



INSTITUTE for ALTERNATIVE FUTURES

THE FUTURE OF MECHANICAL ENGINEERING 2028

An Environmental Scan for ASME and the

**Global Summit on the Future of
Mechanical Engineering**

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Table of Contents

Introduction.....	1
1. Developing Sustainably.....	4
2. Engineering Large and Small Scale Systems	7
3. Competitive Edge of Knowledge	9
4. Collaborative Advantage	12
5. The NanoBio Future	14
6. Regulating Innovation	17
7. Diverse Face of Engineering.....	20
8. Designing at Home.....	22
9. Engineering for the Other 90 Percent.....	25
A 2028 Future Survey of ASME Members	28
Endnotes & Sources	33

Introduction

ASME strives to promote the technical and social contributions of engineers to the well-being of humankind. This is a challenging mission to understand and execute in 2008. It is even more challenging to anticipate the future of mechanical engineering by 2028. Yet today's leaders aspire to create a shared vision that will prepare mechanical engineering to achieve its highest performance in the service of humankind.

ASME will convene a Global Summit on the Future of Mechanical Engineering April 16-18, 2008 in Washington, DC. More than 120 engineering and science leaders will gather to analyze significant changes in mechanical engineering and define a vision for the future of the profession. ASME partnered with the Institute for Alternative Futures (IAF) to identify important changes over the next 20 years to help frame the summit conversation.

IAF explored two important questions for ASME. What are the profession's grand challenges and great contributions between now and 2028? And what will be the critical knowledge and competencies that the profession will need to succeed in the 2028 world of mechanical engineering? This environmental scan outlines the future possibilities for change. During the summit, leaders will examine these changes, listen carefully to expert panels and to one another, and discover the aspirations that will define and drive the profession to its preferred future.

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 with ASME members and surveyed members to get the profession's sense of what might have a significant impact on the profession.

The nine drivers of change described in this report grapple with many of the grand challenges faced by society over the next twenty years. They reflect the needs, wants and desires of people around the globe. They also explore what mechanical engineering will need to do well in order to do this good work in the world. For each driver, IAF offers a forecast of what might happen and explains how these changes could affect mechanical engineering.

To help the summit participants focus on major patterns rather than the unknowable details of each change, IAF has kept these explanations succinct and to the point. The report does include extensive endnotes and sources for those who want to dive more deeply into the background research for each driver. In this report, the drivers are introduced in the order of importance that the ASME focus groups gave them in November 2007.

This order tracks closely with the results of the ASME membership survey on the 2028 future (summarized at the end of this report). In the survey, members were asked to react to statements that characterized these changes and their potential significance. Their general validation of this scan suggests ASME members do recognize these changes as part of their expected future. Studied together in this report, the drivers of change add up to a challenging and inspiring time ahead for mechanical engineering.

Here are the nine drivers and forecasts briefly summarized.

1. 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.

2. 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.

3. 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.

4. 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 by the integration of competitive markets with new methods of collaboration.

5. NanoBio Future: Nanotechnology and biotechnology will dominate technological development in the next 20 years. In 2028, nanotechnology and biotechnology will be incorporated into all aspects of technology that affect our lives on a daily basis. They 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.

6. 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.

7. 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.

8. 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.

9. Engineering for the Other 90 Percent: By 2028, globalization and new business models will increasingly drive the development of mechanical engineering projects that serve the poorest 90 percent of humanity – the four billion people who live on less than \$2 a day.

1. 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.

The key trends and developments behind this driver include:

- Large-scale industrialization of China, India and other emerging markets
- Intense interest in energy resources of all types to meet global consumption demands
- Global climate change and a reduction in peak oil production
- Projected water shortages, diminished biodiversity and natural resource scarcities
- The pressure to seek resources in difficult or fragile environments

According to a recent McKinsey survey, business executives expect sustainability and the environment to affect shareholder value far more than any other societal issue over the next five years. Indeed, their concern now exceeds that of consumers.¹ The race is underway to find economically feasible and environmentally neutral solutions.

This anxiety on the part of organizations is not without justification. 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.² At the same time, rapidly emerging nations, particularly China and India, promise to increase the demand for energy even as traditional supplies dwindle. Indeed, the U.S. Energy Department has estimated that these two countries will drive a more than 40% increase in global demand for oil by 2030.³

The increased demand for natural resources, especially oil, will drive exploration and production of natural resources in difficult or fragile environments. Declining oil fields in OPEC countries combined with new discoveries of deep sea oil fields will demand exploration and production in more challenging environments both geographically⁴ and politically.⁵ There will also be a push for drilling and mining

in environmentally fragile environments as resource shortages emerge leading to a demand for technologies and techniques that are more sustainable.⁶

Currently, only a small percentage of the world's energy needs are met by alternative energy sources. The engineering of abundant and sustainable energy sources, including improvements to geothermal, tidal, hydrogen, wind and solar power, will be a critical issue for the first half of the twenty-first century. Energy efficiency also will be a priority in new technology and processes from the development of new automobiles to manufacturing systems.

Parallel to this, an emerging consensus on the existence, if not the causes, of global climate change increases the likelihood that many societies in 2028 may need to devote substantial resources to mitigating this threat. Indeed, within the next twenty years, climate change is expected by many scientists to reach an irreversible "tipping point" after which effective intervention in the trend will be far more difficult to achieve.⁷

Climate change and the increased competition for resources are exacerbating a global water crisis. A report drawn up by the World Commission for Water in the 21st Century, presented at the World Water Forum in The Hague references what it calls "the gloomy arithmetic of water." The report estimates that in the next two decades human use of water will increase by around forty percent, and that seventeen percent more water than is available will be needed to grow the world's food.⁸ While twenty-nine countries were estimated to be experiencing water stress in 1995, the World Bank projects that by 2025, about forty-eight countries will experience water stress.⁹

Sustainability has been broadly defined by the World Commission on Environment and Development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."¹⁰ In the context of these growing global challenges, there is increasing urgency for all sectors to accelerate their capacity to ensure greater sustainability for present and future generations.

Impact for Engineering

Mechanical engineers will be expected to develop and apply new technologies to both the production and use of energy to respond to the challenges of peak-oil and climate change. In ASME's 2008 survey on the future of the field, about three-quarters of respondents agree that the profession will play a pivotal role in

addressing energy issues. They will be pressed to develop new technologies and techniques for drilling and mining in challenging environments from the ocean floor to the arctic tundra. And they will play a pivotal role in scaling up the use of alternative energy sources to meet global demand.

The global-scale implementation of processes to reduce greenhouse emissions, including large-scale carbon sequestration systems, also represents a substantial challenge that could naturally fall to mechanical engineers. About three-quarters of ASME members surveyed on this agree that the profession will play a critical role in addressing climate change. Innovations are likely to be all the more important in emerging economic regions like China and India, where inclusion in first-generation development could minimize the need for costly retrofitting.¹¹

Over the intermediate term, there is likely to be increasing demand for more energy efficient temperature control systems for the built environment. Here, mechanical engineering as a discipline may be able to draw on its traditional strength in thermodynamics to implement innovative techniques to incorporate efficient natural ventilation and mechanical cooling mechanisms.¹²

A number of approaches to framing sustainable engineering are beginning to emerge. In their 2002 book, *Cradle to Cradle: Remaking the Way We Make Things*, William McDonough and Michael Braungart seek to outline production techniques that are not just efficient but are essentially waste free. In contrast to “cradle to grave” engineering, in “cradle to cradle” production all material inputs and outputs are seen either as technical or biological nutrients to be completely recycled.¹³ Similarly, in the 1997 book, *Biomimicry: Innovation Inspired by Nature*, Janine Benyus makes the case for drawing on natural organisms and systems as the inspiration for more ecologically balanced engineering solutions.¹⁴

Some have advocated for the engineering profession to take a far more aggressive role in combating environmental challenges. The nascent discipline of “earth systems engineering” advocates the active engineering and management of complex environmental systems¹⁵ to mitigate the effects of climate change. While many opponents balk at invasive interventions in poorly understood global systems, any potentially catastrophic environmental developments over the next few decades could greatly increase the likelihood of wide-scale adoption of this approach.¹⁶

2. Engineering Large and 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.

There are a number of forces favoring the growth of systems engineering:

- The convergence of bio, nano and info technology with mechanical engineering
- An increasing number of large, complex engineering and construction projects in a global world
- The need to optimize outcomes and manage risk in these complex systems

Many mechanical engineers will work in two expanding frontiers, very small and very large scale systems, over the next 20 years.¹⁷ They will find their discipline in demand at the convergence of bio, nano and information technologies as tiny machines are moving from the laboratory into commercial application in manufacturing, medicine and other industry sectors.¹⁸

Mechanical engineers also will work in multidisciplinary teams on mega projects that must interface with global markets, societies and ecosystems. In an era of global instability, designing and protecting lifeline systems of critical national infrastructures will be crucial.¹⁹ The emerging field of earth sciences engineering expects to take advantage of very small technologies to study and perhaps intervene in the large scale systems of the earth.²⁰

Multi-scale engineering will incorporate systems engineering practices. Practitioners will be adept at integrating different disciplines, customer and stakeholder requirements, and multiple interacting systems. Engineering systems that require design capabilities on a multi-scale basis present unprecedented challenges for optimizing expected outcomes while limiting unintended consequences.²¹ These engineers will be in demand as project leaders to integrate basic components and subsystems into higher value solutions.

As systems reach a high level of complexity it becomes difficult to predict their behaviors.²² This introduces a serious and growing ethical dimension for engineers.²³ In some situations, engineers will be designing ahead of what science understands about how these very small and large systems work.²⁴

Impact for Engineering

While many mechanical engineering educators believe systems engineering should be a priority, few undergraduate engineering schools have reformed their curriculum. The traditional curriculum teaches simple systems.²⁵ Engineers also will need greater knowledge of the social context in which they are operating to work in multidisciplinary and global project teams.²⁶

Education programs, technology and standards for systems engineering will emerge as the importance of systems engineering becomes apparent. Engineering education programs that focus on systems engineering will help establish the body of knowledge needed to understand and deal with complexity.²⁷ Simulation technologies will evolve over the next 20 years to model complex systems.²⁸ The development of standards is the sign of maturity of a practice and they provide a framework for the development of best practices.²⁹

3. 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.

