2028 Vision for Mechanical Engineering

A report of the Global Summit on the Future of Mechanical Engineering

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ASME
SETTING THE STANDARD

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Mechanical engineering will evolve and collaborate as a global profession over the next 20 years through a shared vision to develop engineering solutions that foster a cleaner, healthier, safer and sustainable world.

ASME convened more than 120 engineering and science leaders from 19 countries representing industry, academia and government to a global summit in Washington, D.C., April 16-18, to imagine what mechanical engineering will become between now and 2028. They examined the grand challenges confronting our world and aspired to be at the fore-front of developing new technologies to address energy, environment, food, housing, water, transportation, safety, and health. They underscored the joy of discovery, creation and application of engineering solutions that improve human life. They affirmed that the benefits of mechanical engineering must reach everyone through global partnerships and locally appropriate development.

The Summit participants identified the need to create greater public awareness of the essential contributions of engineering to quality of life consistent with a sustainable world. Other critical choices the profession must make on this path to the vision include focused efforts to improve:

- Advocacy to influence political decision making on issues related to science, engineering and technology;
- Multi-disciplined and systems engineering approaches to multi-scale systems;
- Partnerships among academic, industry and government to expand research and development and develop the next generation of engineers, and
- Lifelong learning for globally competent engineers and engineering leaders.

ASME selected speakers and invited leaders who could give a global context to the 2028 vision. Participants worked to understand how the profession might respond to the grand challenges and what critical knowledge and competencies mechanical engineers will need over the next 20 years. Through these discussions, they identified the key elements of the 2028 vision, what the critical path forward might be, and what critical uncertainties must be anticipated. ASME offers this summit report, speaker presentations and futures research to the global mechanical engineering profession, its various professional societies, engineering leaders, industry, academia, governments, and the public as a resource. This 2028 vision can be the beginning of a great collaboration to give the world what it needs most from mechanical engineering between now and 2028.

A 2028 VISION CALLS MECHANICAL ENGINEERING TO GRAND CHALLENGES AND GREAT CONTRIBUTIONS

2028 Vision for Mechanical Engineering

Technology Serving People

Strategic Themes For Mechanical Engineering

- Developing new technologies to meet grand challenges in energy, environment, food, housing, water, transportation, safety, and health
- Creating global, sustainable engineering solutions that meet the basic needs of all people
- Fostering global partnership and locally appropriate development
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In three rounds of intense group discussion over two days, the participants in the Global Summit on Mechanical Engineering worked toward one outcome: defining the elements of a shared vision that will keep the profession at the forefront of grand challenges and great contributions over the next 20 years. They sifted through many priorities and possibilities and collaborated to express shared aspirations for mechanical engineers worldwide. This is the vision at the heart of their hope for the future: *Mechanical engineering will develop engineering solutions that foster a cleaner, healthier, safer and sustainable world.*

Mechanical engineers are critical to technologies that serve people. They are widely represented in both the traditional and alternative energy industries. They have the knowledge and skills needed to design new energy sources, make existing energy sources cleaner and improve the efficiency of current and emerging technologies.

Mechanical engineers can be at the forefront of developing new technology for environmental remediation, farming and food production, housing, transportation, safety, security, healthcare and water resources. In doing so, engineers can create sustainable solutions that meet the basic needs and improve quality of life for all people around the world.

As they create these engineering solutions, mechanical engineers will need to be mindful of the experience of previous generations. The growth of nations like China and India provide wonderful opportunities for everyone. However, bringing more than a billion people into the global middle class will tax the world's resources and environment if we repeat the mistakes previous countries made during the process of industrialization.

Helping these countries develop sustainably is not just a challenge for them, but a challenge for the world and for mechanical engineering as a profession. It will require new, cleaner technologies, new social systems to share the burden of developing sustainably and a new understanding in developed nations of quality of life. As one breakout group participant remarked, "developed nations cannot dictate to developing nations that they don't also have a right to the amenities of modern life."

Mechanical engineers will need new knowledge and skills to implement systems engineering approaches across multi-scale systems. New simulation software designed to mimic the emergent properties of complex systems will help mechanical engineers anticipate system requirements and outcomes.

A 2028 VISION CALLS MECHANICAL ENGINEERING TO GRAND CHALLENGES AND GREAT CONTRIBUTIONS

Significant public support will be needed to meet the grand challenges and mechanical engineers must be plugged into the political system. Mechanical engineers need to make sure the public and policy makers are aware of the capabilities mechanical engineers offer to a sustainable world. In the highest levels of government in the United States and other countries, there is a lack of policy makers with science or engineering experience. In partnership with other science and engineering professions, mechanical engineering will need to make sure policy makers have the knowledge and skills to make informed decisions regarding science, engineering, technology and innovation.

One participant observed that "engineers create that which never was." In meeting the grand challenges facing society, mechanical engineers have the opportunity to tap into the creativity that makes the profession special. The profession can convey the joy of discovery that has always been inherent in the great mechanical engineers throughout history to the next generation. As the profession demonstrates its ability to contribute to a better human experience, young people will be drawn to a career where practitioners experience the joy of turning tough problems into breakthrough solutions serving all people.

CRITICAL CHOICES ON THE PATH TO THE 2028 VISION

Achieving this 2028 vision for mechanical engineering will require professional organizations and leaders to make a number of critical choices. As one summit participant commented on an expanding list of critical choices in his discussion group, "these are not really choices, but things mechanical engineering must do." They should be viewed as part of a critical path the profession must follow to create the engineering solutions expressed in the 2028 vision.

Increase Public Awareness. Engineering organizations are obliged to provide clearly-stated, objective, scientifically-based, and technologically sound information that clearly defines risk versus reward and benefits versus consequences of new technologies as they affect all people across the globe. It is also incumbent on these organizations to explain the potential of the engineering profession, more than any other established profession, to improve the quality of life for all people.

Update Lifelong Learning. Because of the accelerating rate of change in the development of new scientific discoveries and technological breakthroughs, the current practices of universities and professional societies are not adequate to prepare globally competent engineers and engineering leaders. How can these institutions, as currently structured, prepare students for jobs that don't yet exist and use technologies that have not yet been invented, in order to solve problems that have yet to be defined? What should be the core knowledge of the discipline to meet future requirements? What learning strategies will be most effective in engaging young people in learning basic technical knowledge and in acquiring higher order thinking skills to innovatively solve problems? What will be the processes for lifelong education to help all mechanical engineers stay current with technological advances and increasingly complex systems? There is an urgent need to address these questions in a collaborative way that strengthens a global engineering workforce.

Take Leadership Seriously. Mechanical engineers must accept a new imperative to take a leadership role in political, social, industrial, professional and cultural arenas to bring the engineer's perspective to larger social issues. Diverse pathways are needed for engineering leaders that encourage diversity in the profession and attract and retain the best and brightest people. Recruiting this talented engineering workforce is becoming a challenge in most countries.

Advocate for Informed Public Policy Decisions. Many global priorities will compete for public attention over the next 20 years. Mechanical engineering leaders and the organizations with whom they are affiliated must advocate for informed decisions and serious investment related to science, engineering and technology or else watch while the global capacity to solve the grand challenges is compromised. Mechanical engineering leaders must equip themselves to educate decision makers and influence the critical choices (e.g., risk versus reward, benefits versus consequences) society must make in the areas of innovation and sustainability.

