act as counter-forces, but the politics of international standards will yield to new approaches and business models. Ultimately global trade requires a transparent and integrated system that can keep pace with the rate of innovation.

Relentless Requirements of Trade

Major transnational companies have more than a decade of experience in operating global supply chains of products and expertise. Companies headquartered in developed economies are sourcing key functions to professional experts in India, China, Russia and Eastern Europe. Universal expectations about quality, performance, and safety have become essential to free trade. As Thomas Friedman writes in *The World Is Flat*, "…the more these supply chains grow and proliferate, the more they force the adoption of common standards between companies (so that every link of every supply chain can interface with the next), the more they eliminate points of friction at borders, the more the efficiencies of one company get adopted by the others, and the more they encourage global collaboration."[1]

The World Trade Organization (WTO) advocates international standards in its Barriers to Trade agreement. WTO has established principles for creating an international standard, but it has not endorsed specific processes or organizations. ANSI and its American standards organization members advocate for a flexible system that allows legitimate yet competing, technical approaches to be recognized. The U.S. approach is characterized as voluntary, open with systems of due process, transparent, and flexible enough to respond to market needs. By contrast, "most countries participating in international standards have a single, government-recognized and often government-funded national standards body."[2] The European Union required its member countries to harmonize to promote the free flow of products and reciprocity for testing within the region. This unified front is seen as a powerful voting block within the International Standards Organization where each member country gets one vote in deciding what to recognize as an international standard.

Protectionism Slows Down the Drive to Harmonization

Nations try to advantage their products and services in many ways. Tariffs and subsidies may get the most attention, but standards offer their own subtle advantage. Companies that meet the dominant standards in their market are not eager to retool to meet new standards or to welcome new competitors under an open system of reciprocity. In this era of international terrorism, the WTO recognizes homeland security and safety as acceptable reasons to adopt localized standards and regulations. Nationalism makes all the home teams want a home court advantage in their rules. These kinds of power plays are more likely to be exposed for what they are in an increasingly transparent world where all the actors are watching each other.

Another form of economic protectionism also works counter to global harmonization. Many established standards developing organizations have a financial stake in the sale of their standards. American standards developing organizations, operating under a voluntary, free market system, are particularly vulnerable to a decline in their market share of recognized international standards. The more dependent they are on this source of revenue, the less they can afford to advocate for global harmonization of standards if they are not likely to be *the* international standard.

A Growing Interest in Performance and Management Standards

The WTO and others advocate performance standards as the way to harmonize different standards. "A performance based standard states goals and objectives to be achieved and describes methods that can be used to demonstrate whether or not products and services meet the specified goals and objectives."[3] Performance standards evolve with new technologies and materials. They can accommodate regional differences and solutions. Prescriptive standards specify materials, design and construction methods. A hybrid performance standard might describe expected outcomes but include prescriptive standards as examples of products or systems that meet the performance standard. ASME standards "lean heavily towards being prescriptive standards."[4]

If performance standards become the norm, conformity testing will grow in importance, particularly in a global market where independent third parties are needed to assure transparency and compliance. ISO is emphasizing conformity assessment and has published standard guidelines and a code of good practice.[5] Developing economies may lack the expertise and labs to demonstrate performance and may prefer prescriptive standards that take the guesswork out of meeting global expectations.

A globalized world also needs common expectations about how businesses operate. This has led to a series of ISO management standards such as ISO 9000 which sets quality management requirements and ISO 14000 which sets environmental management requirements and processes for continually improving environmental performance. Now ISO is holding its first meeting this spring to venture into corporate social responsibility. ISO says these guiding principles are not designed to become a management standard or lead to certification, but this is another signal that companies will find it important to clearly demonstrate they are meeting emerging global expectations beyond performance, quality and safety.

Dynamic Development Process for Market Leaders

If global trade sets the pace in harmonization, then the *de facto* international standards will be those standards that evolve simultaneously with new technologies. Collaboration technologies can speed up the standards developing process. ASTM's 2005 Chairman of the Board notes that its Web technology "allows standards developers to propose a standard or revision and complete the balloting process within six months…If a standards developing organization can't respond when a group of stakeholders says [we need a standard], that group is going to go to another [standards developing organization]."[6]

To meet the high degree of proof that a standard is international, its developers have to prove inclusivity. If the only way to fully participate is attending face-to-face meetings, experts are unlikely to collaborate in many standards systems beyond their own nation or those seen as truly international. This is the basis on which centralized government standards systems say they can claim the higher ground in negotiating international standards. To the extent that these countries also invest heavily in technical assistance, they earn acceptance of their standards in government regulations and trade requirements.

Business Models beyond Intellectual Property

A few years ago Siemens' chief standards officer told the ISO General Assembly that many industrial companies including his own believe standards bodies should work toward a world where all standards are free.[7] The European Telecommunications Standards Institute makes its standards available through free downloads from its website.[8] ETSI's business model depends on substantial corporate and organizational membership fees and its members' desire to advance their own intellectual property into the prevailing global standard.

In the U.S., the Veeck vs. Southern Building Codes Congress International case ruled that intellectual property is at risk for any standard adopted into a public regulation. Open sourcing is another challenge to intellectual property. In the intellectual commons movement, contributors freely contribute to new knowledge with the expectation that any contributors are free to use the product. Their only reward is recognition for contributing something worthwhile to advance the field.[9]

ISO held discussions with four major US standards developers to examine possible working relationships. ASME assumed such a secretariat for its boiler pressure vessel standard. ISO has not decided to enter into revenue sharing with organizations that provide their intellectual property as the base document.[10] Resolving incentives and rewards will be essential to future collaborations or outsourcing arrangements in international standards development. Otherwise legacy systems will find it in their best interest to continue what has been glacial progress toward harmonization of global standards.

