SCIENCE, TECHNOLOGY AND INNOVATION : EMERGING IMPERATIVES FOR INDIA

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National Science Day
Armament Research and Development Establishment, Pune

26 February 2010

“Science, Technology and Innovation are social activities. They can not be done in isolation and therefore, we can not disregard its history.”

Thomas Kuhn
The Structure of Scientific Revolutions

हीरक जयन्ती वर्ष 2009-10

"SCIENCE ALONE IS NOT TECHNOLOGY

TECHNOLOGY ALONE IS NOT INNOVATION

Akio Morita
Chairman of the Board
Sony Corporation

INNOVATION

It is the means by which a person creates new wealth producing resources or endows existing resources with enhanced potential for creating wealth

Peter F. Drucker

Harvard Business Review 1985

All things new are not necessarily innovations and all things innovative do not necessarily constitute technological innovation at any stage of development

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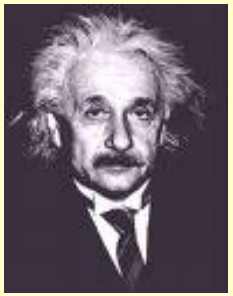
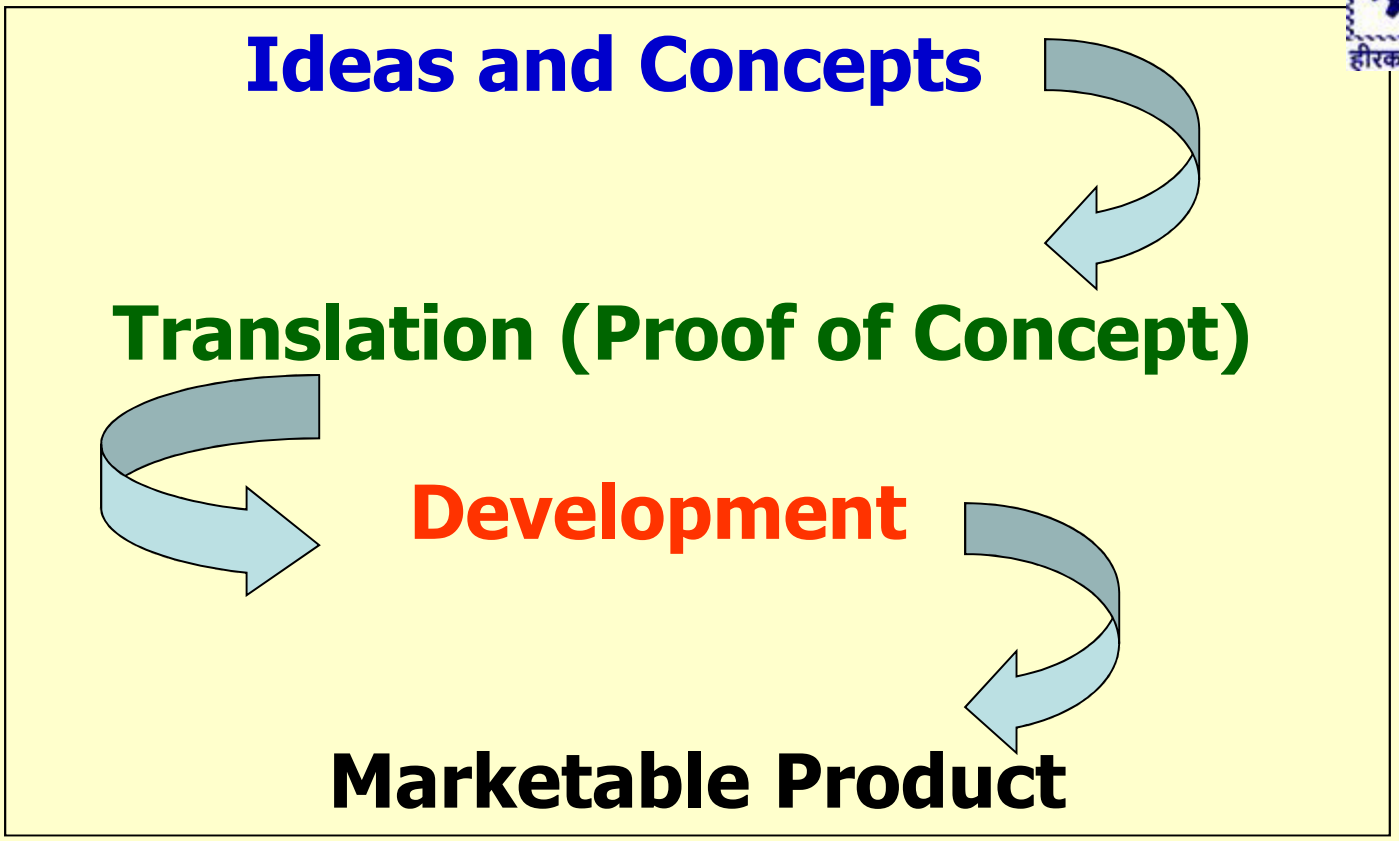
Discovery : Penicillin