Lead in Multidisciplinary and Systems Engineering Approaches. No one country, sector or profession will be able to address the grand challenges alone. The complexity of advanced technologies and the multiple scales (dimensions of size and time) at which systems now interact require engineers, scientists, social scientists, economists and many other professions to collaborate in developing multidisciplinary solutions. Mechanical engineering must be at the forefront of implementing systems engineering approaches across multi-scale systems.

Develop Partnerships and Collaborations. A global spirit of collaboration and partnership is essential to achieving the 2028 vision. Mechanical engineering will need to embrace partnerships among industry, government and academia to support and expand research and development and recruit and educate the next generation of mechanical engineers. Events like the Global Summit on the Future of Mechanical Engineering and other initiatives to convene key stakeholders within the global community will help create the camaraderie and consensus to rally behind a shared vision.

PREPARING FOR THE CRITICAL UNCERTAINTIES AHEAD FOR MECHANICAL ENGINEERING

Achieving a better future for the profession will require foresight, patience and preparation among the profession's leaders. Mechanical engineers must monitor and manage changing conditions as they strive to create engineering solutions for a cleaner, healthier, safer and sustainable world. Our interconnected world demands international will and cooperation, thoughtful decision-making that places global interests ahead of national interests on the part of all nations, across different cultural traditions and political systems. The profession must evolve as world population grows and greater migration makes mechanical engineering a global profession.

Natural or man-made calamities, such as the 2008 tragedies in Burma and China or 9/11 in the United States in 2001, can have a tremendous impact on future developments. World response to such events and conflicts can change the course of the future and determine the challenges policy-makers tackle first.

The ecosystem is complex and its tipping points are not well understood. We do not know how much time we have to create the solutions that ensure sustainability. Global resources, related to energy and water, are already stressed and likely to be more so as the population grows to more than eight billion people. The requirements for infrastructure and social programs for this growing global population will be great.

Having the resources needed to deal with the grand challenges is anything but certain. Will society have the will to make the necessary investments in research and development? Will today's leaders invest in education systems that enable young people to be educated in the technical disciplines?

Technological choices can have unintended ethical, environmental and social consequences. Will mechanical engineering be ready to provide wise leadership to navigate these challenges? The future decisions of policy-makers on issues such as regulation, liability and intellectual property will have a tremendous impact on technology development and the global economy.

Critical Uncertainties for Path to the 2028 Vision

- **Will there be the will to make the choices and investments for the grand challenges?**
- **Will there be sufficient international cooperation to address the grand challenges?**
- **Will we enable young people to be educated in the technical disciplines?**
- **What will be the response to future conflicts and natural disasters?**
- **How will national regulations and international conventions impact technology development?**
- **How will population growth and migration impact engineering?**
- **How much time do we have to address environmental priorities?**
- **Will societies build on lessons learned?**
- **How will mechanical engineering adapt to a multi-disciplinary world?**

Change is not predictable in any dynamic system. Mechanical engineering will need to monitor the rate of change across key systems such as education, industry and society. While technologies may move at a surprising rate of change, institutions, cultures and economies can be slower to change.

As many of the speakers reminded the Summit participants, mechanical engineering should look to its history of accomplishments and lessons learned to inspire the next generation of problem solvers. Yet the grand challenges of energy, water and food are great at the global scale and they must now be addressed. Whenever society has needed great contribution from mechanical engineering in the past, the profession has stepped up to the challenge. All that will be different in 2028 is the increased scope of the challenges and the increased number of people who will be living in a cleaner, healthier, safer and sustainable world because mechanical engineers believed they should.

ANTICIPATING THE GRAND CHALLENGES AND 2028 WORLD OF MECHANICAL ENGINEERING

Mechanical engineers design the solutions that generate economic development for communities and countries and contribute in tangible ways to a society's quality of life. Two grand challenges for the next 20 years captured the imagination of the Summit participants, developing sustainably and engineering solutions for all, and inspired this 2028 shared vision: ***Mechanical engineering will develop engineering solutions that foster a cleaner, healthier, safer and sustainable world.***

Mechanical engineers with a decade or more of experience can attest to how much their world has changed during their careers. In the next 20 years, mechanical engineering is certain to experience continuing and surprising changes. Summit participants were particularly concerned about how to prepare the mechanical engineer of 2028 to have the critical knowledge and competencies required in the future. They are looking to a future characterized by engineering large and small scale systems, meeting the competitive edge of knowledge and embracing the collaborative advantage, regulating global innovation, anticipating the diverse face of a global engineering profession, preparing for the technological capabilities of the Nano-Bio future and designing at home. The following pages of this report will look at each challenge more closely.

Developing Sustainably

Rapidly developing economies are adding to global environmental pressures and competition for energy, water, and other high-demand resources. Mechanical engineering will be challenged to develop new technologies and techniques that support economic growth and promote sustainability.

One of the most critical challenges facing mechanical engineers is developing engineering solutions that will foster a cleaner, healthier, safer and sustainable world. Maria Prieto-Laffargue, President-elect, World Federation of Engineering Organisations, observed that "mobility, complexity and sustainability are critical challenges. Engineering needs to become a dynamic discipline with an array of skills…the world is not now divided by ideology, but by a have/have not technology gap. New technology is on its way."

In many cases, Prieto-Laffargue emphasized, the necessary tools to combat problems like poverty and many environmental issues already exist. What are needed are more and better engineering solutions that are tailored to specific places and situations.

G.K. Pillai, Chairman and Managing Director of Heavy Engineering Corporation, a large Indian manufacturer of massive machine forgings, anticipated that the depletion of natural resources, pollution control, global warming, water shortages, population growth and improving conditions in the developing world, will be key challenges facing civilization as a whole. Peak-oil, the point at which total global oil production begins to fall from a maximum attainable level, is widely projected to occur within the next decade.[1] Within the next twenty years, many scientists expect that climate change will reach an irreversible "tipping point" after which effective intervention will be far more difficult to achieve.[2]

Climate change and the increased competition for resources are exacerbating global shortages of food and water. The high price of oil has spurred large investments in biofuel production from food staples such as corn, soybeans and sugarcane. High prices and food scarcity have caused food riots across the world. Many of these same people are also facing extreme water shortages. Twenty-nine countries were estimated to be experiencing water stress in 1995, and the World Bank projects that by 2025, about forty-eight countries will experience water stress.[3] In the next two decades, human use of water will increase by around forty percent, and seventeen percent more water than is available will be needed to grow the world's food.[4]

Rapidly emerging nations, particularly China and India, promise to increase the demand for natural resources even as traditional supplies dwindle. The growing middle class in China and India is including more meat and dairy in their diets and driving up demand not only for these foods, but also the grains needed to produce meat.

The growing global middle class is also driving automobiles more. The U.S. Department of Energy has estimated that China and India will drive a more than 40% increase in global demand for oil by 2030.[5] Rohit Talwar, Chief Executive of Global Futures and Foresight in London, highlighted the example of the new Tata Nano as one of the latest in a series of new products designed specifically for the growing middle class in China and India. The Nano is designed to be a complete car and will sell in India for one lakh (roughly $2,500).[6] The Nano and other cars like it will transform transportation in the developing world just as the Model T transformed the United States. It will also, despite its excellent fuel economy, dramatically increase the global demand for oil, and generate higher levels of carbon dioxide emissions and air pollution.