An alternative outcome to global harmonization of standards is just as likely. In a world where fast-moving transnational companies or regional economic interests have a compelling need to move a technology forward, they will simply set interoperability guidelines and blow by the standards developing organizations as they rush to market. Once they have sold millions of products, their way becomes the *de facto* standard without any consensus meetings or published standards documents. For many standards in the future, this is the trump card that companies who want to set the market will play to overcome the impasse now present in the international politics of standards development.

Implications for ASME: A real threat to a major source of revenue
An opportunity to refocus codes and standards

Simply stated, the "cash cow" is at risk. The new ASME Standards Technology, LLC, is a good example of how to innovate and this start-up venture should be supported. These additional strategies could safeguard ASME's leadership in codes and standards:

- **Aggressively Pursue Global Leadership.**
  - Be more entrepreneurial early in the research and development process to develop standards with new technologies, i.e. nanotechnology. This may require new strategic partnerships with other organizations, including other SDOs.
  - Increase advocacy with the U.S. government to promote global recognition of American standards developing organizations.
- **Influence De Facto Standards.**
  - Maintain a focus on serving the public interest with codes and standards that satisfy government processes, while placing more emphasis on influencing how de facto standards develop in the marketplace.
  - Become more flexible in serving customers who move quickly on a market opportunity and those industries the standards impact.

Impact on Balanced Scorecard Objectives: 11 high, 5 medium impacts
Notable High Impacts:

1. Develop new products and business development capabilities through a culture that is adaptive, continually evolving (risk taking), entrepreneurial and agile.
2. Accelerate time to market.

2. Technology Innovation Networks

Global leadership in engineering is becoming a race for brains where research and development and creative cultures foster invention and application. Networks will be able to emulate the advantages of geographic innovation clusters where industries gain "performance advantages through co-location. With a cluster, related or complementary businesses share specialized infrastructure, labor markets and services that can result in synergies, efficiencies and ultimately a critical mass of entrepreneurial and industrial strength in a region."[11]

Global Leadership in Engineering

The U.S. remains the global leader in the engineering services industry with Western Europe, Japan, Canada, Australia, Israel, and the Asian Tigers (Hong Kong, Singapore, South Korea, and Taiwan). However, China, India, Brazil, Taiwan and Russia are quickly becoming global competitors in technology and engineering.[12] When ASME examined global markets, it made "Big Emerging Markets" a priority, because corporations are outsourcing key engineering functions to these countries.[13]

China's strategy gets attention: "China's real long-term strategy is to outrace America and the E.U. countries to the top…China's leaders are much more focused than many of their Western counterparts on how to train their young people in the math, science and computer skills required for success…how to build a physical and telecom infrastructure… and how to create incentives that will attract global investors. What China's leaders really want is the next generation of underwear or airplane wings to be designed in China as well."[14]

The Race for the Brains: Accessing Human Capital

The hubs of innovation clusters are universities, their graduates and the companies they create. A study of the Massachusetts Institute of Technology's impact on innovation showed MIT graduates have founded 4,000 companies, creating at least 1.1 million jobs worldwide and generating sales of $232 billion.[15]

If the numbers of students are an indication, the U.S. and Europe are lagging in the race for engineering brains. "Of the 2.8 million first university degrees in science and engineering granted worldwide in 2003, 1.2 million were earned by Asian students in Asian universities, 830,000 were granted in Europe, and 400,000 in the U.S. …Science and engineering degrees now represent 60 percent of all bachelor's degrees earned in China, 33 percent in South Korea, and 41 percent in Taiwan."[16] The U.S. with half the world's colleges and universities still enjoys a human capital advantage if students continue to attend these schools. "New immigration controls have resulted in a 32 percent drop in the number of international student applications in 2004 and the number of foreign students whose visas were rejected rose to 35 percent."[17]

Americans make a mistake when they assume the growing number of professional jobs outsourced to other countries results solely from lower wages in these countries. This may be how the trend began, but it will be companies and organizations racing to find the expertise they need that will sustain this trend and establish a new global norm that expertise determines where the jobs go.

Fueling the Future through R&D

Long before significant innovations hit the market, some government or company invested in basic R&D to create new knowledge. Sweden, Finland, Israel, Japan and South Korea each spend more on R&D as a share of GDP than the U.S.[18] The U.S. federal government invests more heavily in life sciences than physical sciences and engineering ($28 billion compared to $5 billion).[19] While the US remains a leader in R&D, it depends on corporate funding and venture capital more than government investment to keep the pump primed in engineering.

A Geographic Place or a Network of Possibilities?

Because innovation is often described as a contact sport, clusters have typically had a geographic location. "The combustion behind innovation is inherently regional—on the ground where research, business and workers come together to turn ideas into products, processes and services. Optimizing for innovation nationally means strengthening the regional capacity for entrepreneurship."[20] The serendipity of "knowledge spillovers" is more likely with geographic proximity.

