Proceedings of the China-India-US Workshop on Science, Technology and Innovation Policy

Section I

Executive Summary

Contents

Proceedings of the China-India-US Workshop on Science, Technology and Innovation Policy

Section I
Executive Summary

A. Rationale

Much has been written about the emergence of India and China as emerging or, better, re-emerging powers on the world scene, and it is often stated that science and technology are essential keys to their re-emergence.[1] Yet few if any detailed comparative studies exist about their science policies, capabilities, or likely future trajectories.[2] There are few U.S. experts on science and technology policies in both India and China. Additionally, relatively few Indian scientists and scholars have in depth familiarity with science, technology, and innovation policies and trends in China, nor Chinese scientists and scholars with in depth familiarity with science, technology and innovation policies and trends in India. This is unfortunate given that both have large research systems and well respected, established science, engineering, and technological communities, and both are attempting – with considerable success - to strengthen and reorient their science, technology and innovation systems to meet the challenges of the 21st century.

As a partner in research, a source of advanced training for Indian and Chinese students, as a frequent host at universities to visiting scholars from the two countries, and as a model of a successful national innovation system which both countries have studied and selectively emulated, the United States has a vital interest in the attempts of both countries to further develop their capabilities in science and technology, and to integrate them into their overall national systems of innovation. An enhanced understanding of the science, technology, and innovation policies, the dynamics of the technical communities, and the changing nature of institutions for research and innovation in the two countries will therefore become increasingly important to the United States. India and China likewise have shown increased interest in each other's innovation systems, as exemplified by when Chinese Premier Wen Jiabao signed an agreement for enhanced science and technology in Delhi during a four day state visit to India in April 2005.

---

1. It has been estimated that when the Roman Empire was at its zenith, it accounted for approximately one-fifth of the world's economy. At that time, India is estimated to have accounted for one-third and China for one-fourth. J. Thomas Ratchford and William A. Blanpied, "Paths to the future for science and technology in China, India, and the United States," *Technology in Society*, v. 30, #s 3-4, August-November 2008, p. 212.
2. *Technology in Society*, referenced above, is a special issue on China, India and the United States and could well qualify as one of the first such comparative studies, although each article is written by a Chinese, Indian or US expert and few make any attempt at comparative analysis. Copies of this issue were distributed to all workshop participants at a special session on July 9.

Science policy specialists in both China and India would like to join with their counterparts from the United States in initiating a program of internationally collaborative comparative analyses. As a first step towards structuring an inquiry of this sort, and identifying critical research questions, a China-India-US Workshop on Science, Technology and Innovation Policy was organized at the National Institute for Advanced Studies (NIAS) in Bangalore, India, from July 7-9, 2008.

B. Organization, Objectives and Participants

Organization. The workshop was organized by the **George Mason University Science and Trade Policy Program**, the Political Science Department of the **University of Oregon**, the **National Institute for Advanced Studies (NIAS)** in Bangalore, and the **Institute for Policy and Management of the Chinese Academy of Sciences (IPM/CAS**). It was supported by the **Indo-US Science and Technology Forum**, with additional support provided by **NIAS** and **CAS**.

Decisions regarding specific agenda items, topics and participants were determined by a three-member **Organizing Committee** composed of the Chinese, Indian, and U.S. co-chairs for the workshop: **Prof. Mu Rongping**, Director-General of IPM/CAS, **Prof. Dilip R. Ahuja**, ISRO Professor of Science and Technology Policy at NIAS, and **Richard P. Suttmeier**, Professor-Emeritus of Political Science and the University of Oregon. **William A. Blanpied**, Senior Research Scholar at George Mason University, served as executive secretary to the organizing committee.

Objectives. A principal objective of the workshop was to provide a venue where experts from the three countries could meet and discuss common interests. A second, corollary objective was to provide opportunities for the participants to discuss possibilities for future collaborative projects – for example, subsequent, more in-depth workshops, bi-or tri-national collaborative research projects, or both, initiate concrete collaborative ideas, and even to initiate such collaborations during the workshop itself. A final, important objective was to stimulate the interests of a new generation of scholars in studies comparative analysis of the research and innovation systems of these three countries.

Participants and Observers. Six Chinese, 20 Indian, and 15 U.S. experts participated in the workshop, including four Indian and six US rapporteurs. (A full participant list appears as Appendix A.) The Indian participants included five particularly distinguished individuals who made special presentations at the workshop (see agenda, Appendix C.):

- **Shri Kapil Sibal**, Minister of Science, Technology, and Earth Sciences, Government of India;
- **Dr. K. Kasturirangan**, Director, *National Institute of Advanced Studies*;
- **Prof. C.N.R Rao**, National Research Professor, *Jawaharlal Nehru Institute for Advanced Scientific Research*;
- **Dr. R. Chidambaram**, Principal Scientific Advisor to the Government of India; and

- **Prof. Samir K. Brahmachari**, Director-General, *Council for Scientific and Industrial Research*.

Young Scholars. In order to further the objective of interesting a new generation of scholars in studies comparative analysis of the research and innovation systems of China, India and the United States, four US young scholars were selected by means of a national competition to participate in the workshop as among the 15 US participants supported by the **Indo-US Science and Technology Forum**:

- **Dr. Bethany Lyles Goldblum**, Post-Doctoral scholar, Dept. of Nuclear Engineering, University of California, Berkeley;
- **Ms. Rachel Parker**, Graduate Student, Department of Sociology, University of California, Santa Barbara;
- **Dr. Lisa-Saum Manning**, Post-Doctoral Fellow, Security Studies, Brookhaven National Laboratory; and
- **Ms. Tricia Wang**, Graduate Student, Department of Sociology, University of California, San Diego.

These Young Scholars served as co-rapporteurs (in four cases along with Indian co-rapporteurs) for the various workshop sessions. Following (or in advance of) the workshop, they visited sites of professional interest in India both within and outside of Bangalore. Each of them has written a short paper based in part on their prior professional experiences, as well as insights gained at the workshop and their additional professional visits in India. These papers appear in Section VIII of these proceedings.

C. Structure

The organizing committee, meeting on September 25, 2007, following a conference on China and India at the **US National Academy of Sciences** decided to structure the workshop around three specific case studies of science, technology and innovation policy in China, India, and the United States:

- **Power Generation by Coal,**
- **Information Technology,**
- **Pharmaceuticals**

Accordingly, Sessions II, III, and IV of the workshop focused on one of these three case studies.

On the morning through the early afternoon of July 7, most participants made visits to the facilities of two highly regarded Bangalore-based firms, both of which have a substantial presence elsewhere in India and abroad: **Infosys** and **Biocon**. These visits were an appropriate prelude to the subsequent workshop discussions on Information Technology and Pharmaceuticals.

Session I, held on the evening of July 7 and chaired by ***Dr. K. Kasturirangan***, Director of the National Institute of Advanced Studies, inaugurated the workshop with greetings from ***Dr. Norman Neureiter***, on behalf of the **Indo-US Science and Technology Forum**, and ***Prof. Mu Rongping*** on behalf of the **Chinese Academy of Sciences**. There followed keynote addresses by ***Prof. Carl Dahlman***, Luce Professor of International Relations and Information Technology, **Georgetown University**, and ***Prof. CNR Rao***, National Research Professor, *Jawaharlal Nehru Institute for Advanced Scientific Research*. ***Shri Kapil Sibal***, Minister of Science and Technology, Government of India, formally opened the workshop with his inaugural address. Finally, ***Prof. Dilip Ahuja***, ISRO Professor of Science and Technology Policy, **National Institute of Advanced Studies**, offered a vote of thanks to all the speakers, and then adjourned the session.

Session V, chaired by ***Prof. Samir K. Brahmachari***, Director-General, *Council of Scientific and Industrial Research*, Government of India, was held on the afternoon of July 9 as the closing session of the workshop. The session opened with a keynote address by ***Prof. Chen Jin*** of *Zhejiang University*, Hangzhou, China. Session rapporteurs then provided 10 minute summaries of the first four workshop sessions (see Section VII.). Following these presentations, ***Prof. Brahmachari*** gave a presentation highlighting his vision for innovation in India. Following a general discussion, each of the three workshop co-chairs provided brief summaries of their impressions of the workshop – and their hopes and expectations for the future.

Immediately following Session III on July 8, ***Dr. R. Chidambaram***, Scientific Advisor to the Government of India, provided a keynote address on "Research and Innovation", followed by a special presentation by ***Dr. A. Mitra***, Executive Director of the *Indo-U.S. Science and Technology Forum* on "Indo-U.S. Science and Technology Cooperation – Perspectives and Opportunities."

Immediately following Session IV on July 9, ***Mr. Rodney Nichols***, President and CEO Emeritus of the *New York Academy of Sciences*, described the objectives and contents of a special issue on "China, India and the United States" of the quarterly journal, *Technology in Society* (see reference 1). ***Dr. Amitav Mallik*** and ***Prof. Roddam Narasimha***, two of the five Indians who had contributed articles to the journal, as well as ***Prof. Mu Rongping*** and ***Dr. William A. Blanpied***, who had also contributed, then made brief remarks, following which copies of the journal were distributed to all workshop participants. Since *Technology in Society* is printed in India, the participants were among the first to have such copies.

D. Continuity

The July 2008 Bangalore workshop followed eight seminars, forums and workshops referred to collectively as dialogues, held on an approximately annual basis since 1999.[3] Two of these earlier **Sino-U.S. Science Policy Dialogues**, which had been supported jointly by the **National Natural Science Foundation of China** and the U.S. **National Science Foundation**, were tri-national events: the **China-Japan-US Seminar on**

3. Proceedings of all these dialogues can be accessed at www.law.gmu.edu/nctl/stpp/us_china.php

Science, Society and the Internet, held at the **East-West Center** in Honolulu, Hawaii, in December 2003, with additional support from the **Japan Society for the Promotion of Science**, and the **China-Korea-US Seminar on R&D Related to Emerging and Re-emerging Infections Diseases**, held at **Boston University** in December 2005, with additional support from the **Korea Science and Engineering Foundation**. The Bangalore workshop was the third such tri-national dialogue. From the admittedly biased perspective of this editor, it was the best of the three, possibly because China and India, as the world's most populous nations and widely acknowledged as the world's principal re-emerging economies with impressive and expanding science and technology resources, present both challenges and opportunities for the United States.

The China-India-US Workshop on Science, Technology and Innovation Policy was supported by the **Indo-US Science and Technology Forum**, with additional support from the **Chinese Academy of Sciences** and the **National Institute for Advanced Studies**.

The US components of the seven science policy dialogues which preceded the July 2008 Bangalore workshop were supported in part by a grant from the U.S. **National Science Foundation** to **George Mason University's Science and Trade Policy Program.** ***J. Thomas Ratchford***, Distinguished Visiting Professor at George Mason University, served as Principal Investigator on all these NSF grants as well as principal US organizer of all Sino-U.S. Science Policy Dialogues since October 1999.

A detailed description of the George Mason US-China program appears as Appendix E.

E. Keynote Addresses

Four keynote addresses were presented during the three days of the workshop by the following distinguished speakers:

1. ***Prof. Carl Dahlman***, Luce Professor of International Relations and Information Technology, *Georgetown University* (July 7)
2. ***Prof. C.N.R Rao***, National Research Professor, *Jawaharlal Nehru Institute for Advanced Scientific Research* (July 7)
3. ***Dr. R. Chidambaram***, Principal Scientific Advisor to the Government of India (July 8)
4. ***Prof. Chen Jin***, Research Center for Science, Technology and Education Policy, *Zhejiang University*, Hangzhou, China (July 9)

Prof. Dahlman opened his keynote presentation entitled, "Role of Science and Technology in National Innovation Systems," by summarizing global trends that are acceleration innovation:

- Acceleration in the rate of creation and dissemination of knowledge
- Increasing globalization due to decreasing communication and transportation costs
- Increasingly global character of knowledge
- Multinational corporations as the main generators and disseminators of knowledge

He emphasized that investments in knowledge are now almost as large as investments in machinery and equipment and that in most developed countries knowledge intensive services provide a greater percentage of GDP than technology intensive manufactures.

Prof. Dahlman noted that East Asia's share in global GDP has experienced the fastest growth among all developing regions. China and India are becoming major players on the global, reflecting two unbundlings: in India, an unbundling of services. Projecting at 2000-2006 rates, China and India are set to be the largest and second largest economies in the world by 2018, as measured in terms of purchasing power parity.

Next, he turned his attention to innovation and national systems of innovation (NSI). Innovation, he stressed, is not just about research and development (R&D), but also about organization and business models. National innovation systems can be compared by such measures as:

- The acquisition of global knowledge
- The creation of knowledge: i.e., both R&D inputs and outputs
- The use of knowledge, gauged by productivity per worker and the dispersion of productivity levels within economies

Prof. Dahlman then provided detailed comparisons of China, India and the United States in terms of these measures and, on this basis, listed a number of policy issues related to their national systems of innovation. Key challenges for the three countries as well as other developed and emerging developing countries include:

- Environmental constraints
- Poverty and increasing inequality
- Increasing global systemic risk

Win-Win areas include:

- International collaboration on global public goods research
- International collaboration on pre-competitive research
- Sharing of best practices on managing large research systems
- Strategic alliances among firms for private research

Prof. Dahlman concluded that although there are many serious challenges, science and technology can play key roles in helping to resolve them. China, India, and the United

States are key players in this respect. Finally, there is potential for greater cooperation and collaboration among governments, universities, research institutes, and firms.

