PROCEEDINGS OF THE SYMPOSIUM ON BASIC RESEARCH – IT'S ROLE IN NATIONAL DEVELOPMENT

87^{TH} ANNUAL SESSION OF NASI

8^{TH} -10^{TH} DEC 2017

Venue: Savitribai Phule Pune University, Ganeshkhind Road, Pune

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II. PRESENTATIONS FROM INVITED SPEAKERS

Dedicated to Late Prof. MGK Menon for his monumental contributions to Basic Research and its Application for National Development

Foreword

Dr. Anil Kakodkar

Recent times have seen a surge in research related to innovation, invention and translational product orientation. The 'Make in India' and 'Start-up' programmes launched by the government are now gaining momentum; but its coherence with basic research and competitiveness in the global playing field is an issue, which demands greater attention. Basic research should remain the cornerstone/foundation of the transformational technology's edifice. There are several dimensions to this, such as accelerating excellence in research, capability to translate a new scientific idea into a new technology, sustaining a conducive innovation eco-system, nurturing entrepreneurship etc.; nevertheless, basic research has to remain our nation's highest priority in all the disciplines.

NASI envisions the cultivation and promotion of Science & Technology in all its branches through several programs organized in different parts of the country Basic research in India, and its role in national development, was taken up as the theme approved by the NASI-Council. Dr. Manju Sharma, Past President, NASI took the responsibility to organize a symposium on this subject during the 87th Annual Session of NASI, at Savitribai Phule Pune University, Pune on December 8-10, 2017.

A comprehensive programme was held at Pune and very eminent scientists addressed the gathering.

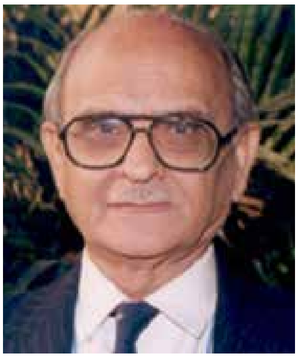
Late Prof. MGK Menon, Past President of NASI had been the Chief Architect of NASI in the last three decades. He also advocated Basic Research very strongly at various forums whenever he got an opportunity. His address to Indian Science Congress in 1981 at Mysore was a trail blazer and was subsequently published in Current Science. We have included that in this volume as the lead paper.

We have published this volume as a tribute to Prof. MGK Menon. The articles contained in this proceeding would help the policy makers and also the younger generation enthusing them to pursue basic research as far as possible keeping in mind the national development.

I am extremely thankful to Prof. P. N. Tandon and Dr. Manju Sharma who took the initiative to bring out this volume, without their efforts, it would not have been possible.

(Dr. Anil Kakodkar)
President, NASI

Preface



Prof. P. N. Tandon

Dr. Manju Sharma

National Academy of Sciences India (NASI) has traditionally been selecting a topic of socially relevant science subject for a symposium at its Annual Session. This year the Council decided to devote the eighty seventh session to Basic Research – its role in National Development. Realising that this subject was a matter of deep concern to Late Prof. M.G.K. Menon, one of the architects of rejuvenated NASI, it was decided to dedicate the Proceedings of this Symposium in his honour. With the permission of Indian Sciences Congress Association, Prof. Menon's Presidential Address to the 69th Session of the Science Congress at Mysore on "Basic Research as an integral component of a self reliant base of Science and Technology" is being reproduced in this proceedings. One of the Editors of this volume (Prof. P. N. Tandon) was requested by the President, NASI, Dr. Anil Kakodar, to contribute in writing his thoughts on the subject since he could not attend the Symposium personally.

The Editors are thankful to all the Participants for providing a copy of their talk to enable the publication of this volume. The submitted papers have been rearranged and are not in the order these were presented. The initial papers deal with the importance of basic research. This is followed by a series of papers highlighting the role of the translational research. Some examples are then provided illustrating the S&T based product development. As with all the Proceedings the presentations do not follow a predetermined format, but provide the essence of the individual talks.

In the end some of the Recommendations emerging from the presentations and discussion that followed have been summarized.

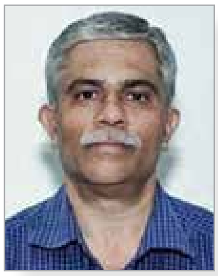
(Prof. P. N. Tandon)
National Research Professor
Former President, NASI

(Dr. Manju Sharma)
Distinguished Woman Scientist Chair, NASI
Former Secretary, Department of Biotechnology,
Govt. of India

I. INAUGURAL SESSION

Welcome Address

Prof. Nitin R. Karmalkar
Vice Chancellor
Savitribai Phule Pune University



Very Good Morning to one and all!