Globally there is a huge market for mechanical engineering that serves the poorest among us. Currently, it is estimated that around four billion people live on less than $2 per day. By 2030, almost two billion additional people are expected to populate the earth, ninety-five percent of them in developing or underdeveloped countries. This large and growing population will need access to food and clean water, effective sanitation, energy, education, healthcare and affordable transportation.

This market is not populated by poor victims of circumstance, but resilient and creative entrepreneurs and potential customers. There is tremendous value in helping these people achieve a better quality of life. Integrating this growing population into the world economy will create a more prosperous and stable world for all.[7] However, as discussed in developing sustainably, there will be global challenges to help improve the quality of life for a growing population while preserving the environment.

Serving this population requires a restructuring of how engineers are taught to approach their profession. At present, most engineering schools do not address the needs of destitute people, even though many of these people live in industrialized countries. Yet, the needs of the underserved for engineering solutions are likely to increase as population grows. Teaching engineers how to develop locally appropriate engineering solutions for the underserved is a key to developing sustainably. For example, Engineers Without Borders is fostering sustainable development and teaching engineers valuable skills for the future.[8]

Engineering Large & Small Scale Systems

Engineers in 2028 will work at the extremes of very large and very small systems that require greater knowledge and coordination of multidisciplinary and multi-scale engineering across greater distances and timeframes. A new field of systems engineering will incorporate much of the knowledge and practices of mechanical engineering.

Charles Vest, President of the U.S. National Academy of Engineering, predicted that the flow of technology from tiny and 'mega-scale' systems "will be the big story of the twenty-first century." Two new frontiers will have a large impact on engineering. The first frontier is increasingly smaller spatial scales and decreasingly smaller time scales. This frontier lies at the convergence of biotechnology, nanotechnology and information technology, and requires mechanical engineers to work across traditional disciplinary boundaries. The second frontier is "larger and larger systems of great complexity and, generally, of great importance to society." This frontier addresses the largest challenges facing the world in energy, environment, food, manufacturing, product development, logistics, and communications. Both frontiers will increase the complexity engineers are required to manage necessitating new knowledge and skill sets.[9]

Mechanical engineers of today and tomorrow must be prepared to work in these two expanding frontiers. They must be able to conceive and direct projects of enormous complexity that require a highly integrative view of engineering systems. Employers will demand engineers adept at integrating different disciplines, addressing increasingly complex customer and stakeholder requirements, and treating multiple interacting systems. They will rely heavily on simulations and computer aided design in the development and management of complex systems. Computer simulations will become better at modeling complex systems and will be a valuable tool for engineers to optimize expected outcomes while limiting unintended consequences.

For example, Mark Burgess, the chief engineer in Boeing's Phantom Works division, pointed out that early in his career, he spent two years generating CFD grids. Those same grids now can be generated instantly using engineering software. Twenty years from now, Burgess anticipates "highly integrated and seamless systems capable of generating reliable results even for non-expert users." Such systems, he argued, are likely to have very intuitive user interfaces perhaps reminiscent of the ease now designed into the programs that create the customized e-commerce experience of Amazon.com.

Competitive Edge of Knowledge

In 2028, the ability of individuals and organizations to learn, innovate, adopt and adapt faster will drive advanced economies. Mechanical engineering education will be restructured to resolve the demands for many individuals with greater technical knowledge and more professionals who also have depth in management, creativity and problem-solving.

Engineering knowledge and skill is vital for the competiveness of modern societies. Newly industrialized countries are keenly aware of the advantages of engineering and are dramatically increasing the numbers of engineers they graduate annually. India,[10] China[11] and Mexico[12] are all increasing the numbers of engineers their universities and technical institutes produce.[13]

In his presentation, Lu Yongxiang, President of the China Academy of Sciences and President of the Chinese Mechanical Engineering Society, highlighted how accelerated global transfer and translation of technology is driving global industrialization. China is at the forefront of these changes with world leading industrial parks like the Z-Park in Beijing. The Z-Park is one of many national high-tech zones that act as incubators for innovation in technology, business, and financing.

The entry of more engineers into the global workforce will make the profession much more global and competitive. Engineering service companies of all types will be competing globally for both projects and employees. They will demand engineers with more than just technical skills. Future mechanical engineers will need to be creative,[14] adept at problem solving,[15] and able to take a multidisciplinary, systems level understanding of problems. Future engineers will need to be life-long learners adept at turning information into knowledge and mastering new skills.[16]

Miguel Yadarola, President of the Pan American Academy of Engineering, pointed out the importance and difficulty of moving engineering education in Latin America beyond theoretical and abstract knowledge to real world skills. "Increasingly," Yadarola said, "engineers will need to act as high-level strategic thinkers and opinion formers" as engineering and scientific advances drive economic growth and globalization.

The United States, among other countries, will need to increase their openness and the ability of their engineers to work in global teams. "It is estimated that only somewhere between ten and thirty-four percent of Americans have passports," said Deborah Grubbe, BP International's Vice-President for Group Safety and Industrial Hygiene.

The United States once used its openness to foreign students and engineers as an advantage. However, the U.S. is making immigration more difficult for highly talented students and workers at the same time other countries are replicating successful U.S. programs. For example, the European Union revealed plans last year for a Blue European Labour Card that would be similar to the American Green Card.[17]

The increased breadth and complexity of modern engineering practice are straining the standard four-year curriculum for engineering education. The field of engineering is "driven by globalization and the empowerment of people previously excluded from participation in a knowledge economy," observed James Duderstadt, President Emeritus and University Professor of Science and Engineering at the University of Michigan, "yet, even as engineering grows in regions like China and India, it is held in relatively low esteem in the developed world and in the United States government support has sharply declined." Summit participants from other developed countries agreed this observation holds true for their countries as well.

The key to increasing the esteem of engineering, and producing world class engineers, argues Duderstadt, is to broaden engineering education so that it is comparable to other established professions like architecture and law. Moving forward there is a need to build a "guild culture" of professionals who identify more with the profession itself than with their individual employers. This would require a more systematic approach to education with greater emphasis on completing graduate-level professional schools of engineering.

However, an alternate but complementary future scenario could occur. In this future, the profession of engineering relies more on technicians that take on many of the routine technical tasks. This would parallel changes in the medical profession where "physician extenders" are taking over many routine tasks for medical doctors.[18] Mechanical engineers with advanced degrees would spend a higher amount of their time troubleshooting very difficult technical issues, managing complex systems and overseeing the work of technicians. This would mirror trends already seen in outsourcing many engineering tasks and the growth of engineering technicians.[19]

Collaborative Advantage
The dominant players in all industries in 2028 will be those organizations that are successful at working collaboratively. The 21st century will be defined not by conflict but by the integration of competitive markets with new methods of collaboration.

Globalization, according to Charles Vest, "is one of the three great future sources of opportunity for engineers." Many would argue that globalization is making location irrelevant. As journalist and author Thomas Friedman observed in *The World Is Flat,* globalization has "accidentally made Beijing, Bangalore, and Bethesda next door neighbors"[20]. Yet, those that study technology and innovation policy realize that location does matter. Technology innovation clusters around leading research universities and sources of venture capital.

More profound than the discussion of location is the way globalization is pushing nations and organization to both compete and collaborate. Global competition is forcing firms worldwide to search for economic partners to take advantage of new markets that they could not handle by themselves. They are sharing the risk of developing expensive technologies and new business models through joint ventures amongst themselves and partnerships with public and non-profit organizations.