Prof. Rao provided an animated keynote address on the role technology and innovation in India, encouraging the recognition of “science as the foundation of technology and innovation.” He emphasized that the manufacturing of consumer goods in India and China should not be confused with innovation – still largely dominated by the United States – and claimed that increased goods production is less desirable than increased knowledge. Despite some murmuring and lamenting by US colleagues, **Rao** feels strongly that, at present, the United States is leagues ahead of India and China in scientific research, with the latter countries requiring sustained quality enhancement in order to compete. He cited data indicating that over 60 percent of global scientific research publications are from the United States and that within the United States, prolonged innovation at all levels of education has allowed for small universities and research laboratories to evolve into global centers of excellence in science and technology. He referred to a 2007 by the US National Academy of Sciences entitled, *Above The Gathering Storm,* which includes recommendations for the future of science and technology in the US, including:

- improved K-12 science education,
- cultivation of a long-term outlook, and
- establishment of the country as the most attractive site for higher education.

Rao suggested that implementation of these recommendations would benefit India and China, as well.

He then turned to the extraordinary recent progress by China, including an explosion in the number of scientific publications. China now dominates in the quantity of research publications in the field of material science. Chinese nationalism contributes positively to achieving higher standards for research in China, whereas this patriotism is lacking in India. India is further plagued by the poor quality of its science and education sector. However, India has committed more money in science and engineering in the last four years than in the entire period of its independence. It matriculated 600,000 engineering undergraduate students last year alone. It is hoped that the creation of new infrastructure and human resources will facilitate the formation of the required critical mass for success in the fields of S&T in India.

In conclusion, **Rao** suggested a view of the future in which the rise of the large middle class in China and India will drive consumption in the global economy, and will propel these countries into leadership positions in global innovation.

Dr. Chidambaram opened his presentation entitled, “Research and Innovation,” by remarking that innovation policy is very much in the air these days, as evidenced by three international and Indian conferences he had attended during the past nine months. He emphasized that because India is so large and so diverse and because change is occurring at such a rapid pace, it is impossible to talk about a single innovation policy.

Dr. Chidambaram provided two very different examples of recent innovations in India:

1. A new type of advanced heavy water reactor, and
2. Identification of recharge zones to drying springs, after which artificial recharge structures can be installed and the rates of discharge increased three to nine fold.

He emphasized that in the early stages of development, GDP growth rate may not be related to scientific output and appears to be related more to innovation capacity. But long-term sustainability of a high GDP growth rate – in the face of global competition – requires advanced scientific capability while, of course, retaining innovation capacity. An intangible part of the innovation ecosystem is the courage to take risk. The greater the innovation, the higher is the risk in converting it into a marketable product or process. The Indian Government is looking for ways to help make this risk manageable.

India's 11th Five-Year Plan includes a proposal – since accepted by the government - for a multi-gigabit, low latency, National Knowledge Network. The National Knowledge Network and grid connectivity will be needed for collaborative research and collaborative innovation.

Dr. Chidambaram emphasized that current "exciting" areas of basic research in developed countries are, though not consciously and not always, "directed" by the interests of the industries. However, India *must* be in these areas because usually they also involve excellent science and perhaps also can help Indian technology in the long term. These points had been emphasized in 1944 by **Dr. Homi Bhabha** in proposing an institution that would emerge, a year later, as the **Tata Institute of Fundamental Research** in Bombay, now Mumbai. In its execution, and in the requirement of no other deliverables than knowledge generation, directed basic research is no different from conventional basic research. So the university based researchers should be comfortable with this kind of research.

In conclusion, **Dr. Chidambaram** suggested that the challenge for India is to achieve "coherent synergy" among its diverse programs, and to keep programs with very different short-term goals consistent with a long-term direction for the country. India can become a global innovation leader, provided it uses technology foresight to make the right technology choices in a national perspective, nurtures a robust innovation ecosystem, backs these choices by directed basic research, leverages international cooperation to reinforce its own innovation strategies, and maintains coherent synergy among these efforts.

Prof. Chen opened his presentation entitled, "A New Innovation Policy towards Open and User Centered Innovation," by noting that two of China's priority strategies, as enunciated in its Medium- and Long-Term Plan for Science and Technology Development (2006-2020) are to become: 1) an innovative country with increased R&D

expenditures, larger numbers of patents and, where appropriate, its own standards; and 2) a harmonious country in terms of employment, environment, and happiness.

He remarked that technological innovation, which China is undertaking, is a risky activity with large investments and high rates of failure. With increasing competition, companies that don't innovate will die. However, most innovations fail. The idea of *open innovation*, introduced by Chesbrough in 2003, means that companies' rely on internal in addition to external ideas, and internal as well as external paths to market. Open innovation emphasizes the role of other departments besides internal R&D departments, R&D cooperation with other organizations, and the integration of internal and external knowledge.

Prof. Chen remarked that many scholars believe that innovation should be the responsibility of all employees in a company: e.g., salespersons, workers, R&D personnel, managers and after service providers. **Prof. Eric von Hippel** has emphasized that research in a range of field shows that many significant innovations are, in fact, developed by users rather than manufacturers. Two examples of open innovative companies in China are:

- **The Haier Corporation** in which every one is a "strategic business unit," and
- **The Baosteel Corporation**, in which the notion that "all members are innovators" has made the company an extraordinarily innovative performer.

From 1949–78, in **Prof. Chen's** view, the Chinese government adopted a closed, indigenous innovation perspective; from 1978 onward, it has maintained an open technology acquisition perspective. He hopes that starting immediately, the perspective will be one of open R&D and open, indigenous innovation. He suggested three government policies that could help in this respect:

1. Adoption of a "respect for all innovators" policy, and raising general public awareness of open innovation and collaborative user innovation.
2. Strive to reduce the cost of information and communications technology services to promote the exchange of problem-solving content among all people.
3. Provide an "innovation-friendly" intellectual property rights environment.

As an illustration of his second suggested recommendation, **Prof. Chen** explained that *Hangzhou City*, where *Zhejiang University* is located, is setting up a "Wireless City" program. This will mean all the people in Hangzhou can access the Internet totally free from the end of 2008. "Computer plus brain" will allow more users to innovate and to collaborate at any time and from any geographical location. The case of Hangzhou shows that both the Chinese central government and local governments can and often will support some information and communications technologies as free public goods, because they are vital tools for collaborative innovation work. These tools will aid the emergence and evolution of the open and user-centered innovation paradigm in China, and will assist China in its program of fast technological catch-up, enabling it to more quickly join the leading innovator countries in the world.

Turning to his recommendation concerning intellectual property rights (IPR), he admitted that appropriate enforcement is still a serious problem in China. On the other hand, strict enforcement without regard to legal and traditional “fair use” rights can hinder knowledge diffusion, unfairly impede follow-up innovation, and adversely affect social welfare.

In conclusion, **Prof. Chen** suggested that the Chinese government should take measures to protect IPR to increase firms’ incentive to innovate. At the same time, it should take appropriate measures to loosen IPR to encourage the exchange and diffusion of knowledge, and to create better conditions for additional innovations by open and user-innovators and others. To this end, at an early stage the government should move to lower the level of IPR in sectors such as universities and public research institutes so that innovators can more freely access the knowledge these institutions develop.

F. Session I – Inaugural

The inaugural session of the workshop was chaired by ***Dr. K. Kasturirangan***, Director of the *National Institute for Advanced Studies* (NIAS). He explained that NIAS is an institution founded on a trilateral partnership by industry, government and academia, is dedicated to finding scientific solutions for India as well as the world. NIAS has been in existence for exactly 20 years and provides a nonpartisan platform for discussion, operating under the ideology that “There is no problem for which science cannot make a contribution.” **Dr. Kasturirangan** vision was that the workshop will contribute toward strengthening the public-private partnership in research, given that future progress in science and technology demands collaborative research.

Dr. Norman Neureiter, Co-Director of the *Indo-US Science and Technology Forum* and Director of the *Center for Science, Technology & Security Policy at the American Association for the Advancement of Science*, emphasized the importance of developing cooperative collaborative scientific relationships between China, India and the United States, stressing that the development of science and technology in these countries will define the shape of the world to come. The US-India collaboration in science and technology dates from the early 1960s; the US-China collaboration dates back to the 1970s. Both provide precedents for successful international national cooperation in research and education. Given the rising energy demand in India and China, it is the imperative that China, India and the United States engage in multinational collaborative research and innovation in several key sectors, including the three to be considered in detail in the workshop. One important objective of the workshop is to catalyze such cooperation.

Prof. Mu Rongping, Director-General of the *Institute of Policy and Management of the Chinese Academy of Sciences* (CAS*)*, greeted the workshop participants on behalf of CAS. He recognized the importance of a global view of science and technology, as well as innovation capacity with regards to such crucial issues as energy security, climate change and global transformation. **Prof. Mu** called for a linkage between the natural and social sciences to address these vital concerns via an integrated approach, incorporating science and technology as well as government policy. He further encouraged utilizing the workshop as a platform for China-India-US collaboration.

Prof. Carl Dahlman, Luce Professor of Science, Technology and International Affairs, *Georgetown University*, then presented the first of two keynote addresses given during the inaugural session of the workshop. The second keynote addresses given during this session was presented by ***Prof. C.N.R. Rao***, National Research Professor at the *Jawaharlal Nehru Centre for Advanced Scientific Research.* Highlights of both these presentations appear in Section E of this executive summary. Highlights of these addresses appear in Section E of this executive summary.

Shri Kapil Sibal *Minister for Science, Technology and Earth Sciences in the Government of India* formally opened the workshop with his inaugural address. He began by noting a host of new global concerns for the 21^{st} century, including soaring oil prices, global warming, climate change, food shortages, rising poverty and energy shortages, which require global strategies to resolve local issues. He claimed that the stock phrase "Think globally, act globally," is insufficient to address these issues. He went on to state that it is not even enough to "Think globally, but act locally," because many solutions for the West are not affordable as far as India is concerned. The affordability of proposed solutions is a critical factor, highlighted by **Minister Sibal**, as he put forth the question, "What is the cost to help a village in India?" To be effective, solutions must fulfill the necessary parameters of accessibility, affordability and excellence. An example of successful technology that meets these criteria is the fuel-efficient Tata Nano, the world's cheapest car. He encouraged workshop participants to "Think locally. Act locally." Many areas don't have the finances, resources or technology necessary for self-provision. Thus, global success in science and technology will be limited to those who can meet the requirement of affordability.

India needs education for its people and the world needs human power. By collaboration, the world can move to address the problems we are now facing. **Minister Sibal** claimed that if India is given the resources, the world will see a mushrooming of talent. Despite a nearly 300 percent increase in funding for research and education in science over the past four years, India has not yet been able to fully realize international opportunities for investments in education. Currently, state institutions, without a national mission (yet requiring national permission), have been a hindrance to progress in India. More decision-making powers must be devolved to the states to facilitate the creation of world-class research institutions. **Minister Sibal** noted that India has had robust growth in technological areas, such as information technology, which does not require sophisticated hardware, but has been a victim of technology denial regimes that impede advancement in other sectors. Technology constraints have limited progress in India and the Indo-US nuclear deal represents a means to do away with these denial regimes. The deal opens doors of international cooperation, not only in the nuclear energy sector, but also in many technological areas for India.

Given India and China's demographic strength and economic growth, it is clear that these two countries will play a significant role in shaping the coming world. Further, the global nature of problems such as climate change, epidemic diseases, and energy shortages concerns require strategies to address these issues that are global in nature. **Minister Sibal** closed by stating that the global community has a financial as well as fundamental interest in the growth and prosperity of China and India and the only way progress can happen is via collaborative science, technology and innovation.

G. Session II – Power Generation by Coal

The chair, ***Dr. Arcot Ramachandran***, of the *Energy and Resources Institute*, New Delhi, opened the session by noting that design is the key to innovation. Design is often neglected because the focus tends to be much more on research and development (R&D). He went on to explain that innovation through design needs to be more strongly emphasized.

According to **Dr. Ramachandran**, "King Coal" is plentifully available indigenously [in India and elsewhere] and will easily last for the next 100 years or so. In recent years, coal has been coming back into the picture as a main source of energy to meet the needs of developing countries, and the effect on the environment through increased greenhouse gases is not sustainable. He called for a need to develop clean technologies to ensure that clean coal will be available for power solutions for future generations.