In the future, innovation networks will increasingly supplement or even replace geographic clusters because collaboration technologies reduce the need for physical proximity. While spillovers may happen more frequently in face-to-face situations, there is an increasing capacity to build virtual teams. BP has found once people have had an initial chance to interact, they can do a surprising amount of work together electronically. BP's forward strategy is to identify the 5, 10 or 15 areas where it needs technology leadership and then build a network of major clusters who have this expertise, whether these people are in Cambridge, the U.S., Russia or China.[21]

The National Innovation Initiative confirms that the "changing nature of innovation demands new knowledge and learning networks that can facilitate communications and collaboration at the frontiers of many disciplines and that can cross organizational boundaries between academia, industry and government."[22] Friedman describes the future aptly: with "new forms of collaboration made available to more and more people, the winners will be those who learn the habits, processes and skills most quickly—and there is simply nothing that guarantees it will be Americans or Western Europeans permanently leading the way… On such a flat earth, the most important attribute you can have is creative imagination—the ability to be the first on your block to figure ways to create products, communities, opportunities and profits."[23]

An Ecosystem for Innovation

The National Innovation Initiative describes the architecture of innovation as an ecosystem, "a multi-faceted and continual interaction among many aspects of our economy and society."[24] The critical success factors in this innovation ecosystem can be susceptible to a number of future variables:

- Flexible and mobile workforce. Aging populations may be less flexible and mobile.
- Stable and transparent government. The global trend toward democracy could foster the conditions for even more innovation clusters.
- Supportive regulatory frameworks. Different societies apply different values and cultural norms to the controversial edges of science and technology.
- Availability of financial capital. Foreign direct investment is a key indicator of expected rates of return and anticipated stability. National debt and the strength of national currencies also create volatility.
- Efficient use of resources. In this knowledge economy, the new wealth of nations is how well resources are managed, not how much can be extracted.
- A willingness to engage in risk taking and creative destruction to create something new. Nations and companies practicing foresight are quicker to recognize changes that favor new alternatives.

Implications for ASME: Make innovation an association priority
Become a facilitator of innovation networks

ASME has the ability to become the innovator in mechanical engineering technologies and practices and should move in this direction. This could mean developing leading edge technologies, focusing on applied innovation, or transferring existing technologies that are appropriate to developing economies.

ASME also could develop a role as an unbiased third-party convener and facilitator of innovation networks. ASME is playing this role in its work with the Department of Homeland Security. A comparable role could be assumed on a global basis. ASME can make membership more valuable by helping its members organize into innovation networks and advocating for the research and development resources to support their learning.

Impact on Balanced Scorecard Objectives: 11 high and 6 medium impacts
Notable High Impacts:

1. Become indispensable to young engineers.
2. Enable self-forming communities of interest.
3. Share best practices and lessons learned.

3. Systems Thinking

By applying systems thinking, mechanical engineering can achieve greater resource productivity to "do more with less" energy, water and materials. This is critical for meeting the global challenges of energy and water, hunger, poverty, and environmental sustainability. Improvements by a factor of 4 or even 10 are possible over the next 50 years. Mechanical engineers can play a lead role by utilizing multidisciplinary teams using a whole-system multiple-benefit approach.

Global Grand Challenges of Energy and Water

Our society faces critical challenges on energy and water over the generation ahead to make it possible for global development to continue without economic breakdown and social and political chaos.

- Global petroleum production will peak and then begin to decline steadily within the foreseeable future. The International Energy Agency (IEA) estimates oil will peak between 2013 and 2037; while more pessimistic analysts believe the peak could occur before the end of this decade.[25] The world economy must move rapidly away from dependence on petroleum, which will help solve rather than aggravate global climate change.
- Some 80 countries, constituting 40 per cent of the world's population, were suffering from serious water shortages by the mid-1990s, and it is estimated that in less than 25 years two-thirds of the world's people will be living in water-stressed countries unless major improvements are made in water technologies and management strategies.[26]

Addressing energy and water will create the capabilities needed for other major challenges including hunger, poverty, the environment and terrorism. This chart from an Institute for Alternative Futures 2004 scan found consensus on the global grand challenges that should be a priority.

HUMANITY'S TOP PROBLEMS FOR THE NEXT 50 YEARS **Richard Smalley** Rice University 1996 Nobel Prize	**HIGH NOON: TWENTY GLOBAL PROBLEMS** **J.S. Rischard** World Bank Vice President for Europe 2002	**LONG-TERM GOALS FOR GOVERNMENTS** **Woodrow Wilson International Center for Scholars** NASA-sponsored cross-government project, 2002	**STATE OF THE FUTURE REPORT** **Millennium Project, UN University** Global Challenges Assessment Delphi, 2003
Energy	Energy/ Global Warming	No human lacks access to clean water and food	End water shortages and water pollution
Water	Water Deficits	Provide clean and abundant energy	Provide clean energy for all
Food	Biodiversity and Ecosystem Losses	Eliminate major infectious and inherited diseases	End hunger

Advanced Resource Productivity

The single most important future requirement is to improve resource productivity – to cut waste, do more with less, and generate more wealth from every unit of natural resources used. Moving toward advanced resource productivity involves a conceptual revolution in engineering. Much of engineering is about using all kinds of resources more productively, but most of the technological efforts of the past century were devoted to increasing labor productivity – even if that required much greater use of energy, water and materials. Now, however, a growing number of technologists and economists are arguing that the largest opportunities for further progress involve optimizing the use of resources.

In this view, shifting the emphasis in engineering toward resource productivity can produce dramatic improvements relatively easily because resources of all kinds are used so wastefully now. Incandescent lamps convert only 10% of the electricity into light. In conventional automobiles, 80-85% of the energy in gasoline is wasted in the engine and drive train before it gets to the wheels. Over 80% of the water used for irrigation typically evaporates or leaks away before it ever gets to the roots of crops. The global economy as a whole processes a material flow of roughly a half trillion tons per year, but little more than one percent of that enormous flow ever gets embodied in a product and is still there six months after sale.[27] Focusing engineering on reducing these high levels of waste represents a new direction for technological progress that can open major new business opportunities while dramatically lowering pollution, which is really a form of material waste that should be "designed out."