Dignitaries on the dias,

Hon'ble Sri Vidhyasagar Rao ji, Governer of Maharashtra,

Prof. Anil Kakodkar ji, Former Chairman, Atomic Energy Commission, Dr. Manju Sharma, Convenor of the Symposium, Dr. Kiran Kumar Ji, Chairman, ISRO; Office Bearers of NASI, delegates who has come to attend this three days workshop; I, welcome all of you on behalf of SVP Pune University.

The achievement of Pune University are accomplished in 70 years and during these 70 years long journey, this university has been recognized as the 10^{th} rank public university at the National Level and the recent accreditation by NAAC has given 3.60 score and A+ grade to this particular university. This university is spread over 411 acres land that is the campus area but apart from that this is affiliating university, so more than 600 art colleges are affiliated under the Pune University. Apart from that, 180 management institutes and almost equal number of science institutes are also affiliated. So it's a large number, more than about 7.5 lakhs students get graduated every year. But despite this particular set of large structure, people on the campus both humanities as well as in science department are doing wonderful research and that is reflected in the number of publications that we have achieved in last five years; it is more than 4500 in number. And during the recent schemes i.e. announced by the Hon'ble Prime Minister of India; the Institutions of Eminence, the University stands a better chance because we actually are in the 32 institutes that generally are qualified for this particular scheme. And I am very sure we are competent enough to achieve this particular slot of excellence and eminence. We have been doing very hard work for it. More than almost last two and half months, 60 of my colleagues are working day and night to make that particular proposal possible and yesterday at 11.30 the signature has been done and today morning it would be submitted. So, even the deadlines have also been met. So, I am very proud, basically on my colleagues who have been doing relentlessly both in teaching and research sector.

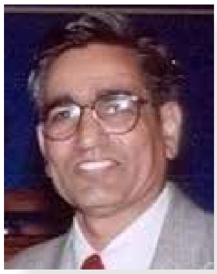
This is one of the premier institutes and I am proud that fellow, colleagues from this particular university have accepted the invitation. I have accepted basically, and invited the NASI to hold their symposium here in the campus of Pune University. I remember it was during Prof. Kolaskar Sir's time, almost 13-14 years back when Prof. MGK Menon was the President of NASI, we had this opportunity previously; and today under the leadership of Prof. Kakodkar Ji, we will host this particular conference on the campus.

The topic that has been chosen is 'Basic Research - its Role in National Development'; a very appropriate theme and I am pretty sure that the deliberations that we will have in coming next three days to a great extent will ignite the minds of the teachers who are doing work on the campus and the extent it will precipitate further for taking up the challenges and basically basic research which would help in developing this Country.

So, once again welcome you all and thank you so much.

About the Pune Chapter

Dr. Dilip Dattaray Dhavale
Chairman
NASI Local Chapter



The Pune Chapter of NASI organized three workshops, development of teaching learning material for Std X, lectures at schools and 87th Symposium during April 1, 2017 to March 31, 2018.

The National Academy of Sciences India (Pune Chapter), Royal Society of Chemistry and Science Park, SPPU had organized 4-day workshop on "**Professional Development program for Science Teachers**" during 10-13 April 2017.

The workshop was inaugurated on April 10, 2017 at 10.00 pm at Science Park in presence of Mrs. Vimala Oak, Facilitator, Prof. Dilip Dhavle and Prof. Dipalee Malkhede, Co-ordinator of the workshop. Dr. Harshada did anchoring of the inaugural function. There were 32 participants from Pune, Ahmadnagar, Nashik, Solapur, Jambhori of which 8 had attended the 2 day workshop of RSC, all 3 modules. Participants were the mixed group from State (Marathi and English medium schools), CBSE and ICSE board.

The First day was devoted in choosing the lessons from Std. X science book. The participants were divided in 6 groups and were asked to write the learning outcome of the lesson assigned individually. The common difficulty of teachers to clearly state what students would be expected to do/solve/demonstrate/identify on learning the topic they had taken was discussed with some examples. The flow of the various headings in the chapters of the book was coming in the way of the teacher thinking. A few of the active learning techniques were handled through experiential learning. They visited research labs and sophisticated instruments from Department of Chemistry, SPPU. The home work was given to the participants to identify direct reading materials to be made from the book for the lesson identified. In this manner, the skill building of each teacher of the group was attempted.