At present, the world consumption of power is 15 terawatts of power, and this is set to increase to 30 terawatts by 2050. Based on these numbers, **Dr. Ramachandran** posed the question: how can India have a sustainable energy system? He went on to explain that neither coal, oil, nuclear energy, nor natural gas will ever fully replace one of the other energy sources completely. He suggested that rather, it is likely that each will have an impact on the other – that is, they will only supplement one another. This will continue at least through this century.

Dr. Ramachandran pointed out that no new nuclear power station has been built in the US in the past 30 years. In Japan, Korea, and India to some extent, there have been advancements on promoting nuclear power. In parts of Europe, however, where public acceptance is arguably higher, and certainly necessary (France has ~70% power generated by nuclear but rest of EU needs to be on board) these seems to be a model from which to emulate.

Dr. Ramachandran noted that there are 80 billion tons of coal in India and that even with increased demand and consumption, coal reserves in the country will last for next century. He raised the issue that R&D for clean coal technology has not happened at the rate at which it should. It has been receiving considerable more attention recently, but still not enough.

The key, he explained is to encourage the utility industry to keep up with the trend of increased power efficiencies. Some questions to consider include: what are the technologies for the longer term? What are the next generation technologies likely to be: fuel cells? Integrated Gasification Combined Cycle (IGCC)?

He emphasized that governments, utilities providers, manufacturing facilities, and research institutions must work together to deal with high ash coals in a sustainable way. In India alone, "energy" is spread across five separate ministries, so a call for a more coordinated effort is needed at the national and international levels. To this end, it is imperative to cooperate internationally to meet the challenges posed by global warming and industrial development. **Dr. Ramachandran** warned that "we cannot leave it to the market" to save our planet for future generations.

Dr. Ramachandran concluded his remarks by quoting economist **Jeffrey Sachs**: "all this will require a new global approach to problem solving... new budgetary incentives... particularly in developing countries. Rich countries should support these activities heavily... this will be an exciting time for scientists and engineers facing the challenges of global warming and sustainable development."

Dr. Ramachandran then called on ***Prof. Wang Yi***, *Institute of Policy and Management, Chinese Academy of Sciences*, to give his presentation, entitled, "Clean Coal-based Power Generation Technology Options in China."

Prof. Wang began by noting that installed thermal power capacity in China increased from approximately 50 Gigawatts in 1980 to 250 Gigawatts in 2000, and continues to increase exponentially. 95 percent of China's power plants are coal fired. In 2006, China accounted for 38.5 percent of the world's coal consumption, while China, India and the United States accounted for approximately 65 percent. By 2025 China is likely to be the world's principal consumer of coal. He then displayed graphs that projected the country's energy demand, electricity generation, and installed power capacity through 2050, with the likely power source projections indicated.

In recent years, China's coal-based power generation technology has developed very rapidly consistent with energy efficiency and environmental targets. These technologies include supercritical (SC) and ultra-supercritical (UCS) units. According to **Prof. Wang**, since 2007, 60 percent of the world's new SC and USC units are located in China.

Integrated Gasification Combined Cycle (IGCC) technology has better performance potential than either SC or USC technologies, although such systems are expensive and construction costs/kilowatt hour twice as expensive as SC and USC units. China has four IGCC demonstration projects under construction, with 15 more in the pipeline. He described polygeneration as a technology that can produce useful byproducts such including methanol, hydrogen, and ammonia, in addition to power. IGCC could be combined with polygeneration system development in order to reduce costs and would be a more comprehensive approach than either SC or USC.

Coal gasification, required for both IGCC and polygeneration technologies, and is common in ammonia production. Polygeneration is a concept used for many years by the chemical industry. In the more advanced concept, electrical power generation and carbon capture become new features.

Prof. Wang concluded as follows:

- Coal use must shift from combustion to gasification-based technologies.

- A clean coal technologies strategy offers the opportunity for meeting near-term environmental and energy security goals at lower costs than a "business as usual" approach.

- Clean use of coal based on gasification and polygeneration is a large and necessary component of such a strategy for China's long-term development.

- The percentage of IGCC units should be increased strategically relative to SC and USC units.

Dr. Ramachandran then called on ***Dr. James R. Katzer,*** *Exxon Mobil and Massachusetts Institute of Technology (retired)* to give his presentation entitled, "Coal-Based Power Generation – US Research and Innovation."

Dr. Katzer began by explaining that the focus of his presentation would be on the key elements that support, drive, and provide technology advances for coal. Traditionally, most technology development would be done in industry by the technology based power generation suppliers in the United States. However, because of the very small number of coal-fired power plants that were constructed in the country over the last 20 years, the industry had severely downsized just to survive; and technology development activities have been minimal, similar to the situation in the US nuclear industry. This limits the ability of these companies to develop innovative technologies in the face of a changing future. Thus, there has been a need for a sustained source of funding and a research and development strategy that is based on meeting the changing needs of the industry. This strategy needs to be aligned with a clear, firm, and unchanging policy as to what the industry must meet in the future; such a clear policy signal will drive the development of the required new technology.

Advanced Pulverized Coal (PC) power plants represent a promising set of technologies for increasing thermal efficiencies for electrical power generation. Such plants can be designed with Amine-based carbon dioxide capture capabilities. Oxygen-driven power generation – or oxy-fuel pulverized coal generation/capture technologies - show potential to lower carbon dioxide emissions and avoids costs of other PC capture technologies. Several such demonstration plants are under active development. Integrated Gasification Combined Cycle (IGCC) generating plants, with and without carbon dioxide capture, also show considerable promise for increased thermal efficiencies.

Dr. Katzer then turned to the topic of carbon capture and sequestration (CCS) in which carbon dioxide either prior to or following combustion in a power plant is transported by pipeline to a location suitable for underground sequestration. The more promising sites for such sequestration are depleted oil and gas fields and saline reservoirs. Many such potential sites exist in the United States. It will be essential in carrying out the first demonstrations of CCS technologies to convince the general public that such technologies are not hazardous to public health or the environment.

One problem in developing advanced coal combustion technologies in the United States is lack of adequate government support for early stage research and development (R&D). The key organization supporting power generating technology research and development has been the U.S. Department of Energy (DoE) through its "Clean Coal" program. This program has focused on developing technologies for emissions reduction from pulverized coal power plants and on developing and demonstrating IGCC as the next generation, cleaner technology. The total clean coal program has typically been about $350 million per year, which **Dr. Katzer** believes is woefully inadequate. There has also been a program to support coal/energy research in academic laboratories for about 30 years. The role of university research is to develop new data on the performance of specific processes, specific components, or new materials or to develop new sensing technology and/or control approaches.

There is always a need for new innovative technology in coal-based power generation to improve operations, increase generating efficiency and reduce emissions. However, it is important to note the coal-based power generation is a mature technology and has been highly optimized in many respects. To meet the needs of the future with respect to emissions and particularly carbon dioxide emissions reduction, technology already exists and needs to be commercially demonstrated and optimized on the commercial scale of power generation.

Dr. Katzer emphasized that it is still too early to pick winners for coal-based power generation with carbon dioxide capture. However, even with carbon dioxide capture and sequestration, coal can provide electricity at a cost competitive with nuclear and wind power generation.

Technologies for carbon dioxide capture with generation are all commercial, but will benefit from R&D and operation at scales to improve cost and performance.

Dr. Katzer concluded his presentation by recommending that in the United States, three to five large-scale carbon capture and sequestration projects of one million tons of carbon dioxide per year should be developed using different generation technologies, focusing on different geologies, and operated for several years to resolve outstanding technical, scientific, liability, policy, and regulatory issues.

Dr. Ramachandran then invited ***Dr. R.R. Sonde***, *Thermax Corp., Ltd.*, to give his presentation.

Dr. Sonde noted that with just about 1300 megawatts of power generation after independence in 1947 to the current installed capacity exceeding 130,000 Mw in generation-transmission-distribution network and 40,000 Mw in captive generation form – and these numbers are growing- is an indicator of the quantum leap the electricity sector has undergone in the past six decades. However, the demand for electricity is growing at a faster pace than the supply resulting in a huge overall shortage exceeding eight percent - peak shortage in excess of 12 percent- causing a major bottleneck in India's development. There are over a 100,000 villages without electricity. Of all the infrastructural necessities, electricity occupies a major part and the deficit in its availability is proving lethal to India's ambition of becoming a global super power by 2030.

Until the mid-1970s, the monolithic formations of state electricity boards, the political interferences in running these boards, inefficiencies and mal practices in the distribution sectors, resource constrain and a complete lack of well defined overall policy instructions contributed in no small measures in making electricity sector one of the major impediments to India's growth story. Added to this in good measure, is the weaker availability of fuels for the generation sector and the increasing dependence on coal. Coal sector development is yet another story which has contributed to the current woes of electricity sector.

Dr. Sonde emphasized that traditionally, the electricity sector has grown based on coal as the backbone of power generation. About 68 percent of electricity comes from coal based thermal power generating plants, 27 percent comes from hydro, and gas based combined cycles. The balance (five percent) comes from nuclear and wind. Initially the state electricity boards were responsible for setting up the generation plants with an exception of Tata's in the western part of the country - Mumbai (Bombay in those days) and DVC in the eastern part contributing in a limited way. However, post 1975, with the dismal performance of the state sector – there were few states which were exceptionally efficient – the central government intervened and set up the public sector units to take up the generation of electricity. This was perhaps the first turn around of the Indian electricity sector and soon the impressive performance from the central sectors created a positive response and paved way for a complete overhaul of the electricity sector as a whole leading to the current national electricity policy.

When India started building its engineering human power – and today India produces over a million graduates in science and engineering – the focus entirely shifted from research in engineering sciences to that of plant engineering and project management. This did have its flip side in that India could therefore build large capacity plants and operate and maintain them very well. The high capacity factors achieved in many of India's power generating plants bears a testimony that even with such adverse quality of coal, today the operating power plants achieve a capacity utilization plants in excess of 90 percent with the average exceeding 70 percent.

Clearly, as **Dr. Sonde** noted, India has made impressive progress in science and technology and today is considered as one of the leading nations in software technologies, nuclear, space and some niche areas like pharmaceuticals and automobiles parts. There is cutting edge research going on in the field of nuclear science and space. India is almost considered as a developed nation in these fields and in-fact is a leading member of major global R&D efforts like CERN project in Geneva, Switzerland, for particle physics and basic research on investigation of structure of universe or the ITER project in Southern France on fusion power as ultimate perpetual source of energy.

The electricity sector, for reasons he mentioned earlier, completely missed such development. The rapid need to develop capacities in the electricity sector, the sensitivity of the cost of electricity resulted in the focus being always short term in nature. It is surprising that there is no national level research and development (R&D) institution – as, in nuclear, space and biotechnology - dedicated to the electricity sector.

India is growing at a rapid pace at an annual rate of 8 to 9 percent GDP growth. This has necessitated the need of increased energy supply both in the electricity as well as the transport sector. India needs to quadruple its energy supply, and towards that the integrated energy policy (IEP) document prepared by the planning commission of India reflects the challenges being faced in meeting the demand of electricity from the current 130,000 megawatts to about 817,000 megawatts - a mammoth task indeed.

As both **Prof. Wang** and **Dr. Katzer** had emphasized in their presentations, **Dr. Sonde** stressed that coal will constitute a major source of electricity with more than 60 percent of the electricity being met by coal alone. The poor and dwindling resource of coal in India is a critical issue which hurts the electricity sector. The high ash content with high alpha quartz value adds up a big challenge for efficiency and reliability for power generation. In-fact, this is one area which requires customization of the technology for meeting the challenge of Indian coal and climate (high surface condenser temperature due to high cooling water temperature) – both in-terms of the design of boilers as well as the materials which form the pressure part components handling highly abrasive ash particles.

Thus, according to **Dr. Sonde**, the increasing demand for electricity, the dwindling availability of fuel, and climate change will result in Indian electricity generation from coal taking a very different pathway which will be technology oriented all the way. This is where there is a changing perspective with respect to policy level initiatives for bringing the R&D into the forefront in following areas:

- **Efficiency enhancement:** Efficiency in the entire value chain from the mining of coal to demand side management of electricity will be a major plank which will be the key driver in this segment. Use of low grade heat, reduction in auxiliary power consumption, advanced controls, super critical technologies, and water conservation are the areas where academic institutions and R&D laboratories will work with the power industry to develop India-centric technologies.

- **Fuel management technologies:** Technologies in coal washing, coal utilization, and gasification to produce power through a combined cycle with integrated facility for conversion of coal into liquid fuels will be the other area where there will be focus for undertaking R&D which is specific to Indian conditions.

- **Clean energy technologies:** Technologies in renewable energy systems like solar, wind, hydro and biomass will certainly form the backbone of future technologies and India will take all the steps necessary to meet this challenge. This calls for a mission-based approach with global collaboration. Models are being developed for meeting this challenge.