The report to the Club of Rome, *Factor Four*, argued that current best practice and foreseeable engineering advances could quadruple resource productivity over the next fifty years. Much of this improvement, they argued, could be done at negative cost and much more could be made profitable by using market-oriented policies. In 1994 a group of sixteen scientists, engineers, economists, and entrepreneurs from Europe, the U.S., Japan, England, India and Canada published the *Carnoules Declaration* challenging engineers and designers to leapfrog to Factor 10, a tenfold improvement in resource efficiency.[28]

Since then, the concepts of Factor 4 (a 75% reduction in energy and materials intensity) and Factor 10 (a 90% reduction) have become part of the international dialogue among business and government leaders, especially in Europe. The European Union has recommended that governments adopt Factor Four efficiency goals as part of their commitment to sustainable development, and the governments of Norway, the Netherlands and Austria have publicly committed to achieving Factor Four. Both the United Nations Environmental Program and the World Business Council for Sustainable Development are urging governments to adopt Factor 10 as a long-range goal.

Systems Integration and Design

Advanced resource productivity requires systems integration, not reductionism. It demands optimization, not rules of thumb. It requires multidisciplinary teams doing extensive work at the front end of projects to find strategies that optimize "whole systems" instead of parts. Traditional design approaches often result in optimizing components for single benefits rather than whole systems for multiple benefits. A whole-system multiple-benefit approach to design and engineering is the only way to jump beyond incremental improvements to Factor 4 or Factor 10.

A number of recent works including *Natural Capitalism*[29] by Paul Hawken and colleagues in the U.S., the *Manifesto for Ecodesign*[30] by Ryoichi Yamamoto at Tokyo University and the "Report On An Eco-Design Training Program for 50 Small and Medium Sized Enterprises"[31] by Friedrich Schmidt-Bleek in Germany set out principles for this approach to engineering and design. They also give examples of engineering applications in automobile design, fluid handling and air handling, drive power, lighting, HVAC systems, building design, irrigation, and industrial water use. Amory Lovins and colleagues at the Rocky Mountain Institute are initiating a multi-organization project, including several U.S. national laboratories, to develop casebooks illustrating and explaining this approach.[32]

New Systems and Retrofits

Dramatic improvements in resource productivity are easiest to achieve in new systems. This means that China, India, Mexico and other developing nations have an opportunity to move ahead of the U.S. in several areas of technology, as occurred when they leapfrogged over older material-intensive telecommunication technology and embraced wireless networks. Their economic development will go more smoothly, swiftly and safely to the extent that they make advanced resource productivity the centerpiece of their technological progress.[33]

While the U.S. and other industrial nations also have many opportunities to install new systems, they face challenges of renewing and retrofitting existing technical systems to increase their efficiency. This is an area where much more research is needed. More attention is also needed to the design of systems with the capability to absorb new technology in order to extend their practical life spans and increase the amortization of development and construction costs. Many servers today, for example, are built to be upgradeable, allowing components to be easily placed or pulled without interrupting the network.

Implications for ASME: Make the paradigm shift to systems thinking
Accept a grand challenge

Mechanical engineers and ASME need to embrace the importance of systems thinking to meet the demands of a complex world reflected in these strategic issues.

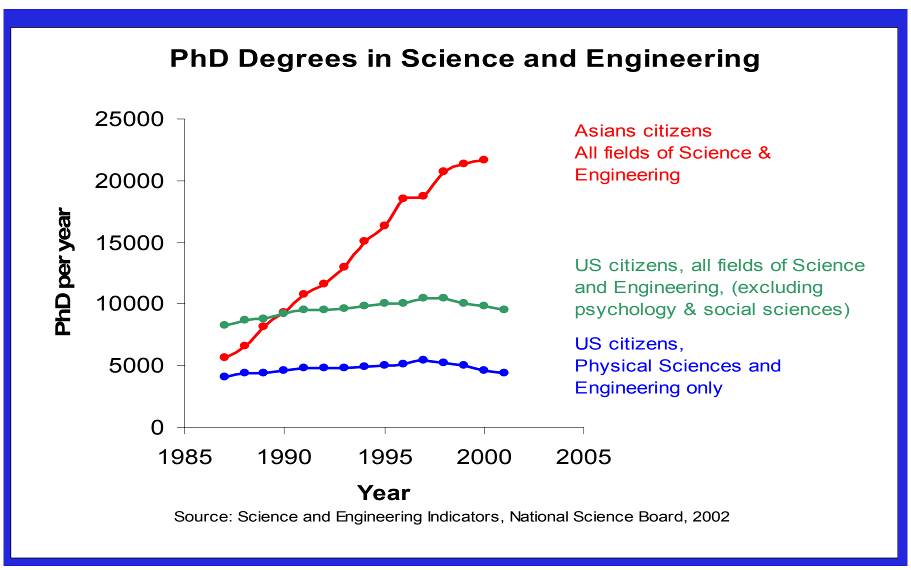
ASME is shifting from a focus on the parts to seeing the whole with its Continuity and Change initiative. ASME needs a new core of volunteers who may not be emerging from the current association structure, including corporate CEOs and people who may be outside the engineering team.

ASME needs to take the initiative and be the convener of a grand challenge to inspire the membership and attract people into mechanical engineering. Examples of grand challenges include resource productivity, sustainability and energy.

Impact on Balanced Scorecard Objectives: 4 high and 13 medium impacts
Notable High Impacts:
1. Identify and address future markets and applications.
2. Grow revenue through new products and global growth.

4. Attracting and Educating Tomorrow's Engineers

A fundamental challenge for mechanical engineering and engineering in general in the U.S. and Europe is how to attract more young people to the field. The overall production of engineers and physical scientists in the U.S. is not keeping up with the needs and opportunities in the economy, even though these fields are the basis of most wealth creation.



Nobel Laureate Richard Smalley, professor of Physics and Chemistry at Rice University, argues that "We need a New Sputnik Event or galvanizing mission to inspire U.S. citizens into the physical sciences and engineering."[34] Smalley regularly asks audiences to nominate the world's most important and difficult problems, and always finds that problems such as energy, water and the environment top the resulting list. He argues that engineering schools need to articulate an exciting, positive vision of the contributions that engineering can make to meet these global challenges. If Smalley is correct, the future of mechanical engineering may depend on how well the profession can appeal to young people's idealism and desire to contribute to something truly worthwhile.