There are a number of forces driving the *Competitive Edge of Knowledge* including:

- Increased competition for engineering talent worldwide
- Growth in engineering education in the developing world
- The accelerating pace of change in technology and other areas
- The demand for engineers to master non-technical skills

Engineering knowledge and skill is vital for the competitiveness of modern societies. The developed world has benefited greatly from the clusters of science and engineering talent found at leading research universities and laboratories.³⁰ Newly industrialized countries appreciate how much science and engineering contribute to economic development and are rapidly developing their native talent and clusters of engineering companies around their leading universities and research labs.³¹

Newly industrialized countries are dramatically increasing the numbers of engineers they graduate annually. India,³² China³³ and Mexico³⁴ are all increasing the numbers of engineers their universities and technical institutes produce.³⁵ Universities are also competing globally for talented engineers and engineering students.³⁶ More countries are developing visa systems similar to the HB1 and J1 visas used in the United States to attract top science and engineering talent.³⁷ This global competition for talent has been a tremendous boon for the United States and other developed countries, but has led to a brain drain in many developing countries.³⁸

The ability to create and exchange knowledge is the key differentiator for individuals and companies. Engineering companies and research organizations

build their reputations on specialized knowledge that must be continually updated and shared across teams and generations.³⁹

Individual engineers must be on a sharp and constant learning curve to stay relevant in a competitive knowledge society. Change is accelerating at a rapid pace in everything from technology to business models.⁴⁰ Engineers will need to develop the skills to deal with rapid change.

Future engineers will need a strong technical base of knowledge, but will also be called on to master skills beyond just technical expertise. They will be asked to bring creativity,⁴¹ problem solving,⁴² and a multidisciplinary, systems level understanding of problems.⁴³ Future engineers will need to be life-long learners adept at turning information into knowledge and mastering new skills.⁴⁴

Impact for Engineering

Developing countries are rapidly building up their science and engineering workforce, but the standards of education vary widely between countries. Establishing a global curriculum for engineering would be an aspirational and highly difficult goal for the profession. The more likely future is continual voluntary harmonization of engineering education across boundaries.⁴⁵

The increased breadth and complexity of modern engineering practice are straining the standard four-year curriculum for engineering education. In ASME's 2008 survey on the future of the field, about three-quarters of respondents agree that they will need to acquire new knowledge outside the traditional domain of mechanical engineering. Additional subjects of study need to be included at both the undergraduate and graduate levels.⁴⁶ At the same time many professions are making room for more general requirements to prepare students to be creative, problem-solving lifelong learners.⁴⁷

Engineers, like many other professionals, will be required to expand their educational requirements to obtain, maintain and nurture their knowledge base and skills to be competitive in a global marketplace.⁴⁸ Engineering in developed countries could resemble other highly educated professions where a post graduate degree is required for success if not entry into the profession.⁴⁹

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.⁵⁰ 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.⁵¹

4. 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 a conflict but by the integration of competitive markets with new methods of collaboration.

By 2028, there will be increasing collaboration among firms and other organizations for the conduct of all aspects of an industry: research, development, production, marketing, distribution, etc.⁵² Collaboration will not just be vertically or horizontally between industrial firms⁵³, but also decentralized across innovation networks among professionals⁵⁴ and anonymous cooperative ventures. There are several major forces driving the collaborative advantage:⁵⁵

- Increasing competition due to opening markets to foreign competitors⁵⁶
- Increasing technological complexity for which all the necessary core capabilities cannot be economically accumulated and sustained in one organization
- Increasing speed with which products are being created and rendered obsolete
- Continued confluence of information and communications technologies decreasing the cost of collaboration

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.⁵⁷

Firms are collaborating to remain competitive in the framework of a larger number of competitors and a more volatile market.⁵⁸ The international marketplace is growing rapidly and by 2028 there will be less distinction between international and domestic markets due to falling trade barriers. This new marketplace will only get more competitive.

Increasing technological complexity raises the requirements for core capabilities. An organization working on the development of airplanes has to integrate knowledge in a variety of different areas (engineering, aeronautics, materials, chemistry, economics, communications, etc.). Each of these disciplines has become increasingly complex forcing firms to search outside their indigenous capabilities. Some firms may retain all these various knowledge fields in house, but find collaboration with other firms gives them greater speed to commercialize a product or service and capitalize on it before it becomes obsolete.

While increasing technological complexity raises the costs of core capabilities, increasing technological advancement has decreased the costs of collaboration. The rapid expansion of high speed, massive data networks has led to the rise of both unorganized and formal collaborative efforts. The development of wikis⁵⁹ and virtual worlds⁶⁰ will only increase this kind of technologically facilitated collaboration.

Impact for Engineering

Mechanical engineering has already begun to feel the impact of collaborative networks in its business practices. Industrial titans like GM and GE have already joined many different corporate alliances to share risk and access core capabilities.⁶¹ Engineers in the future will expect collaboration with organizations and individuals outside their domain to be a required core capability.

A more profound change that will happen in the next 20 years for mechanical engineers will be the increased use of collaborative technologies such as wikis and virtual worlds. Wikis, inspired by the success of open source software, will allow engineers to tap into the collective wisdom of an organization or a network of stakeholders. The key benefit of this kind of technology is that it allows for mass peer review of ideas.⁶² Mass peer review facilitates feedback and redesign in the earlier phases of engineering development before the much more expensive prototype and production phases.

5. The NanoBio Future

Nanotechnology and biotechnology will dominate technological development in the next 20 years. In 2028, nanotechnology and biotechnology will be incorporated into all aspects of technology that affect our lives on a daily basis. They 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.

The drivers pushing nanotechnology and biotechnology to the forefront of technological advances are:

- Research and venture capital funds flowing into nanotechnology and biotechnology
- The transition from the basic research phase into development and commercialization
- Better standards and processes for nanotechnology and biotechnology
- Policymakers recognizing the potential of nanotechnology and biotechnology for solving critical problems

Governments and the private sector from the United States to India have been investing billions of dollars into nanotechnology research and development.⁶³ Biotechnology continues to show strong investment by governments and venture capitalists.⁶⁴ Both nanotechnology and biotechnologies have successfully made the transition from basic research to the development of products and services.⁶⁵

Nanotechnology, one of the newest and most exciting fields of research,⁶⁶ is emerging as an important platform technology that will enable a range of other technologies.⁶⁷ 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.⁶⁸ Nanotechnology has also been vital in developing new generations of processors and new materials and coatings.⁶⁹

Future advances in nanotechnology will provide engineers with a host of new materials, processing techniques, and coatings for their use in new products. For example, carbon nanotubes promise to vastly increase the strength and reduce

the weight of materials. Materials made using carbon nanotubes are six times lighter than steel and are 500 times stronger.⁷⁰ Carbon nanotubes are perfect electrical conductors and are the best known substance for conducting heat. The potential uses – from lighter automobiles to more efficient televisions to a space elevator – are limitless.⁷¹ In other areas, nanotechnology applications are equally amazing. Nanotechnology could be used to create more efficient solar cells⁷² that produce electricity cheaper than coal, to deliver drugs to precise cells in the body,⁷³ and to build terabyte data chips the size of postage stamps.⁷⁴

Biotechnology has already contributed to the development of life saving medicines and food crops.⁷⁵ But this is only the beginning. For all the amazing progress in biotechnology over the last couple decades – biotechnology is still in an early formative stage. Tom Knight, a senior research scientist at MIT, likes to compare the state of cell biology today to that of mechanical engineering in 1864 before the adoption of standardized thread sizes for nuts and bolts in the United States. It is the standardization of nuts and bolts that enabled the construction of complex devices from simple, interchangeable parts.⁷⁶

Biotechnology is on the verge of a similar evolution with the development of synthetic biology as a unique discipline.⁷⁷ Knight and his colleagues are developing hundreds of different interchangeable genetic components they call BioBricks. The goal is to create the nuts and bolts needed to develop complex synthetic organisms that can be used for a multitude of applications that range from producing hydrogen for cars to new drugs for malaria to cleaning up toxic waste.⁷⁸

The biotech future will involve organisms at every level of the production process. It is at this point nanotechnology and biotechnology merge to create the *NanoBio Future*. Organisms will be used to create the building blocks of future materials including nanoparticles. This is beginning to occur with nanotubes being produced by microbes.⁷⁹ In the future, organo-machines⁸⁰ will be designed to be incorporated into industrial processes from materials development, to energy productions, to environmental cleanup.⁸¹ Again, the imagination appears to be the limit.

Both these technologies come with technological risks. There are legitimate concerns about the long-term health and environmental effects of biotechnology⁸² and nanotechnology.⁸³ However, with all the possible benefits to humanity, it is imperative that society works together to minimize the risks and maximize the gains.

Implications for Engineering

The implications for mechanical engineering of developments in biotechnology and nanotechnology are vast. Nanotech and biotech will be part of the core curriculum of every engineer's training in 20 years. Using new knowledge and tools, mechanical engineers will fashion solutions to the most pressing problems of developing new renewable energy, creating new ways to develop sustainably and dealing with acute water shortages. Two sectors of mechanical engineering will be especially affected by nano- and biotechnology--materials and environmental sustainability.

The materials sciences are undergoing a sea change with the developments of nanomaterials. As the production costs for nanotubes falls,⁸⁴ these will be increasingly incorporated into everything that mechanical engineers build. Their increased strength and decreased weight offer huge benefits to all kinds of structures, machinery, devices and production processes.

Many of these new materials will be produced using biotechnological methods. Organo-machines will very likely be the cheapest way to produce new materials and mechanical engineers will have to attain capabilities to manage them. According to a 2008 survey of ASME members, more than a quarter anticipate that nanotechnology will be used in most of the projects they are involved in over the next twenty years and one in four anticipates using biotechnology in their work.

In the area of environmental sustainability, nanotechnology will contribute to the production of more efficient and more cost-effective solar power, hydrogen fuel cells, batteries, and wind turbines. Biotechnology will be involved in the production of biofuels and hydrogen and will also be used by industry to clean pollutants produced during industrial production processes.

6. Regulating 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 becoming an increasingly important part of the competitive advantage of nations and companies. Innovation is also the driving force behind economic growth and the key to solving future global challenges. Intellectual property is a controversial issue as it combines monopolistic benefits – which can harm society – with innovation incentives – which help society. Any regime, domestic or international, regulating intellectual property is therefore very divisive but also very important to the future.

A number of drivers are behind the calls for a reform⁸⁵ of the intellectual property regime. Among these are:

- The increasing costs of patent litigation
- The increasing speed of technological development
- The discombobulating nature of open source innovation models
- The ethical issues associated with certain kinds of intellectual property

By some estimates, IP litigation accounts for more than a quarter of all funds spent on industrial research and development.⁸⁶ This is especially disheartening for complex technologies which depend little on IP 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.⁸⁷ 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.