According to **Dr. Sonde**, the pathways for clean coal technology are country specific: primarily because of the evolution of technologies and also the nature of the coal occurrences in different countries. India is particularly handicapped by the poor but abundantly available coal quality. Clean coal technologies therefore from India's perspective will be those where we can enhance higher efficiency given our adverse tropical climate and poor coal quality using such technologies like economical beneficiation of coal or develop technologies which can handle abrasive coal ash.

Integrated Gasification Combined Cycle (IGCC) is yet another technology which quality of coal plays an important part. Fluid bed gasification technology which appears most appropriate for high ash coal of the type prevalent in the Indian sub-continent has many developmental needs. The design, scale up, control system designs are the principal issues pertaining to IGCC, which requires high end technology collaboration with leading global institutes.

Along with gasification units, equally important are the gas clean up systems, where once again there are major differences which call for different types of gas clean up technologies. IGCC technology, which can become a torchbearer for clean coal technology, needs a paradigm challenging technological development. These developments must happen very rapidly if IGCC technology is going to proliferate. Nothing short of global collaborative program will be able to make this happen.

Carbon capture and sequestration (CCS) is yet another field of clean coal technology development. Low sulphur coal has different connotations compared with high ash coal where post combustion gas clean up technology is concerned. The cost of carbon capture, sequestration in acceptable type of geological formations and over all safety and monitoring for CCS are other issues crying for solutions to be found.

Dr. Sonde concluded his presentation by suggesting that at a global level, there is consensus about coal being the major fossil fuel which will last for several more decades and hence humanity will continue to use it. To make it clean and still make it economically feasible for different types of coal call for a mission based program akin to the Manhattan project where multi-disciplinary, multi-country teams will put their act together in an environment where intellectual property ownership will be global.

“A new strategy”, he emphasized, “will be essential to make this happen."

Dr. Ramachandran then called on two discussants – ***Prof. Duan Yibing***, *Institute of Policy and Management, Chinese Academy of Sciences*, and ***Dr. Susan Su***, *US Patent and Trademark Office* - to comment on the three presentations, after which he opened the session for general discussion.

Several issues were raised and elaborated on by the two discussants and in the general discussion that followed[4].

Although diverse sources of power generation will be essential, including renewables, and nuclear energy, coal will be essential in all three countries for at least the next 20 years, and probably considerably longer. Unfortunately the era of cheap oil, particularly in the United States, has resulted in a sharply declining interest in coal and, as a result, dwindling availability of financial resources for R&D.

The quality of the coal in China, India and the United States, their diversity of resources and, essential to the problem of carbon sequestration, differences in suitable geologic depositories, indicates that there will be different pathways to technological development. In other words, there is no "one size fits all" approach that can be effective in China, India and the United States. In view of this situation, what sorts of international cooperation in power generation from coal can be effective?

In her commentary on the three presentations, **Dr. Su** suggested that research in various "green" technologies offers exciting prospects for engineering graduate students. On the other hand, research underlying power generation by coal is not particularly "sexy." How can graduate students be attracted to careers in this area, particularly since opportunities in the field are likely to diminish within the next two decades? In response, the three presenters noted that the technologies required for developing clean power generation by coal systems actually span a considerable spectrum and that all of these technologies are relevant to other types of systems. Thus, students trained in one or more of these technologies will be able to contribute to the development of a number of power generation systems in addition to coal generating systems.

The use of water required for clean coal technologies could be a significant barrier to their extensive implementation. Indeed, water and energy are two of the most significant challenges for the next decade or more. Clearly, water recycling will be essential to widespread deployment of clean coal systems.

Will intellectual property rights be a major barrier to international cooperation in the development and deployment of clean coal systems? Can governments cooperate to assume licensing costs? It was emphasized, however, that clean coal technology systems are expensive so that intellectual property costs would be relatively small in the overall scheme of things.

---

4. A more complete description of the discussants' comments and the general discussion that followed appear in Section VIII of these proceedings.

In conclusion, questions that were raised to sum up the session related to how and with what technologies, and economies of scale, from the viewpoint of increasing efficiencies and reducing pollution?

The consensus of the three presenters was that the reality is that five years is probably too short a period of time, even though emissions control technologies have improved a lot in both efficiency and cost in past decade. **Dr. Katzer** said “I don’t think it’s a technology failure, I do think it’s a policy failure.”

Dr. Sonde mentioned that the efficiency increases achieved over the past five years might not actually be the returns people want to see and that technological advancement will not ultimately bring down consumption because as it gets more affordable people will use more of it.

The question was raised as to how much money would be needed to do pilot projects in this area? How much scientific cooperation would be necessary to achieve meaningful goals? If we were to make a proposal at the end of the conference, what is the magnitude that we are talking about? The answer to this, according to **Dr. Katzer,** is that there would need to be an increase of about $1 billion per year to do these types of demonstrations and that these would likely need to happen over the next eight to 10 years.

The final remarks of the session were made by **Dr. Sonde**, who noted that funding is necessary here and now. He noted as well that collaboration here and now is essential for India to make the next step to supercritical. India cannot wait for other countries to sell them technologies after they have moved to the next generation. Technologies and know how must be shared today – there are currently plants that are going under construction. Shotgun collaboration must happen through IPR transfer so that that new plants can be successful.

H. Session III – Information Technology

The chair, ***Ms. Bhaya Lal***, from the *Science and Technology Policy Institute, Washington, DC*, opened the session by laying the groundwork for the subsequent discussion on the IT ecology of the three nations. She suggested that several structural changes that have occurred in the world have enabled the forces of globalization, especially in the IT sector, to take hold. Based on a recent National Academies study entitled, *Innovation in Global Industries: U.S. Firms Competing in a New World*, Jeffrey T. Macher and David C. Mowery, editors (Committee on the Competitiveness and Workforce Needs of U.S. Industry, National Research Council, 2008), she highlighted four growing trends:

1. growth of innovative capabilities in a number of economies that 20 years ago were classified as poor
2. growth of sophisticated manufacturing and services-production activities in these and other economies
3. growth of demand for cutting-edge technologies (particularly in IT) in markets outside of the United States

4. growth of “vertical specialization” in many knowledge-intensive industries

Regarding the first of these trends – countries not much involved in research and development (R&D) or product development for global markets even 20 years ago – including China and India – are becoming prominent in these areas. In some of these countries, indigenous firms or subsidiaries of foreign firms are performing fundamental research. In most of them, improvements in innovative capabilities have enhanced the ability of these countries to contribute to the design and development of advanced products, including those in service-based industries such as financial services and logistics.

The second trend is the expansion of production activities outside of the United States in these and other regions. In a number of industries, ranging from semiconductors to flat panel displays and PCs, U.S. firms rely on sites outside of the United States (through ownership or contracts) for a growing share of their production requirements. Much of this offshore expansion in manufacturing activity has occurred in Asia and Southeast Asia, particularly in China, Taiwan, and South Korea.

Ms. Lal noted that the “product cycle” model that influenced academic analysis of U.S. firms’ offshore manufacturing and R&D activities during the 1960s (Vernon, 1966) posited that U.S. firms developed and introduced their most advanced products within their domestic market before marketing and (eventually) manufacturing these products offshore. This is increasingly not true anymore. Consumer markets for wireless and digital devices in countries such as South Korea, for example, are growing more rapidly than are similar markets in the United States. Consumers in these markets demand more advanced applications than is true of consumers elsewhere in the global economy.

The fourth of the trends she discussed was vertical specialization - or the development of an industry structure populated by firms that specialize in one or a limited set of activities who contract with other firms that specialize in different activities within the industry - has become more prevalent. For example, one group of firms in the pharmaceutical industry now focuses on drug discovery and contracts with other firms for drug development (e.g., clinical trials) and post-approval marketing. This type of contract-based collaboration among specialized firms differs considerably from the operations of firms that are vertically integrated in all functions ranging from R&D through manufacturing to marketing.

Ms. Lal concluded her remarks by noting that China, India, and the United States have all benefited from these structural changes. She asked that the speakers in the session focus on the IT ecosystems of each of these countries and how they are evolving in tandem with these changes…

She then invited ***Mr. S. Sadagopan****, International Institute of Information Technology,* Bangalore, to make his presentation.

Mr. Sadagopan's began his presentation entitled, "Information Technologies Landscape," with a "quick snapshot" of the current status of information technologies in the United States, China, and India. US dominance continues in products, development, and services. China is a rising star in manufacturing, local content, and services. India is a rising star in services, new enterprises based on entrepreneurship, and some niche products and services. In short, the United States has been running at great speed for decades, China walking, while India is starting to walk.

Turning to the situation in India, there are now 1.6 million jobs in IT and 1.4 million in IT-enabled services. The value of the IT services market in 2007-08 was $50 billion and is growing at an annual rate of 20 percent. All major multinational IT firms are setting up large bases in India, most with research and development (R&D) facilities. Products with local markets are increasing, as are broad-banding services in the legal and medical professions, for example. Local consumption of IT including banking, e-governance, and telecom billing are becoming more prominent. IT is going to secondary cities in the country such as Mysore, Bhubaneswar, and Mangalore. A transition or, better, an expansion of IT is proceeding from made in India for the world, to made in India by the world, to made in India for India. Enabling public policy has helped the development of IT in India, as has investment by government in critical projects.

Turning to research in IT, **Mr. Sadagopan** suggested that China is doing an excellent job of catching up with the United States with specific focus, increasing the number of its world class universities, and offering incentives to faculty and students to conduct IT-related research. In India, the government has too little money which it spreads too thin. In R&D, the United States has the advantage of scale, China, the advantage of focus. India has the advantage of an open system, but has neither focus nor scale. India has no national R&D strategies. Moreover the legendary leaders of the past, such as **Dr. Homi Bhabha** in atomic energy or **Dr. Vikram Sarabhai** in space, have no current counterparts. Nor are their political leaders with the necessary appreciation of R&D which **Prime Minister Rajiv Gandhi** typified.

Turning to the matters of new technologies and national research strategies, in the United States tradition is still working, although there have been no new major initiatives in recent years. China sometimes is bulldozing, with all its attendant advantages and disadvantages. India has no national research strategy, but sometimes things work, such as in the mobile communications, telemedicine, and e-governance. In short, the United States rests on its laurels, China is catching up rapidly, while India is muddling along and occasionally getting things right.

India, according to **Mr. Sadagopan**, is getting its act together in the matter of intellectual property. The culture of the multinational corporations appears to be rubbing off. In 2007, for example, Texas Instruments filed 500 Indian-based patents, Cisco 450, Huawei 200, Microsoft 180, Philips 130, Info Sys 199, and Wipro 101. As to data needs for science and technology in IT: the United States has established channels for information collection, dissemination and longitudinal research. In China, some universities are getting their acts together. In India, many government departments have started to move in promising directions, then fumbled. The United States is worthy of emulation, but in China there is not much to write home about. India needs to “unlearn” a great deal.

Mr. Sadagopan concluded with recommendations for government:

- It should invest broadly in research and promote IT-related research in particular.
- Government should play only an enabling role.
- Higher education should be “unshackled.”
- Centers of critical mass should be created in key areas of IT research, and on-going research study programs should be created in these centers.
- Incentives for new technologies should be created.
- An intellectual property culture should be developed.

Ms Lal then invited ***Prof. Mu Rongping***, *Institute of Policy and Management, Chinese Academy of Sciences,* to make his presentation.

Prof. Mu opened his presentation, entitled “International Competitiveness of the Industry for Manufacturing Communication Equipment in China,” by considering the development of information and communications technologies (ICT) in China. While China has experienced spectacular economic growth during the past two decades, it has relied primarily on low labor costs and the growth of investment rather than innovation. Currently, more attention is being paid to sustainability, and the development of ICT is important to sustainability.

The United States remains the world leader in ICT, followed by Japan and the European Union. China and India, taken together, are lumped together as “others” and barely register in terms of their ICT resources.

China is currently developing an optical communications system that will link several cities in the country and enable them to make use of high speed communication. This network is being linked to similar networks in Korea and Japan, and to the United States via Europe.

Prof. Mu noted that gauged by the number of ICT-related papers published in SCI (scientific citation index) journals as well as patent applications, China’s productivity is considerably lower than that of developed countries. Additionally, the effectiveness of R&D investments in China is lower than in many developed countries in terms of the quantity of output, and much lower in terms of quality.

Innovation capacity building is a key issue in China. The country is strongly promoting capacity-building in enterprises, while capacity-building for R&D in universities and CAS research institutes is also being emphasized, focusing on the construction of science and technology infrastructure and platforms.

Prof. Mu noted that China's Medium- and Long-Term Plan for Science and Technology in Development (2006-2020) consists of ten chapters, six of them relevant to the development and implementation of ICT in China:

1. S&T and Investment
2. Innovation-oriented government purchase and finance
3. Innovation based on assimilated technology
4. Creation and protection of intellectual property
5. Training human resources for S&T
6. Building an infrastructure/platform for S&T

He concluded by emphasizing that China is experiencing a change from "reform and openness" to "scientific development." That is, China is in transition from reform policy to development policy. Environmental change and sustainable social development have become important global issues. As a consequence, uncertainties in development policy making are increasing. Thus, there is a significant need for international cooperation to explore more effective innovation policies.