Telecommunications and information technology, observes Prieto-Laffargue, "allows global transmission of different kinds of information and engineers are in a prime position to integrate these different approaches." The rapid expansion of high speed, massive data networks has led to the rise of both unorganized and formal collaborative efforts. The development of wikis[21] and virtual worlds[22] will only increase this kind of technologically facilitated collaboration in the future.

New communication and collaboration tools will allow mechanical engineers to tap into the collective wisdom of an organization or a network of stakeholders. The ability to tap a global network will facilitate feedback and improve the development of new technology. The ability to share virtual prototypes of technology and run simulations among a network of individuals is also likely to improve. Engineers will be able to redesign in the earlier phases of engineering development before the much more expensive prototype and production phases.

Regulating Global Innovation

Innovation, within the framework of a global economy, will remain a complex affair in 2028. Fundamental restructuring of the regulation and protection of intellectual property on a global basis is unlikely. As more complex technologies require greater collaboration and sharing of patents, incremental changes will occur to produce equitable and beneficial results for the innovators and those that adopt and commercialize innovations.

Innovation is the driving force behind economic growth and the key to solving future global challenges. A key challenge facing every nation is balancing incentives for innovation with diffusing the benefits of innovation as largely as possible. This will be especially true as more innovation is based on open source methods and complex technologies require greater sharing and access to patents.

"Open innovation is a key trend as companies go for innovation wherever it can be found," Vest observed. Organizations are rapidly moving from innovation methods that wrap up innovations tightly in a layer of secrecy to models that rely on partnering or licensing from other companies. These companies are also partnering with their suppliers and even customers to innovate new products and services.

Another revolution is occurring in open source models of innovation. Individuals around the world have contributed millions of lines of code and millions of man-hours outside a corporate structure to develop open source software. Largely without a monetary incentive, they have produced products that are successfully competing with corporate giants.[23] This model has spread outside the software industry and is being explored in healthcare, biotechnology, manufacturing and other endeavors to various degree of success.[24]

It is clear that change is needed to make global intellectual property regimes more efficient, effective and open. By some estimates, intellectual property litigation accounts for more than a quarter of all funds spent on industrial research and development.[25] This is especially disheartening for complex technologies which depend little on intellectual property rights for the innovation process. Businesses have estimated that in all industry except for chemicals, more than 70% of innovations would still have been accomplished without any IP regime at all.[26] Strong patents are even less important in a world where technologies are rapidly evolving. Complex technology businesses, unlike pharmaceutical companies, cannot depend on their products having a very long shelf life. This can make many cases of patent protections irrelevant and uneconomical.

Finally, there are the ethical debates that surround intellectual property. Until recently, the ethical dimension of the intellectual property debate has been almost entirely focused on the pharmaceutical industry and the problem of denying life saving drugs to people who cannot afford to pay for them. But with advances in genetic engineering and biotechnology, the ethical debate has started to show a more philosophical/religious tone. As biotechnology advances, there will be increasing questions about corporations' rights to not only create living machines but also their rights to patent and profit from what are essentially living objects.

Diverse Face of Engineering

Demand for new technologies will sustain global demand for adequately skilled and innovative mechanical engineers in 2028. Prospective employers will seek and promote people with unique and varied backgrounds to maximize their potential for success in diverse cultures and situations.

The importance of diversity in mechanical engineering was stated throughout the Summit. In one sense, mechanical engineering is at the forefront of a wave of diversity in organizations as the globalization of the workforce continues. In another sense, mechanical engineering struggles with a lack of diversity.

Mass migration of populations is driving increased workforce diversity. In 2028, IAF forecasts that there will be more than 380 million international migrants, more than double the 175 million international migrants at the turn of the century,[27] and larger than the current populations of the United States and Germany combined.[28] Engineers, as a high demand technical discipline, have been at the forefront of this trend as most have studied or worked with colleagues on special student or work visas.

However, the profession struggles to attract and retain women and minorities born in the United States. Deborah Grubbe provided data indicating that the percent of women in the field of mechanical engineering is the lowest of all engineering fields. Within the field, women are both twice as likely to earn an annual income of over fifty thousand a year but are half as likely to earn over one-hundred thousand dollars. Yet, Grubbe pointed out, the inclusion of women on project teams improves business, competitiveness and innovation.

Businesses are demanding diverse experiences among their workforce as a competitive advantage in the marketplace. Experiences based in culture, gender and regional expertise bring new perspectives to the table. These are competitive strengths when developing innovative responses to emerging business opportunities. Teams with diverse backgrounds are better able to generate the wide range of ideas necessary for innovation.[29]

The Nano-Bio Future

Nanotechnology and biotechnology will dominate technological development in the next 20 years and will be incorporated into all aspects of technology that affect our lives on a daily basis. Nano-Bio will provide the building blocks that future engineers will use to solve pressing problems in diverse fields including medicine, energy, water management, aeronautics, agriculture and environmental management.

Charles Vest made the case that the core of technological innovation has shifted from physics and high-speed telecommunications to biology and the environment. The rapidly advancing fields of biotechnology and nanotechnology are at the core of these developments. Many of the greatest opportunities for mechanical engineers lie in the intersection of these two fields of technology.

Early uses of nanotechnology range from the prosaic use of nanofabrics in pants to prevent stains to the exciting developments of new agents for medical imaging. Biotechnology has already contributed to the development of life saving medicines and food crops. Both nanotechnology and biotechnologies have successfully made the transition from basic research to the development of products and services.

Nanotechnology and biotechnology are poised for even greater success over the next 20 years. Nanotechnology can be used to create more efficient solar cells[30] that produce electricity cheaper than coal, to deliver drugs to precise cells in the body,[31] and to build terabyte data chips the size of postage stamps.[32] Biotechnology is on the verge of a revolution in which genetic components are standardized and interchangeable. These standardized components will make it easy to build biological organisms designed for a multitude of tasks ranging from producing hydrogen for cars to new drugs for malaria to cleaning up toxic waste.

Designing at Home

By 2028, advances in computer aided design, materials, robotics, nanotechnology and biotechnology will democratize the process of designing and creating new devices. Engineers will be able to design solutions to local problems. Individual engineers will have more latitude to design and build their devices using indigenous materials and labor – creating a renaissance for engineering entrepreneurs. The engineering workforce will change as more engineers work at home as part of larger decentralized engineering companies or as independent entrepreneurs.

Emerging technologies in computer aided design (CAD), materials, robotics, nanotechnology and biotechnology will likely come together to transform how engineers work. Faster processing[33] and network speeds[34] will soon allow future engineers to design entire products as a system rather than separate pieces.[35] This will expand the capacities of engineers and enable more complex designs to be completed anywhere.

Futurist Rohit Talwar highlighted virtual worlds, like Second Life, as one of the new technologies transforming how we perceive reality. Virtual worlds could soon become truly interactive environments for interacting with colleagues.[36] Combined with advances in CAD systems, it will be possible for mechanical engineers to collaborate in immersive interactive environments where they can design collaboratively, test hypothesis, run models and simulations and observe their creations in three dimensions much as an engineer can observe a car being built with their colleagues on the shop floor.[37]

Home-based personal fabrication will be readily available to turn these computer aided designs into reality. Rapid prototyping[38] and fabrication laboratories[39] are improving and will soon be affordable for those running home offices, teaching classes and those inventing or building as a hobby. Within 20 years, it is likely that home-based personal fabricators will be economically attractive and available to anyone who wants them.[40]

Engineers will be able to act as independent operators interacting with colleagues around the world. They can design at home with advanced CAD systems or in collaboration with their global colleagues in virtual worlds. They will be able to use home-based fabrication technology to test many of their designs. Engineers of the future will have better tools to build careers as individual inventors, independent entrepreneurs and employees in distributed businesses that draw on engineering talent from around the world.