Aside from the danger of litigation costs eating into R&D funds, there are other ways in which IP litigation can be damaging to innovation. Multiple firms can create IP walls and refuse to cross-license their property thereby effectively stalling innovation in a complex technology.⁸⁸ This constant threat of patent infringement is raising industry demands for a different form of dispute resolution⁸⁹ and is increasing the importance of patent pools.⁹⁰ In order to assure that companies can benefit from their innovations in complex technologies that are covered by various different patents, firms are forming partnerships based around patent pools in which all partners have access to all patents from each firm. Patent pooling is clear reaction to the litigious nature of the IP regime but is also serving to reinforce global trends toward corporate collaboration.

Open source models of innovation have even more effectively destroyed the mythos that only strong IP rights can properly incentivize innovation.⁹¹ The Linux operating system and the Firefox web browser are perhaps the two most successful developments of open source software. Individuals around the world have contributed millions of lines of code and millions of man-hours outside a corporate structure. Largely without a monetary incentive, they have produced products that are successfully competing with corporate giants.⁹² Wikipedia, another famous open source project, is arguably the most successful encyclopedia in history and just as accurate as its forbears and its competitors without any monetary gain for its thousands of contributors.⁹³

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.⁹⁴ The Open Source Car⁹⁵ has been singularly unsuccessful but with the decentralization of manufacturing (see the Designing at Home section of this report) there is a very good chance this will change. The IP regime is already challenged to integrate thousands of software developers. It will prove very inadequate when there are not just ten automobile manufacturers but hundreds.

Finally, ethical debates about intellectual property are only likely to intensify. 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. How the government decides to regulate this issue will be important not just to the chemicals industry or the agricultural industry, but to the manufacturing industries as well (see The NanoBio Future section of this report for more information on biotechnology and manufacturing).

Implications for Engineering

Engineering firms working with complex technologies often need access to a complex web of patents and therefore must be vigilant to guard against costly patent infringement. While certain patent reforms could lower the risk of infringement, any fundamental patent reform seems unlikely in the near future due to America's dominant position in the pharmaceuticals market (the industry that most benefits from the current IP regime). Furthermore, increased collaboration, mostly as a result of changes in the technological and global marketplace, will also bring about tricky questions about patent ownership in cooperative ventures for engineering companies.

Open source innovation models will also have some impact on mechanical engineering in the design phase in the immediate term. Mechanical engineers can expose designs to mass peer review online. Further in the future, open source models of innovation will be even more advantageous for engineering firms and free-lancers who are manufacturing at home (again, see Designing at Home). How this will work out for intellectual property remains unclear.

Finally, as the use of biotechnology extends into the manufacturing/industrial sector, engineering firms will increasingly come up against the ethical implications of patenting living objects. These issues will have to be resolved delicately and with plenty of attention to the current context of the ethical debate.

7. 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 trends shaping mechanical engineering into a more diverse profession include:

- The emergence of global business opportunities
- Competition to reach increasingly segmented markets
- Global patterns of mass migration and mobility
- The continued shortage of skilled employees relative to global demand

Increased globalization of the workforce will drive an acceleration of the trend toward greater diversity within organizations. Indeed, a new framing of the diversity dialogue is taking shape, as exemplified by New York Times political columnist Thomas L. Friedman’s book *The World Is Flat*. Friedman defines a flat world as one characterized by a “global web enabled platform for multiple forms of sharing knowledge and work irrespective of time, distance, geography and increasingly even language.”⁹⁶ There will be a need for approaches to inclusion that better reflect and respond to the opportunities of a “flatter world.”

Mass migration of populations will also drive increased workforce diversity around the world. 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,⁹⁷ and larger than the current populations of the United States and Germany combined.⁹⁸

In the past, many multinational companies have lost their way in a business climate where global workforces are as likely to speak Spanish, Hindi or Mandarin as they do English.⁹⁹ Today, though, as more organizations race into the global economy, they are tailoring their diversity policies and practices to the new cultural and business order to a greater degree than ever before,¹⁰⁰

adapting to hundreds of countries, languages and religious practices. Companies are juggling more cross-border teams on all continents and aggressively recruiting diverse talent from Shanghai to Rio de Janeiro.

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.¹⁰¹ In the future, the cultivation of the cross-cultural skills needed to manage global diversity will be important to the operational success of global business models.¹⁰² Optimizing the benefits of greater diversity will demand greater managerial skill.

Impact for Engineers

This trend toward the more diverse face of engineering has already irreversibly taken hold. Even within the United States, by 2004 forty-six percent of engineering master's degrees and fifty-seven percent of doctoral degrees were awarded to foreign nationals.¹⁰³ As all nations seek the competitive edge of knowledge, they will value educating more citizens as engineers and scientists.

Some countries project shortages of skilled workers in many fields, including engineering, as their populations age and fewer young people elect these courses of study. As companies rely more on innovation and customer service to compete against low-cost commodity providers, employers are in a race to attract world class talent that can help them offer this difference. Employers understand they must seek the best and brightest from a more diverse workforce. According to ASME's 2008 survey, fully three out of four respondents agree that the field is headed toward greater ethnic diversity and gender balance.

While globalization will doubtless continue to drive cultural diversity at the international level, achieving more gender diversity may be a greater challenge. In the United States, women now comprise only ten percent of the tenured or tenure-track faculty in engineering colleges¹⁰⁴ and comparable disparities are reported globally.¹⁰⁵ Yet these statistics should by no means be seen as normative. China's national news service reports that, at present, more than a third of engineers in that country are women.¹⁰⁶ Gender diversity now exists in many professions and current efforts should bring it to mechanical engineering as well by 2028.

8. 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.

The process of innovation in engineering will be democratized as many inventors anywhere in the world will have the tools needed to design, create and develop. Advances in technology and the larger environment favor the potential of *Designing at Home* including:

- Advances in computer aided design and low-cost prototyping and fabrication technologies
- Better information and communication technologies for collaboration
- A competitive work environment, higher transportation costs and a demand for a higher quality of life

Future CAD systems will have a profound impact on engineering design. Computer aided design (CAD), first developed more than 40 years ago, has transformed how engineers work.¹⁰⁷ Faster processing¹⁰⁸ and network speeds¹⁰⁹ will soon allow future engineers to design entire products as a system rather than separate pieces.¹¹⁰ This will expand the capacities of engineers and enable more complex designs to be completed anywhere.

Virtual worlds, which are gaining in popularity and technical sophistication, could soon become truly interactive environments for interacting with colleagues.¹¹¹ By 2028, it will be possible for 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.¹¹²

Virtual worlds will enable engineers to interact with colleagues from around the world and make it easier for engineering companies to run decentralized organizations.¹¹³ Decentralized organizations, which rely on telework among employees or outsourcing of work to independent engineers, will be more competitive as transportation costs rise¹¹⁴ and companies find it difficult to build and maintain office and manufacturing space.¹¹⁵

Home-based personal fabrication will be readily available to these independent engineers. Rapid proto-typing¹¹⁶ and fabrication laboratories¹¹⁷ are becoming cheaper. Within five years, better technology and larger production runs will lower the cost of 3D printers to ranges 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.¹¹⁸

Impact for Engineering

Engineers will have more opportunities to become entrepreneurs and take advantage of this distributed model for work. Likely changes for engineers include:

- More engineers working as independent contractors virtually collaborating with colleagues around the world
- More distributed patterns of work for engineers where they utilize advanced CAD and fabrication systems to design from home
- Better quality of life for engineers¹¹⁹

The ability to design and prototype from anywhere will create more global competition for engineering services. Companies will be able to outsource design work to individual engineers and add engineers as needed to projects. Companies will still keep the highest value work in-house to ensure quality and preserve competitive advantage over competitors, but almost all lower level technical work is likely to be outsourced.

Engineers will have all the tools they need at home to do high quality design and to collaborate with colleagues around the world. This will improve quality of life as less time and money is spent commuting on increasingly congested roads. Home based design and fabrication will also encourage more children to explore, invent and create. A recent U.S. survey found four in ten young people imagine having their own business some day.¹²⁰ Likewise, young people in China, India and emerging economies see entrepreneurship as the best route to prosperity.

These new capabilities will empower social entrepreneurs to meet local needs in less advantaged or remote areas. These communities may not have the technical expertise to develop solutions to their own problems. Entrepreneurial engineers will be able to design customized products and solutions that are appropriate to local conditions.

9. Engineering for the Other 90 Percent

By 2028, globalization and new business models will increasingly drive the development of mechanical engineering projects that serve the poorest 90 percent of humanity – the four billion people who live on less than \$2 a day.

Engineering for the Other 90 Percent will demand innovations in business processes, engineering solutions and approaches. The trends shaping this change include:

- Maturation of massive consumer markets in emerging regions
- Continued attractiveness of off-shoring and global outsourcing practices
- Growing access to communications technologies in poorer communities

The largest but poorest socio-economic group increasingly represents opportunities for local entrepreneurs, innovative nongovernmental organizations and global companies. Currently, it is estimated that around four billion people live on less than \$2 per day.¹²¹ By 2030, almost two billion additional people are expected to populate the earth, ninety-five percent of them in developing or underdeveloped countries.¹²²

Professor C.K. Prahalad, in his book, *The Fortune at the Bottom of the Pyramid*, proposes that businesses, governments, and donor agencies stop thinking of the poor as victims and instead start seeing them as resilient and creative entrepreneurs as well as value-demanding consumers. He proposes that there are tremendous benefits in choosing to serve these markets in ways responsive to their needs. Today's poor can become tomorrow's middle-class. There are also poverty reducing benefits if businesses work with civil society organizations and local governments to create new local business models.¹²³

As this report illustrates through the exploration of the collaborative advantage, competitive edge of knowledge, designing at home and developing sustainably, it is becoming technologically and economically feasible to engineer products and services for the underserved. Nations and companies see the talent and market

potential of these populations and see the strategic importance of helping them secure economic and social stability. The flow of communications and knowledge exchange make the problems of once remote communities seem immediate. In a more mobile world, more people are making personal connections through public and private organizations and as individuals and social entrepreneurs.

Impact for Engineering

Increasingly, engineers are likely to be called upon to devise cost-effective ways to increase access to food and clean water, effective sanitation, energy, education, healthcare, revenue-generating activities, and affordable transportation for the other 90 percent of humanity.