Ms. Lal then invited ***Mr. Peter Harsha****, Computing Research Association, Washington, DC*, to make his presentation.

Mr. Harsha began his presentation, entitled "U.S. Innovation and Information Technology Research and Development," by noting that while economists had once struggled to see the payoff for industry in increased investments in Information Technology (IT) - economist Stephen Roach in 1986 noted this "productivity paradox" by showing that between 1975 and 1985, despite huge increases in organizational expenditures on IT, there were virtually no gains in organizational productivity over the period there is now a large body of research that points to just the opposite conclusion.

In *Digital Prosperity: Understanding the Economic Benefits of Information Technology Revolution* (2007), authors Robert D. Atkinson and Andrew S. McKay do a very admirable job of surveying the available research on IT's impact on the new economy, explaining the processes by which information technologies enable productivity growth, enable the economy to run at full capacity, enable goods and services to be allocated more efficiently and enable the production of higher quality goods and services. They also note the ways IT drives innovation:

- IT gives researchers powerful new tools;
- IT enables small firms to significantly expand R&D;
- IT boosts innovation by giving users more of a role;
- IT lets organizations better manage the existing knowledge of its employees.

A significant reason for the dramatic advance in computing technology and the subsequent increase in innovation and productivity is the "extraordinarily productive interplay of federally funded university research, federally and privately funded industrial research, and entrepreneurial companies founded and staffed by people who moved back and forth between universities and industry," according a 1995 report by the National Research Council.

The 1995 NRC report, *Evolving the High Performance Computing and Communications Initiative to Support the Nation's Information Infrastructure*, included a compelling graphic illustrating this spectacular return. The graphic was updated in 2002. It charts the development of technologies from their origins in industrial and federally-supported university R&D, to the introduction of the first commercial products, through the creation of billion-dollar industries and markets. The original 1995 report identified nine of these multibillion-dollar IT industries. Seven years later, the number of examples had grown to 19 – multibillion-dollar industries that are transforming our lives and driving our economy.

Mr. Harsha emphasized that there is a complex interplay between federally-supported university-based research and industrial R&D efforts. In some cases, the initial ideas came from industry, but government-supported university research was necessary to advance the technology. In other cases, such as timesharing, graphical user interfaces, and the Internet, the ideas originated in the universities long before they matured to a point where subsequent research by industry helped move the technologies towards commercialization.

The great majority of industry-based research and development is of a fundamentally different character than university-based research. Industry-based research and development is, by necessity, much shorter term than the fundamental research performed in universities. It tends to be focused on product and process development, areas which will have more immediate impact on business profitability. On the other hand, university research can afford to be more long-term in character.

Another important characteristic of the IT R&D ecosystem is that it is very interdependent. Developments in Internet-working technologies led to the development of the Internet and World Wide Web (and the rise of Yahoo and Google), but also to developments in local area networking and workstations. Work on timesharing and client and server computing in the 1960s led to the development of e-mail and instant messaging. In addition, this interdependence increasingly includes subfields beyond traditional IT, helping enable whole new disciplines like bioinformatics, optoelectronics, and nanotechnology.

It is essential to note the long incubation period for these technologies between the time they were conceived and first researched to the time they arrived in the market as commercial products. In nearly every case, that lag time is measured in decades. This is the clearest illustration of the results of a sustained, robust commitment to long-term, fundamental research. The innovation that creates the technologies that drive the new economy today is the fruit of investments the federal government made in basic research 10, 15, 30 years ago.

Mr. Harsha explained that the current program coordinating the U.S. federal government's investments in IT R&D is called the Networking and Information Technology Research and Development program (NITRD). Currently, NITRD consists of $3.3 billion in IT R&D funding spread across 13 federal agencies, coordinated by the Interagency Working Group on Information Technology Research and Development of the National Science and Technology Council.

Given the structure of the NITRD program, coordination can prove difficult. Though each agency is represented within the Interagency Working Group on IT R&D, the Interagency Working Group has no budget authority over any of the participating agencies. Each agency controls its own budget and sets its own goals for IT R&D spending exclusively on the perceived appropriateness that that funding to the agency's mission will be approved by the US Congress.

As a result, there tends to be a sharp bias in the federal IT R&D portfolio towards short-term, application-oriented development -- a fact noted in the most recent review of the NITRD program by the President's Council of Advisors for Science and Technology (PCAST). So-called mission agencies - like the National Oceanic and Atmospheric Administration (NOAA) or the National Aeronautics and Space Administration (NASA) - tend to invest in applications geared to their respective missions, while leaving the long-term research to research-focused agencies like the National Science Foundation (NSF) and the Defense Advanced Research Projects Agency (DARPA). However, recent changes in research policy at DARPA have altered this productive IT R&D ecosystem in ways that cause great concern to the IT R&D community.

The two dominant federal agencies in the development of the discipline of computing and the resulting innovation in IT have been the U.S. National Science Foundation (NSF) and DARPA. The fact that the agencies have had two significantly different approaches to funding IT R&D has been an overall benefit to the discipline. Historically, NSF has focused on funding smaller awards to the individual investigator; in the process ensuring a broad range of research in the field was performed. DARPA, created in response to the Soviet launch of Sputnik and charged with insuring the nation was never caught "flat-footed" by a technologically superior adversary again, has historically focused on larger awards and building communities of researchers to address critical research problems – creating centers of excellence, many of which formed the basis of some of the top computer science departments in the country.

But in addition to a diversity of funding sources, the discipline (and, by extension, the nation) has been well-served by especially visionary program managers, especially at DARPA, drawn from university and industrial research labs who knew the discipline well and were given the flexibility to take risks with the research they supported with their program funds.

Unfortunately, according to **Mr. Harsha**, there is significant concern building within the academic computing research community that DARPA has lost much of what made it so important to the discipline by adopting policies that discourage university participation in defense-related IT R&D. Of particular concern is DARPA's recent focus on shorter-term research efforts, its implementation of a "go/no go" decision matrix for DARPA funded research projects, the classification of research on certain topics (for example, cyber security), and restrictions on the participation of foreign nationals (e.g., U.S. graduate students who are not U.S. citizens).

As a result, the only agency funding long-term, basic computer science research to any significant degree is NSF, which noted in its FY 2008 budget request that it funds 86 percent of all federal obligations for basic computer science research in US universities. The agency is beginning to show the strain of being the only "game in town," with proposal rates up significantly and award rates recently well below the agency's averages.

In its report on the NITRD program in 2007, PCAST emphasized this concern by noting that the most critical need in the program is to "rebalance the NITRD investment portfolio to include more long-term, large-scale, multidisciplinary IT R&D." The committee also found that there are needed changes in IT education efforts, training the IT workforce, technical areas in which the NITRD program invests, the rate of technology transfer, and NITRD's own planning and assessment processes.

Mr. Harsha concluded by emphasizing the PCAST report's conclusion that failing to make these necessary changes to the IT innovation ecosystem would constitute a significant threat to U.S. leadership in networking and information technology. And a failure to lead in IT innovation may constrain the pace of U.S. innovation across the economy, imperiling many of the gains those innovations have enabled.

Ms. Lal then called on two discussants – ***Prof. Amitav Mallik,*** *former member, National Security Advisory Board (India)*, and ***Prof. Duan Yibing***, *Institute of Policy and Management, Chinese Academy of Science* - to comment on the three presentations, after which she opened the session for general discussion.

Several issues were raised and elaborated on by the two discussants and in the general discussion that followed[5].

Prof. Mallik noted that the term "eco-system" came into use with the advent of IT to describe the synergies brought about by factors such as human resource availability, funding support, and government-academia linkages. The United States manage to create such eco-systems more effectively before others; China appears to be imitating the United States,, while India seems to finding it hard to do. Although innovation is widely emphasized, the priorities are not always shared; for example, in some contexts the focus is on adding features, whereas in others it is on lowering costs. Since IT encompass many technologies and techniques and thrives in an open global ecosystem, is co-innovation conceivable between the three countries so that we achieve IT for all?

5. A more complete account of the discussants' comments and the general discussion that followed appear in Section VIII of these proceedings.

Responding to discussants, **Prof. Sadagopan** suggested that one area of cooperation would be to identify imaginative ways of cutting back on health care costs. Bio-informatics can cut down on drug development costs, for example. GE's design and manufacture of ultra sound scanners in India for the world market. Within India, some initiatives have been made in the areas of health and education. Presently, though, it touches only about two percent of the population. In a country with 300 million people below the poverty line, there is a need to a identify strategies to scale such efforts.

Dr. William Blanpied asked about the role of IT in inclusive innovation; that is, innovation intended to advance the social and economic well being of a country's population. To this, ***Dr A. K. Chakrabarti*** pointed to two initiatives: 10 million community service centers are being established in the country. Each center will serve six villages and offer a range of IT-enabled services. Second, mobile payment forums supported by the Reserve Bank of India take advantage of the proliferation of mobile phones in the country to provide enhanced livelihood opportunities with things such as access to updated prices.

Dr. Blanpied inquired about the impact that perceptions that student of opportunities in IT-related areas have on the number of students enrolling in computer and math-based majors in the United States? What are the perceptions of foreign born students? **Mr. Harsha** responded that over 50 percent of the graduate students enrolled in computer and mathematics are foreign born. This means that the United States should ask why US-born students are not going into IT research. He identified the following reason: 1) cyclicality in enrollment corresponding to the boom and bust of the US IT industry; 2) perceptions among students that such studies involve long hours of programming in isolation; and 3) the long-term viability of a profession where jobs are likely to be off shored to low-cost locations in countries such as India and China

Prof. Carl Dahlman posed a question about how decisions about standards and protocols fit within overall national IT policies. **Prof. Sadagopan** responded by pointing out that, unlike China, India has refrained from creating its own national standards. Instead, it has begun to participate in global fora where standards are set so that Indian firms have an early advantage in building product not only for the domestic market but also to capture segments of the global market. **Mr. Harsha** said that governments must ask how preferences for IT policies support specific architectures, and that national IT policy must not constrict innovation.

Ms. Tricia Wang wanted to know the role of national IT policy in either accommodating or reshaping the international internet regime? **Prof. Sadagopan** responded that given international diversity in culture, language, content, ideology, notions of privacy and so on, a one-size fits all global internet regime is unrealistic. Instead, he argued for a framework that is malleable enough to accommodate national variations.

Ms. Wang then asked how Indian IT policies enable IT adoption and innovation without promoting indifference among the local political elite. Specifically, the government of India had a head start over China in creating an internet network, but because the Indian network was created with UN funds, once the UN pulled out, neither the government nor the local political elites understood the value of such a network. How can India's new IT policy ensure that a national policy would be accepted by local politicians? **Prof. Sadagopan** reemphasized the importance of an enabling role for government. There is a good deal of misconception that a market economy means the abdication of state responsibilities. Rather, the state continues to have a crucial role in the provision of public goods, especially in the creation of an infrastructure for higher education and research.

Prof. Dahlman asked about the prospects for international collaboration with a decrease in government funding in the United States? **Mr. Harsha** responded that indeed international collaborations can make up for the lack of national funding sources. However, this raises questions for national security. He pointed out that in a global research environment, attention should be given to who finances IT research, and the composition of research students in terms of their nationality.

A significant theme throughout the session was that IT policies and policy changes in China, India, and the United States will, of necessity, be rooted in each of these countries social and political environment. However, many commonalities and convergences are also apparent which would invite international cooperation.

For example, a nurturing environment acknowledges the importance of a diversity of approaches to funding in terms of:

- balanced institutional allocation of research funds,
- promotion of cross-institutional collaboration and flow of ideas,
- easy movement of ideas and people between private and public institutions, and
- support for timely and strategic research areas.

Paying attention to IT policy as a means to IT innovation will be central to each country's pathway. The underlying emphasis of the session was that successful IT policy leads to economic growth and social stability. Integrated IT innovative policies are reflective of successfully globally integrated societies.

I. Session IV – Pharmaceuticals

The chair, ***Prof. Wen Ke***, from the *Institute of Policy and Management of the Chinese Academy of Sciences*, opened the session by noting that all countries of the world face growing challenges, including increasing populations, health, ageing, and inequality. China, India, and the United States combined are now, and will most likely remain, the largest market for pharmaceuticals. Clearly, there is a great need for innovation in the pharmaceutical industry, which is characterized by considerable diversity and complexity.

Almost all human beings desire to live long lives as well as healthier lives. Due to its one child policy, young couples in China must now afford to support four ageing people.

While this situation is not so critical in India or the United States, it is becoming significant. International cooperation in innovation in the pharmaceutical industry should help us resolve the problems of an ageing population that a reasonable quality of life during their twilight years.

Experience indicates that the proportion of health-related expenditures to total consumption increases with the development of national economies and the enhancement of peoples' living standards. The economic development of China and, to a somewhat lesser extent India, during the past decades have been nothing less than miraculous. However, neither country has made the requisite expenditures on pharmaceuticals and other elements of the health care industry.