NEXT STEPS TO A 2028 PREFERRED FUTURE

The Global Summit on the Future of Mechanical Engineering 2028 gave a representative group of global mechanical engineering leaders an opportunity to examine changes in our world and reflect on how relevant mechanical engineers might be to the challenges ahead. The profession has the ability to learn and adapt its discipline and practices to lead the response to the grand challenges and great contributions of the next 20 years. Will the profession exercise the commitment and determination to be as meaningful to the quality of human life in the future as it has been throughout history? Are leaders willing to be at the forefront of developing engineering solutions for a globally sustainable world in which critical resources are insufficient and far too many people lack the basic needs of life?

The critical path forward is less about mechanical engineering as a technical discipline and far more about the choices that the profession's leaders will make. Will they be willing to exercise leadership in all dimensions of business, public and personal life? Will they welcome into their ranks people who have traveled diverse pathways to offer their talents to a world in need of solutions? And how ready is the profession to collaborate and partner with other organizations and sectors that must guide the direction of a world that is too complex and interdependent for any one institution or profession to control?

When the problems could be better defined and scaled to a single company or country, a different expertise and leadership style could produce a good outcome. As mechanical engineering looks to 2028, leaders will value people with diverse expertise and experience. They will bring this global profession together to keep the promise of technology serving people. They will inspire men and women everywhere to believe that grand challenges are a rallying cry for a profession that is ready for the adventure of making the difficult doable.

A GLOBAL PROCESS FOR ENGAGING IN DEFINING OUR PREFERRED FUTURE

ASME has a long track record of studying the trends and issues likely to shape the future of mechanical engineering. For the past decade, this research has pointed definitively to this time when the global environment is influencing the profession as much if not more than national or local conditions. For its 2008 environmental scan, ASME convened more than 120 engineering and science leaders from 19 countries representing industry, academia and government to a global summit to imagine what mechanical engineering will become between now and 2028. The Summit was held April 16-18, 2008 at the National Academy of Engineering in Washington, DC.

ASME partnered with the Institute for Alternative Futures (IAF) to help the summit participants prepare to do their best work in anticipating the major forces of change. IAF reviewed major reports on the future of engineering, past ASME environmental scans and futures briefings, and related reports, briefings and writings from leading thinkers in other disciplines. IAF also conducted focus groups at the ASME International Congress and Exposition and surveyed members through a Web-based survey to determine which trends and issues they believe will be significant. IAF described nine drivers of change in an environmental scan report to frame the future context for summit participants.[41]

A steering committee of ASME leaders and executive staff invited speakers and leaders who could give a global context to the 2028 vision. In three rounds of intense group discussion over two days, the participants in the Global Summit on the Future of Mechanical Engineering worked toward one outcome: defining the elements of a shared vision that will keep the profession at the forefront of grand challenges and great contributions over the next 20 years. They sifted through many priorities and possibilities and collaborated to express this hope for their future: *Mechanical engineering will develop engineering solutions that foster a cleaner, healthier, safer and sustainable world.*

Futurist **Rohit Talwar,** Chief Executive of Global Futures and Foresight in London, opened the conference with a look at the grand challenges facing the world and the roles mechanical engineers might play in the future. As the population grows in Africa and Asia the center of gravity for the global economy will shift as well. This population growth requires energy alternatives and sustainable development. Mechanical engineers need to unleash their imagination to meet these grand challenges and make great contributions. Talwar offered Dubai as an example of engineering coupled with imagination driving great contributions to society. Dubai is investing in a new era of innovation and grand designs with new hotels like the Hydropolis, the first undersea luxury resort, and the Al-Taqa Energy Tower, a commercial high rise designed to produce its own energy with zero emissions.

Charles M. Vest, President of the U.S. National Academy of Engineering, opened the panel session tasked with exploring grand challenges and great contributions for mechanical engineering. From a technological standpoint, Vest predicted that the greatest opportunities for engineers would be in the areas of biotechnology, nanotechnology and information technology. The flow of technology from tiny and 'mega-scale' systems "will be the big story of the twenty-first century." He forecasted great advances in the areas of energy, sustainability, security and health care.

G.K. Pillai, Chairman and Managing Director of Heavy Engineering Corporation, a large Indian manufacturer of massive machine forgings, gave a historical overview illustrating that mechanical engineering has been the biggest driver of social change. Looking forward, Pillai anticipated that the depletion of natural resources, pollution control, global warming, water shortages, population growth and improving conditions in the developing world will be the key challenges facing civilization as a whole.

Masaki Shiratori, President of the Japan Society of Mechanical Engineers, presented a number of "technology roadmaps" developed for the Ministry of Economy, Trade and Industry. The Society is focusing on specific technologies such as high-temperature heat flux heat reduction, heat pump hot water supply, micro- & nano-biomechanics, automobile fuel efficiency and energy machine efficiency. These roadmaps show how the technologies may develop and their possible social and economic impacts over time. He described an annual "Machine Day" that celebrates the contributions that mechanical engineering has made to society as well as a series of ceremonial projects undertaken for the Society's one-hundred-and-tenth anniversary celebrated in 2007.

Maria Prieto-Laffargue, President-elect, World Federation of Engineering Organisations, pointed out that "grand challenges and great contributions could not be more relevant as we must react to challenges completely different from those of the twentieth century." She urged participants to reflect on the key role mechanical engineering can play in an interdependent knowledge economy.

Professor **Lu Yongxiang,** President of the China Academy of Sciences and President of the Chinese Mechanical Engineering Society, emphasized the role that science and engineering have played in the evolution and development of society. Lu observed that basic technologies and disciplines are merging in an internet linked and increasingly knowledge-based society. This process, he added, will be accompanied by changes in the values of science and technology and sustained respect for cultural diversity.

Deborah Grubbe, BP International's Vice-President for Group Safety and Industrial Hygiene, shared her insights as a leader in the American Institute of Chemical Engineers. Engineering work is becoming more international in scope, more diffuse and interdisciplinary, yet companies need to retain deep technical expertise.

The President of the Pan American Academy of Engineering, **Miguel Yadarola,** shared his concern that engineering education in many Latin American countries is based on theoretical and abstract knowledge that discourages the growth of professional attitudes. In addition to more science-oriented engineering, he argued that the profession should also focus on training mechanical engineers to apply their trade as effectively as possible in producing goods and services.

James Duderstadt, President Emeritus and University Professor of Science and Engineering at the University of Michigan, observed that engineering is driven by globalization and the empowerment of people previously excluded from participation in a knowledge economy. Yet, even as engineering grows in regions like China and India, it is held in relatively low esteem in the developed world and in the United States government support has sharply declined. The key to producing more world-class engineers, he said, is to broaden education so that it is comparable to other established professions like architecture and law.