The vanguard of such a movement is already coming together. On an organizational level, 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.¹²⁴

Historically, the "appropriate technology" movement, which emerged partially in response to the energy crisis in the 1970s, led the way in consciously addressing the other 90 percent from an engineering and design standpoint. In this context, appropriate technology for developing nations was often defined around simplicity. A cloth sari folded four times, for example, was used to filter cholera bacteria from water. Similar innovations included the use of concentric clay pots to preserve fresh vegetables and a disposable drip irrigation system used for one season.¹²⁵

Examples of modern innovative approaches along these lines were recently highlighted by the Cooper-Hewitt National Design Museum in New York as part of an exhibition honoring inventions dedicated to "the other 90 percent."¹²⁶ Yet, the problems that many of these designs addressed are likely to be remote to the day-to-day experiences of many engineers. For example, one design tackled a job that millions of women and girls spend many hours doing each year — fetching water, often by balancing heavy jerry cans on their heads. It is

backbreaking work and sometimes causes crippling injuries. In response, the Q-Drum, a circular jerry can, was engineered to hold twenty gallons of water, and rolls smoothly enough for a child to tow it on a rope.¹²⁷

At present, most U.S. engineering schools do not typically 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. Unlike previous engineering movements targeting emerging regions, “bottom of the pyramid” ventures generally operate as profit-making but consciously non-exploitive businesses. It is argued that this approach adds both greater sustainability and greater dignity to the development of emerging regions.¹²⁸

Even beyond the humanitarian dimension, the downsides to ignoring these untapped markets are potentially enormous. Given the right conditions, serving viable markets that emerge for the other 90 percent could well be a crucible of 21st century innovation. Indeed, game-changing technologies and ideas could well emerge from this segment that impact business in the industrialized world as well.

A 2028 Future Survey of ASME Members

ASME surveyed its members in January 2008 on the changes they expect to see in their careers and the field of mechanical engineering over the next two decades. The largest number of respondents anticipate mechanical engineering will contribute to resolving the energy crisis as sustainability becomes an essential engineering outcome. These members expect they will be collaborating across disciplines and need an expanding base of knowledge and experience to do their jobs. The survey respondents agree with the likely significance of the changes described in this Institute for Alternative Futures environmental scan.

More than 1800 ASME members participated in this web-delivered survey. The most common job title was “Senior Engineer” (at seventeen percent) followed by “Project Engineer” (at ten percent). A Bachelor’s is the highest degree attained for two-fifths of the respondents; twenty-eight percent have a Master’s; and twenty-four percent have a PhD. Ages were distributed evenly among intervals between thirty-one and fifty. Ninety-one percent of respondents were male.

How Mechanical Engineering Will Contribute to the Future

Energy and sustainability are expected to be very important to the field of mechanical engineering. Ninety-one percent of survey respondents agree that mechanical engineering will play a pivotal role in developing new energy sources. About three quarters agree that mechanical engineering will play a pivotal role in addressing climate change.

Four out of five respondents anticipate they will be expected to engineer for product lifecycle or “cradle to cradle design”. Three quarters anticipate that designing for sustainability will become a large employment segment for mechanical engineering. Half of the survey respondents agree that inexpensive technological advances like desktop manufacturing will drive a boom in inventions from emerging markets and home inventors. Three-fourths see the great potential for mechanical engineers to develop more effective business models, products and process designs for working in developing regions.

How Engineering Careers May Change

Nine out of ten survey respondents expect to work in interdisciplinary projects. They express strong agreement with the statement “I will increasingly need to coordinate multiple disciplines to complete more complex projects.”

The vast majority of survey respondents anticipate devoting substantial time to acquiring new knowledge. Eighty-four percent agree that they will “need to invest an increasingly greater amount of time and effort acquiring new knowledge and skills to remain competitive.” This knowledge will come from areas outside the traditional purview of mechanical engineering, according to seventy-three percent of the respondents.

Half of ASME’s respondents agree that schools will offer a fundamentally different curriculum. Three-quarters anticipate the need for soft skills, language skills and cultural competency. The survey participants offered a wide variety of examples of the professional knowledge they will need in the future. Software skills and modeling were often cited, as were materials science and thermodynamics.

The survey respondents also anticipate that technological advances will change the way they work. Fifty nine percent of participants, for example, anticipate they will be involved in collaborative or open source networks. More than half anticipate that they will spend a significant amount of time conducting collaborative modeling and experimentation in virtual worlds.

Fifty-seven percent agree that competing nations will train more mechanical engineers. In the written comments, however, some respondents express concern that people will find other careers more attractive than mechanical engineering.

Fewer respondents anticipate dramatic changes in their careers as a result of nanotechnology and biotechnology. Only twenty-nine percent agree or strongly agree that nanotechnology will be involved in the development of most devices, products and services they will engineer. Only a quarter anticipate that they will use biotechnology to create and develop devices, products and services. It should be noted that this environmental scan anticipates that these technologies will have a much greater impact on their careers than these respondents currently perceive.

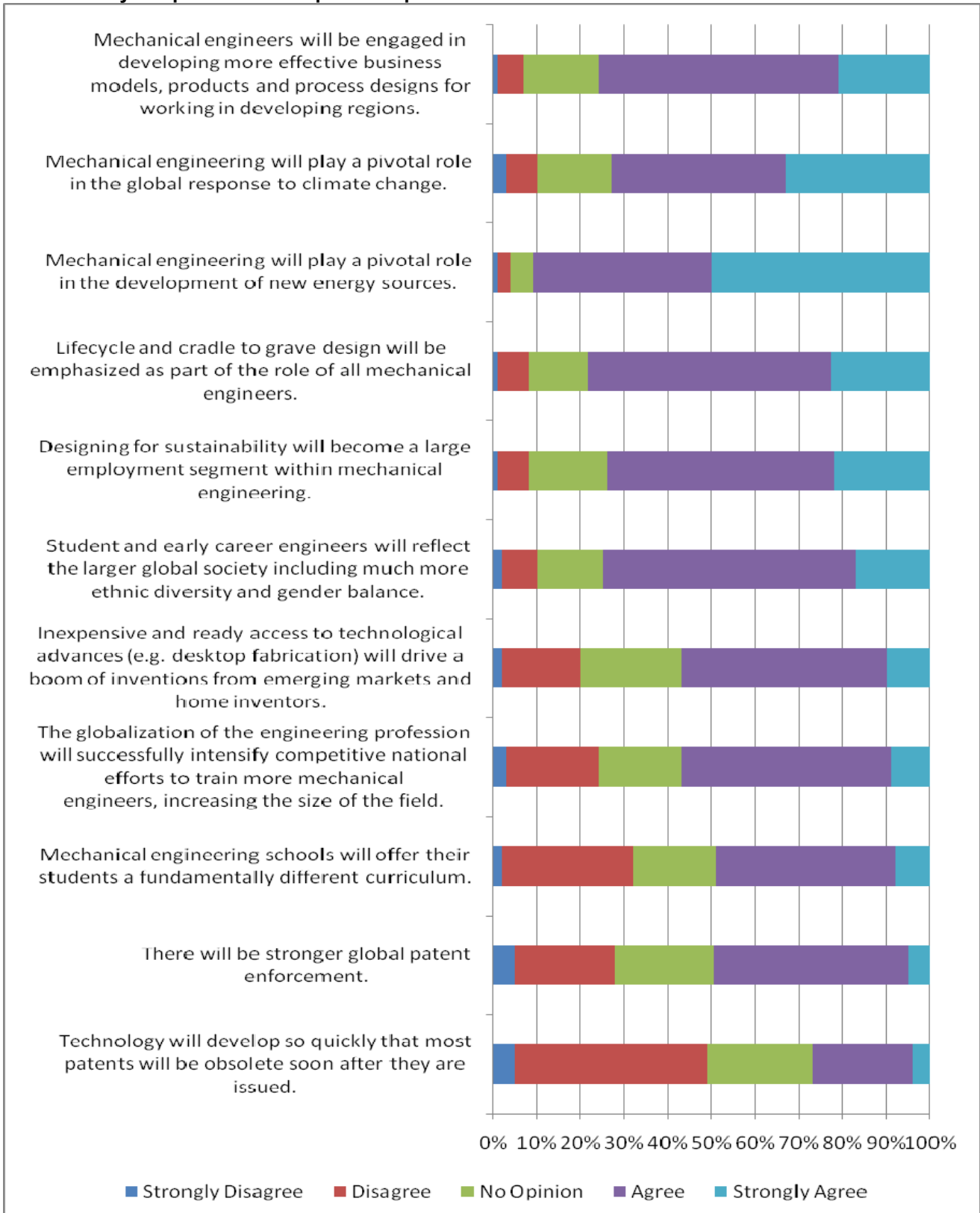
A Field Open to Adapting to the Future

Taken as a whole, the survey results suggest a profession with a relatively high awareness and openness to substantial change. Participants clearly see emerging issues as important to both their own careers and to the field as a whole. Given this high degree of awareness and readiness, mechanical engineering leaders should be quite able to guide the field and the profession into making great contributions to a preferred future.

Survey Responses: Participants' Career Expectations



Survey Responses: Participants' Expectations for the Field as a Whole



Endnotes & Sources

Developing Sustainably

¹ Executives see most sociopolitical issues as risks rather than opportunities. This includes their perspective on the environment. However, their optimism on this issue has increased even as global concern has intensified.

The McKinsey Quarterly (Nov. 2007) *Assessing the Impact of Societal Issues: A McKinsey Global Survey*.

² 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*.

³ 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>

⁴ The successful test of extremely deep sea drilling technology in 2006 in the Gulf of Mexico has opened up the possibility of drilling in a range of oil fields previously thought inaccessible. The record-setting well drilled by Chevron is more than five miles deep, including more than a mile of ocean depth. Promising areas for this extremely deep sea drilling include the coast of Brazil, the North Sea of Britain, the Nile River Delta of Egypt and spots off the coast of West Africa.

Morrison, M. (Sept. 7th, 2006) Plenty of Oil—Just Drill Deeper. *BusinessWeek*. Retrieved 2/13/2007 at http://www.businessweek.com/investor/content/sep2006/pi20060907_515138.htm?chan=top+news_top+news+index_investing

New discoveries of oil reserves are likely to be of the deep sea or extremely deep sea variety. For example, the recent discovery of the Tulpi oil field off the coast of Brazil has started speculation that the field may be only one field of a potentially larger reservoir of 70bn to 100bn barrels of light oil.

(Feb. 12th, 2008) A Big Oil Discovery. *The Economist Online*. Retrieved 2/12/2008 at http://www.economist.com/agenda/displaystory.cfm?story_id=10677726

⁵ Last year, unrest in the Niger Delta threatened the supply of oil coming out of the chronically mismanaged and unstable African nation. More than 150 foreign employees were kidnapped in 2006 and currently foreign employees are escorted by armed guards and armored cars. The unrest continues with frequent shut-ins of production by Western oil companies. Similarly, Iraqi oil production stuttered almost to a halt after the invasion due to security concerns, corruption, sabotage and maintenance problems, and is only recently returned to pre-war levels. In the

future, production is likely to be in politically unstable places as reserves of cheap oil and minerals are depleted in stable countries.