Invention : Light Bulb

Relativity



Innovation : Retail Store

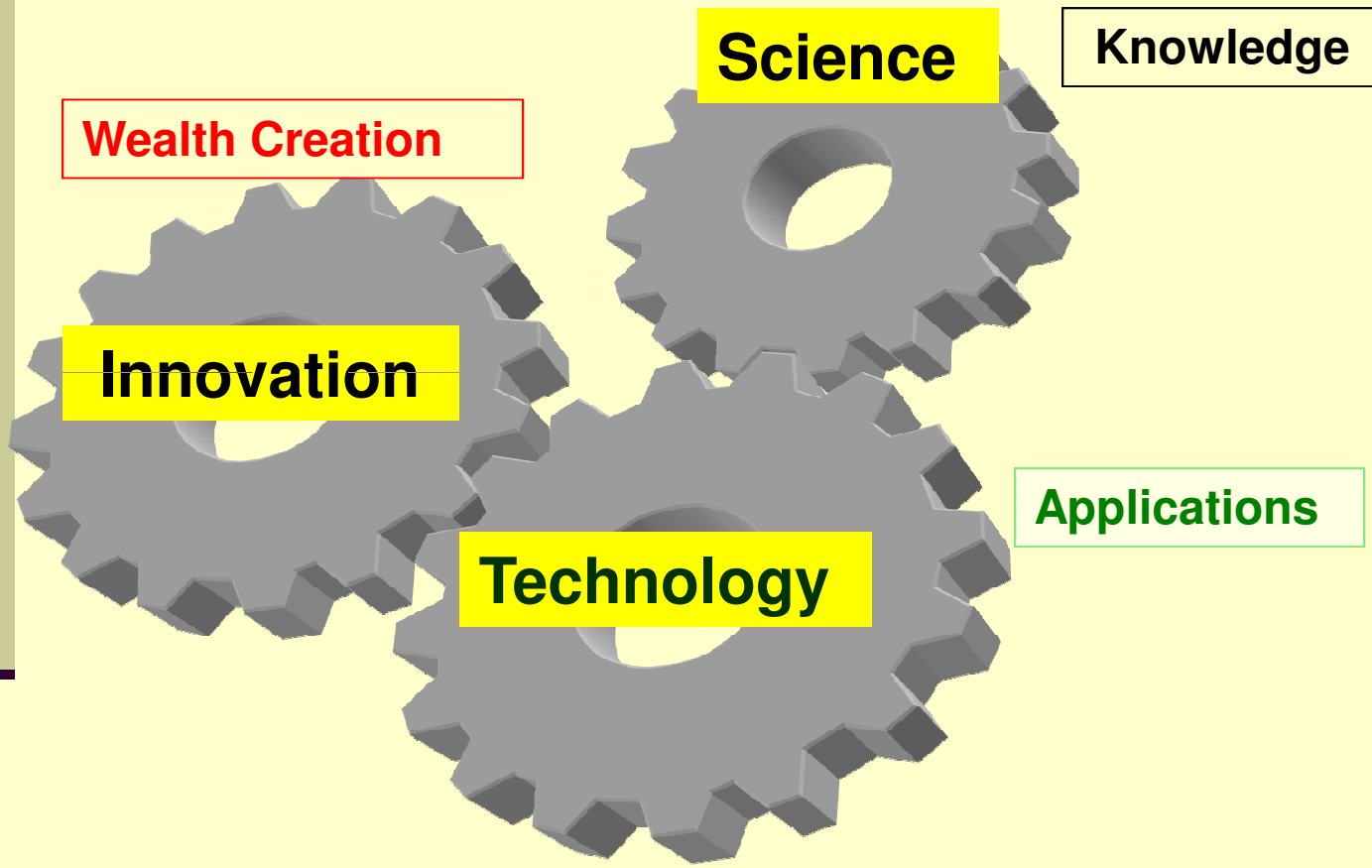


Success in the laboratory does not always translate into success in the market place

GDP DRIVERS

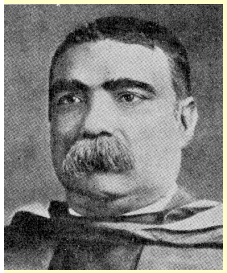
- **Population (consumption)**
- **Productivity**
- **Innovation**
- **Debt**

INTER LINKAGES OF SCIENCE, INNOVATION AND TECHNOLOGY



Building block of the knowledge economy

REVIVAL OF INDIAN SCIENCE

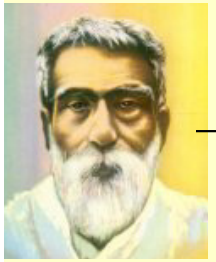


Asutosh Mukherjee (1864-1924)

- First Indian to publish a paper (1881)

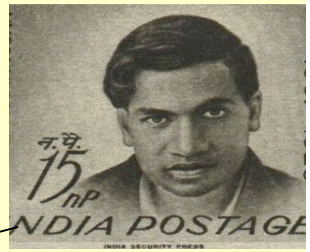
J. C. Bose (1858-1937)

- Microwave communication, semiconductor
- Missed the 1902 Nobel (Marconi)
- "Satyagraha": Salary boycott



P. C. Ray (1861-1944)

- First to do research in Chemistry
- Established Bengal Chemical and
- Pharmaceuticals (1901)



S. A. Ramanujan (1887-1920)

- FA fail (1908), First paper 1911, FRS (1918)

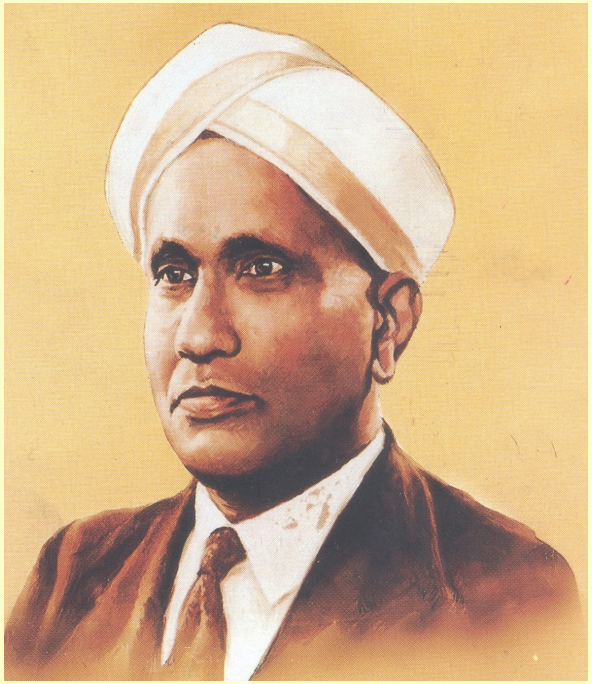
DR. MAHENDRALAL SIRCAR (1833-1904) and INDIAN ASSOCIATION FOR THE CULTIVATION OF SCIENCE

1863	Mahendralal stood first in M. D. Exam.
1870	Starts campaign for India's first Scientific Research Institute.
1876	IACS founded. Received no aid from British Government till 1926.
1876-1904	Lectures started. Laboratory/Library constructed. But no research!
1907	19 years old Raman starts research at IACS and receives the Nobel Prize in 1930.

MAHENDRALAL'S VIEWS ON IACS

"The sole function will be science-learning & science- teaching. We should carry on unaided by the (British) Government or more properly speaking, without seeking its aid. I want *freedom* for the institution. I want it to be solely native and purely *National.*"

"I reiterate my conviction that if our country is to advance at all & take rank with civilized nations, it can only be by means of science. To this end, I've given the best portion of my life, but I am sorry to leave this world with the impression that my labours have not met with the success it deserves." (*Last letter*, Nov. 1903)



C. V. Raman
1888-1970

1906 Stood 1st in M.Sc. (did not attend classes!!)
1906 Published first paper
1907 Assistant Auditor General, AG`s Office, Calcutta
1908 Starts research at IACS

RAMAN ON M.L. SIRCAR

"Dr. Sircar devoted a life-time of labour to the institution he created and equipped for the advancement of science in India. Its doors were open awaiting the arrival of someone. That arrival happened to be myself. Sircar did not alas, live to see his aims accomplished.