Mark Burgess, the chief engineer in Boeing's Phantom Works division, shared a retrospective look at how the requirements of aerospace engineering have changed during his career. "From 1970 to 1983," Burgess pointed out, "fully one-third of Fortune 500 companies at the beginning of this period went out of business." Keeping track of change is necessary not only to survive but also simply to remain competitive. He identified three factors, advancing information technology, evolving engineering methods and changing business models, which are likely to have a tremendous impact on the field over the next generation. Thirty years ago Boeing project teams worked from a centralized location. Today the company is a leader in relying on global teams, yet he attests that these teams still have much to learn about communicating effectively in projects that span the globe.

Summit speakers and participants organized their learning and strategic conversations around the grand challenges facing a global society and the critical competencies and knowledge the future world of mechanical engineering will require. Key observations from the summit speakers and findings from the IAF environmental scan report on the drivers of change are summarized in the next section.

ASME offers this summit report, speaker presentations and futures research to the global mechanical engineering profession, its various professional societies, engineering leaders, industry, academia, governments, and the public as a resource. This 2028 vision can be the beginning of a great collaboration to give the world what it needs most from mechanical engineering between now and 2028.

END NOTES

[1] Intense debate continues over the exact timing of peak oil. While alternative energy sources cannot provide anywhere near the energy required globally, there is also debate over the degree to which another fossil fuel, coal, could be substituted for petroleum use over the intermediate term.

Duncan, R. (2003) Three World Oil Forecasts Predict Peak Oil Production. *Oil and Gas Journal.*

[2] Many scientists argue that this point will come sooner rather than later. Some recent estimates hold that this tipping point would be reached as early as 2010, if it has not been passed already.

Fairbridge, R. (Aug. 2006) Global warming and the Tipping Point. *International Journal of Environmental Studies,* 63 (4).

[3] The World Bank (2004) *Water Resources Sector Strategy: Strategic Directions for the World Bank.* Retrieved 11/28/2007 from: http://www.wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2004/06/01/000090341_20040601150257/Rendered/PDF/28114.pdf

See also: Alcamo, J., Henrichs, T., Rosch, T. (2000) *World Water in 2025: Global Monitoring and Scenario Analysis for the Commission on Water for the 21st Century.* Earthscan Publications.

[4] ITT Industries (2006) ITT Industries Guidebook to Global Water Issues. Retrieved 11/28/2007 from: http://www.itt.com/waterbook/toc.asp

[5] Energy Information Administration (2007) International Energy Outlook 2007. US Dept. of Energy. Retrieved 11/15/2007 from: http://www.eia.doe.gov/oiaf/ieo/index.html

[6] One lahk is 100,000 rupees (roughly $2,500 U.S. or €1,700). The Nano uses 2 cylinder rear mounted gas engine (623 cc) to help maximize interior space. It's light body and small engine help it achieve an impressive 50 miles per gallon.

(Jan. 10th, 2008) A "people's car" from India. *The Economist.* Retrieved 3/12/2008 at http://www.economist.com/business/display story.cfm?story_id=10498699

[7] Professor C.K. Prahalad advanced the notion of building a base of customers among the poor as a sound business strategy in his book The Fortune at the Bottom of the Pyramid. The same logic of empowering the poor as entrepreneurs was behind the awarding of the 2006 Nobel Peace Prize to Grameen Bank and its founder Muhammad Yunus.

Prahalad, C.K. (2006) *The Fortune at the Bottom of the Pyramid.* Wharton School Publishing

[8] Engineers Without Borders is a global nonprofit humanitarian organization that has been established to partner with developing communities worldwide to improve their quality of life. The partnership carries out sustainable engineering projects, while involving and training internationally responsible engineers and engineering students. The activities of Engineers Without Borders range from the construction of sustainable systems that developing communities can own and operate without external assistance, to empowering communities by enhancing local, technical, managerial, and entrepreneurial skills.

Engineers Without Borders- International (2007) Retrieved 11/10/2007 at http://other90.cooperhewitt.org/

[9] Charles M. Vest outlined the growing importance of these two systems at the Summit, but has spoken in greater detail on the topic at the National Academy of Engineering (NAE) annual meeting on October 10, 2005. These remarks are included in an NAE article entitled, Educating Engineers for 2020 and Beyond, by Charles M. Vest, available at http://www.engineeringchallenges.org/cms/7126/7639.aspx

[10] India produced three times as many engineers in 2005 than the United States and two times as many engineers as all of Europe. By 2009, India is set to more than double its output of engineers (more than 400,000 engineers). The growth in engineering talent in India is striking even though these numbers include both information technology specialists and engineers receiving less than a four year degree.

Mallaby, S. (Jan. 2nd, 2006) In India, Engineering Success. *The Washington Post,* page A13. Retrieved November 6th, 2007 from http://www.washingtonpost.com/wp-dyn/content/article/2006/01/02/AR2006010200566.html

END NOTES

11 China has been dramatically increasing its spending on science & engineering education as well as R&D. In China, national spending for all R&D activities rose 500% from $14 billion in 1991 to $65 billion in 2002. The number of doctoral degrees awarded in China has also increased 50 fold since 1984.

Hicks, D. (Summer 2004) Asian Countries Strengthen Their Research. *Issues in Science and Technology* 20 (4):75-78.

12 Mexico currently has more engineering students enrolled full-time (451,000 students) than the U.S. (370,000).

ASME Strategic Issues, Opportunities and Knowledge Committee (July 2006) *Mexico Is Churning Out Engineers.* ASME.

13 In the footnotes of this section, IAF has provided some estimates of engineers and engineering students in developing countries. This is not without peril. Gathering hard numbers for these countries can be challenging. There is also the danger of comparing engineers with different levels of talents and skills. Both China and India have different standards of education combined with severe shortages of qualified teachers – many of the engineers listed would not meet muster as engineers in the United States and could best be qualified as technicians.

Bracey, G.W. (May 21st, 2006) Heard the One About the 600,000 Chinese Engineers? *The Washington Post.* Retrieved online 11/19/2007 at http://www.washingtonpost.com/wp-dyn/content/article/2006/05/19/AR2006051901760.html

The best study doing apples to apples comparisons of engineers in the United States, India and China was completed by Duke University. Looking just at bachelor degrees in engineering, the U.S. does much better, producing 137,437 engineers compared to 112,000 in India and 351,537 in China for 2004. Normalizing for population, the United States still produces more bachelor and sub-bachelor level engineers per 1 million resident citizens than both China and India.

Gereffi, G., V. Wadhwa, B. Rissing, K. Kalakuntla, S. Cheong, Q. Weng and N. Lingamneni (2005) *Framing the Engineering Outsourcing Debate: Placing the United States on a Level Playing Field with China and India.* Duke University. Retrieved 12/11/2007 at http://memp.pratt.duke.edu/downloads/duke_outsourcing_2005.pdf

14 Many of the routine technical skills once performed by engineers are increasingly being carried out by machines or software programs. This trend will accelerate over the next 20 years as advances in A.I. and robotics continues to accelerate. Creative skills will be an important competitive advantage for engineers. A growing number of engineering schools are giving students both course work and hands-on practice in creative innovation.

Institute for Alternative Futures (2005) *Six Strategic Issues Shaping the Global Future of Mechanical Engineering.* ASME.