Mouawad, J. (April 21st, 2007) Growing Unrest Posing a Threat to Nigerian Oil. *The New York Times*. Retrieved 2/13/2008 at <http://www.nytimes.com/2007/04/21/business/worldbusiness/21oil.html>

Amanze-Nwachuku, C. (Feb., 14th, 2008) Nigeria: Oil Export Suffers Setback. *allAfrica.com*. Retrieved 2/14/2008 at <http://allafrica.com/stories/200802140319.html>

Hafidh, H. (Dec. 17th, 2007) Iraqi Oil Is Easing Supply Strain. *Wall Street Journal*. Retrieved 2/14/2008 at http://online.wsj.com/article/SB119748269157924065.html?mod=googlenews_wsj

⁶ While mining and drilling can never be completely sustainable or environmentally friendly, there are ways that can be used in the future to reduce its impact on the environment. Examples include using genetically modified bacteria to leech metals out of ore, sequestering carbon dioxide produced through drilling and using genetically modified organisms for environmental remediation.

(July 14th, 2006) The Midas Bug - the Bacterial Alchemy of Gold. CSIRO Press Release. Retrieved 2/13/2008 at <http://www.csiro.au/news/ps20d.html>

Perlman, D. (July 14th, 2003) Mining Bacteria's Appetite for Toxic Waste. *San Francisco Chronicle*. Retrieved 2/13/2008 at <http://www.sfgate.com/cgi-bin/article.cgi?file=/c/a/2003/07/14/MN103893.DTL>

Petrisor, I.G., Lazar, I. and Yen T.F. (Nov, 2007) Bacterial Mining. *Petroleum Science and Technology*, 25 (11): 1347-1352.

McKee, B. (2002) *Solutions for the 21st Century*. International Energy Agency. Retrieved 2/13/2008 at http://www.iea.org/textbase/papers/2002/tsr_layout.pdf

⁷ 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).

⁸ ITT Industries (2006) ITT Industries Guidebook to Global Water Issues. Retrieved 11/28/2007 from: <http://www.itt.com/waterbook/toc.asp>

⁹ 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.

¹⁰ While a number of definitions of sustainability exist, this one, arrived at by the UN Bruntland Commission, represents a plurality consensus.

Sen, A. (Dec. 2000) Human Development and Economic Sustainability. *World Development*. 28 (12).

¹¹ A detailed discussion of the environmental challenges posed by the emergence of economic strength in traditionally less-developed regions can be found in:

Myers, N., Kent, J. (2004) *New Consumers: The Influence of Affluence on the Environment*. Island Press.

¹² Hammond, G. (2003) Engineering sustainability: thermodynamics, energy systems, and the environment. *International Journal of Energy Research*. 28 (7).

¹³ McDonough, W., Braungart, M. (2002) *Cradle to Cradle: Remaking the Way We Make Things*. North Point Press

¹⁴ Benyus, Janine (1997) *Biomimicry: Innovation Inspired by Nature*. Harper Perennial
Benyus has also co-founded Biomimicry Guild, the Innovation Consultancy, to help innovators learn from and emulate natural models in order to design sustainable products, processes, and policies that create conditions conducive to sustainability.

¹⁵ Arizona State University Environmental Scientist Braden Allenby is often credited as one of the originators of the concept of Earth Systems Engineering. He has outlined his view of the topic in:

Allenby, B. R. (2005). *Reconstructing Earth: Technology and Environment in the Age of Humans*. Washington, DC: Island Press. Retrieved 11/15/2007 from
<http://www.loc.gov/catdir/toc/ecip059/2005006241.html>

¹⁶ From an engineering standpoint, the debate surrounding the issue of Earth Systems Engineering center on both technical feasibility and desirability of the process. Both of these dimensions are well covered by the report *Engineering and Environmental Challenges: A Technical Symposium on Earth Systems Engineering*.

National Academy of Engineering (2002) *Engineering and Environmental Challenges: A Technical Symposium on Earth Systems Engineering*. National Academy Press.

Engineering Large and Small Scale Systems

¹⁷ Charles M. Vest, now president of the National Academy of Engineering, outlined these two frontiers while speaking to a National Academy of Engineering (NAE) annual meeting on October 10, 2005.

“One frontier has to do with smaller and smaller spatial scales and faster and faster time scales, the world of so-called bio/nano/info. This frontier, which has to do with the melding of physical, life, and information sciences, offers stunning, unexplored possibilities, and natural forces of this frontier compel faculty and students to work across traditional disciplinary boundaries.”

“The other frontier has to do with larger and larger systems of great complexity and, generally, of great importance to society. This is the world of energy, environment, food, manufacturing, product development, logistics, and communications. This frontier addresses some of the most daunting challenges to the future of the world.”

Engineers of today and tomorrow must be prepared to conceive and direct projects of enormous complexity that require a highly integrative view of engineering systems.

Remarks 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>

¹⁸ The Massachusetts Institute of Technology (MIT)'s Mechanical Engineering Department is leading the way in positioning itself in tiny technology research. The department believes that the miniaturization of devices and systems of increasing complexity will accelerate as "the physical understanding of the nanoworld expands" and "wide-spread commercial demand drives the application of manufacturing of micro- and nanosystems." Tiny technology research cuts across all of the five broadly divided disciplines of mechanical engineering.

Available at MIT website, http://web.mit.edu/Engineering/tt/mech_e.html, retrieved 11/28/07.

¹⁹ The "lifeline system" concept was developed to evaluate large, geographically distributed networks during hazardous natural events. These lifeline systems are linked to the economic well being, security and social fabric of the communities they serve and failure of the system leads to disastrous consequences as seen during Hurricane Katrina or during the Boxing Day Tsunami in 2004. They are also the key components of any rebuilding project. The six principal systems are electric power, gas and liquid fuels, telecommunications, transportation, waste disposal and water supply. Lifeline systems all influence each other – and require a certain amount of systems level thinking to build resiliency.

O'Rourke, T.D. (2007) *Critical Infrastructure, Interdependencies and Resilience*. National Academy of Engineering. Retrieved 12/03/07 at <http://www.nae.edu/nae/bridgecom.nsf/weblinks/CGOZ-6ZQQRH?OpenDocument>

²⁰ As discussed in the *Developing Sustainably* section, there is a growing movement to develop Earth System Engineering as a discipline designed to study the largest and most complex system of all. The National Academy of Engineering is exploring the concept that ESE can become a means to understand the complex interactions between natural and human-made systems, to predict and monitor more accurately the ecological impact of engineered systems, and to devise engineered systems for the mutual benefit of natural and human-made systems. Retrieved 11/28/07 at the National Academy of Engineering website, <http://www.nae.edu/NAE/engenvcom.nsf/weblinks/NAEW-4NHMBR?OpenDocument>

²¹ The fellows of the International Council on Systems Engineering have outlined a process for engineering and integrating very complex systems. This consensus process uses the acronym SIMILAR to describe the steps: state the problem, investigate alternatives, model the system, integrate, launch the system, assess the performance and re-evaluate. One dissenting fellow suggests that the future of systems engineering will be processes that optimize systems rather than those that minimize problems. Retrieved 11/29/07 at the ICOSE website, <http://www.incose.org/practice/fellowsconsensus.aspx>

²² William Wulf, former president of the National Academy of Engineering, described the challenges of engineering incredibly complex systems in a 2003 keynote address on emerging technologies and ethical issues. The complexity of new technical systems in information technology, biotechnology and nanotechnology is so great that it is impossible to predict their behavior.

Wulf, W. (2004) in *Emerging Technologies and Ethical Issues in Engineering: Papers from a Workshop*, October 14-15, 2003. National Academies Press, available at http://www.nap.edu/catalog.php?record_id=11083

²³ Wulf observed in his 2003 keynote address that new technical systems are so complex that it is impossible to predict their behavior. This creates a challenging macro level ethic question for the profession. How can we make ethical decisions when we cannot predict what the outcomes of engineering a system will be?

The Army Corp of Engineers and the Florida Everglades are a good example of the ethical conundrum in question. The Army Corps of Engineers is undertaking a massive engineering project to “remediate” the Everglades. The Everglades are one of the most complex natural ecosystems in the world and almost impossible to understand completely. Part of the reason for the massive undertaking is to restore the unintended consequences previous generations had on the incredibly complex system when they drained areas of the Everglades to make places where people can live, work, and shop. It is almost certain that engineering a system as complex as the Everglades will have consequences that are entirely unanticipated. Ibid.

²⁴ In 2002, ASME commissioned an environmental scan by Global Foresight Associates that highlighted the importance of systems engineering. Mechanical engineers will need to expand their expertise from macroscale systems to micro and nanoscale systems as described by MIT’s move into tiny technology research. The move into tiny technology will create increased complexity that “will create additional challenges in analysis, design and synthesis...in many cases render[ing] the current paradigms of system behavior and structure obsolete...” Mechanical engineers will need to adopt new perspectives, consider alternative solutions to problems, and actively recruit input from fields outside science and engineering.

Global Foresight Associates (2002) *The Convergences of the Life Sciences & Engineering*. ASME.

²⁵ A survey of southeastern engineering schools found universal agreement that they should be teaching complex systems to prepare tomorrow’s engineers but in fact few are doing this.

Craig, Nadia, Veronica Addison, James Russell, Michelle Maher and Wally Peters. (2005) *Benchmarking the Integration of Complex Systems Study in Southeastern Mechanical Engineering Programs*. Retrieved 12/03/07 at <http://www.me.sc.edu/Research/Iss/Papers/Benchmarking%20SE%202005.pdf>

²⁶ Patricia D. Galloway, a former president of the American Society for Civil Engineers, says engineering education must incorporate social elements. “Engineers must become more aware of the need to work in teams, consider social issues, understand political and economic relations between nations and their peoples and understand intellectual property, project management, multilingual influences, and cultural diversity, as these factors will drive the engineering practice of the 21st century. It will become essential that engineers know how and when to incorporate social elements into a comprehensive systems analysis of their work.”

Galloway, P.D. (2007) *The 21st Century Engineer, A Proposal for Engineering Education Reform*, p. 4. ASCE Press.

²⁷ The study of complex systems is already growing in importance thanks to the support of some select institutions and multi-disciplinary science and technology programs. The leader in complexity science, the Santa Fe Institute, has pushed the development of complexity science and their work has sparked the creation of a number of institutes and departments dedicated to complexity science or the understanding of complexity as it relates to a certain field of science or engineering. Examples include the Center for the Study of Complex Systems at the University of Michigan and the Krasnow Institute for Advanced Study at George Mason University.

²⁸ The development of better information technologies will enable systems engineering. Some of these new technologies and their impact are discussed in the *Designing at Home* section of this report. Simulation technology will emerge as a design tool and engineers will be able to take advantage of improved processing power to understand the “relationships between design variables, to predict performance, and to anticipate the lifecycle of the project itself.”