(Reply to Civic Reception Given by Mayor of Calcutta, 1931)

A. L. Sircar, Son of M.L. Sircar, 21 November 1907

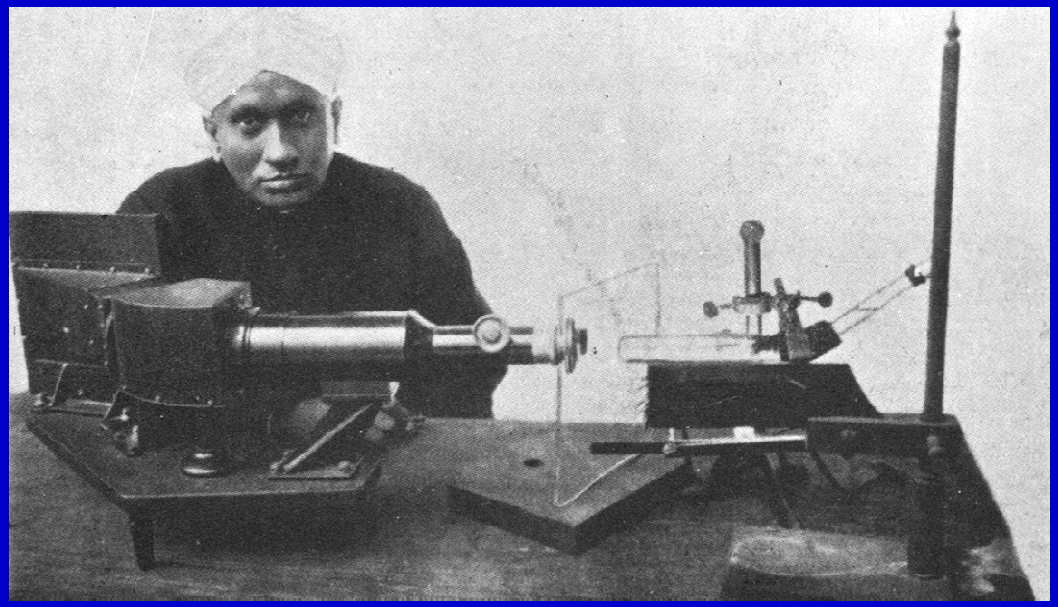
"We have got a young student with fine intellect, doing research in our laboratory. A side issue of his work has been published in *Nature* (24 Oct, 1907). The prophecy of the great man (MLS) is now going to be fulfilled. If circumstances do not go against us, Raman will be the brightest ornament of IACS."

ASUTOSH ON RAMAN'S SACRIFICE

"I admire the courage and spirit with which Raman exchanged a lucrative official appointment for a university Professorship. This instance encourages me to entertain the hope that there will be no lack of seekers of truth in the Temple of Knowledge which it is our ambition to erect."

"Sir Asutosh ventured to ask an young and unknown official to devote himself to the pursuit of knowledge under the aegis of the Calcutta University. This, on his part, was an act of courage. But for the action of Sir Asutosh, my scientific career would long ago suffered an abrupt termination."- C. V. Raman

THE RAMAN EFFECT



1928: Raman announced on 28 February, used sunlight & eyes
1930: Raman receives the Nobel Prize.
1998: *International Historic Chemical Landmark* (ACS)

I would like to stress the practical value of scientific researches to be carried out at in the National Chemical Laboratory, although I do not believe that utility is the main incentive to scientific work. It is in man's attempts to study nature and to understand her secrets that science finds its best motive. For this reason, I believe that good laboratories alone are not sufficient to produce scientific work but it is the ability of the individuals who work in the laboratory that counts.

I am sure that individuals of exceptional ability will work in the NCL and work for the advancement of science

Sir C.V. Raman, NL
January 3, 1950, Pune

JEWELS OF INDIAN SCIENCE IN PRE INDEPENDENCE PERIOD

- CV Raman
- S Ramanujan
- Sir KS Krishnan
- SNBose
- Sir M Visvesvaraya
- JC Bose
- Birbal Sahni
- PC Ray
- MN Saha

5 Indians were elected to FRS during 1937-46

Five were elected also during 1997-2006









Such people continue to occur. They are in smaller percentage on account of democratization of science

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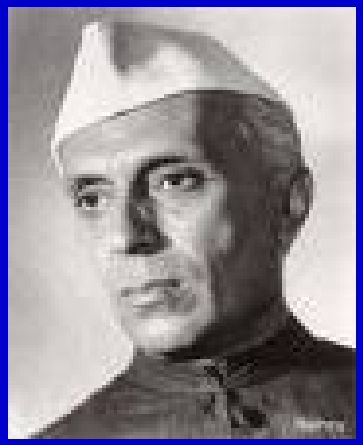


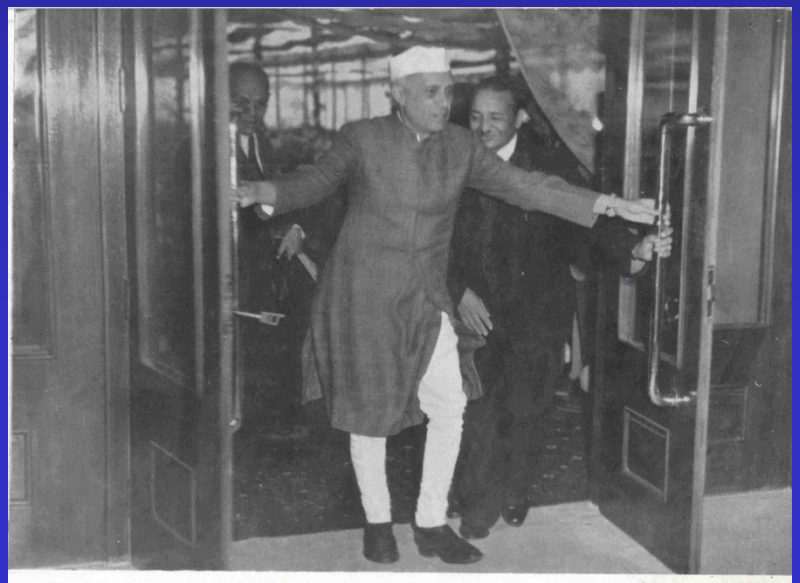
FREEDOM AT MIDNIGHT: NEHRU'S DREAM OF SCIENCE

- **"It is science alone…. that can solve the problem of hunger and poverty.. of vast resources running to waste, of a rich country inhabited by starving people"**
  - **Jawaharlal Nehru**
- **National prosperity dependent on effective combination of three factors: technology, raw materials and capital**
- **Commitment of first Indian Prime Minister to science was total**

There is talent in our country. But the question is how to tap that talent and give opportunities to the young men and women of India, who had the requisite ability. I hope that so far as these laboratories are concerned they would help to some extent at least in opening the doors to a large number of young men and women and give them opportunity to do good work for the country in the cause of science and in application of science for the public good

With these words I declare this Laboratory open

Pandit Jawaharlal Nehru
January 3, 1950, Pune



The opening of the National Chemical Laboratory

SCIENCE LEADERS: WHO LINKED SCIENCE WITH PURPOSE

- **The vision of political leaders like Shri C. Subramanian and scientific leaders like Dr M.S. Swaminathan has led to the First Green Revolution enabling India to produce over 200 million tons of food grains today through the use of high yield variety seeds.**
- **Dr. Varghese Kurien through milk co-operative movement, led India to become the largest producer of milk.**
- **Dr. Homi Bhabha established the TIFR, leading to nuclear science and research. Today India has 14 reactors producing nearly 4000 MW electrical power. Department of Atomic Energy targets 50,000 MW of power by 2030.**

SCIENCE LEADERS: WHO LINKED SCIENCE WITH PURPOSE

- **Professor Vikram Sarabhai's space vision enabled India to acquire the capability to design, develop, build and launch any type of satellite from Indian soil.**

- **Professor Shanti Swarup Bhatnagar created multiple CSIR laboratories in various disciplines for developing and transferring the technology to Indian industry including drugs for many tropical diseases.**

- **Dr Kothari was in the mission of creating a chain of DRDO laboratories for promoting self-reliance in critical technologies and strategic systems.**