On second day, in the first half; the material made by teachers was examined in small groups for knowing if it was a self-learning material or not. The difficulty of teachers in writing interesting small paragraphs for a portion of the chosen concept seems to be real since the skill of writing and the ability to make it interesting they had never done. Compounded difficulty was that the text must generate information as I/O or left side-right side or a table. This was a daunting task and more ALT were introduced. There was a hands-on activity to build a concept based gadget like alarm based on bi metallic properties, solar powered boat, saltwater torch, levitating train etc. As home assignment teachers had to bring some ALT for the concepts in the chosen topic and write some open-ended questions.

On third day, they learnt more ALT, laboratory work and discussed the ALT. They had a demonstration of a few experiments of Physics like circuits in series, parallel, its effect on resistance, current, then development of electromagnetism etc. Thus put up the ALT together and discussed the remaking ALT to be made.

On fourth day, they had gallery walk and presentation by each group. The teachers pointed out the concepts which had not been captured at all or not too well. This feedback session was done very well by teachers themselves. There was a discussion of all the 6 lessons identified by the groups, This the teachers liked very much. They called it version 1 and now they have taken the questions that other teachers asked to be incorporated to get the version 1 of ALT based lesson plans for some of the topics (Acids and bases, Chemistry of Carbon compounds, Electromagnetism, Periodic Table and Electricity).

The valedictory function was organized on April 13, at 3.00 pm. Mr. Dinkar Temkar, Dy. Director of school education, Pune Region, Mr. Ershad, RSC Co-rdinator, Dr. Kattee, Mrs. Vimala Oak and Prof. Dipalee Malkhede were present on dias. Few of the participants shared their experiences about the workshop. All the participants were satisfied the way workshop was conducted and objectives were achieved. This might have happened the first time in the history of RSC workshop that participants could plan six lessons using active learning tools in this workshop.

About the Annual Symposium

Dr. Manju Sharma, Convener
Distinguished Woman Scientist Chair, NASI
Former Secretary, DBT, Govt. of India

L.M. Lederman the Noble Laureate said in a symposium on Science and Human Goals in the 21st century:-

"Educating children in basic science, so that they become better informed and appreciate both the power and limits of science, is essential if they are to be sufficiently equipped to survive the next millennium."

- The millennium development goals also focus on the importance of sustainable development. This symposium would be discussing the Role of Basic Research in National Development. When we are talking of the development, obviously at the back of our minds is sustainability. Therefore science and scientific research become very relevant. The programme has been drawn in consultation with an Advisory Committee and the Co-convenor Dr. Chary.
- Efforts have been made to consider the basic minimum requirements of human kind and focus R&D towards that. The areas converted are:-
  - Agriculture, nutrition and food security
  - Environment - related issues like biodiversity, pollution abatement and climate change
  - Biomedical Research
  - Material Science (Housing, construction etc.)
  - Research Translation to Industry and Commercialization
  - Employment Generation.
- A Panel discussion has also been organized to discuss on this very important subject views of eminent scientists. The lectures would also be given by renowned scientists.
- It is expected that some recommendations would arise out of the discussions for further implementation.
- The NASI has been organizing a Symposium on a subject of National importance every year during its

Annual Session. It is the oldest of the science academies founded by a nationally and internationally renowned scientist Prof. Meghnad Saha in 1930. The Founder said **"But the main function of the Academy should be towards cultural improvement by contributions to human knowledge."**

- The importance of the academy's is also reflected in the statement of Albert Einstein as follows:

  "Prof. M N Saha to whom Physics, particularly, Astrophysics, is indebted for many valuable contributions, has reported to me about the academy of Sciences, which has been called into existence at Allahabad with a high object."

- Since then with its mandate of Science and Society many programs have been undertaken which relate to the welfare of society such as:

  Science communication especially in rural areas, science education, technological empowerment of women, availability of safe drinking water, S&T interventions for tribal welfare projects, awareness building amongst Defence Personnel, Networking with R&D and academic institutions etc.

- Number of Fellows 1759
- Number of Members 1730 - a unique feature of the academy
- Local Chapters – 18
- Women Sensitisation – 24 workshops, nutrition, drudgery, employment
- Several Fellowships and awards
- River Galleries
- Rich Library
- Inter Academy Panel
- It is evident that the academies play a pivotal role in the progress (particularly application) of Science and Technology in the country.
- NASI has made best efforts to take S&T interventions to the grass root level and encourage the scientists to contribute towards this. However it has never lost the attention it has paid to Basic Research as the theme of this symposium.