The Educational Challenge

Students attracted to mechanical engineering today will work in a future of rapid change and innovation, multidisciplinary project teams, and advanced information technology. Biology will be increasingly central to many areas of engineering, and manufacturing, energy, transportation, and agriculture will all be going through a technological transformation to use energy and other resources more efficiently and minimize impacts on the environment. The challenge of educating tomorrow's engineers to succeed in this kind of environment is perhaps the greatest challenge facing the engineering professions today.

A Premium on Creativity

As the routine technical tasks engineers once performed are increasingly carried out by machines, creative skills will be more essential to gaining a competitive advantage.[35] A growing number of engineering schools are giving students both course work and hands-on practice in creative innovation.[36] The Mechanical Engineering Department at the University of Virginia has been a leader in this area. It offers two courses, "Invention and Design" and "Creativity and New Product Development," which immerse students in creative design problems.[37]

Putting a premium on creativity will challenge engineering schools to change their organizational cultures to reduce students' "fear of mistakes" in creative endeavors. In traditional approaches to teaching, student's mistakes are judged as "failures." But in organizational cultures dedicated to rapid innovation, taking risks, running experiments, making mistakes, catching them quickly, and learning all one can from them is the approach most likely to succeed. Silicon Valley during the 1990s exemplified how the pace of innovation accelerates when there is a willingness to try new things, risk mistakes, and learn from them.[38]

A Field of Teams

Tomorrow's most successful engineers will be those that are effective team players. Technical systems are becoming too complex for one engineer to design or understand. Engineering projects are increasingly performed by teams of workers, many of whom are not engineers.[39] Engineers need to be able to work and communicate their ideas in multidisciplinary teams. Institutions have begun to recognize the need for educating engineering students about team dynamics. Students at Rensselaer Polytechnic Institute, for example, are required to take modules in leadership and professional development which address the basic requirements for well-functioning teams, provide team-work experiences, and provide opportunities to make team presentations. [40]

Multidisciplinary Engineering

Teams involved in complex engineering projects typically include people trained in many different fields of engineering and require some members whose knowledge bridges across different fields. Several large engineering universities, including Purdue University, Boston University and The Cooper Union now allow students to major in "interdisciplinary engineering", which permits them to integrate the study of engineering with mathematics, science, another engineering discipline, business, biomedicine, or other fields. [41]

Corporate managers also increasingly expect engineers to have a basic understanding of business finance, business plan development, budgeting and financial analysis.[42] The Enterprise Program at Michigan Technological University attempts to equip students with business skills and real life problem solving skills. Students enroll for six semesters and work in business-like settings to develop solutions to real world problems supplied by industry.[43] The Learning Factory, a concept pioneered in 1994 by Penn State University, the University of Washington and the University of Puerto Rico-Mayaguez, is a well known example of an industry/university partnership designed to integrate design, manufacturing and business realities into the engineering curriculum. The centers provide a space where multidisciplinary teams of students can work on real engineering projects prior to workplace entry.[44]

Growing Biology

Rapid developments in biofuels, bio-based materials and catalysts, and a whole new emerging realm of bio-production or industrial biotechnology insure that biology will play an increasingly important role in many areas of engineering. Schools like Virginia Tech, have begun to offer programs in Biological Systems Engineering[45]. In 2004, Rensselaer Polytechnic Institute created a new course in biology and made it a required course for all engineering students. It is an unconventional course that aims to give students an overview of relevant areas of biology and how they can be applied to engineering.[46]

Green Engineering

The only way to reduce environmental impacts while accommodating population growth and achieving economic growth is to bring about a wholesale transformation in the technologies that today dominate manufacturing, energy, transportation, and agriculture. This is the fundamental reality driving the emergence of "green" or environmentally advanced engineering. Green engineering aims to use energy and materials more efficiently, minimize waste and pollution, find substitutes for toxic materials, and develop cradle-to-cradle designs that treat "waste" from any one process as "food" for another. It goes beyond "environmental technology" in the conventional sense (cleanup technology such as flu gas scrubbers or catalytic converters for auto exhaust systems) to address the challenge of making *all* technologies more environmentally benign.

Virginia Tech is one of the schools making major curriculum changes to foster this approach to engineering. Interested students can obtain a recognized concentration in Green Engineering in addition to their primary engineering degrees. New Green Engineering core courses have been developed along with new interdisciplinary elective courses. In addition, several required courses, including the university's introductory course in engineering principles, have been modified to include substantial "green content." The University of California-Berkeley, MIT, the University of Michigan and other schools are creating programs in related areas such as green design and manufacturing, green business practice, and industrial ecology.[47]

Information Technology for Learning and Practice

Engineers need to graduate with proficiency in the use of modern information technologies. Design, project management and other fundamental aspects of engineering practice are now largely software-based. In an increasingly global economy, more and more projects will involve virtual collaboration. Moreover, whatever specialty within engineering one is pursuing, there are communities of interest somewhere on the Internet sharing their knowledge and experience.

Increasingly sophisticated simulations and models will play a growing role in engineering education and practice. Design simulations cost much less than a large physical design center and give engineering students the opportunity to work with tools and systems that are too large and expensive to actually have on campus. The University of Oklahoma has created the simulation "Sooner City" for its civil engineering students. Students virtually design steel structures and participate in virtual surveying. The resulting Sooner City is a virtual city; a combination of all students' simulated designs viewed in three dimensions over the web.[48] In engineering practice, simulations will be increasingly important in areas like virtual prototyping and design-for-the-environment.