SCIENCE AND TECHNOLOGY LANDSCAPE

- **Rapid changes**
- **Definition of science has broadened to include applications and innovations**
- **Closer links between knowledge systems of science and wealth generation and economy have been established**
- **Innovation has emerged as the buzz word in global platform**

FOUR PILLARS OF A KNOWLEDGE ECONOMY

- **The policy and educational framework**
- **The innovation system**
- **Education and life long learning**
- **Information and communication technology infrastructure**

C. Dahlman
The Four Pillars of the Knowledge Economy
1999

THE NATIONAL INNOVATION SYSTEM (NIS)

Celebrating Sixty Years of Science
हीरक जयन्ती वर्ष 2009-10

Knowledge $\xrightarrow{\text{NIS}}$ **Goods and Services**

NIS is a complementary system of

- **Knowledge producing organization (universities, research institutes)**
- **Macroeconomic and regulatory policies that affect technology diffusion**
- **Information and communication technology infrastructure**
- **Social, cultural, political factors and accessibility to global knowledge pool**

NIS is a combination of policies, institutions and linkages which diffuse and utilize innovation for economic growth

C. Freeman
The National System of Innovation in Historical Perspectives, 1977

THE INDIAN NATIONAL INNOVATION SYSTEM : HIGHER EDUCATION

- Central, state and private (deemed) universities
- Indian Institute of Science (IISc)
- Indian Institute of Science Education and Research (IISER)
- Indian Institute of Technology (IIT)
- Indian Institute of Management (IIM)
- National Law University
- National Institute of Technology (NIT)
- Institute of Medical Sciences
- Industrial Training Institutes (ITI)
- Colleges

THE INDIAN NATIONAL INNOVATION SYSTEM : HIGHER EDUCATION AND RESEARCH

- **IIT = 8, IIM =7, NIT = 10, IISER = 2, Central Universities = 18, State Universities = 217, Private (deemed) Universities = 130, Colleges = 17,625, Institute of Medical Sciences = 6, Medical Colleges = 783, Teacher Training Colleges = 900**
- **Total enrolment = 15 million**
- **Number of engineers graduating per year > 300, 000**
- **Number of Ph.D's granted in science and engineering = 6000 ; aspiring to increase it to 15000 by 2015**
- **Expenditure on education : 4.5% of GDP**

SCIENCE AND TECHNOLOGY IN INDIA : A CHRONOLOGY

•Council of Scientific and Industrial Research	1945
•National Chemical Laboratory	1950
•The Atomic Energy Act	1948
•Bhabha Atomic Research Center	1957
•First IIT at Kharagpur	1954
•All India Institute of Medical Sciences	1957
•First Agricultural Research University at Pantnagar	1960
•Indian Space Research Organization	1969
•Launch of First Sounding Rocket	1963
•Department of Science and Technology	1971
•First Atomic Device Detonation (Pokharan)	1974
•First Indian Satellite, Aryabhata	1975
•Department of Ocean Development	1981
•National TV Network	1982

SCIENCE AND TECHNOLOGY IN INDIA

The three phases

- **The infrastructure build up phase (1947-60)**
- **The assessment and reorientation phase (1960-80)**
- **The accountability and performance phase (1980-90)**
- **The economic liberalization and market orientation phase (1990 -)**
- ***Science and Technology policy statements***
- **Science policy resolution 1958**
- **Technology policy statement 1983**
- **Science and technology policy 2003**

  - Reforms in academic scientific systems

  - Measures to increase public private partnership in R&D

  - Importance of Intellectual Property as an instrument of wealth creation

THE INDIAN NATIONAL INNOVATION SYSTEM : INSTITUTIONS OF GOVERNMENT

- The Atomic Energy Research Establishments
- The Council of Scientific and Industrial Research
- The Indian Council of Medical Research
- The Indian Agriculture Research Institutions
- The Indian Space Research Organization
- The Defense Research and Development Organizations
- The Indian Metrological Department
- Research Institutes of the Departments of Science and Technology, Biotechnology and Ocean Development
- Ministry of Non Conventional Energy Resources
- Ministry of Communication and Information Technology
- Ministry of Environment and Forests

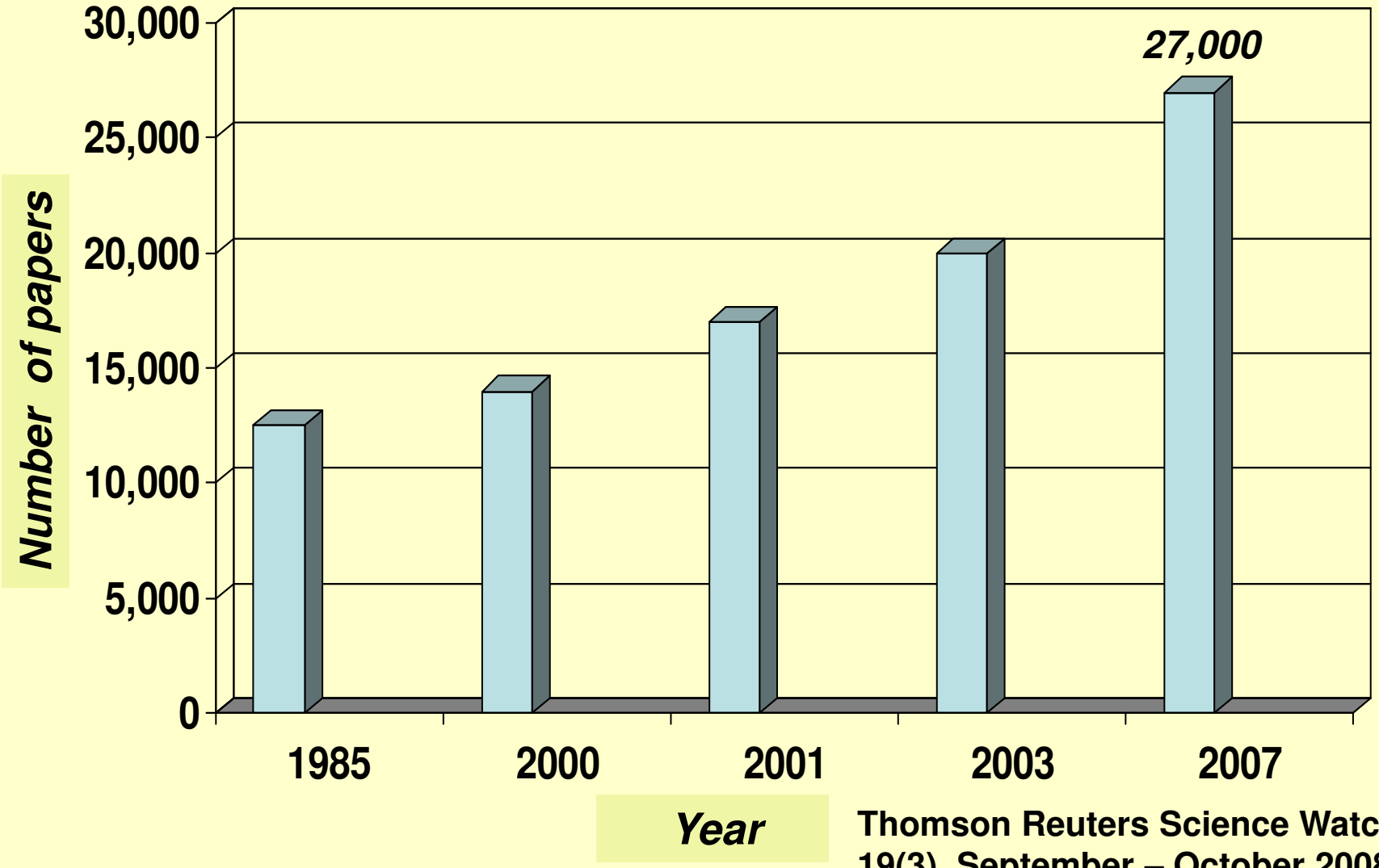
SCIENTIFIC AGENCIES AND RESEARCH INSTITUTES IN INDIA