Role of Space Research in National Development

Dr. Kiran Kumar
Secretary, Department of Space
Chairman, Space Commission
Chairman, ISRO

Very Good Morning to you all,

Hon'ble Shri C. Vidyasagar Rao, Governor of Maharashtra

Dr. Anil Kakodkar, President, NASI

Dr. Nitin Karmalkar, Vice Chancellor, Savitri Phule Pune University

Prof. Dilip Dattatray Dhavale, Chairman, NASI, Pune

Dr. Manju Sharma, Convenor, NAI-DST Distinguished Woman Scientist Chair Professor

Prof Veena Tandon, General Secretary, NASI, Allahabad

Research and development are crucial for national development and economic growth. Technology which results from research and development is often at the core of the innovation and the subsequent implementation thereof creates new value. Therefore, the vision for research is at the forefront of nation's economic, social and environmental development. With the availability of strong intellectual capital in the country, the research environment in India provides a significant opportunity across the domains of science and technology. Moreover, with the government's support, the R&D sector in India is all set to witness some robust growth in the coming years.

In this context, I appreciate the role of National Academy of Sciences for taking up proactive steps towards popularizing science and basic research, creating a unique platform for interaction and exchanging the research outcomes for the benefit of the society.

I sincerely thank Organizers for inviting me to address the august gathering on occasion of 87th Annual Session of NASI and Symposium on 'Basic research – its role in national development'. Following the theme, I would recount a brief overview on the **'Role of Space research in National Development'.**

Since the space programme was set up in 1969, India had commenced its journey in space research in a modest way. Over the five decades, India has developed sophisticated space technology systems that play a significant role in sectors ranging from natural resource management to societal development. Indian Space programme consists of distinct elements such as, Space transportation systems such as PSLV and GSLV; Satellites for Communication and broadcasting, Navigation, Earth observation, Space science studies and related application programmes.

In R&D front, ISRO is involved in developing enabling technologies for high-performance and lightweight aerospace systems subjected to extreme environments encountered in space environment and planetary entry. I would mention some of major research activities which include:

Aerospace engineering (viz., flight dynamics, orbital mechanics, wind tunnel studies, flow field analysis); **Launch Vehicle structures** (viz., structural analysis modeling and simulation of stability analysis, experimental mechanics); **Space Materials & Processing** (viz.,Light and super alloys, high temperature materials and coatings, powder metallurgy & materials characterization); **Composite Materials** processing and control; **Propellants, Polymers, Chemicals** (viz.,characterization, testing, thermal protection materials, adhesive ceramics thermal paints, polyimides, Li-ion batteries) **Avionics, Guidance & Control** (viz.,Sensors & instrumentation, power electronics, signal processing, onboard inertial systems, trajectory simulation and analysis).

While emphasizing the technological advancements in launch vehicles, satellites and space technology applications, Indian space programme is oriented towards contributing to national development and reaching its benefits to the society. So far, Indian Space Research Organisation (ISRO) has launched 93 Indian satellites for various scientific and technological applications which include remote sensing, meteorology & ocean observations, disaster warning, telemedicine, tele-education, mobile communications, radio networking, search and rescue operations, and scientific studies of the space. Currently, India has an operational constellation of 15 Communication satellites, 7 Navigation satellites, 18 Earth Observation satellites and 2 space science satellites, including the Mars Orbiter. I would briefly elaborate the R&D activities and technology development in the areas of space transportation and launch vehicle.

Launch Vehicle

Development state of art technologies in the launch vehicle area is of much importance in order to enhance the capability in launching services through heavy lift launcher and to emerge as potential player in the global launch services business. In this regard, India has achieved a milestone with successful launch of GSLV-MkIII-D1, on 5th June 2017, which can launch upto 4-tonne class of communication satellites into Geosynchronous Transfer Orbits (GTO).

Towards developing advanced and cost-effective space transportation technologies such as re-entry, re-usability and Scramjet propulsion, ISRO is pursuing the projects through technology demonstration missions. The Space capsule Recovery Experiment (SRE) demonstrated the successful orbiting, de-orbiting and the technologically complex descent and recovery in 2007. The first flight of the Reusable Launch Vehicle – Technology Demonstrator (RLV-TD), a winged body vehicle, in 2016, demonstrated critical technologies such as autonomous navigation, guidance & control and reusable thermal protection system. Experimental data from this mission will serve as a useful input for the development of a fully reusable launch vehicle.