Pink, D.H. (Feb., 2005). Revenge of the Right Brain. *Wired.* Retrieved 12/13/2007 at http://www.wired.com/wired/archive/13.02/brain.html

Richards, L.G. (Spring 2005) Everyday Creativity: Principles for Innovative Design: Cutting Ed Online; James Madison University Department of Integrated Science and Technology. Retrieved 12/13/07 from http://www.isat.jmu.edu/cuttinged/spring05/creativity.html

15 During the focus groups run by IAF at the 2007 ASME Congress a number of participants identified the ability of mechanical engineers to solve problems as a key attribute of current engineers that will be just as vital or more vital in the future. In particular, the accelerating pace of change combined with the grand challenge of identifying new ways to develop sustainably will task the problem solving skills of future engineers.

Institute for Alternative Futures (2007) *The Future of Mechanical Engineering 2028: Focus Group Research Highlights.* ASME.

16 Lifelong learning is a very simple concept that the need for both formal and informal learning continues throughout an individual's lifetime. Many businesses, unions and other organizations are promoting lifelong learning among their employees as a way to keep current in a rapidly changing environment. Policy-makers are pushing lifelong learning as an important competitive advantage for their workers in an increasingly competitive global economy. At the individual level, distance learning has provided many individuals the ability to keep current and pursue education long past college.

Graham Guest (March, 2006) Lifelong Learning for Engineers in a Global Context. *The Engineers Journal:* 60:2. Retrieved 11/15/2007 at http://www.engineersireland.ie/uploads/Files/EngineeringMagazines/%7B04EF9B7BC14647BB9BE5DCCB5BCC0705%7D_LIFELONGLEARNING.PDF

END NOTES

Organisation for Economic Co-operation and Development (April 2007) Qualifications and Lifelong Learning. Retrieved 12/13/2007 at http://www.oecd.org/dataoecd/10/2/38500491.pdf

17 The international nature of engineering is readily apparent in the U.S. A quarter of all engineers in the U.S. are foreign born and foreign born engineers make up more than 60% of the doctoral candidates at U.S. schools.

National Science Board. (2006) Science and Engineering Indicators 2006. Two volumes. Arlington, VA: National Science Foundation (volume 1, NSB 06-01; volume 2, NSB 06-01A).

Australia has been increasing the number of foreign engineers trained and working in the country. Graduations of foreign students taking engineering courses as a percentage of all graduations have grown from 9% in 1994 to over 30% in 2003.

Cockbain, P. (2006) Engineering Skilled Migration. Engineers Australia. Retrieved 10/30/2007 at http://www.engineersaustralia.org.au/shadomx/apps/fms/fmsdownload.cfm?file_uuid=18F73A3A-DCA4-578B-D2B5-408FCA18B14E&siteName=ieaust

18 Healthcare systems in the United States have been struggling to deal with rising demand for services, higher costs and a shortage of primary care doctors and many medical students have opted for more lucrative specialties. The answer for many healthcare systems has been the use of "healthcare extenders" such as physician assistants and nurse practitioners. Both have advanced degrees (usually 2 years) in medicine and work under the supervision of a medical doctor. Both are rapidly growing professions. Physician assistants are the 4th fastest growing profession in the U.S.

Other developed countries are experiencing the same problems as the U.S. and are looking to increase the number of "physician extenders". Canada, the United Kingdom, Australia and Holland are all running pilot projects that incorporate physician assistants into their healthcare systems and are looking to increase the number of physician assistants graduating from their programs.

David McCabe (Aug. 28th, 2008) The Next Wave: "Physician Extenders"? Canadian Medical Association Journal. Retrieved 2/19/2008 at http://www.cmaj.ca/cgi/content/full/177/5/447

19 While not universal, this is the model in a number of countries where the Technical Engineer is defined by the completion of a 2 or 4 year degree in a technical engineering field.

20 T. Friedman (2005) *The World is Flat: A Better History of the Twenty-First Century.*

21 Wikipedia is the most famous and successful wiki however many private organizations and groups have taken advantage of wiki technologies to create databases of information for their own use. One interesting example is the intelligence agencies of the United States. The U.S. intelligence community has developed Intellipedia as a top-secret wiki for spies and Feds to share top secret information.

Michael Seringhaus (Nov., 2nd, 2007) 'Intellipedia'? CIA Jumps on Wiki Wagon. Yale Daily News. Retrieved 12/17/2007 at http://www.yaledailynews.com/articles/view/18753?badlink=1

22 Virtual Worlds originally developed as an extension of multiplayer gaming. With the rise of virtual worlds such as Second Life – which now has population over 6 million – virtual worlds ceased to focus exclusively on gaming and instead have become portals for communication, information, business, and social life.

(November, 2007) Tomorrow's Technologies in Brief. *ASME Strategic Issues and Trends Brief.* ASME Strategic Issues, Opportunities and Knowledge Committee.

23 Two open source programs are competing directly with Microsoft and achieving significant amounts of market share. Firefox, a rival web browser released in 2004, has captured close to 17% of the market in January 2008 according to marketshare.net. The Linux operating system competes directly in the server market and has captured over 12% of the market according to market tracker IDC.

Marketshare statistics for Firefox retrieved 2/20/2008 at http://marketshare.hitslink.com/report.aspx?qprid=0&qpdt=1&qpct=3&qpcal=1&qptimeframe=M&qpsp=108

Marketshare statistics for Linux retrieved 2/20/2008 at http://www.linux-watch.com/news/NS5369154346.html

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24 Open source models of innovation do appear to have their limits (it is integral that product users are able to test and modify products at an affordable cost) but those limits are expanding. The Open Source Car is a good example. It has been singularly unsuccessful to date. However, with manufacturing becoming more decentralization of manufacturing there is a very good chance that open source manufacturing will become more viable.

See http://www.theoscarproject.org/, http://www.osgv.org/, and http://www.autoindetoekomst.nl/website/, for various attempts at an open source car – none of which has yet to produce a working prototype.

25 For those interested in the history of intellectual property law – there are few better reviews than Innovation Needs Patents Reform. William Kingston gives an excellent history of the intellectual property in America with it foundations based on the individual inventor to the development of corporate R&D and the rewriting of the patent laws at the behest of the pharmaceutical companies in the 1952 to the current debates about costs and reform.

W. Kingston (2001) *Innovation Needs Patents Reform. Research Policy:* 30.

26 This reflects the fact that innovation in complex technologies is much more difficult to securely protect. There are many ways to work around intellectual property in computers or automobiles so that a firm could create essentially the same product but with slightly different components. This is not true with chemicals as the outcome is intimately tied to the exact form of certain molecules. As such, Industry executives have predicted that without strong IP regulations, innovation in pharma would be cut by 75% or more. In other industries, IP is not as important at all and instead firms value secrecy, production lead times and learning curves as a means of appropriating profits from innovation.

Cohen, Walsh, and Nelson (Feb., 2000) Protecting their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not). *National Bureau of Economic Research.*

27 Forecast for international migrants based on the rate of growth recorded by the Global Commission on International Migration. The forecast assumes roughly 2.8% annual growth from the estimated 200 million international migrants in 2000. It is also consistent with the doubling of international migrants from 1975 to 2000, albeit from a larger base.

Global Commission on International Migration (2005) Migration in an Interconnected World: New Directions for Action. Retrieved October 31st, 2007 from http://www.gcim.org/attachements/gcim-complete-report-2005.pdf

28 *The Economist.* (August 27th, 2007) *Pocket World in Figures: Largest Populations.* Retrieved November 3, 2007 from www.economist.com

29 The business case for diversity has frequently cited increased innovation as a result of multiple perspectives across a wide variety of industries. See, for example:

Van der Vegt , G.S. (2003) Joint Impact of Interdependence and Group Diversity on Innovation. *Journal of Management,* 29 (5).