•Agriculture	84
•Defense research	53
•CSIR	38
•Medical research	27
•Science and technology	17
•Atomic energy	14
•Electronics / IT	14
•Space	8
•Biotechnology	5
•Other Government research institutions	285
•State level research institutions	777
•R&D centers of companies and "non-profit" research bodies	1351
Total	2673

INDIAN SCIENCE SCORE CARD

- **Indian science has done well in areas of technology denial, whether it be atomic energy, space, defense**
- **Indian science in academic sector has grown, but much slower than other emerging nations or with reference to her potentials**
- **The growth model selected is exactly the same as those used by other nations.**
- **Is there a gap in our pursuit of science from first principles? Are we losing the integrative logic in search for rigor of the western science?**

GROWTH OF INDIAN SCIENCE



Thomson Reuters Science Watch
19(3), September – October 2008

INDIA AND TECHNOLOGICAL INNOVATION : AN EVOLVING LANDSCAPE

- India is poised to play a key and distinctive role in the emerging knowledge economy
- A long national tradition of scholarship in arts and sciences and a burning desire among the young to be educated against all odds
- A strong and growing educational infrastructure to cater to the aspiring millions of young men and women
- Generous state support to S&T
- India is becoming attractive for Indian professionals to either stay back or return back
- India's ensuing demographic profile will make available more educated and qualified professional in the age group of 20 to 35, the youngest work force in the world

INDIA AND TECHNOLOGICAL INNOVATION : AN EVOLVING LANDSCAPE

Some noteworthy successes

- **The Green Revolution (Agriculture)**
- **The White Revolution (Milk)**
- **The Blue Revolution (Space)**
- **The Grey Revolution (IT and Communication)**

INDIA AND TECHNOLOGICAL INNOVATION : AN EVOLVING LANDSCAPE

Some noteworthy successes

- **Energy (Hydrocarbons, Nuclear Power, Solar and Wind)**
- **Space and aerospace (Helicopters, Combat and Small Civilian Aircrafts, Unmanned space launches, Communication and Weather Sattelites)**
- **Healthcare (Low Cost Generics, Drug Discovery based on "Reverse Pharmacology" Principles, Vaccines and Biopharmaceuticals**

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GLOBAL LEADERSHIP OF INDIAN MANUFACTURING

Product	Company	Rank
Viscose fiber	Birla Viscose	1
Two wheelers	Hero Honda	1
Bicycles	Hero Cycles	1
Laminated packaging	Essel Propack	1
Polyester	Reliance Industries	1
Pyridine	Jubiliant Organosys	2
Liquor	United Breweries	2
Automotive forging	Bharat Forge	2
Optical storage media (CD/DVD)	Moser Baer	3
Brake Lining and radiator caps	Sundaram Fastners	3
Cephalosporin	Orchid Chemicals	5

PRODUCTS AND SERVICES FOR THE EMERGING MARKETS : WEALTH AT THE BOTTOM OF THE PYRAMID

- A four door automobile for less than $ 2000
- A mobile phone for less than $ 25
- A PC for less than $ 200 less than
- Lowest cost producer of off –patent generics
- Long distance calling at less than 10 cents per minute
- A heart valve at less than $ 400
- A by pass coronary surgery for less than $2500
- A cataract eye surgery at less than $100
- A baby diaper or female sanitary napkin at less than 10 cents per single use
- Shampoos , tooth paste and other personal care products at less than 3 cents per single use
- Vaccines that can be transported without a cold chain
- Full human genome sequencing in seven days at <$1000
- The lowest cost Supercomputer (132 Terraflop, ranked 13 th in the world)

Performance

Haves

Have - Nots

Price

Performance

Haves

Have - Nots

Price

Have - Nots	Haves
	

Performance

Price

CHALLENGE FOR INDIA'S GROWTH

- **Can India become an affluent nation in one generation?**
- **Can India escape the middle income trap? This occurs when countries cannot compete with low-wage, low-income economies in manufacture/exports or with advanced economies in skill intensive innovative activities.**
- **Sustained growth is harder to achieve. Lessons need to be from the growth story of Phillipines, S. Africa and Brazil**

If India can sustain a GDP growth of 8-9% for the next 30 years, its per capita income can grow from US $ 1000 to US $ 10,000!

India 2039, Centennial Group, Brookings Institution

INDIA'S GLOBAL POWERHOUSES:HOW THEY ARE TAKING ON THE WORLD : NIRMALAYA KUMAR (HBS)

- Indian companies must aspire to be the poet , not merely the scribe
- Indian exports of software or licensing IP amounted to only ~US$ 450 million
- Must go beyond renting out IQ and start creating IP
- Premium for innovation and branding : Apple`s 30 GB iPod ; Manufactured in China and consists of 424 parts of which 300 cost 1cent or less. The most expensive component is the display module made in Japan and costs US$ 20! The cost of iPod is about US$3.70 iPod sells for $224 and Apple`s gross profit per phone is $84
- Infosys and Microsoft began about the same time (1981 and 1975 respectively). Microsoft 2008 revenue is $60 billion with profits of $22 billion. Infosys revenue is 44 billion and profit 41 billion.
- Challenge : "Outsourced and made in India" to "Imagined and owned in India"
- Innovation requires heavy capital outlay up front which may not be recovered if the product fails to find enough customers. In contrast service revenues are labor intensive and more predictable.
- In India imitation still crowds innovation. Invention may be a wonderful thing but Indian companies still prefer that it be done on someone else's balance sheet

RESURGENCE OF INDIAN NATIONAL INNOVATION SYSTEM : KEY DRIVERS OF TRANSFORMATION

Economic factors

- Strong economic fundamentals
- Appreciating rupee / huge foreign exchange reserves
- Increasing consuming class
- Strong top / bottom line growth in manufacturing and service sectors
- Exports emerging as focus of growth
- Competitive business environment

Enablers

- Improved infrastructure, such as, ICT, roads, primary / secondary school education
- Increasing private investments in higher education
- Venture financing for early stage innovation
- Public-private partnership in R&D
- Higher education in English
- Greater functional autonomy to R&D institutions
- Greater budgetory resources for NIS