First experimental mission of ISRO's Scramjet engine towards the realization of an Air Breathing Propulsion System has been successfully tested. With this flight, critical technologies such as ignition of air breathing engines at supersonic speed, holding the flame at supersonic speed, air intake mechanism and fuel injection systems have been successfully demonstrated. The successful development of the scramjet engine would enable significant reduction in the lift-off mass by eliminating the need to carry the oxidizer along with the fuel during the atmospheric phase of the flight of a launch vehicle. This is an essential technology for low cost access to space.

ISRO is also working on advanced propulsion technologies such as Semicryogenic propulsion and spacecraft electric propulsion. The Semicryogenic propulsion capability will enable development of advanced launch vehicles with heavy lift capability.

Communication

Communication is the backbone of any developmental processes of a Nation. The communication satellites called – 'INSAT satellites' are placed at geostationary orbits and have contributed significantly in national development. INSAT satellites are the main stay for the television broadcasting and provide connectivity to TV transmitters. It also networks radio stations, provide rural area communications, business communication, tele-education and tele-medicine services.

Since commissioning in 1983, the Indian National Satellite (INSAT) system has brought in vast advancement and providing a wide range of services in telecommunications, television broadcasting, radio networking, meteorology and disaster management services. Next generation of satellites, INSAT-3, INSAT-4 and the GSAT series expanded the increased number of transponders in C, Ext C, S and Ku bands. Today, there are 277 transponders in 15 communication satellites.

Besides providing communication backbone in the country, these satellites are also used for telemedicine, connecting specialty hospitals in India's major cities to hundreds of hospitals in rural and remote areas of the country. Similarly, tele-education through satellite connectivity helps in establishment of virtual classrooms in distant areas in order to provide the educational services and disseminate relevant information for awareness creation for the target audience. It also plays a vital role in delivering cyclone warnings and is used in search and rescue operations.

The advancement of INSAT satellites are marked by the key technological elements like earth, star & sun sensors, gyroscopes, control electronics, thrusters and thermal devices are realized using indigenous capabilities and substantial enhancements are brought in by adopting most modern techniques to miniaturize these. High Throughput Satellites (HTS) are capable of providing multitude increase in the throughput using spot beam techniques. ISRO has launched the GSAT-19 the first satellite in this category and plans to add another three in next two years.

Navigation

Indian regional navigation satellite system (IRNSS) called Navigation with Indian Constellation 'NAVIC', is yet another area addressing the developmental needs. It is an independent navigation system to provide position, navigation and timing services over India and its surrounding region up to 1500 Km. The NavIC will be useful to the people of the country by supporting applications like terrestrial, aerial and marine navigation, vehicle tracking, fleet monitoring, survey & mapping services, resource management, location based services, fishing, precision timing, time synchronisation, atmospheric & scientific studies, disaster management, etc. Particularly for the fishermen, a mobile-App using the position and navigation capability has been developed and tested for the fishermen community, using 1st generation NavIC receivers.

Extensive field trials were conducted, using 36-channel NavIC receivers, for NavIC constellations performance evaluation across the country in association with the academic institutions. NavIC baseband processor chip for Standard Positioning Services (SPS) is realized with 180 nm technology. The development of RF chip is in progress.

Ruggedized hybrid (NavIC and GAGAN) receiver have been designed, developed and tested on PSLV & GSLV launch vehicles for determining trajectories. The capacity is being enhanced for future launch vehicle missions.

Further, ISRO in association with Airport Authority of India developed and realized the space based augmentation system namely "GPS Aided GEO Augmented Navigation (GAGAN)", for catering to Civil Aviation services. The GAGAN Signal-In-Space is available through GSAT-8, GSAT-10, and GSAT -15 satellites and has been certified for the en-route navigation and precision approach. India become third country in the world to have such capability and the implementation of GAGAN has several benefits to the aviation sector in terms of fuel saving, saving in equipment cost, flight safety, increased air space capacity, high position accuracy and so on. The non aviation approach includes location information, assets mapping, geo-fencing etc.

Earth Observation

Earth Observation is one of the core segments in the domain of space technology applications. It utilizes basic physics of electromagnetic spectrum ranging through ultraviolet to microwave and estimating the geophysical properties and interaction with the earth features. Over the time, study of earth and the surrounding atmosphere gained importance, to acquire the synoptic observations from space. During 80's focused programme started to design, develop and launch remote sensing satellites with a variety of instruments onboard using either imaging or sounding techniques. These satellites are capable of providing data to cater to various applications ranging from land and water resources, infrastructure planning and study of ocean and atmosphere.