Shaw, W.H. (March, 2005) In a World of Rapidly Advancing Technology, Someone Has to Keep Things Under Control in *Engineering Management*, Retrieved November 30, 2007 at <http://www.memagazine.org/supparch/emmar05/makingsns/makingsns.html>

²⁹ Ibid.

Competitive Edge of Knowledge

³⁰ A good example of the importance of a leading science and engineering university to the creation of high tech clusters of businesses is MIT. 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.

Friedman, T.L. (2005) *The World Is Flat: A Brief History of the Twenty-first Century*. New York: Farrar, Straus and Giroux, pp. 244.

³¹ China, India, Brazil, Taiwan and Russia are quickly becoming global competitors in technology and engineering. All of them are building up their investment in basic research and encouraging the development of clusters of industries around their leading universities. China, for example, has made strides over the last five years in moving from manufacturing to design.

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

³² 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>

³³ 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.

³⁴ 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.

³⁵ 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 would 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

³⁶ 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).

In Canada, foreign trained engineers are becoming a larger part of the workforce. Ontario is a good example. For the past two years, Professional Engineers Ontario has licensed more foreign-trained engineers than those trained in Canada. One-third of the 70,000 licensed engineers working in Ontario were trained abroad.

Grewal, S. (Sept. 13th, 2007) Engineers breaking new ground. *Toronto Star*. Retrieved 11/9/2007 at <http://www.thestar.com/article/255475>.

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

³⁷ The HB1 visa is a temporary work visa (three years with a three year extension) for educated workers with at least a bachelor's degree. It is often used by high-tech companies in the U.S. to hire foreign scientists and engineers. The J1 visa is primarily used by foreign students at American universities and is vital to attracting and retaining the graduate students in science and technology who do a lot of the research at universities.

While many politicians in the United States are pushing for greater restrictions on visas to the U.S. for both security reasons and in response to an anti-immigration sentiment in the public after the failed Bush immigration plan – Europe is looking to open up their immigration policies for highly skilled workers and view the American visa system as a compelling model.

(Dec. 11th, 2007) Europe Wants World's Brightest As America Keeps Limits Tight. *CNN Money*. Retrieved 12/13/07 at <http://money.cnn.com/news/newsfeeds/articles/newstex/IBD-0001-21601556.htm>

The Blue European Labour Card or Blue Card was proposed earlier this year by the European Commission to draw more highly skilled workers like engineers. It would have many of the same characteristics of the U.S. Green Card although it would not give migrants permanent status. At the national level, both France and Britain have developed new immigration systems to encourage highly educated workers. These measures should drive the migration of engineers in Europe and aid member states as they seek to remain economically competitive.

(March 20th, 2007) EU mulls its own version of the US Green Card scheme. *EUbusiness.com*. Retrieved on November 9th, 2007 at http://www.eubusiness.com/Living_in_EU/eu-blue-card.24.

(October 23rd, 2007) Key parts of the EU's proposed Blue Card work visa plan. *International Herald Tribune*. Retrieved on November 9th, 2007 at <http://www.ihf.com/articles/ap/2007/10/23/europe/EU-GEN-EU-Blue-Card-Visa-Glance.php>.

³⁸ Sub-Saharan Africa and Latin America are the hardest hit by brain drain. Qualified workers from sub-Saharan Africa, who make up just four percent of the total active population, constitute over 40 percent of those who go overseas, according to World Bank figures for 2005. Almost all Latin American countries send at least 10 percent of their population with a tertiary education abroad, with some sending 50 percent or even higher. A startling example is Jamaica, which sends more than 77 percent of its population with tertiary education abroad – mostly to the United Kingdom.

For immigrants to the U.S., the hardest hit countries are Egypt, Ghana, and South Africa. More than 60 percent of immigrants from those three countries have a tertiary education. Other countries with high percentages of immigrants to the U.S. with a tertiary education include the Philippines (vast majority), India (75%), Guyana (70%), Korea (53%) and China (50%).

Carrington, W.J. and E. Detragiache (1999) How Extensive Is the Brain Drain? *Finance and Development*, vol. 36 (2). Retrieved November 9, 2007 at <http://www.imf.org/external/pubs/ft/fandd/1999/06/carringt.htm#author>

Surprisingly, rich, developed countries are not immune to brain drains. Doctoral recipients in the U.S. from countries in Europe, Israel and Asia often opt to stay inside the U.S. Israel lost 25,000 high tech workers to the U.S. and other countries due to cuts in R&D funding. The U.S. has also lost highly qualified researchers due to the outsourcing of design and other processes to India and China and restrictions on funding for stem cell research. Most worrying for the U.S. are new regulations and restrictions on education and work visas after 9/11 that may be sending many qualified workers and students in the U.S. back to their countries of origin.

Webber, A.M. (Feb., 2nd, 2004) Reverse brain drain threatens U.S. economy. *USA Today*. Retrieved November 9th, 2007 at http://www.usatoday.com/news/opinion/editorials/2004-02-23-economy-edit_x.htm

Krieger, M. (Nov., 8th, 2007) Brain-drain threatens to set back hi-tech. *The Jerusalem Post*. Retrieved November 8th, 2007 at [http://www.jpost.com/servlet/Satellite?cid=1192380770958&pagename=JPost%2FJPArticle%2FShoFull](http://www.jpost.com/servlet/Satellite?cid=1192380770958&pagename=JPost%2FJPArticle%2FShowFull)

Wadhwa, V. (August 27th, 2007) The Reverse Brain Drain. *BusinessWeek*. Retrieved November 9, 2007 at http://www.businessweek.com/smallbiz/content/aug2007/sb20070821_920025.htm

³⁹ The importance of knowledge transfer was a key theme in a series of focus groups conducted by IAF at the 2007 ASME Congress held in Seattle. Early career engineers identified the transfer of knowledge from the Baby Boomer generation as a key challenge they will face in their careers. The focus groups also recognized the importance of sharing knowledge across fluid teams of engineers around the world.

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

⁴⁰ The accelerating pace of change in technology is something that almost everyone who works in a technology heavy field, or marvels at their suddenly obsolete one year old personal computer, understands intuitively. The increasing pace of change in technology can be seen most clearly in information technology where cost and performance are doubling every year and a half. If that trend holds, and it has held for the last 20 years at least, information technology, as measured by price performance and capacity, will multiply by 1,000 in less than a decade and 1 billion in 25 years.

Kurzweil, R. (July, 16th 2007) Embracing Change. *The Philadelphia Inquirer*. Page D1.

⁴¹ Many of the routine technical skills once performed by engineers are increasingly being carried out by machines. 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>

⁴² 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.

⁴³ See also in this report the section on *Engineering Small and Large Scale Systems* for more information on the challenge of systems level thinking.

⁴⁴ 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

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>

⁴⁵ There are two trends that will drive the harmonization of engineering education. One is the continued growth of large multinational engineering corporations. They will expect certain skills and knowledge from their newly hired engineers and will press policy-makers and educators to provide those skills in engineering education. The second is the continued growth of newly industrialized and developing nations – particularly India and China. As these nations move to provide more value added engineering services and products they will continue to improve and update their schools of engineering.

⁴⁶ Galloway, Patricia D., Ph.D., P.E. (2007) *The 21st Century Engineer, A Proposal for Engineering Education Reform*, p. 4. ASCE Press.

⁴⁷ The majority of senior members of the engineering profession were graduates of baccalaureate programs. However, these engineers had significantly more engineering education – with a successful completion of between 145 and 160 credit hours. While the amount of new knowledge in engineering education has increased the amount of credit hours needed to graduate with an engineering degree has dropped to between 120 to 135 credit hours due to various requirements for general education by legislatures and universities. Continued erosion of the base of engineering education threatens to make engineering a trade rather than a profession in the global market. Ibid.

⁴⁸ In 2005, the National Academy of Engineering recommended that the four-year engineering bachelor's program be considered merely a pre-engineering or engineer-in-training degree and that a master's degree be considered the professional degree in *Educating the Engineer of 2020: adapting Engineering Education to the New Century*.

Committee on the Engineer of 2020 (2005) *Educating the Engineer of 2020: adapting Engineering Education to the New Century*. The National Academy of Engineering. Retrieved online 12/17/2007 at http://books.nap.edu/openbook.php?record_id=11338&page=R1

⁴⁹ Many professions are updating their requirements for entry. In U.S. health care, physical therapists and audiologists have recently made a doctorate the entry level degree for the profession. In the marketplace for scientists most companies are demanding a master's education for anything more than entry-level positions. This is particularly true in research oriented companies and laboratories. Many social science related professions, such as economists, social work and urban planners require an advanced degree for most positions. In the focus groups conducted by IAF there was a consensus among attendees that a bachelor's degree in engineering would not be enough to get one through a career in the next 20 years. The early career engineers in particular saw advanced training as a prerequisite for a successful career in engineering.

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

Bureau of Labor Statistics (2007) Occupational Outlook Handbook (OOH), 2006-07 Edition. Retrieved 12/13/2007 at <http://www.bls.gov/oco/home.htm>

⁵⁰ Healthcare systems in the United States have been struggling to deal with rising demand for services and higher costs for care at the same time that big payers such as Medicare and managed care plans have cut down on payments for services. They have also been struggling with 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. Physician assistants have grown from 4 Navy Corpsmen in the first physician assistant program at Duke University in 1965 to over 4,500 physician assistants graduating every year in the United States. They 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>

⁵¹ 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.

The press has been vocal in talking about the growth of engineers in newly industrialized countries – in particular India and China. However, the education of these engineers is more akin to an engineering technician or technical engineer. They would seem to be the counter-argument to the movement of engineering to a profession where post-graduate degree is the norm. Instead, one can look at the huge growth of engineers abroad, and the outsourcing of work to them, as a system where engineers in the developed world are moving to higher educational standards and higher value work and outsourcing routine technical tasks abroad. This could be analogous to the situation in American medicine where more routine tasks are under taken by “physician extenders”.

Collaborative Advantage

⁵² Worldwide the most valuable and complex technologies are developed by collaborative networks that self-organize. Firms that will succeed in the future will be able to bring together and integrate the diverse knowledge and skills needed to innovate and develop complex technologies such as aircraft, automobiles and telecommunications equipment.

R. Rycroft (2003) Self Organizing Innovation Networks: Implications for Globalization. George Washington University Retrieved 12/17/2007 at http://www.gwu.edu/~cistp/research/SelfOrganizing_RWR_2.24.03.pdf

⁵³ Vertical collaboration involves firms along a supply chain from designer, manufacturer, marketer, whole-seller, and retailer and has been relatively common and unremarkable. Horizontal collaboration involves joint ventures and cooperative agreements among organizations on the same level – i.e. competitors. Incidence of horizontal collaboration has increased in recent times and is a new development of the global economy.