Indian National Innovation System Resurgence and Revival

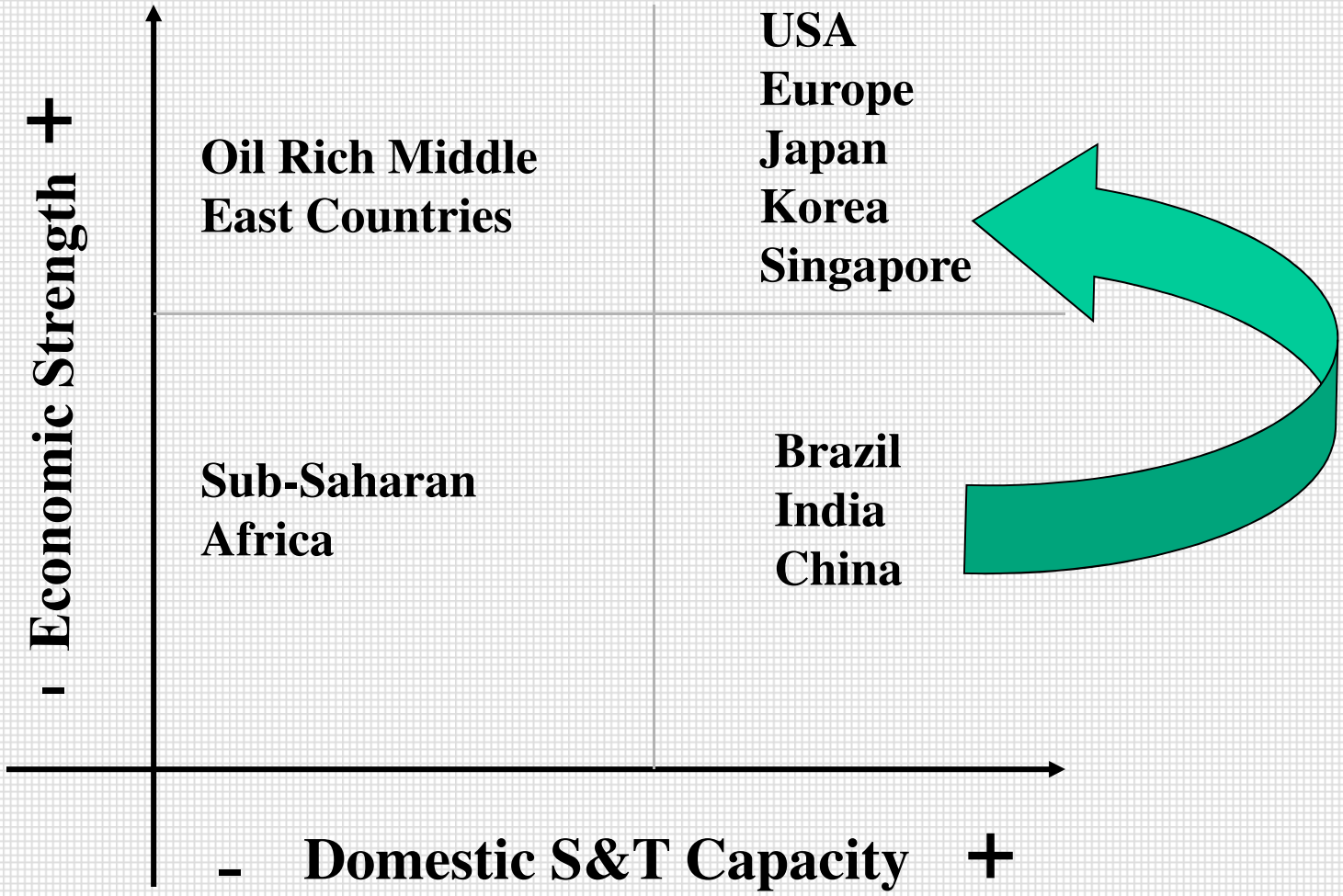
Drivers

- India emerging as R&D hub for global companies
- Young S&T talent pool
- Favorable demography >70% population <35 years age!
- Favorable IP regime post 2005
- Strong diaspora with high technical and managerial skills

Performance of NIS

- Improved focus and spread
- Change in mindset – from being just generators of knowledge to creators of wealth

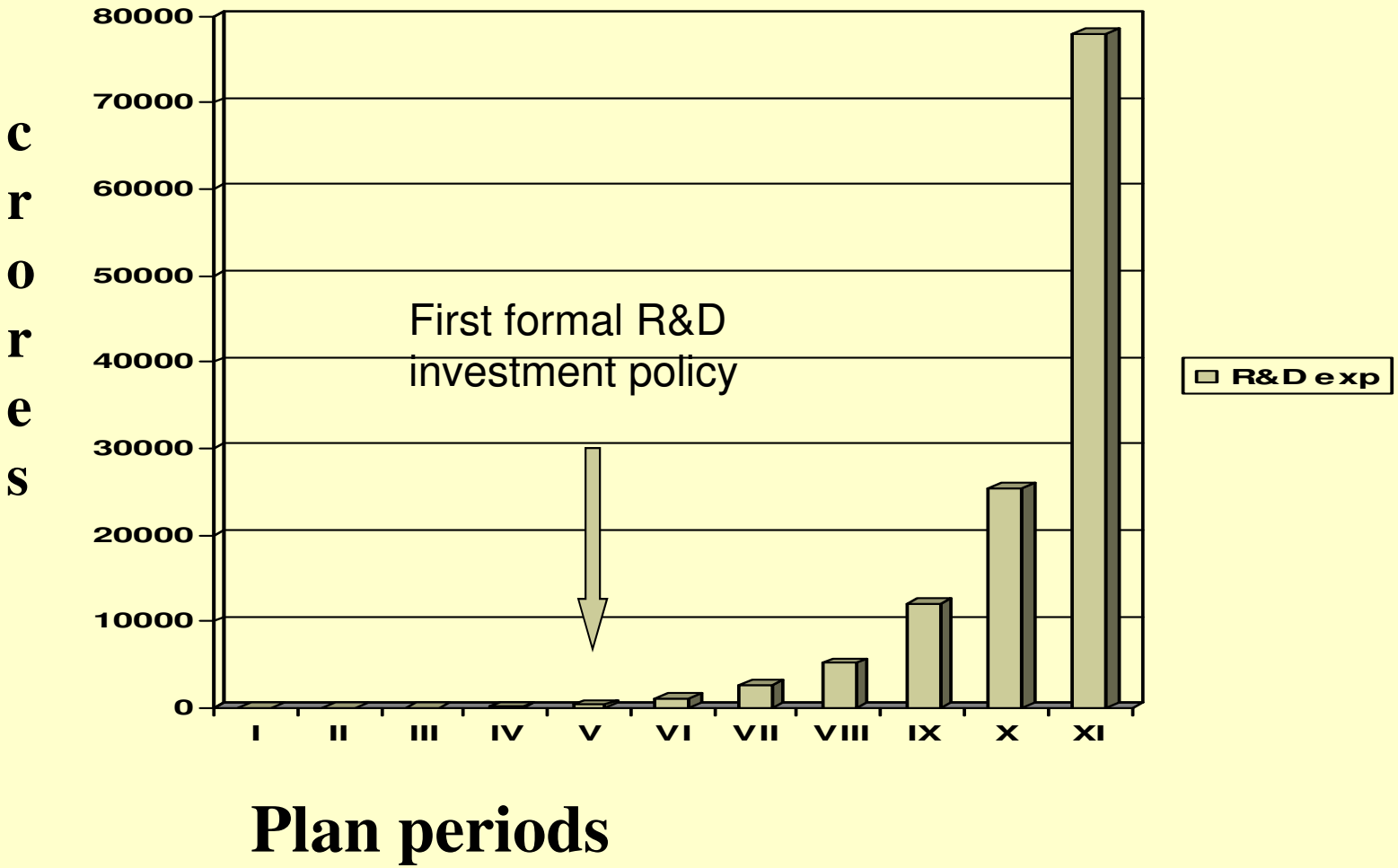
Relationship between Domestic S&T Capacity and Economic Strength