Availability of data from the operational remote sensing satellite systems starting from IRS-1A to Resourcesat series of satellites facilitated applications in field of agriculture, water resources, forestry, land use, coastal zone and from regional scale to national scale. Similarly, Oceansat series of satellites with ocean colour monitor sensors provided immense opportunity for oceanic observations. The need was felt to carryout mapping and monitoring of dynamic features on the earth surface at various scales. The objective was to scan same area at multiple resolutions from satellite platform. Towards this three-tier imaging sensors were developed for Resourcesat series of satellites to get the image data at resolutions of 55m (AWiFS), 24m (LISS-III) and 5.8 m (PAN). These satellites are the work-horse satellites for number of mapping activities, and thereby contributing significantly in managing the natural resources of our country.

As the cloud covers obscure optical remote sensing during monsoon season imaging RADAR was considered to be the viable option. C- band Synthetic Aperture Radar sensor was develop with multi-polarization channels and was flown on board the RISAT-1 satellite in 2012 for resource monitoring particularly during Kharif season, flood monitoring and disaster management applications.

Beginning with the early experiment of coconut root-wilt disease during late sixties, Indian Remote Sensing Programme has grown into a full-fledged operational programme. Today, satellite data is being effectively used to support socio-economic security, sustainable development, disaster risk reduction and governance towards minimizing the regional imbalances and social inequity. While addressing such goals, the convergence of earth observation with geospatial technologies enabled creation of comprehensive spatial data infrastructure as national repository for catering the need of multiple applications.

Thus, through the application-centric space programmes, India has established a strong set of operational applications of space systems to meet the fundamental priorities of the Government of India, helping to improve the quality of life of citizens and enabling societal transformation.

Towards enabling food security, space based inputs have been providing valuable and timely information in the agricultural sector for estimating crop acreage and forecasting of crop production for major crops well in advance of harvesting; soil and water conservation activities for watershed development in the dryland areas; suitability assessment for expanding horticulture; analyzing the cropping systems for intensification and diversification; monitoring the crop losses due to flood and drought; pest and diseases; and also identifying potential fishery zones to enable increased fish catch.

Decision making in agricultural production system is a complex process in which risks faced by the farmers need to be considered for an informed decision to be made. Some of the major risks include severe drought, floods, cyclonic systems, temperature and crop pest and diseases. The research studies are on in order to develop forewarning models for crop pests and diseases such as stem borer, leaf blight and aphids for selected crops. Short-term weather anomalies, crop stages, alternate hosts are the major factors of onset, persistence and large-area outbreak of pests and diseases. Using systematic data records on pest-disease surveillance, satellite based assessment, agro-met products, crop stages are being employed to make the models applicable on spatial domain.

Space technology is contributing to achieve water security as well by providing inputs for improved frequency and scale of mapping for surface water spread; enhancing the irrigation potential and improving the water use efficiency in the irrigated command areas; village level ground water prospecting and recharge structure planning; rejuvenation of small water bodies and tanks for irrigation.

As the non-renewable energy resources are fast depleting, exploration for renewable energy sources is the only alternative. In this context, satellite based inputs are being used towards assessing the potential of renewable energy resources and site suitability for energy harvesting. It leads to enhance utilization of renewable energy through potential assessment of solar, wind, wave, and hydro power. Insolation data from Indian Meteorological satellite such as Kalpana, Insat-3D and Insat-3DR is used for estimation of solar power potential and hotspots identification for solar energy harvesting.

With INSAT-3D, INSAT-3DR and SCATSAT-1 are in orbit, there is an increased availability of meteorological data for applications like numerical weather prediction, rainfall estimation, cyclone detection and tracking etc. Rainfall retrieval algorithm using satellite microwave brightness temperatures and its validated using ground based rain gauge data, weather forecasts are being extensively validated with high density rain gauge network over Indian regions. These forecasts are of significant value especially during times of heavy rainfall, cyclone, heat wave, fog etc. Heat wave forecasts were also carried out with the model forecasts which had assimilated INSAT-3D and 3DR temperature data. Improved assimilation schemes to utilize products like land surface temperature were carried out.