Lifelong Learning

Because engineering changes so rapidly, institutions must be in place to provide engineers with lifelong continuing education. It is estimated that 70 percent of the engineers that will be in the workforce in 2020 are already in the workforce today. Due to low rate of entry of new engineers in the U.S., current engineers need to continuously acquire new skills and knowledge in order for the nation to remain competitive.[49] To meet this challenge, employers need to develop in-house training programs and educational institutions need to involve engineers from industry in planning curricula for continuing education. State licensure boards need to develop practical guidelines for lifelong learning requirements for professional engineer licensure.[50] Currently 29 states have set annual or biennial requirements for the number of continuing education hours an engineer must pursue in order to remain a licensed professional. [51]

IBM offers an example of what needs to be done. IBM offers over 2,000 web-based courses, provides career planning guidance for its employees on its human relations website, and offers interactive simulations targeted at employees designed to build skills in key areas of management.[52] The Massachusetts Institute of Technology is another example of innovation in lifelong learning for engineers. It makes its course content openly available online and provides free on demand video, searchable by keyword, covering significant MIT public events.[53]

Implications for ASME: Recruiting students is a U.S. challenge
Identifying curriculum priorities

Recruiting students is a problem only in the U.S. and Europe. Asian countries may be more successful because students have greater awareness of how engineering contributes to the economy and quality of life. U.S. students may not understand the opportunity for meaningful careers in engineering. These additional observations were offered:

- ASME needs to define the metrics for success in recruiting students.
- Partnering with other engineering associations may be the best strategy.
- Recruiting women to engineering would have the greatest impact on the number of students.

ASME could play a greater role in identifying relevant curriculum priorities as it did with design, sustainability and teamwork. Other new opportunities include:

- Taking advantage of the jumpstart that advanced placement credits give most students on basic knowledge to introduce more interdisciplinary learning, such as biology, systems thinking and integration engineering, and business knowledge such as entrepreneurial skills.
- Becoming a third-party credentialing organization for education institutions and programs anywhere.
- Acting as a resource to academic programs in other countries, i.e. China.
- Operating a for-profit university.

Impact on Balanced Scorecard Objectives: 7 high and 9 medium impacts
Notable High Impacts:

1. Continue to serve our core customers, such as Academia.
2. Increase/expand market-relevant content.

5. Collaborative Learning Communities

Learning is the new currency of social networks as peers use collaboration technologies to create open access to the world's knowledge and creativity. These collaborative learning communities are creating the conditions for a 21st century renaissance.

Social Networking

New ideas and practices spread through social networks. Social network researchers find that the more open networks are with "weak ties" among the individuals, the greater their capacity to exchange a wider range of information. There are now more than 200 social networking sites on the Web that help connect people, such as Friendster, Tribe.net, and LinkedIn. Some of the online features of these networking sites are automatic address book updates, viewable profiles, and the ability to form new links through "introduction services".[54]

Individuals and organizations that bridge between two or more networks amplify the knowledge and extend the relationships within multiple networks.[55] While communities of practice are definitely social networks, they may not have the degree of diversity that fosters the interdisciplinary learning so essential to the future of science and engineering. The future architecture of online learning communities will network people who are drawn to shared challenges, but who may bring very different knowledge and experience.

Open Access to Knowledge

The explosion of content available through the Web has forever changed public expectations about access to knowledge. An intellectual commons is emerging where collaborators offer open access to their intellectual property and invite their peers to help refine their thinking. This accelerates research and invention and makes learning a community process. The intellectual commons runs on social capital with all participants expected to share their best thinking and knowledge.

MIT astonished educators everywhere when it elected to put up every course, syllabi, lecture notes and quizzes for its 1,800 courses. MIT uses free chat room software in some course sites designed to highlight comments rated as valuable by the users. Now many other colleges are converting a few courses each year.[56]

Typical of the free software and open-source movement, Creative Commons offers a system of flexible copyrights that allows creators to make their works of all types available free for certain uses. Creative Commons' stated goal is to "not only increase the sum of raw source materials online, but also to make access to that material cheaper and easier." In this system of reserved rights, people accept credit for their work in exchange for the opportunity to build greater awareness of their ideas and creativity.[57]

The Public Library of Science is opening the doors to scientific and medical literature once confined to expensive professional journals. PLOS is a nonprofit of scientists and physicians committed to making the world's scientific and medical literature a public resource. Its chairman is former National Institutes of Health Director Harold Varmus, also a co-recipient of the Nobel Prize. All materials in the five journals are published under an open access license.[58]

Perhaps the most exciting possibilities for open access are in the National Science Foundation's vision of a cyberinfrastructure that enables grid communities or collaboratories. What NSF envisions is "ubiquitous, comprehensive digital environments that become interactive and functionally complete for research communities in terms of people, data, information, tools and instruments that operate at unprecedented levels of computational, storage and data transfer capacity." As an NSF panel noted, this vision "also has profound broader implications for education, commerce, and social good." [59]

Scientific and technical publishing is moving toward "more of a continuous-flow model… Raw data, processed data, replays of experiments, and deliberations that are mediated through a collaboratory can be captured, replayed and re-experienced. Working reports, preprint manuscripts, credentialed or branded documents, or even post-peer-review annotated documents can now become available at varying times to different people with diverse terms and conditions."[60] Under this approach, peer review moves to an open review and rating system that weds a continuous critique with the content. These preprint services and open archives face intense opposition from traditional journal publishers with a subscription-based business model.