See Cravens, Piercy, and Shipp (Sep. 96) "New Organizational Forms for Competing in Highly Dynamic Environments: the Network Paradigm." *British Journal of Management*: Vol. 7 Issue 3.

⁵⁴ For an understanding of decentralized networks and their organization see <http://web.uconn.edu/ciom/Open1C.pdf>. For more information on the importance of innovation networks see any of the numerous articles on them, for example – Ritter, Thomas, and Hans Gemunden, "Network competence: Its impact on innovation success and its antecedents," *Journal of Business Research* 56 (2003) 745– 755.

⁵⁵ See <http://www.step.no/reports/Y1998/0598.pdf> for a good but somewhat dated report on the trends that are underlying increases in collaboration

⁵⁶ Increased global competition due to the crumbling of trade barriers and the improvement of business practices in developing economies is addressed by numerous famous authors from Peter Drucker to Joseph Stiglitz to Pat Buchanan. Global competition is also increasing international collaboration. The NSF science and engineering indicators has tracked new industrial technology alliances rising from 200 to more than 700 since 1990. <http://www.nsf.gov/statistics/seind06/pdf/c04.pdf>

National Science Board. (2004) *Science and Engineering Indicators 2004* Arlington, VA: National Science Foundation (NSB 0401).

⁵⁷ An example of such risk sharing is found in the development of next generation high definition video technologies. Each of the competing technologies (Blu-Ray and HD DVD) is backed by a consortium of electronics companies that normally act as competitors in the open market. Toshiba's recent decision to withdraw HD DVD from the market was sparked by the exit of a key partner, Warner Bros, from their consortium.

⁵⁸ The forces that are driving firms toward collaboration are the same forces that are behind the high level of uncertainty and volatility in the marketplace today – increased competition allowing the market to grant little leeway in terms of price and increased technological development making valuable technologies quickly obsolete, causing firms always to be in the race to innovate new products. Those who fail or succeed - fail or succeed bigger and faster than ever before.

⁵⁹ Wikipedia is clearly 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>

⁶⁰ 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.

⁶¹ GM has been involved with numerous alliances or joint ventures over the years with the likes of Daewoo, Hitachi, Isuzu, Nissan, and Toyota. GE is involved with multiple joint ventures with leading firms like Honda, Pratt & Whitney and Fanuc robotics.

⁶² The concept and term, mass peer review, comes out of the open source software movement and often refers to the review and improvement of code by the community.

The NanoBio Future

⁶³ In 2006, it is estimated that more than \$10 billion dollars were invested in nanotechnology worldwide. The leader in nanotechnology research was the United States with substantial funding from multiple government agencies. In January 2007, the European Union launched its largest ever program for research and technological development – devoting \$4.5 billion for nanotechnology. Other countries such as Russia, India, Japan and China have earmarked several billion USD for future nanotechnology investment.

Manghirmalani, R. (Dec. 13th, 2007) Wall Street Will Resume Nanotechnology Financing. *MeriNews*. Retrieved 12/17/2007 at <http://www.merinews.com>

⁶⁴ Biotechnology companies have steadily gained venture capital funding and are one of the leading sectors for venture capital funding. In 2003 and 2004 biotech companies received 11% of total venture capital investments in 2003 and 2004—more than triple their share of 4% received in 1999 and 2000. A recent survey ranked biotechnology as one of the leading areas for venture capital spending in 2008 along with the Clean Technologies sector, media and the next generation internet companies.

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).

National Venture Capital Association (Dec. 13th, 2007) *Venture Capitalists Predict 2008 Trends*. Retrieved 12/18/2007 at <http://www.marketwire.com/mw/release.do?id=803488>

⁶⁵ In the development of new technologies the most difficult phase is the translation of basic research done in the laboratory in small batches to the development of real products. Part of the problem is the gap between basic research and development, often called applied research, is underfunded by both governments and industry. It is too close to the market for government funding and too far away from commercial viability for industry funding. Venture capital, tax credits, special government programs or other incentives are often needed to fill the gap. Both biotechnology and nanotechnology have successfully crossed this gap with new products and applications in healthcare, agriculture, energy and other areas already reaching the market.

⁶⁶ The early career engineer focus group conducted by IAF clearly highlighted nanotechnology as the new hot area of research in today's research laboratories.

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

⁶⁷ Nanotechnology tends to be a catch all for exciting research at the nanoscale in fields from biology to materials science. Its broad application and ability to enable a wide range of other technologies means that the term nanotechnology will likely fade from the commercial and policy discussions over the next ten years although it will remain an important part of research and development. Nanotechnology is difficult for individuals to identify with since it crosses so many

scientific disciplines and its benefits to a wide range of products are invisible to the eye. But its impact over the next 20 years will be profound.

Jo Twist (July 28th, 2004) Myths and Realities of Nano Futures. *BBC News*. Retrieved 12/13/2007 at <http://news.bbc.co.uk/2/hi/science/nature/3920685.stm>.

⁶⁸ The range of new nanotech products is fairly long with the mostly commonly cited being the development of better tennis balls by companies like Wilson's nanotechnology enhanced Double Core tennis balls and Docker's Go Khakis line of pants with nanofibers designed to prevent stains. There are a wide variety of nanoparticles that are being used as imaging agents from monocrystalline iron oxide nanoparticles used in magnetic resonance imaging to nanoparticles with radionuclides attached for PET and SPET imaging.

Ehman, R.L., W.R. Hendee, M.J. Welch, N.R. Dunnick, N.R., L.B. Bresolin, R.L. Arenson, S. Baum, H. Hricak, J.H. Thrall. (2007) Blueprint for Imaging in Biomedical Research. *Radiology*: 244:12-27. Retrieved online 12/16/2007 at <http://radiology.rsna.org/cgi/content/full/244/1/12>.

⁶⁹ The continuation of Moore's Law over the next 10 to 20 years will depend on developments in nanotechnology. Moore's law is the observation that the computing power available at a given price doubles every 18 months. Current generations of processors from Intel and AMD already incorporate transistors at 90 nm. Research by IBM could eventually use the spin of individual atoms to develop memory and turn molecules on and off to create new processors.

Press Release (Aug., 2007) IBM Unveils Two Major Nanotechnology Breakthroughs as Building Blocks for Atomic Structures and Devices. Retrieved 12/18/2007 at <http://www-03.ibm.com/press/us/en/pressrelease/22254.wss>

⁷⁰ See http://www.news.com/The-stuff-of-dreams/2009-1008_3-5091267.html?tag=nl for a good explanation of carbon nanotubes and see <http://www.brightsurf.com/search/da/Carbon+Nanotubes/1/Carbon+Nanotubes+news.html> for recent carbon nanotube news.

⁷¹ The space elevator is one application of nanotechnology that was brought up in the ASME Focus groups. It would involve developing a tether of ultra fine and strong carbon nanotubes stretching from earth to a body rotating around the earth in geosynchronous orbit. A climbing device attached to the tether could then be used as an "elevator" to lift materials from earth to outer space. Some futurists and technologists believe that advances in nanotechnology could make a space elevator feasible within the next decade.

L. David (March 27th, 2002). The Space Elevator Comes Closer to Reality. *Space.com*. Retrieved 12/18/2007 at http://www.space.com/business/technology/space_elevator_020327-1.html

⁷² 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.

⁷³ 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>.

⁷⁴ 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 existing flash memory drives.

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

⁷⁵ The use of biotechnology in agriculture is one of the most controversial applications of technology behind only some uses of biotechnology in therapeutic cloning. Many environmentalists are fundamentally opposed to the use of genetically modified organisms in agriculture and many countries have imposed bans or restrictions on the use of genetically modified organisms. Despite those restrictions, the development and use of genetically modified organisms is large and growing. For example, in the U.S., biotechnology plantings represented 46 percent of the total corn crop, 76 percent of the cotton crop and 86 percent of the soybean crop in 2004.

United States Department of Agriculture (2007) Frequently Asked Questions about Biotechnology. Retrieved 12/15/2007 at http://www.ucsusa.org/food_and_environment/genetic_engineering/current-uses-of-biotechnology-in-agriculture.html.

⁷⁶ Rick Weiss (Dec. 17th, 2007) Synthetic DNA on the Brink of Yielding New Life Forms. *The Washington Post*: A01 Retrieved online 12/17/2007 at <http://www.washingtonpost.com/wp-dyn/content/article/2007/12/16/AR2007121601900.html>

⁷⁷ Synthetic biology is the combination of biological science and engineering to create new and novel biological functions and systems. It is closely related to genetic engineering, but it is much more focused on developing foundational technologies and standards to make the process of engineering biology easier and more reliable. The ultimate goal of synthetic biology is the widespread use and creation of synthetic (man-made) DNA to create new life forms with unique biological functions and processes. Ibid.

⁷⁸ Ibid

⁷⁹ Recently two engineers from the University of California at Riverside have discovered unique bacteria that can produce semi-conducting nanotubes. The discovery of organic nanotubes opens the door to the future creation of nanomaterials by biological organisms created through synthetic biology. This could make nanomaterials cheaper and easier to make as well as being more environmentally friendly.

(Dec. 7th, 2007) Nanotube-producing bacteria show manufacturing promise. *BrightSurf.com* Retrieved 12/17/2007 at http://www.brightsurf.com/news/headlines/34699/Nanotube-producing_bacteria_show_manufacturing_promise.html

⁸⁰ The concept of organo-machines emerged from the early career engineer focus group held at the 2007 ASME Congress. The idea is that many functions over the next 20 years will not be completed by machines, but by organic constructs created by using genetic modification. The development of interchangeable genetic components will facilitate the creation of organic constructs within design parameters similar to the creation of machines today.

Biotechnology holds implications for engineering that are just as important, but less obvious. A researcher in the early career engineer group forecast that the materials mechanical engineers will be working with over the next 20 years will include organic constructs. Mechanical engineering will include organo-machines and mechanical engineers will need to know more than Hooke's law – they will need to know biology and chemistry as well.

⁸¹ Currently, biotechnology is being used to produce fuels and scientists are experimenting with ways to create organisms that clean up industrial pollutants. Organomachines was also discussed at the early career development focus group held by ASME at the 2007 ASME Congress.

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

⁸² The concerns with biotechnology are widespread. Many environmentalists are worried about the loss of genetic diversity and genetic drift caused by genetically modified plants and animals. There are also well founded concerns about the technology falling into the wrong hands – those who try to design a super virus. As the technology becomes cheaper and easier to use these concerns will grow. This is to say nothing of the ethical dilemma about toying with the creations of the Creator (whether it be God or Nature).