China and India are both characterized by dual economic structures. Many people have become rich or comparatively rich, while a majority of their populations remain poor and cannot afford large expenditures on medicine. Since the cost of medicines in the United States is high, many people in that country are not able to afford the medicines they require.

Thus, all three countries are facing the tasks of reducing the cost of medicine and developing innovations making medicine and the entire health care system more relevant to the needs of our publics.

The problem of developing new, effective, and moderately priced medicine is also characterized by the high costs of research and development (R&D) and clinical trials, and the long periods between R&D and the commercialization of safe and effective medicines. International communication and collaboration should help to alleviate these problems.

Prof. Ke closed by suggesting three goals for the session on pharmaceuticals:

1. Highlight the development of these three counties in the pharmaceutical industry.
2. Discuss their responsibilities and problems for promoting health development all over the world.
3. Explore possibilities for pharmaceutical R&D collaboration between the three countries.

She then called on ***Prof. Robert Kneller***, *Research Center for Advanced Science and Technology, University of Tokyo*, to make his presentation entitled, "The Importance of New Companies for Drug Discovery and Development: an Analysis of the New Drugs Approved by the FDA 1998-2003." His presentation analyzed the institutional origins of new, and particularly innovative, pharmaceuticals: i.e., university research groups, biotechnology firms, in addition to their countries of origin. He concluded that most innovative and potentially high-risk pharmaceuticals originate in university research and research by biotechnology companies, most of which are located in the United States, Canada, and Australia. In contrast, large pharmaceutical firms appear to focus on improving proven, safe drugs.

Prof. Kneller's analysis was based on the origins of all the 169 new drugs approved by the US Food and Drug Administration (FDA) from 1998 to 2003. It shows the types of organizations (pharmaceutical companies, biotechnology companies, and universities) that are discovering innovative drugs and the countries/regions in which these discoveries are being made. The variations are striking and have implications for public health and the types of organizations, business environments and public policies that promote the discovery and commercialization of innovative drugs.

His analysis uses as in indicator of innovativeness (in terms a drug's response to unmet medical needs and its scientific/pharmaceutical originality) whether it is a new therapeutic biologics (NTB), an new molecular entity (NME) accorded priority review (pNME) by the FDA, or an NME accorded only standard review (sNME). By administrative definition, priority status is an indicator of innovativeness with respect to meeting medical needs, i.e., drugs are accorded priority review if they offer *substantial benefit over currently marketed drugs* [emphasis added]. It is also a reasonable indicator of scientific, technical and conceptual innovativeness. Most of the pNMEs represent previously unapproved classes of chemical compounds, whereas, in the case of most of sNMEs, the FDA has approved at least one other drug in the same chemical class with similar physiologic action.

sNMEs are most likely to originate from established pharmaceutical companies (75 percent). In contrast, NTBs are most likely to originate in universities or biotechnology firms (88 percent). pNMEs are about equally divided between pharma and non-pharma origin. Overall 68 percent of university discovered drugs were developed initially by biotechnology firms. However, among university-discovered sNMEs, only 47 were initially licensed to biotechnology firms, in contrast to 75 percent of university-discovered pNMEs and 88 percent of university-discovered NTBs. In other words, not only are biotechnology firms important overall for developing university discoveries, but the synergy seems strongest in the case of university drugs offering the greatest health benefit. sNMEs are most likely to originate from established pharmaceutical companies (75 percent). In contrast, NTBs are most likely to originate in universities or biotechnology firms (88 percent). pNMEs are about equally divided between pharma and non-pharma origin. Overall 68 percent of university discovered drugs were developed initially by biotechnology firms. However, among university-discovered sNMEs, only 47 were initially licensed to biotechnology firms, in contrast to 75 percent of university-discovered pNMEs and 88 percent of university-discovered NTBs. In other words, not only are biotechnology firms important overall for developing university discoveries, but the synergy seems strongest in the case of university-based drugs – that is, NTBs - offering the greatest health benefit.

In summary, according to **Prof. Kneller**, without biotechnology firms, it is hard to imagine that the pace of discovery and development of NTBs and pNMEs would have been as rapid as it has been. In the United States, Canada, and Australia, biotechnology firms have not only substituted for large pharmaceutical companies in the area of drug discovery. Additionally, outside of these three countries, not only is drug discovery confined mainly to large pharmaceutical companies (with a roughly 10 percent contribution from universities that transfer directly to large pharmaceutical companies), but also drug discovery leading to marketed drugs is limited mainly to drugs similar to those already on the market, except in Switzerland and in the case of a small number of innovative drugs that have potential to become blockbusters. This suggests a risk adverse drug discovery and development strategy on the part of established pharmaceutical companies that focuses resources on already proven classes of drugs, except for a few projects aimed at innovative compounds for high-demand markets.

Government support for biomedical research in universities – via the National Institutes of Health (NIH) in the United States, for example, is obviously an important factor in the initial stages of research that may ultimately lead to new and innovative drugs. But even if government support for biomedical R&D and the way it is distributed are major factors underlying the discovery of larger than expected numbers of pNMEs and NTBs, the fact remains that biotechnology firms have been crucial in turning government funded research results into actual drug discoveries (or in carrying forward early stage development of discoveries made in universities). If government funding alone were the major factor, why have not pharmaceutical companies taken advantage of this and become leaders in pNME and NTB discovery in the United States, Canada, and Australia as well? With all their resources, why have they left it up to biotechnology firms and universities in their countries to discover a majority of the drugs that are most innovative and most responsive to health needs? Perhaps it is the combination of generous, well-allocated government funding - coupled with a variety of social, institutional and financial factors that create a supportive environment for new companies - that have made biotechnology firms particularly well suited to discover and develop drugs based upon pioneering university research. At the same time, large pharmaceutical companies may have realized that it makes business and even scientific sense for them to rely to universities and biotechnology firms (and the capital markets that fund them) to assume the risks associated with discovering innovative drugs and bringing them to the proof of concept stage.

Prof. Kneller's study shows that new companies (biotechnology firms) and universities that license to these firms, account for the discovery of at least half of the new drugs that respond to unmet medical needs and also at least half of the drugs that are first in class compounds and that are the most scientifically innovative. These companies are located almost exclusively in the United States, Canada and Australia, with a few in the UK, one in Japan and none in continental Europe. The contrast between the types of drugs discovered in regions where there are few biotechnology firms and regions where they are active in drug discovery indicates that biotechnology firms and universities are not simply substituting for drug discovery that would otherwise occur in established pharmaceutical companies. Neither can a simple division of drug discovery efforts according to market size, with pharmaceutical companies pursuing discovery of drugs with high sales potential and leaving the low sales drugs to be discovered by biotechs and universities, explain the observed patterns. Rather, the sales data are consistent with established pharmaceutical companies, especially those outside the United States, concentrating discovery and development efforts on low risk, non-innovative drugs, except for a few innovative drugs that have blockbuster sales potential.

Even so, large pharmaceutical companies have not been able to match the new biotechnology firms in discovering NTBs, which have the highest mean sales of all classes of drugs. Without biotechs, the number of new innovative drugs that meet unmet medical needs would probably be significantly less than it is today.

Prof. Kneller concluded his presentations with two questions that have so far remained in the background:

1. What is it about biotechnology firms that tends to make them more innovative (at least as a group) than established pharmaceutical companies, or, more generally, what it is about the innovation systems in North America and Australia that enables biotechs to be engines of innovation?

2. In countries with different innovation systems, where biotechnology firms are unlikely to become major engines of drug discovery in the near future, what alternatives are there to increase discovery and commercialization of innovative drugs?

Prof. Wen then called on ***Prof. Javed Iqbal****, Director, Institute for Life Sciences, Hyderabad,* to give his presentation.

Prof. Iqbal began his presentation, entitled "Innovation in Indian Pharmaceutical Industries," by noting that multinational corporations are searching for means to broaden their capacity for drug development while decreasing costs. As a result, pharmaceutical firms are forging partnerships to gain revenue and develop their own expertise. These advances of R&D in India have happened during the past decade with the greatest momentum occurring over the last five years.

There are several modes of pharmaceutical research and development (R&D) in India, including:

- Original proprietary research;
- Research partnerships with multinational corporations;
- Contract research organizations (CROs) which are typically contracted to perform specific stages of drug discovery, development, or testing; and
- Generics, active pharmaceuticals (APIs), and manufacturing.

Prof. Iqbal cited two examples of pharmaceutical opportunities in India:

1. Companies such as **Dr. Reddy's** Laboratories, *Glenmark*, in Hyderabad, are developing proprietary drug candidates, with the intent of forging marketing partnerships with multinationals; and
2. **Dr. Reddy's** Laboratories can conduct preclinical trials for 40 to 60 percent less than the cost of comparable activities in the United States.

Indian companies appear to be able to attract US-educated and trained scientists and engineers more readily than their Chinese counterparts. However, despite a leap in the number of clinical trials in India and China, the total numbers remain small compared with the United States and Europe.

Dr. Reddy's Laboratories provide an example of an Indian company that is pursuing parallel approaches to obtaining revenue at different stages in the pharmaceutical value chain. Four-fifth's of his discovery work is on precedented drugs; the remainder focuses on unprecedented therapeutic areas.

Prof. Iqbal concluded by naming many Indian companies that are moving to value-sharing relationships with multinational firms:

- Aurigene, with: Forest, Novo Nordisk, Johnson & Johnson, Merck, and Proctor and Gamble;
- Ranbaxy, with Glaxo Smith Kline and Merck
- Advinus Therapeutics with Merck
- Suven Life Sciences with Eli Lilly
- Syngene with Bristol-Myers Squib
- Chembioteck with Forest
- Jubilant Organosys with Eli Lilly
- GVK Biosciences with Wyeth
- Nicholas Parimal with Eli Lilly and Merck

Prof. Wen then invited ***Prof. Xiao Guangling,*** *Institute of Science and Technology and Society**,** Tsinghua University*, to give his presentation.

Prof. Xiao's presentation, entitled "Medical Industry Status and Development Trend in China," was divided into three parts: 1) the medical industry's development in China; 2) development trend of the medical industry in China; and 3) main measures of development of the medical industry in China.

China now has 834 large and medium-sized medical enterprises, and its output of medicinal chemicals now ranks second in the world. Considerable research and development (R&D) is being devoted to the standardization of traditional Chinese medicine. China's medical industry is centered in the eastern area of the country with the proportion of gross product value of 10 eastern provinces and cities being 69 percent of the total. Sichuan the western part of China is the principal province of studies of traditional Chinese medicine.

In 2007, foreign trade in China's medical products reached $38.6 billion, an increase of 25.6 percent over the previous year. The value of exported medical products was $24.6 billion, that of imported products $14 billion. Asia, Europe and North America remain both the three major export and import markets.

Between 1985 and 2001, China sanctioned 1193 new medical products, with 12.4 percent being medicines of the first class. However, only a few have become internationally famous innovative medicines. According to the National Intellectual Property Bureau, there were 22,582 medical patent applications between 1996 and 2006, with 7718 of them granted. Among these, there were 14,859 domestic patent applications (including those from Hong Kong and Taiwan), with 4925 of them granted.

China has already become one of the largest medical markets in the world. However, it is among the lowest in terms of per capita medical expenditures. Per capita medical expenditures are less than $10 – approximately one-thirtieth to one-fortieth of those in the United States and Europe. The Chinese medical industry will enter a period of rapid development during the next five to 10 years, because of the country's aging population, improving standards of living, the quickening of industrialization and urbanization, the promotion of new rural cooperative medical services, and the enlargement of social security.

As the cost of factors of production including workforce and land resource costs rise, the development of the Chinese medical industry is entering a period of structural adjustment. Energy and raw materials shortages will be the principal restrictions of its economic development; this challenge is one that the medical industry must face in the medium- and long-term future. Market competition in the medical industry will become fierce as the country strengthens environmental protection, intellectual property protection, and faces rising production costs.

According to the Chinese government's 11th Five Year Plan, the overall goal with respect to the medical industry is to strengthen international competitiveness so as to enter the leading ranks of the world in some fields, thus laying a solid foundation for the country to become medically powerful.

Prof. Xiao emphasized that international cooperation would advance the internationalization of the medical industry to the benefit all nations. China should encourage multinational corporations in the medical industry to invest in China, establish R&D organizations, and carry out contract and joint research projects. Domestic enterprises should be encouraged to launch the work of registering and marketing their products abroad, establish foreign R&D facilities, invest in foreign set-up enterprises, and support the development of biotechnology products with intellectual property rights. Chinese medical enterprises should actively participate in the formulation and revision of international standards.

He concluded that China should extend the coverage of medical insurance in the country, advance the reform of its health care system, accelerate financial innovations and venture investment development, and adopt a tax policy giving preferential treatment for promoting the development of the biomedical industry.