EMERGING S&T LANDSCAPE OF INDIA

- S&T landscape of India is undergoing structural alterations
- For the first time since 1970, India is establishing a large number of institutions of higher learning and research
- Pursuit of science had remained passion driven.
- Links between science and technology on the one hand and manufacture and economy on the other had distanced from each other for long
- Technology has for the first time has entered the centre stage in the national agenda
- S&T linkages with socio economic and industrial sectors are being established

R&D INVESTMENTS OF INDIA : SINCE IST PLAN PERIOD: POWER OF EXPONENT



CHANGING R&D STRUCTURE IN INDIA: 1950 - 2000

- **Positives**
  - **Ten fold increase in universities**
  - **Specialized national laboratories from a few to 300**
  - **R&D investment from 20 crore in first plan to 68000 crore in 11th plan**
  - **R&D expenditure as a percentage of FNP from 0.01% to 1% ..**
  - **R&D centres within industries from practically nil to over 1000, engaging over 50000 people and involving expenditure of Rs. 600 crore/year**
- **Gaps**
  - **Annual Output of PhDs in science and engineering has remained low at 4000-4500 while other big league nations moved ten fold.**
  - **Full time Equivalent researchers remained low as compared to other big league nations**

CHAMPIONING FOR LARGER OUTLAY FOR SCIENCE

- Outlays for science have grown at 250% from plan to plan during 9th and 10th plan periods
  - 400 % increase seems right for the 11th plan over 10th
- Rate of growth GERD has not kept pace with GDP growth; the percentage investment for R&D has remained at 0.8% over GDP with 3:1 share of public and private investments in R&D;
  - Increase from 0.8 to 1.3 % share of GDP by 2012 on current prices sought
- Trebling the current investment into basic research;
  - Total support is estimated at Rs 2500 crores per year. Trebling seems next feasible step

INDIA`S SCIENTIFIC PROWESS

- **Number of science Ph D's per year : 5000**
- **Number of engineering Ph D's per year : 1000**
- **Number of scientists working in public R&D : 1,20,000**
- **Number of scientists working in private R&D : 37,000**
- **Number of scientists retiring per year : 5,000**
- **Number of R&D personnel per million : 136**

Wealth creation through science, technology and innovations must largely occur in public institutions !

Research and Higher Education : Indian Challenges

Science

Engineering

Medicine

→ Scientific Research "Science"

Humanities, Social Sciences, Economics and Management

Fragmentation Vs Integration

SCIENCE & ENGINEERING

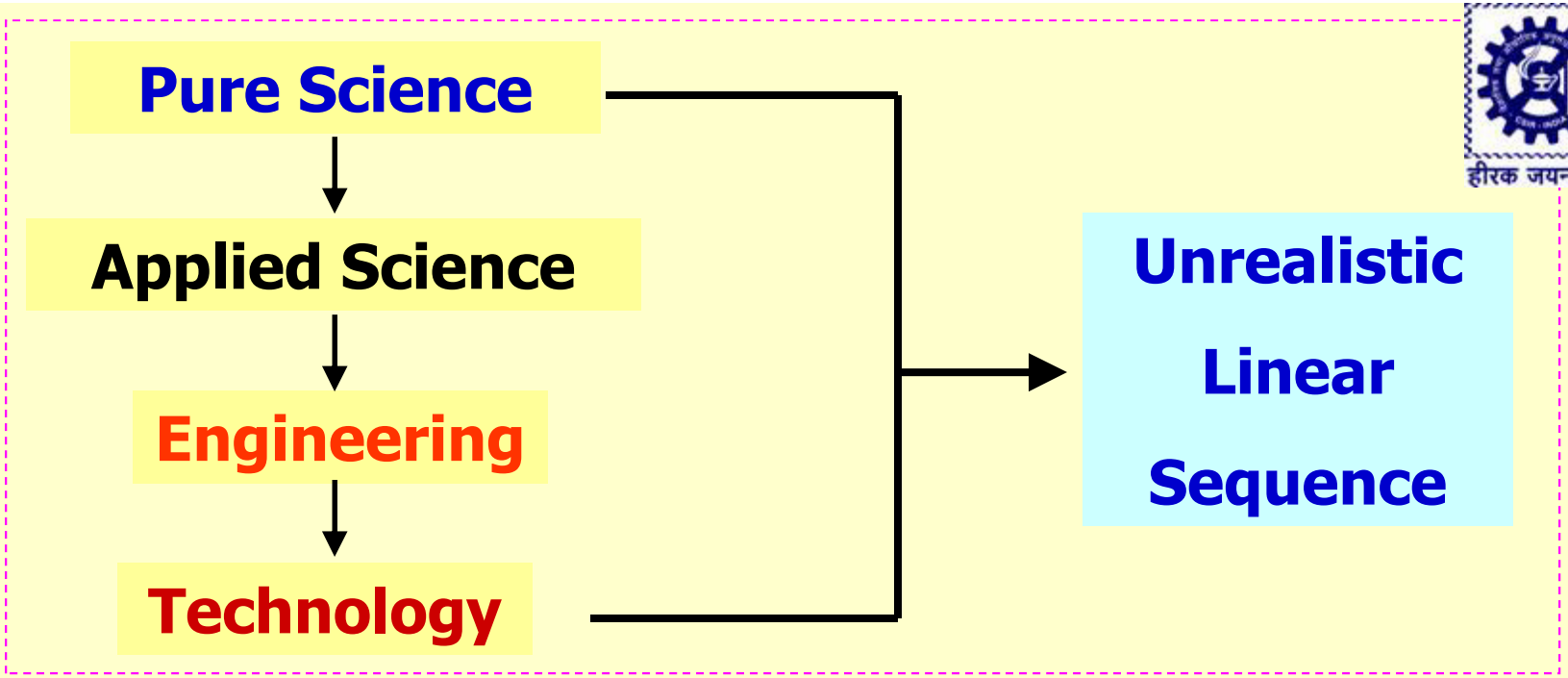
Scientists as Inventors

"Often considered distinct, engineering and science are frequently difficult to distinguish"

Henry Petroski, American Scientist, 2008, Vol 96, 368.