⁸³ While the pace of investment in research and development of nanotechnologies has grown rapidly, the amount of dollars spent on researching the effects of nanoparticles on public health and the environment has not kept pace. Early studies have shown that certain kinds of nanoparticles, including nanotubes and buckyballs, can damage animal cells. There are further fears that nanoparticles could cause breathing problems, damage brains cells or damage DNA. The [Woodrow Wilson Center's Project on Emerging Technologies](#) is exploring these issues.

⁸⁴ Current costs of carbon nanotubes range from \$600/kg to \$90,000/kg depending on the specific type. See <http://www.cheaptubesinc.com/pricelist.htm> for a list of prices.

Regulating Innovation

⁸⁵ The biggest proponents of IP reform are generally the high technology firms, in particular software firms like Microsoft which are especially susceptible to the predations of “patent trolls.” One of the major reforms proposed by Microsoft and other technology firms is to limit damages to the economic value of the patents in question. This will place a greater burden on the courts to determine economic value and reduce the power of “patent trolls” to engage in blackmail by threatening lawsuits and impede innovation.

Jenn Markey and Mike McLean (May, 8th, 2007) Patent Reform: Is This the Year? EETimes Online. Retrieved 12/20/2007 at <http://www.eetimes.com/news/latest/showArticle.jhtml?articleID=199400075&pgno=3>

⁸⁶ 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 its 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.

⁸⁷ 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 hardly 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*.

⁸⁸ For a classic article on this phenomenon see Merges and Nelson (1990) On the Complex Economics of Patent Scope, *Columbia Law Review* 90:4.

Merges and Nelson give examples where pioneer inventors refuse to license their inventions to competitors who have developed more efficient models or designs thereby significantly harming innovation and competition. Perhaps the most famous example comes with Edison's light bulb which was not improved upon for years because of IP constraints. On the other hand, Merges and Nelson counter with examples in the semiconductor and computer industries where firms cross-licensed and created patent pools assuring innovation and competition.

⁸⁹ Currently, dispute resolution is handled by a patent court. Some IP reform advocates are calling for a compulsory expert arbitration system which could greatly reduce the cost of litigation. In any appeal, the respondent (i.e., the party who had accepted the decision of the expert arbitration) would be provided with financial aid for their defense, greatly reducing the massive financial advantage that large corporations currently possess. See Kingston for more details.

⁹⁰ For a broad discussion of patent pools, see Lerner, Tirole, and Strojwas, "The Structure and Performance of Patent Pools," 2003 available at http://idei.fr/doc/conf/sic/papers_2003/tirole2.pdf. Patent pools were initially popular in the U.S. in the early 1900s but drastically receded in the anti-trust world. They are only recently making a comeback as several judicial and enforcement decisions have been made to encourage them.

⁹¹ Open Source Software is software in which the code behind the software is open to anyone and anyone can modify the code but no one can patent the code. For an intellectual perspective from an open source developer see Eric Raymond's *The Cathedral and the Bazaar* at <http://www.catb.org/~esr/writings/cathedral-bazaar/cathedral-bazaar/>.

⁹² 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>

⁹³ Research done by the academic journal *Nature* found that Wikipedia had only slightly more errors on average than *Encyclopedia Britannica*, considered the so-called golden standard of

encyclopedias. Wikipedia also has more than 20 times the number of articles and is updated on a regular basis to reflect new discoveries and current events.

Giles, J. (Dec., 15th, 2005) Special Report: Internet Encyclopedias Go Head to Head. *Nature* 438: 900–901

⁹⁴ For a discussion of the necessary requirements of an Open Source model of innovation see Osterloh and Rota (2007) Open Source Software Development – Just Another Case of Collective Invention? *Research Policy* 36 (2007).

⁹⁵ 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.

Diverse Face of Engineering

⁹⁶ Universally cited as the reference point for countless other debates on the nature of globalization, Friedman's book does an excellent job of laying out the conventional logic of a global economy.

Friedman, T. (2005) *The World is Flat: A Brief History of the Twenty-first Century*. Farrar, Straus and Giroux.

⁹⁷ 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>

⁹⁸ *The Economist*. (August 27th, 2007) *Pocket World in Figures: Largest Populations*. Retrieved November 3, 2007 from www.economist.com

⁹⁹ For an interesting historical perspective on the process of adaptation to business in a multinational business environment see:

Negandhi, A. (June, 1983) Cross-Cultural Management Research: Trend and Future Directions," *Journal of International Business Studies*, 14:2.

¹⁰⁰ The most widely cited recent framing of this argument is found in the work of Richard Florida; this work also makes a compelling case for the need for encouraging innovation and diversity, *per se*.

Florida, R. (2005) *The Flight of the Creative Class: The New Global Competition for Talent*. Collins.

¹⁰¹ 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).

¹⁰² Magala, S. (2005) *Cross-Cultural Competence*. Rutledge.

¹⁰³ Engineering Workforce Commission of the American Association of Engineering Societies, *Engineering and Technology Degrees, 1973–2003*.

¹⁰⁴ American Society for Engineering Education, *Profiles of Engineering and Engineering Technology Colleges, 2003*.

¹⁰⁵ See for example Horwitz, H. (2002) First International Network of Women Engineers and Scientists Is Underway. Retrieved 11/19/2007 from:
http://www.theinstitute.ieee.org/portal/site/tionline/menuitem.130a3558587d56e8fb2275875bac26c8/index.jsp?&pName=institute_level1_article&TheCat=2201&article=tionline/legacy/INST2002/ct02/ffirst.xml&

¹⁰⁶ (Nov. 5th, 2004) More Than a Third of Chinese Engineers are Female. *Peoples Daily Online* Retrieved 11/28/2007 at http://english.peopledaily.com.cn/200411/05/eng20041105_162910.html

Designing at Home

¹⁰⁷ The basics of design can be traced back to the Renaissance and the celebrated architect and inventor Filippo Brunelleschi. Brunelleschi's basic six step design would remain the standard for engineering design for 500 years until the advent of Computer Aided Design (CAD) more than 40 years ago.

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

¹⁰⁸ 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>

¹⁰⁹ 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*.

¹¹⁰ 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.

¹¹¹ 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.

¹¹² 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 Thilmay (2004) Turn on the Light. *Mechanical Engineering Design*. Retrieved 12/10/2007 at <http://www.memagazine.org/supparch/medes04/thelight/thelight.html>

¹¹³ Companies will look to telework and outsourcing to reduce costs. Better information and communication tools will make it easier for workers to collaborate online and for employers to monitor employee performance. By taking advantage of telework they maintain smaller and cheaper decentralized offices. Rent and land prices will increase as urbanization fills up the central core of cities, higher energy costs will make it more expensive to heat and cool those buildings while road and airport congestion will make it more expensive to require employees to come into a central office.

¹¹⁴ Oil prices recently closed above the \$100 a barrel mark in 2008 – and are likely to return to that price unless growth in China and India slow or more stability returns to major oil producers including Iraq, Iran and Nigeria. Most oil experts are also embracing the “peak oil” theory that states we are at or near the global peak of oil production. Even the most optimistic scenarios envision global peak oil around the 2030 timeline.

There are numerous alternate technologies for transportation, but all require significant investment and development. Until these technologies are mature, it is likely that energy and transportation costs will continue to rise. Businesses and consumers will look for ways to conserve energy – including doing less commuting and travel for work.

Robert Olson and Craig Bettles (November, 2007) An Alternate Peak Oil Scenario. *Institute for Alternative Futures*. Retrieved 12/11/2007 at <http://www.altfutures.com/news/Nov07.htm>

¹¹⁵ Many countries, states and cities are updating their zoning, permitting and environmental regulations to encourage sustainable growth. Some of these changes include new green building standards, congestion pricing for roads, ride share programs, green energy mandates, green labeling, carbon taxes and tighter restrictions on air and water pollutants. Many of these changes have made it more expensive to run centralized offices and manufacturing facilities. Over the next 20 years, there will be more of these regulations as governments attempt to deal with global warming and other environmental threats.

¹¹⁶ 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

¹¹⁷ **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.

¹¹⁸ 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_QDTPDQ

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.

¹¹⁹ The majority of workers in 2028 will be from generation X and Y. These generations place a very high premium on quality of life and environmental concerns compared to previous generations. They are also much more comfortable using technology. They will embrace more

distributed work as an opportunity to increase their quality of life by cutting down commuting times while at the same time preserving the environment by reducing the pollution associated with long commuting times.

¹²⁰ The Kauffman Foundation released a Harris Poll survey on November 13, 2007 that shows America's young people want to be their own boss. The Foundation commissioned Harris Interactive to conduct an online survey of 2,438 youth ages 8 to 21 about entrepreneurship. It shows that four in 10 young people would like to start their own business in the future, while another 37 percent believe starting their own business is a possibility. Retrieved 3/13/08 at <http://www.kauffman.org/items.cfm?itemID=939>

Engineering for the Other 90 Percent

¹²¹ There is debate surrounding these figures. While Prahalad estimates that around 4 billion people live on less than \$2/day, estimates vary. In 2001, the World Bank estimated the number of people living on less than \$2/day at 2.7 billion. Discrepancies are often the result of different methodologies for estimating and calculating consumption.

World Bank (2007) Data and Statistics Website. Retrieved 11/18/2007 at <http://web.worldbank.org/wbsite/external/datastatistics>. The World Bank, 2005.

¹²² This estimate was released in a 2001 United Nations report as part of a downward revision of earlier UN estimates.

United Nations (2002) *World Urbanization Prospects. The 2001 Revision: Data Tables and Highlights* retrieved 11/17/2007 at <http://www.un.org/esa/population/publications/wup2001/wup2001dh.pdf>

¹²³ Prahalad, C.K. (2006) *The Fortune at the Bottom of the Pyramid*. Wharton School Publishing

¹²⁴ Engineers Without Borders- International (2007) Retrieved 11/10/2007 at <http://other90.cooperhewitt.org/>

¹²⁵ The Appropriate Technology Sourcebook catalogs literally hundreds of these innovations and could well serve as a valuable primer as engineering for emerging regions reemerges as a longer-term priority.

Darrow, K. & Saxenian, M. The Complete Appropriate Technology Sourcebook (1993) Available online at: <http://www.villageearth.org/atnetwork/atsourcebook/>

¹²⁶ The Cooper Hewitt Design Museum (2007) Design for the Other 90%. Retrieved 11/14/2007 at <http://other90.cooperhewitt.org/>

¹²⁷ Additional background information on the Q-Drum project is available online at: <http://www.qdrum.co.za/>

¹²⁸ Prahalad, C.K. (2006) *The Fortune at the Bottom of the Pyramid*. Wharton School Publishing