A methodology to derive tropical deep convective cloud core with cloud top altitudes from Megha Trapiques -SAPHIR data has been developed. INSAT-3D/3DR derived atmospheric motion vectors continue to be important source of wind measurements over the region. INSAT-3D derived parameters like stability indices, fog, etc., are being utilized for short range forecasting or nowcasting. Estimation of

Cloud fraction was retrieved using radiance and reflectance measurements from thermal infrared (TIR) and visible (VIS) channels respectively along with water vapour (WV) channel from INSAT-3D/3DR, which acquire data round the clock at 15 minutes intervals.

Biodiversity is important for sustaining the ecosystem process and services. A research project was carried out using space based inputs towards conservation of rich bio-resources of our country. In this regard, Indian Space Research Organization and Department of Biotechnology have implemented biodiversity characterization at landscape level using satellite derived parameters and geospatial modelling. A webportal called Biodiversity Information System (BIS) has been devised for accessing the databases.

Basic research on earth system sciences provides the physical basis for understanding global processes and its impacts on human lives. Earth system science helps researchers to carryout multidisciplinary studies across the various disciplines such as geology, glaciology, meteorology, oceanography, paleontology, ecology and space science. The space based data sets forms the crucial inputs to observe and study the interactive processes in a systematic way in the domain of biosphere, geosphere and atmosphere and its impact on earth system. The synoptic coverage of the globe by these satellites helps in capturing the state of the earth system through image data. Time series geophysical products generated using these data sets from earth observations satellites ingested into the global and regional models in order to predict climate variability and its change over time. ISRO is working on the future missions towards addressing the need for improved revisit capability, enhanced availability high resolution data, availability of stereo data and hyperspectral data for spectroscopic studies.

Space Science Missions

Basic and advanced research in astronomy, driven by the curiosity of mankind, is unfolding the mysteries of the Universe with newer inventions. Today we observe the Universe from earth and from space, in all wavelengths of the electromagnetic spectrum, from radio waves to gamma rays, using advanced sensor technologies. In ancient times, knowledge of the constellations and the motion of the stars and sun were invaluable for the development of navigation. In fact, it is still used today, a precise knowledge of the positions of stars helps satellites orient it in space.

In India, space science experiments have been initiated with the launch of Aryabhata satellite. Subsequently, astronomy payloads have been flown on Bhaskara-I, SROSS series of satellites, IRS-P3 and GSAT-2 satellites as piggy back instruments.

Science missions often lead to advancements in technology/operations e.g. the development of interplanetary navigation, communication, and autonomous operations in the case of Mars Orbiter Mission (MOM), indigenous development of UV optics and X-ray optics in the case of AstroSat.

Three space science missions accomplished so far are Chandrayaan-1, Mars Orbiter mission (MOM) and AstroSat. Chandrayaan-1 led to the first confirmed evidence of water in moon. There are over 150 publications and the data from the payloads are still being analysed. MOM and AstroSat are currently operational. Mars Orbiter completed three years in its orbit on September 24, 2017, surviving well beyond its designed mission life of six months. Data acquired during the first and second year of the mission are released to public for free download and scientific research. About 2000 users have registered and downloaded 515 gigabytes of data for scientific studies.

India made a significant contribution to the global astronomy by placing a space observatory ASTROSAT, which enables simultaneous multi-wavelength (from Ultraviolet to X-Ray) observations of stars and galaxies, to enhance understanding of the universe and astronomical phenomena. ASTROSAT, completed two years in orbit in September 2017. The Cadmium Zinc Telluride Imager (CZTI) onboard Astrosat provided inputs for locating the source of the latest gravitational wave (GW170817) event detected on August 17, 2017. Fifty seven research papers have been published in peer reviewed journals, based on development of instruments and the acquired data.

In the field of planetary science, development of precision technologies through basic research helps in placing spacecrafts to Moon and Mars.

Further, ISRO is planning to launch Chandrayaan-2 mission consisting of an orbiter, a lunar lander and a rover. The inter-planetary missions established India's acumen in the global stage and opened up number of opportunities for collaboration with the leading space agencies in the world.

ISRO is working on India's first solar space mission Aditya-L1. The satellite will be placed in a halo orbit around the Sun thus enabling continuous viewing of the Sun and also measuring the charge particles emanating from the sun during active periods and during coronal mass ejection events of the sun. A small satellite called XpoSat is being developed to measure X-ray polarisation of X-ray emitting objects in the sky.

Science payloads have been identified for the next Mars orbiter mission and a mission to Venus. The satellite configuration is under study. Missions to asteroids, comets, farther planets and human habitation of other planets are themes being discussed not only by space agencies but also by private ventures and therefore space exploration is likely to grow by leaps and bounds in the coming decades.