30 Nanosolar has already begun to produce thin-film solar cells at a cost of around $1/watt with continued decreases in price and increases in performance expected. You can view their technology at www.nanosolar.com. Popular Science recently named thin-film solar their #1 innovation of 2007.

Michel Moyer (2007) The New Dawn of Solar. *Popular Science*. Retrieved 12/15/2007 at http://www.popsci.com/popsci/flat/bown/2007/green/item_59.html.

31 Nanotechnology enabled drug delivery systems are well advanced with a number of systems already on the market. Advances include improved injectable drugs, implantable drug delivery systems and better forms of pills, patches and topical creams.

(July, 3, 2005) Nanotechnology to revolutionise drug delivery. InPharm Technologist. Retrieved 12/18/2007 at http://www.in-pharmatechnologist.com/news/ng.asp?id=58523-nanotechnology-to-revolutionise.

32 Researchers at Arizona State University have developed a new technique for manipulating charged copper particles at the molecular scale. The technology, if it can be scaled for commercial production would be one-tenth the cost and 1,000 times more energy efficient than current flash memory drives.

See http://www.wired.com/gadgets/miscellaneous/news/2007/10/ion_memory for information about nanotechnology and computer memory storage.

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33 Since Gordon Moore observed Moore's Law in a 1965 article in Electronics magazine there has been a steady exponential growth in computing power and a corresponding drop in the cost of computing. Moore's law is the observation that the computing power available at a given price doubles every 18 months. Moore's law will likely remain constant for the next 10-20 years at which point there are a number of promising technologies to keep the development of low-cost computing power.

(Nov. 13th, 2007) Moore's Law. *The Economist.* Retrieved 12/10/2007 at http://www.economist.com/displaystory.cfm?story_id=10128167

(March 11th, 2004) Why Speed Isn't Everything. *The Economist.* Retrieved 12/10/2007 at http://www.economist.com/search/displaystory.cfm?story_id=E1_NQSSDGP

(Dec. 6th, 2007) Hafnium and chips. The Economist. Retrieved 12/10/2007 at http://www.economist.com/search/displaystory.cfm?story_id=10202680

S.V. Sreenivasan, C. Grant Willson, and Douglas J. Resnick (April, 2004) Small Print. Mechanical Engineering. Retrieved 12/10/2007 at http://www.memagazine.org/backissues/membersonly/april04/features/nanosmpr/nanosmpr.html

34 In the next five to ten years, the majority of the world will have access to broadband. In the developed world, WiMax and Wireless Mesh Networking will solve the last mile problem for delivering broadband in rural areas. In cities in the developed world, there will be continued roll out of fiber optic cable to the home. These fiber optic cables will enable more services and faster than current broadband speeds. Even more powerful wired and wireless super broadband technologies are in development at research labs. Assuming some of these technologies make it out of the lab to the marketplace we will see much more powerful wired and wireless networking technology that can provide wired and wireless broadband at multiples of current speeds rolling out over the next 15 to 20 years.

(July, 2007) Tomorrow's Technologies in Brief. *ASME Strategic Issues and Trends Brief.* ASME Strategic Issues, Opportunities and Knowledge Committee.

John Toon (March 16th, 2006) Optical-Wireless Convergence: New Network Architecture Delivers Super-Broadband Wired and Wireless Service Simultaneously. *Georgia Tech Research News.*

35 Engineering for large and small scale systems is one of the most important challenges facing future engineers (see the *Engineering Multi-scale Systems* section for more information). Next generation CAD systems that allow full scale system design will be an important new tool for engineers, but one that will require a new perspective of engineering.

36 Virtual worlds are becoming big business. Companies such as IBM and Toyota have invested millions of dollars in developing assets in virtual worlds such as Second Life. Virtual worlds have a long ways to go. Like early versions of the internet - bugs, glitches and server crashes are common. Established businesses are only recently experimenting with virtual worlds and are still learning best practices for using virtual worlds for learning, collaboration and networking. However, by 2028, these early versions of virtual worlds will be replaced with much more stable and sophisticated virtual worlds that allow engineers to collaborate and network with other others in three dimensions.

(November, 2007) Tomorrow's Technologies in Brief. *ASME Strategic Issues and Trends Brief.* ASME Strategic Issues, Opportunities and Knowledge Committee.

37 The idea of immersive interactive environments emerged from a workshop held by IAF for its 2029 Project which was a broad based futures look at research and development in biomedical R&D. A significant portion of experts in information and communication technologies felt that developments in individualization, speech recognition, and haptics were driving the development of virtual worlds where researchers are able to collaborate in new ways.

Jonathan Peck and Craig Bettles (2005) The 2029 Report: Achieving an Ethical Future in Biomedical R&D. Institute for Alternative Futures. Retrieved 12/10/2005 at http://www.altfutures.com/2029/The%202029%20Report.pdf.

Jean Thilmany (2004) Turn on the Light. Mechanical Engineering Design. Retrieved 12/10/2007 at http://www.memagazine.org/supparch/medes04/thelight/thelight.html

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38 Rapid prototyping is a collection of technologies that fabricate objects directly from CAD data often adding and bonding layers of material to build new objects. Rapid prototyping machines, such as 3D printers, are available for costs as low as $5,000. An open source prototyping machine can be built by enterprising individuals for as little as $2,500. These prices are likely to drop down further over the next five to ten years, just as conventional paper printers saw a dramatic decrease in cost.

(Nov., 2007) Best of What's New 2007: Print Your Own Parts. *Popular Science.* Retrieved 12/11/2007 at http://www.popsci.com/popsci/flat/bown/2007/hometech/item_79.html

39 Fabrication laboratories (fab labs) are small scale workshops with the tools to create nearly anything. Common tools include cutters for sheet material, computer controlled mills and lathes, 3D printers and printed circuit board milling systems. The cost for a fab lab is roughly $20,000. The Center for Bits and Atoms (CBA) at the Massachusetts Institute of Technology (MIT) has been promoting and developing better fab labs and bringing them to underserved communities from Boston to Ghana. The goal is to empower these communities to design and create products and solutions for problems that major companies will never tackle – and in the process to develop inventors and entrepreneurs in the communities that need them most.

40 Neil Gershenfeld, the engineer and director of the CBA, believes that eventually the fab labs of today will morph into a single, universal fabricator that can make almost anything. Within 20 years, fabricators would give people the power to create anything in their heads and share plans over the internet to create an "open-source" world of manufacturing. This could democratize manufacturing – allowing everyone to design and create or pull open source design for a range of products.

(June 9th, 2005) How to Make (almost) Anything. *The Economist.* Retrieved 12/11/2007 at http://www.economist.com/search/displaystory.cfm?story_id=E1_QDPTPDQ

Michelle Delio (September 9th, 2004) Ghana Gets a Fab Lab. *Wired Magazine.* Retrieved 12/11/2007 at http://www.wired.com/science/discoveries/news/2004/09/64864

Neil Gershenfeld (2005) *Fab: The Coming Revolution on Your Desktop-from Personal Computers to Personal Fabrication.* Perseus Books Group: Cambridge, MA.

41 Institute for Alterative Futures. (2008) *Future of Mechanical Engineering 2028.* ASME. Available at www.asme.org.