The future is already present in Wikipedia, which describes itself as the free content encyclopedia anyone can edit. Started in 2001, it already boasts a half million articles. Wikipedia has a platform that allows registered users to collaborate in writing and revising the content. It also makes effective use of hyper-text to guide the learner to related knowledge. This hyper-linking makes use of the Web's capacity for multimedia learning. Just as the encyclopedia was once the introduction to new subject areas, Wikipedia has become a platform for professionals to explain their field to the general public. Here is Wikipedia's definition of mechanical engineering:

> **Mechanical engineering** is the application of physical principles to the creation of useful devices, objects and machines. Mechanical engineers use principles such as heat, force, and the conservation of mass and energy to analyze static and dynamic physical systems, in contributing to the design of things such as automobiles, aircraft, and other vehicles, heating and cooling systems, household appliances, industrial equipment and machinery, weapons systems, etc.[61]

Participatory Media

In this era of participatory media, the people can now be their own reporters, writers, publishers, directors, and producers. Blogs and podcasting, downloadable radio based on MP3 technology, are the hottest forms of participatory media now, but what they signal is a profound and permanent shift in communications that will take many future forms. A generational divide is opening up in which younger people like the engaging and multi-media style these new forms offer. A recent CNN/USA Today/Gallup poll found that 56% of Americans haven't heard of blogs and only 3% read them daily. But 44% of online Americans aged 18-29 are reading them often.[62]

Business Week offers this assessment of how different the future will be for established media: "In a world chock-full of citizen publishers, we mainstream types control an ever- smaller chunk of human knowledge. Some of us will work to draw in more of what the bloggers know, vetting it, editing, it and packaging it into our closed productions. But here's betting that we also forge ahead in the open world. The measure of success in that world is not a finished product. The winners will be those who host the very best conversations."[63] Rupert Murdoch advised the American Society of Newspaper Editors that news providers "become places for conversation" where the people "engage our reporters and editors in more extended discussions."[64]

Traditional publishers scoff at the quality of these citizen publishers, and pragmatists question whether people will commit free labor to consistently deliver a valuable product. In a world where people measure success by their standing in their social network, global recognition may be more than enough for some people. "Most blogs are open to the world. As the bloggers reach each other, comment and link from one page to the next, they create a global conversation.[65]

Implications for ASME: Acknowledging peer review is a product
Understanding what open access means to revenues

Peer-reviewed engineering articles and resources are a value-added service to members who rely on the validity of ASME information and an important benefit for academic members under existing tenure systems. With the growing use of adjunct professors, this need may decline.

Publishing under the current model is ASME's second largest source of revenue and the association's dependence on it impedes its ability to consider alternative approaches. ASME should take care not to become a closed system in a world favoring open systems for learning and publishing. As public attitudes shift, ASME will need a viable balance between its "bricks and mortar" programs and electronic channels. These collaborative learning communities are appealing to young engineers who need technical information on demand to do their jobs and appreciate the chance to stand out for their expertise. Members may also value access to discussions with a wide variety of experts.

Impact on Balanced Scorecard Objectives: 15 high and 2 medium impacts
Notable High Impacts:

1. Stimulate individual membership growth with different membership models.
2. Digitize and repackage content.

6. Bioconvergence: Biology Meets Engineering

Biotechnology is the use of cellular and biomolecular processes to solve problems or make useful products. A first wave of developments in biotechnology primarily affected health care. A second wave focused on agriculture. And now a third wave of *industrial biotechnology* is moving forward.[66] This third wave will have much larger impacts on all the traditional engineering disciplines than the earlier developments in health and agriculture.

Several areas of industrial biotechnology are already successfully competing with traditional manufacturing, and progress in this area is a key to achieving industrial sustainability. Spiders make webbing as strong as Kevlar but much tougher from biological digestion of flies without needing boiling sulfuric acid and high-pressure extruders. The abalone assembles inorganic materials into an inner shell twice as tough as ceramics without using a furnace.[67] Learning to understand and emulate such energy-efficient, low-temperature, low-pressure biological processes will have revolutionary impacts on materials science and all areas of engineering.

Biotechnology and Engineering

The powerful convergence between biology and engineering is creating ideas and products that reach into every aspect of society. Examples of the explosive growth and diversity of new areas of expertise include:

Bioagricultural Engineering	Bio-catalysis
Biochemical Engineering	Bio-energy, Bio-fuels
Bioinformatics	Biomaterials
Bionanotechnology	Biopharmaceuticals
Bioreacting Engineering	Bioremediation Engineering
Bioprocessing Engineering	Biosensors Engineering
Biological Systems Engineering	Genetic Engineering
Metabolic Engineering	Molecular Engineering
Protein Engineering	Tissue Engineering

Engineers are playing an important role in creating the basic tools of biotechnology such as the molecular imaging devices, high throughput analyzers and the computer tools and databases for making sense of huge amounts of data. And engineers are playing an even larger role in translating advances in bioscience into new processes and products through applied research, design and manufacturing. These include biomonitoring devices, bioremediation solutions, bioplastic materials, and new manufacturing facilities for producing biological drugs, biomaterials and biofuels.

The Scale of the Biotechnology Enterprise

Biotechnology is undergoing a technological revolution like that of IT in the 1970s, based around dramatic new capabilities (e.g. in genetic sequencing and manipulation) similar to those occasioned by large-scale integration. Despite false starts, it has reached a critical mass for exponential growth in terms of knowledge, infrastructure, financing and convergence with other disciplines. Engineering is becoming a major player in facilitating this process, while insights and products of biotechnology are dramatically changing the materials and processes of engineering. These forces in turn are changing the education and careers of engineering professionals and the fates of professional societies.