Prof. Wen then called upon two discussants – ***Dr. Vijay Chandru***, *Strand Life Sciences*, and ***Prof. Aaron Levine***, *Georgia Institute of Technology* – to comment on these three presentations, after which she opened the session to general discussion.

Significant issues raised by these discussants and in the open discussion were[6]:

Dr. Chandru noted that the innovation chain breaks when going between academia and pharma—the person who discovers the drug loses touch with the process once it goes to pharma. The stock market is an important issue: Indian companies list on stock market only when they are highly profitable. There isn't an investment community to support innovative research for the venture-capital, small producing companies. Instead, they go with revenue-producing models that are more service-oriented. He emphasized that the mushrooming of Contract Research Organizations (CRO's) and the drawing back of the Indian *diaspora* has had a big effect on the culture of innovation, and this happens when the value chain brings back talent from the United States.

With reference to **Prof. Xiao Guangling's** presentation, **Dr. Chandru** was impressed with the incredible numbers showing the growth of the Chinese medical industry. He mentioned the large presence of traditional medicine and that, in the move towards standardization of traditional medicine, India should learn from China.

Before closing, **Dr. Chandru** brought up a theme close to his heart: the intersection of computation and theoretical research and development. He mentioned that there's a dryness in the new molecule pipeline: for example, in 2007, $36 billion were spent on finding new molecules, but only 18 were approved by the U.S. Food and Drug Administration (FDA).

The second discussant, **Prof. Aaron Levine**, began by postulating about how firms in India, China, US, fit into the value chain and how they are starting to move up the value chain. He noted that the United States has a mature pharmaceutical industry with players who fall into all parts of the chain. This field is led by giant multinational corporations (MNC's) such as Merck, but it is also influenced by small biotechnology firms such as university spin-offs that play a crucial role in the discovery and development of innovative new drugs. India and China are also becoming important large players but their pharmaceutical industries are less mature and they don't always cover complete the value chain as thoroughly.

Prof. Levine brought up several points for further discussion, such as the ethical concerns about clinical trials on treatment-naïve populations when drugs under investigation that are meant for western wealthy populations, or using traditional medicine as a starting point to identify new compounds. He also thought that MNC

6. A more complete account of the discussants' comments and the general discussion that followed appear in Section VIII of these proceedings.

collaborations could give these firms access to a growing domestic markets in China and India, but noted several barriers to these collaborations, such as: intellectual property protection, regulation for new/unproven treatments, including medical tourism for Westerners in India and China.

Responding to some of the issues posed by the discussants, **Prof. Kneller** asserted that to make the environment for new companies better, they needed better access to capital (through taxation of investors and companies) and the freedom for new companies to make international alliances to license intellectual property. Moreover, university researchers should be allowed to work with companies, but this interaction must be regulated. For example, **Prof. Kneller** proposed that faculty could consult, work for companies, and hold stock - but this interaction should not be unregulated and the primary responsibility of university faculty should be teaching and there should be a conflict of interest statement in place regarding their non-instructional activities.

Dr. Iqbal said that partnerships with a more knowledgeable partner would be valuable, as accountability and culture are very important. Many pharmaceutical companies in India are still driven by the family model, and accountability is an important issue. He noted several important issues when choosing a partner, such as money and profits, but the most important consideration is the complementarity and scientific skills.

Prof. Xiao noted that cooperation in China is mainly with the United States and Europe, and that foreign companies give China foreign medicines that are produced in China.

Prof. Carl Dalhman then posed the following questions. How important was this period of ignoring patents for building up India's pharmaceutical industry? And how did China do it without patent infringement? Also, cost is a big barrier for globalization of pharmaceuticals (especially in Phase 3 and 4). Are there any Indian/Chinese companies that are big enough to get to Phase 3 or 4? And, finally, why is there a dearth of small molecules, despite the large amount of spending? And how does traditional medicine factor into this in terms of policy implications and MNC involvement?

Dr. Iqbal noted that in January 2005 India joined the World Trade Organization (WTO) and accepted its guidelines on patents. Indian pharma wasn't very big at that. **Dr. Ranjeev Reddy**, in the early 1990's, was the pioneer in the development of the Indian pharmaceutical industry. He thought that the future was in innovative discovery - that was the beginning of innovation with his lab startup in Hyderabad.

The pipeline for new, innovative pharmaceuticals are dry, according to **Dr. Iqbal**, because of tactical mistake in 90's. He said India "went gaga" over combinatorial chemistry and forgot that replacing the human mind with machines won't give you innovation. Although machines do have their own benefits, human ingenuity can't be replaced. The big innovations happen with small companies and are passed onto big companies. Understanding of biology will help with drug discovery, especially in this post-genome era.

In response to **Prof. Dahlman**, **Prof. Xiao** stated that, in 1992 the patent law in China was changed and as a consequence, in the past 10 years, the number of patents has increased. About three percent of China's industrial expenditures are in the medical industry and he suggested that seven percent of those expenditures will be medical by 2020. He stated that China needs the government to put money in medical research: currently, 14 percent of government research and development money goes into medical research. He suggested that this amount should reach 25 percent in 2020. He concluded by noting that Chinese medicine incorporates both Western and Chinese medical ideas. There have been studies about how traditional medicine works, but as yet, there are no conclusions.

Mr. Rodney Nichols made several points. He said that it is important to note ethical considerations in trying to accelerate any kind of unproven treatment. In the United States, there has been backlash in genetic therapy and research in general could be slowed down if there are not well-informed trials. On an entirely different matter, the venture-capital companies do a deeper, profound analysis of patent being commercialized more than any big companies. These venture-capital companies bring together the best patent lawyers, commercialization, and science. They know the high risk involved, so they work very hard to make their stuff work and have strong financial interests.

Prof. Dilip Ahuja noted that informed consent is rarely "informed" in India, so how can we make sure that the poor aren't exploited? Second, for **Prof. Xiao**, he asked: what is the complementarity between traditional and Western medicine? Is it rural versus urban? Or according to diseases? For example, in India, you go to traditional medicine when Western medicine gives up or has no treatment.

Dr. Iqbal responded that clinical trials are done in a very unethical manner, and India needs a well-established system to regulate, monitor, allow for clinical trials in the country - and it should have the power to send people to jail. He noted that there are issues because people participate in trials because they're paid to do so. There is an urgent need for the government to make an agency to streamline the process.

Prof. Xiao responded to **Prof. Ahuja**, saying that there are both Chinese and Western hospitals. There is a philosophical difference between the two, though: Western medicine wants to kill something, whereas Chinese medicine wants to improve something or to make it stronger. He noted that, if you need to recover quickly, you use Western medicine, but if you're ill for a long time, then you use traditional medicine. This all depends on individual choice, but generally in hospital, they give both Chinese and Western medicine together. He joked that, when you recover, you don't know which medicine worked!

Dr. Adam Goldblum[7], posed several questions for the panelists. How do we lower the cost of drug development/clinical trials? How do we streamline that process? In setting

7. Dr. Goldblum, a bioscientist who works for a US biotechnology company, is the husband of Dr. Bethany Lyles Goldblum, one of four US Young Scholars selected by means of a nationwide competition to participate in the workshop.

up systems in China and India, can one streamline things to make the cost of companies more cost-effective? He noted that biotechnology firms are important in United States and Canada, but Europe is more towards pharma, as **Prof. Kneller**'s paper indicated. These drugs are successful in the United States because biotechnology companies can focus on being pragmatic without concerns about commercialization. Big companies, on the other hand, don't have so much drive because they don't have to be successful right away. They have big drugs making them money all of the time. How can India and China take advantage of that kind of a system to help identify new and promising therapies?

Dr. Iqbal responded that innovation is done with small biotechnology firms which don't have to worry about clinical trials, Phase 4. But in terms of how do we make India more attractive in terms of the preclinical/discovery stage, he proposed a public/private partnership, with Western companies absorbing the cost of the discovery. He noted that people get attached to molecules and they need to get beyond that. Indian pharmaceutical companies need to be more open and work with companies that have complementary skills. India has centers doing open-ended research particularly laboratories in the CSIR (Council of Scientific and Industrial Research) system. They are looking for directed research where they are given a problem they are excited about. He noted that India can cut costs through university/company collaboration, but cutting clinical costs becomes much more difficult, as populations are diverse and trials need to be tailored accordingly.

J. Session V – Summary and Conclusions

Prof. Samir K. Brahmachari, Director-General of the *Council of Scientific and Industrial Research*, who chaired this closing session, first called on the rapporteurs for sessions I through IV to present their summary reports. (These reports appear in Section VIII of these proceedings.) Next, he invited ***Prof. Chen Jin*** of *Zhejiang University* to present his keynote address entitled, "A New Innovation Policy towards Open and User Centered Innovation." (A summary of **Prof. Chen**'s remarks appear in Section E, above; his PowerPoint presentation appears in Section II of these proceedings.)

Prof. Brahmachari then provided a general overview of the innovation process in India. He spoke about the limitations of India's modern education system which he claims has "killed the ability to question" and in doing so has directly hindered the development of a next generation of innovators. Next, he identified the four leading characteristics of innovators as follows:

- The ability to connect the 'unconnectables'
- The ability to see beyond what is visible
- The ability to expect the unexpected
- The ability to celebrate naiveté

Brahmachari acknowledged that the Indian government recognizes the limitations of its education system in fostering innovation, but proposed that innovativeness must be cultivated both in schools and in the home. He stated that cultural changes such as allowing children to question their parents must accompany improvements to the formal education system.

Because much of India's population does not have access to formal education, the Indian government supports two programs, namely the **National Innovation Foundation** and the **Mariko Foundation**, to promote innovation outside of the formal education system. Among other innovations, the **National Innovation Foundation** supported the development of two products that could be very useful in rural Indian conditions. A special cycle, which was propelled forward each time it hit a bump in the road and a pesticide sprayer that could be attached to the sprayer's shoes were both developed with local conditions in mind.

A unique feature of the **National Innovation Foundation** is that it has always focused on designing user friendly products by involving end users in the development process. The development of the pedicab, designed in Calcutta, involved close to 200 end users, most of whom had no formal education. **Prof. Brahmachari** concluded that the key to innovation is tapping knowledge and ideas from all sources.

The session closed with brief remarks from the Chinese, US, and Indian co-chairs of the workshop.

Prof. Mu Rongping expressed his gratitude for India's participation in this year's conference and talked about ways to continue the three-way dialogue among India, China, and the United States. He suggested choosing specific topics for another tri-national workshop which could result in a book or journal issue. **Prof. Mu** also thanked the numerous younger scholars who had come to Bangalore to participate in the workshop, and recognized them as the next generation of innovators.

Prof. Richard Suttmeier restated that the objective of the workshop was to explore the innovation systems of three countries though three case studies. He congratulated the participants for meeting that objective and stated that he expects long-term collaboration among the scholars from all three countries to result.

Prof. Dilip Ahuja wrapped up the session with the following quote: "Whatever one may say of India, it is true, and equally true is its opposite." He cited statements from the various workshop sessions in support of this observation, and reiterated the importance of collaboration among China, India, and the United States in developing new approaches to global innovation.

K. Issues, Challenges, and Opportunities

One of the principal objectives of the China-India-US Workshop on Science, Technology and Innovation Policy was to provide an overview of the current status and trends in each of those countries to those from the two others who very likely were unfamiliar with them. There are few experts in the United States who are conversant with these topics with respect to both China and India. Additionally, since science and technology relations between China and India have historically been negligible and have begun to increase only after Chinese Premier Wen Jiabao, on an official visit to India in April 2005, signed a bilateral agreement designed to increase science and technology cooperation between the two countries. Because of the high quality of the members of the delegations to the workshop from the three countries and their interest in the issues considered, there seems to have been a broad consensus that this objective had been achieved.

There was an apparent consensus among the participants that the proceedings and implicit recommendations of the workshop should be considered by all three of the governments who had sent representatives to Bangalore. That the Indian-organizers managed to attract several high level government policy officials to make special presentations suggests that this consensus will be taken seriously.

A second objective was to bring together experts with common interests from the three countries. It was hoped that by focusing on three different case studies of science, technology and innovation policy – namely, power generation by coal, information technology, and pharmaceuticals – those experts might discover that there would be advantages in maintaining closer communication that might ultimately result in cooperative activities – either in the form of additional focused workshops or joint research projects or, perhaps, both. Although it is still too early to determine the extent to which this objective may have been successful, by the end of the three-day workshop there were at least two different groups that were having rather specific discussions about future cooperation.

Issues presented and discussed at the workshop can be divided into several categories. The most obvious of these are:

- those relevant to a single country vs. those common to all three; and
- those relevant to a single case-study sector vs. those common to all three

With respect to the first: several of the Chinese participants noted that although economic development in China has been nothing less than spectacular, much of that development has been based on manufacturing – often low end manufacturing – and exports, with too little attention paid to integrating research and development (R&D) into an overall strategic plan for the future. As described by **Prof. Mu Rongping** , China's Medium- and Long-Range Plan for Science and Technology Development, 2006-2010, is designed in large measure to overcome this perceived deficiency. It also envisions the production of more basic knowledge about technologies that can produce results that can be taken to market and thus move the country towards more high-end manufacturing.