"The scientist seeks to understand what is : the engineer seeks to create what never was"

Theodore von Karman



Science by itself provides no panacea for individual, social and economic ills. It can be effective in national welfare only as a member of a team. But without scientific progress, no amount of achievement in other directions can insure our health, prosperity and security.

Vannevar Bush

"Endless Frontiers -1946"

HIGHER EDUCATION SYSTEMS: MASSIVE EXPANSION

- **Several new universities have been announced**
- **5 IIT`s, 5 IISER`s, 14 world class universities and 16 Central Universities**
- **Massive support to science education right from high schools**
- **Several Fellowships to encourage students to pursue higher education and research in science and engineering**
- **New interdisciplinary centers of research in advanced materials including nanoscience and technology, health sciences and technology and biotechnology are being set up**
- **Public investment in Science and Technology increased by 200% in the 2007-12 period to US $ 180 billion**

CONCERN OF THE INDIAN SCIENTIFIC COMMUNITY RESULTING FROM INTROSPECTION

- **Growth of Indian science and technology has not been keeping pace with the rate of developments of the research in other countries. India is growing in science and technology but slowly**
- **Competitiveness of India in science measured in terms of publications in papers in journals covered by Science Citation Index does not match the inherent strength of the country.**
  - **Investment of India in science as a percentage of GDP is not growing in tune with global trends**
  - **Talent of India is not attracted to study and careers with science . Is career with science losing attractiveness?**

What is needed? For Science to matter to India more

- Active engagement of talented youth in study and careers with science
- Stronger coupling between research and development and applications
- Increase in innovative activities by private enterprises
- Increase in commercialization of public funded R&D
- Increase in collaboration among academy, research and industry for concept to commercialization
- Increase in inclusive activities for pro-poor orientations of innovative collaborations

INSTITUTIONAL STRENGTHENING AND SYNERGISING

- Formation of new institutions
  - IITs , IISER type institutions
- Rejuvenation of research in University systems
  - Synergy of higher education with research to be fostered
  - Increasing the investments into university sector is on the cards and initiation
  - Unleashing the energy of the youth in scaling new heights in science
- Share of University sector in R&D engagement dipped from 50% to 15% during the last 25 years? How to recover the position?
- National laboratories and the University sector: Are they working in the same knowledge domain. Should they compliment or compete?

Science: In the long term horizon

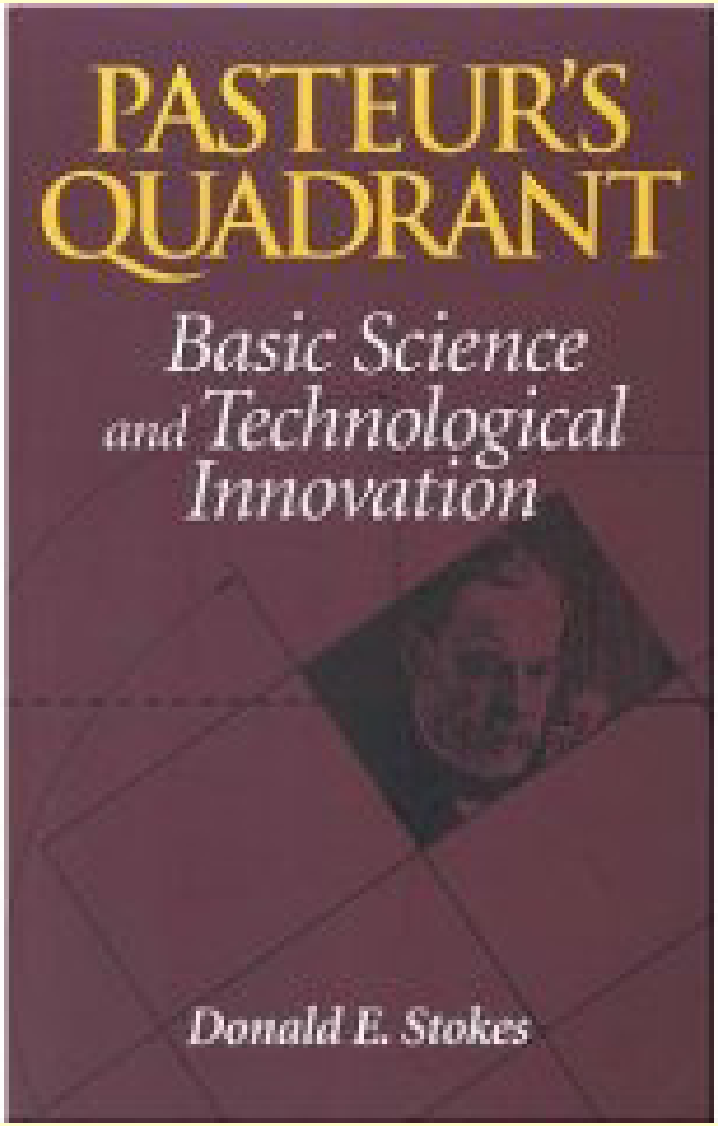
- To invest judiciously into science and innovation infra structure attracting talents, rejuvenating university research and enhancing accountability to the National agenda
- Back investors with funds to connect them to innovators through well structured and program managed through professionals adopting global best practices.
- To enhance private sector participation into R&D and link science and technology to wealth generation and inclusive growth of India.

DESIGNING A LANDSCAPE FOR INNOVATIONS: INHERENT CHALLENGES

- **Correct referencing the purpose of innovation to the social contexts of development and use**
- **Designing and developing the right sized ecology for self sustaining innovation**
- **Landscaping and designing the entire chain of innovation management taking into the cultural DNA of the society and the sociopolitical environment by the development of optimal internal linkages within the knowledge block**
- **Indian Science and Technology Sector is perhaps ideally suited for open source innovations for global and social good would need a special landscape for handling asymmetries of the society**

TASKS AHEAD: TO RENDER INDIAN SCIENCE GLOBALLY COMPETITIVE

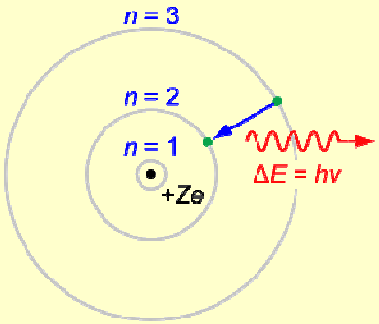
- **Rejuvenation of research in university sector is critical.**
- **Ability of research infrastructure to absorb and utilize resources must be enhanced**
- **Four-fold scale expansion of globally competitive research infra structure is necessary.**


PASTEUR'S QUADRANT
Basic Science and Technological Innovation
Donald E. Stokes

1997

Pasteur's Quadrant

Bohr



Pasteur

Average Academic and Industrial R & D

Edison

Fundamental Research

Use Inspired Research

- Capital is not scarce ; vision is
- The best way to predict the future is to create it

WILL WE SUCCEED?

- "Principle requisite for success in research is not maturity of knowledge but the freshness of outlook which is the natural attribute of youth."

- "Indian mind is not inferior, what we lack is courage and a spirit of victory. If that indomitable spirit were to arise nothing can hold us from achieving our rightful destiny."

Sir C V Raman

THANK YOU


1950-2010
Celebrating Sixty Years of Science
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