In 2002 there were 1,466 biotechnology companies in the U.S. with 194,600 employees and $29.6 billion in revenues (up from $8 billion ten years earlier). Market capitalization was $311 billion in 2004.[68] Biotech companies spent $20.5 billion on R&D in 2002, and about half of the federal government's $56 billion of nondefense research funding in 2004 went to the life sciences.[69] A complex system of research and innovation is evolving with strong collaborations between universities, industry and government labs. A powerful catalyst for growth is the healthcare industry, the largest segment of the American economy with 15.7% of GDP in 2005.[70] Europe, with the United Kingdom in the lead, has about the same number of biotech companies as the U.S., although the U.S. spends three times as much on R&D and raises three to four times as much in venture capital.[71] Japan has the most developed biotech industry in Asia, but South Korea, Singapore, Australia, India and China are making major governmental and private sector commitments. Both India and China have well developed universities turning out over a million scientists and engineers a year and are rapidly developing research and industrial capacities.

The shift of research funding into the life sciences has spurred universities to expand research in a broad range of biosciences. There are over 276 bioengineering degree programs in 122 academic institutions in the U.S. While the 12,400 undergrad and 4,100 graduate bioengineering students represent less than 4% of all engineering students, their numbers have doubled in four years.[72] Job growth for bioengineers in the U.S is projected to increase 26.1% by 2012 compared to a 14.8% growth in engineering jobs overall.[73]

Key Issues for Bioconvergence

- **New engineering professions** – The four traditional disciplines in engineering have spawned their own bioengineering degree programs and cadres of bio professionals. However, the field is evolving so fast that new separate disciplines of bioengineering are likely to emerge. Many hybrid and new specialties are likely to arise. There may be difficulties in establishing appropriate career structures, professional associations and credentials.

- **Changes to professional education** – Biotechnology courses will become a necessary part of traditional engineering education. Educators are working on standardizing a core curriculum for bioengineering, and the field could divide into at least two large categories: biomedical and biological engineering. The rapidly enlarging knowledge base and interdisciplinary nature of biotech is forcing novel changes in teaching techniques.

- **Challenges to professional societies** – New expectations and new competitors are creating new bioengineering associations and novel ways of disseminating information and providing services to professionals.

- **New disciplines need public acceptance and societal ethical standards** – European rejection of genetically modified foods and Americans' concerns over drug safety are two examples of how important it is to effectively communicate with the public and to work with policy makers in establishing ethical standards to prevent a societal backlash and ensure investor support.

- **Globalization** with its diverse expectations, opportunities and lower cost competitors already is a major force shaping biotechnology. America's lead will face many challenges from countries that are turning out skilled engineers and scientists.

- **Risk Assessment and Communication** – The issue of risk assessment is likely to rise on the agenda, and improved capabilities for dealing with bio-risks will be demanded in many engineering professions. There will be an important role for communication about science, technology and engineering, as the applied biosciences involve complex techniques that are difficult for lay audiences to understand.

Implications for ASME: Exploring biology as the grand challenge
Creating a collaborative learning community

ASME should consider the possibility for a convergence of an engineering view in biology that makes understanding biology a potential grand challenge. Since it can be easier to teach biology to engineers than engineering to biology majors, ASME should promote adding a biology course to the engineering curriculum. ASME also should consider reaching out to medical societies and other related professions to explain mechanical engineering's contribution to bioengineering knowledge and explore forms of cooperative membership.

To learn more about bioconvergence, ASME could create a collaborative learning community. Since bioengineering represents future growth, ASME may want to give additional resources to these communities of practice or forums. Other technical divisions should be encouraged to look at how biotechnology will become an important part of their professional spheres.

Impact on Balanced Scorecard Objectives: 5 high and 11 medium impacts
Notable High Impacts:

1. Identify and address future markets and applications.
2. Increase/expand market-relevant content.

Appendix

Impact Analysis of Strategic Issues on ASME Balanced Scorecard Objectives

Note: Marsha Rhea, CAE, IAF senior futurist, made this assessment of how the 2005 environmental scan strategic issues affect the balanced scorecard objectives. The ASME Strategic Issues Committee and staff liaisons reviewed this assessment and found it to be reasonable.

Strategic Objective	**Global Harmonization of Standards**	**Technology Innovation Networks**	**Systems Thinking**	**Educating Tomorrow's Engineer**	**Collaborative Learning Communities**	**Engineering's Contribution to Bio-Convergence**
Continue to server our core customers, such as Academia	M	M	M	H	H	H
Become Indispensable to Young Engineers	L	H	M	H	H	M
Enhance relevance to industry and government	H	H	M	M	H	M
Identify and Address Future Markets and Applications	H	H	H	M	M	H
Grow revenue through new products and global growth	H	H	H	M	H	H
Sunset lower value programs	H	M	M	H	H	M
Run a cost effective operation	H	M	M	L	M	L
Enable self-forming communities of interest	M	H	M	M	H	M
Stimulate individual membership growth with different membership models	L	H	M	M	H	M
Increase/Expand market-relevant content	H	M	H	H	H	H
Digitize and repackage content	H	L	L	H	H	L
Accelerate time to market	H	H	M	M	H	M

Strategic Objective	Global Harmonization of Standards	Technology Innovation Networks	Systems Thinking	Educating Tomorrow's Engineer	Collaborative Learning Communities	Engineering's Contribution to Bio-Convergence
Provide effective representation and advocacy for the engineering profession	H	H	M	M	L	M
Improve coordination and effectiveness of corporate communications	M	H	M	L	H	M
Develop new product and business development capabilities through a culture that is adaptive, continually evolving (risk taking), entrepreneurial and agile	H	H	M	M	H	M
Develop future volunteer leaders	M	M	M	H	H	M
Strengthen environmental scanning and competitive intelligence	M	M	M	M	H	M
Share best practices and lessons learned	H	H	H	H	H	H
Potential Importance	**H=11** M=5 L=2	**H=11** M=6 L=1	H=4 **M=13** L=1	H=7 **M=9** L=2	**H=15** M=2 L=1	H=5 **M=11** L=2

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