Although India has made impressive strides in its economic growth during the past decade, it was the consensus of many of the Indian participants that science and technology had played only a minimal role in that growth, being confined primarily to knowledge-intensive industries, particularly information and communications technologies and, more recently, pharmaceuticals. Additionally, because of the structure of India's national system of innovation, the contributions that could be made by India's university scientists have been relatively insignificant, despite the fact that many of them have achieved internationally recognized status. Moreover, the rise of the knowledge-intensive industries has yet to have had an appreciable impact on the level of poverty in the country.

Although the United States remains the world leader in science and technology as gauged, for example, in terms of numbers of highly cited scientific papers by American scientists in international peer reviewed journals or the number of triadic patents by US inventors. (That is, patents granted by the United States, the European Union, and Japan.) However, there are concerns among US scientists that the country is failing to provide sufficient financial resources to maintain its success in science and technology. A strong case for a more coherent national policy to address these concerns were expressed in a 2007 report by the US National Academy of Sciences entitled, *Rising Above the Gathering Storm*, which **Prof. C.N.R. Rao** referred to in his keynote address. The current financial problems facing the United States, as well as its economy's over reliance on petroleum, could spell severe future problems for the country – problems that a well developed national science policy with clear priorities could help to resolve. The US research university system , by several criteria, the best in the world, may be resting on its laurels and is beginning to face strong competition from universities in Asia. Although China and India rank first and second, respectively, in the number of foreign students enrolled in US graduate schools, as opportunities in their home countries become more attractive, more students are studying in those countries than in the United States or in other countries, particularly in Europe and Australia, that are attractive to students from Asia. Additionally, as pointed out by **Dr. Susan Su** US industries such as coal-related industries are failing to interest new students to conduct research and produce the new innovations in this area. Rather, students are choosing other, "sexier" fields of study related to alternative energy technologies.

There are irritants among the three countries whose experts participated in the Bangalore workshop. While intellectual property rights (IPR) enforcement has improved considerably, Chinese workshop participants admitted that the country still has far to go in that respect. The central government has promulgated admirable IPR laws. However, these are often ignored at the provincial level.

Formerly, India's patent policies not only permitted but according to many, even encouraged IPR infringements, particularly in the pharmaceutical industry. However, this particular irritant has disappeared since 2005 when India aligned its patent policies with World Trade Organization (WTO) norms.

The tendency of many US firms to outsource and offshore its production facilities and even a good deal of its R&D to other countries, particularly China and India, has been a definite source of friction to many in the United States who are concerned about the loss of jobs, even though analysis has demonstrated that those losses have been relatively small, compared with the size of the US labor force. On the other hand, out sourcing can also the usually poorer host countries, as was pointed out by **Prof. Dilip Ahuja**. For example, US pharmaceutical companies that outsource clinical trials to also outsource clinical trials to India, for example, also outsource costs and complications associated with human clinical trial phases, therefore hurting Indian participants who may not be informed about the dangers in participating in drug trials. However, in view of the economic advantages of such outsourcing and off shoring, as was pointed out at the workshop, there is little that the United States can do about halting these trends. A more effective approach would be to train the current and particularly the next generation of US workers, particularly scientists and engineers, in fields where the US industry cannot engage in outsourcing, as well as to encourage US graduate students and post-doctoral scholars to spend time and gain experience in China and India so that they might lay the foundations for fruitful, long-term collaborations. Additionally, Indian authorities should be made aware of, and take appropriate actions to, regulate the outsourcing of clinical trials.

More broadly, the economic emergence or, better, re-emergence of China and India is causing considerable discomfort among many in the United States. However, these trends are inexorable. According to **Prof. Carl Dahlman**, if growth trends in the 2000-06 period persist, by 2018 the Chinese and Indian economies may be the first and second largest in the world, as measured in terms of purchasing power parity. For a decade following the collapse of the Berlin Wall in 1989, the United States was – and for the most part enjoyed - being the world's only superpower. There is no evidence that either China or India aspire to become superpowers. Nevertheless, the United States must accept the inevitable fact that the world is becoming multi-polar and that China and India represent two of its increasingly significant poles. Their significance is being strongly enhanced by their scientific capabilities and resources.

Turning to the three case study sectors discussed at the workshop: coal is no doubt going to be a major source of power generation in China, India, and the United States for the next 20 years, if not longer. So all three countries face the challenge of developing more efficient technologies that also do little or no harm to the environment and lead to global warming through the emission of carbon dioxide and other greenhouse gases. But there are concerns beyond efficiency and environmental problems. For China, domestic demand for energy that exceeds domestic supply causes power generation bottlenecks that lead to inflation and bottlenecks in other industries. Therefore, developing more efficient coal technologies that can better meet domestic supply will help prevent economic inflation.

Several promising technologies exist that need further development, although it is not yet clear which of these will be the most significant in the long run. One problem is that coal-related technologies are not regarded as particularly "sexy" so that a concerted effort must be made to attract good students to devote their careers to power generation by coal. Another problem is that the resources of the three countries differ considerably. For example, Indian coal has high ash content. Carbon sequestration is a promising technology. However, carbon sequestration requires specific geological conditions, which quite obviously differ among the three countries. Another problem related to – but goes beyond - power generation by coal is the way that each country deals with energy-related policy. As **Dr. R.R. Sonde** pointed out, India has yet to develop a coherent strategy or universal electricity grid, whereas China has done much better in this respect. Without a national electricity policy, there is inefficient energy supply and use, unsustainable energy mix, lack of national energy pricing, and insufficient environmental considerations.

To summarize, there is no "one size fits all" solution to the problems of efficient and environmentally-friendly power generation by coal. However, since none of the more promising technologies is yet fully developed, there is considerable scope for information exchange and international cooperation in mounting demonstration projects. This probably would require relaxation of IPR policies, which the three concerned governments should seriously consider since effective cooperation would be beneficial to all three of their countries. International collaboration and exchange of information about how power generation by coal fits into the entire range of energy consumption policy analysis, including petroleum and the use of renewable resources, as several Indian participants stressed. Nuclear power must be one of considered as one of those renewable resources, although it is rarely thought of in that manner. Considerations of enhanced nuclear power for India, as **Shri Kapil Sibal** suggested in his inaugural remarks, lead back to the pending Indo-US treaty that would provide the country partially ignore India's failure to adhere to the international non-proliferation treaty and provide it with substantial assistance in developing its civilian nuclear

Turning to information technology, almost all of the initial advances in the area were made in the United States, which is still dominant. However, China is developing a fast optical network which connects the principal cities in the country, and will ultimately connect with Japan and Korea and, through Europe, to the United States. The spectacular emergence of India's software industry was demonstrated to the workshop participants by means of a visit to the impressive Infosys campus in Bangalore (one of nine in India) during the morning and afternoon preceding the opening of the workshop. Most major multinational corporations (MNC) in the IT industry are sufficiently impressed with the capabilities of China and India that they have opened R&D centers in both countries. Thus, international cooperation in IT has been largely at the firm level. However, further advances will require the solution of fundamental problems through basic research, so that there is considerable scope for cooperation among the three countries represented at the workshop among individuals, universities, and other research institutes.

Another area for fruitful international cooperation would be in e-commerce. E-commerce requires a certain level of freedom of information flow, and since the market is slowly maturing in China, some of its older policies that may have resisted information flow are loosening up. In particular, there is now a great deal of business conducted between India and China, and much of this is coordinated through online websites catering to specific industries that arrange for businesses to meet in one of the two countries.

Cooperation in pharmaceuticals presents still another set of problems. China, according to **Prof. Xiao Guangling**, is doing well in developing its pharmaceuticals industry and exporting its products. Although the Indian pharmaceutical industry, although less well known than its IT industry, is impressive in many respects, as the pre-inaugural visit to Biocon illustrated.

According to **Prof. Javed Iqbal**, the Indian pharmaceutical industry has only come of age during the past five years. Medications with a Biocon label do not appear in the United States or, for that matter, in India[8]. Rather, Biocom and other Indian pharmaceutical companies such as Glenmark, Dr. Reddy's pioneering laboratory in Hyderabad, have been developing enzymes which they market to large pharmaceutical firms, and frequently become contract research organizations (CROs) for such firms. Additionally, pre-clinical trials can be conducted in India at a fraction of the cost of those in the United States. As **Prof. Dilip Ahuja** pointed out, however, serious ethical issues requiring government regulation are associated with conducting such trials involving poor people in developing countries.

Both India and China face the challenge of developing effective drugs that are affordable to members of their non-affluent populations. As **Prof. Wen Ke** noted, this is also a problem in the United States where too large a fraction of the population lacks adequate medical insurance. Clearly there is an almost universal need for inexpensive, effective drugs which would, almost by definition, be based on innovative pharmaceuticals. As **Prof. Robert Kneller** pointed out, innovative pharmaceuticals are almost always developed by university researchers and relatively small biotechnology companies that are often spun off from university departments. But such research by universities and biotechnology companies is confined almost exclusively to the United States, Canada and Australia. In other countries, large pharmaceutical companies develop new drugs, and these are most often of a decidedly non-innovative character.

However, culture plays a role in addition to economics when it comes to drug affordability and culture. The marketing and testing of drugs takes on an entirely different context in different social settings. In India, for example, inadequately trained medical practitioners may prescribe drugs derived from traditional Indian medical systems due to social rather than sound medical reasons. The impressive rise in the Indian pharmaceutical industry exemplified by companies such as **Biocon** which workshop participants were privileged to visit prior to the inaugural session provides grounds for hope that the unfortunate tendency of inadequately trained practitioners in the country may eventually be educated in the sounder, locally-produced drugs.

Prof. Robert Kneller pointed out in his presentation that innovative drugs are most often developed by universities and small to medium sized biotechnology companies often spun off from universities rather than large pharmaceutical firms which rarely innovate. Many workshop participants questioned why drugs needed by poor people not only in China and India but also in the United States never make it to market. It may be not only the lack of innovation that drives large pharmaceutical companies, but marketing as well – that is, marketing to middle and upper classes which can afford their products.

8. This situation may soon change. Biocon, for example, is developing diabetes medication that can be administered orally.

Prof. Kneller pointed out that the small biotechnology companies that develop innovative drugs are confined almost exclusively to the United States, Canada, and Australia. Could China and India encourage the development of small biotechnology firms which, in cooperation with their existing pharmaceutical companies, produce drugs specifically targeted towards their respective populations – as well as to other populations such as the uninsured in the United States? International cooperation involving US university scientists and employees of US biotechnology companies could be of immense importance in this respect, although encouragement by means of effective policies by the respective governments would also be essential.

Beyond the three case study sectors considered at the workshop, there is a great deal of scope for more intense bi-national and tri-national cooperation among scientists, engineers, and institutions in China, India, and the United States. Indo-US scientific cooperation dates from the early 1960s; Sino-US cooperation from the late 1970s; Sino-Indian cooperation is still in its infancy.

India and China have benefited from cooperative projects involving their scientists and engineers with their US colleagues. Many if not most of those US scientists and engineers who have been involved in cooperative projects with colleagues from India and China agree that they have also profited from those cooperative projects. However, among far too many US scientists – including, unfortunately, university scientists – there remains what is sometimes called the "nih syndrome." That is, if it was not invented "here" (that is, in the United States) it is not worth considering.

The world, however, is changing from one in which the United States can no longer expect to be dominant in all things, including science, technology and innovation. Until the 1970s or 1980s, competition was primarily among nations. Then it began to shift towards competition among firms in the same industry – many of them multinational corporations. Now, with the simplicity of communications made possible by the Internet, communication is once again shifting towards competition among individuals. For example, a Chinese pharmaceutical firm can almost equally well contract with an American university researcher to help develop a product through applied research in her/his own laboratory as it can with a Chinese researcher at a university in its own city. Likewise, that same US researcher can almost equally well work with a company at a distance half-way around the world as s(he) can with a company in the same city.

The United States will be ill-served is it does not accept – and educate its population to accept – the inevitable re-emergence of China and India. Likewise, American students of science and engineering will be ill served by their universities by the predominance of the nih syndrome. The United States – and particularly the next generation of scientists and engineers which it is training – should engage vigorously in international cooperative programs, particularly with the re-emerging nations of China and India. Although scientific cooperation with the United States is seen as vital by those two countries, in the United States such cooperation is more often regarded as "frosting on the cake." This attitude must change, and US scientists and engineers who have derived benefits from cooperation with either or both countries should take active steps to bring about such change.

Perhaps 75 percent of the participants in the Bangalore Workshop on Science, Technology, and Innovation Policy were less than 40 years of age. Probably 50 percent were less than 30.

The decision of the Chinese, Indian, and US co-chairs of the organizing committee for the workshop are to be congratulated on their independent decisions to bring so many younger people to Bangalore. Their decisions bode well for the future of science, technology and innovation in our three countries and, therefore, for the three countries themselves.