Conclusion

The space as a vantage point promises several new applications that could benefit the people in the context of improving the quality of their life. Over the years our space programme helped us to learn several things from the developmental perspectives and having grass-root relevance. In fact, optimizing the resources and talents at the national level through the involvement of R&D and academic institutions has been given utmost importance towards developing cutting edge technologies. R&D in space and creating internationally competitive space systems with stringent performance has been another facet of this programme.

I am happy to note that, since its establishment in 1930, National Academy of Sciences has implemented a central paradigm for development of sciences and establishing linkages with society to address the various problems. Truly, the academy has followed the path evinced by great scientist Prof. Meghnad Saha.

I see wonderful lecture topics during this symposium with a series of deliberations across the domain of physical, chemical and biological sciences. The symposium would be of great help and opportunity for the young researchers and scientists to listen and interact with the eminent speakers to know about their practical experiences to carry forward the work and to establish linkages between science and society.

I wish the symposium a great success.

Thank you all.

Presidential Address

Dr. Anil Kakodkar
President, NASI

Hon. Shri C. Vidyasagar Rao, Governor of Mahatashtra and Chief Guest of today's inaugural function of the 87th Annual Session of National Academy of Sciences, India and Symposium on "Basic Research – it's Role in National Development", Guest of Honour Dr. Kiran Kumar, Chairman, Space Commission and ISRO, Our Host Prof. Nitin Karmalkar, Hon. Vice Chancellor, Savitribai Phule Pune University, Dr. Manju Sharma, Past President, NASI-DST Distinguished Woman Scientist and former Secretary DBT Govt. of India, Prof. Dilip Dhavale Chairman NASI-Pune Chapter, Dr. Veena Tandon General Secretary NASI, Past Presidents of NASI, members of council of NASI, distinguished Invitees, Dear Fellows and Members of NASI, participants to the Symposium, Ladies and Gentlemen.

Allow me to add my words of welcome to all of you to this annual event of NASI. I am specially grateful to Hon. Governor for readily consenting to grace today's function. Sir, your message today to this community would be of value since science and society forms an important focus of NASI activities. We are also happy that Dr. Kiran Kumar is with us today. Achievements and contributions of Deptt. of Space are an excellent example of immense benefits that accrue to the society out of a high tech world class program like the space programme besides the tremendous technological achievements that make all of us very proud.

Primary purpose of an Academy like NASI, in my view, is to nurture and sustain an eminent peer body of scientists which fulfils an important social and national necessity. If we accept that science is the key ingredient of development of human kind, then it is in every one's interest to ensure a high level of excellence in our scientific research and its applications for the benefit of people at large. Existence of an eminent peer group is then an essential condition for ensuring excellence and sustaining it. Such a peer group is the key to guidance and mentoring of institutions in their autonomous functioning with a degree of credibility and accountability. An academy, through its process of recognising excellence among scientists, facilitates ready identification of credible peers for guidance, mentoring and independent evaluation of institutions, programmes and individual scientists. There are of course several other important purposes that academies serve, however I thought I should highlight this aspect in the context of the theme of this particular meeting.

Our country is among the fast growing economies of the world. Technology is a crucial factor in economic competitiveness. Ability to build new first of kind technologies, ahead of others, requires a kind of connectedness between basic research and its translation to new products and processes. This requires right institutional value system, appropriate mind set among individual researchers, conducive innovation ecosystem and support to be able to bridge valleys of death that invariably exist in the translation chain. This also requires capacity building among the youth to be able to leverage our demographic dividend for the technological empowerment of our nation. There has to be adequate recognition of the enormous efforts involved in the translation process which at times may well be much larger (may even be by an order of magnitude) than the efforts put in on corresponding research in the laboratory.

NASI has been deeply engaged with researchers, young and old, students, women and members of society at large in a range of activities where science can make a difference. Special efforts have been made towards entrepreneurship development among students. In tune with these efforts, it was felt that discussing role of basic research in national development and related facilitation efforts would be of significant complimentary value. This has been a subject matter of a formal discussion. A sense of this discussion would be presented by our Past President Prof. Ashok Misra during the course of this symposium. This issue is also expected to figure in other presentations devoted to other specific topics and the follow up discussion. A comprehensive discussion on this matter would be of value to us and our stakeholders.

I would like to use this occasion to thank Reliance Industries for instituting awards for industry relevant research and congratulate the awardees of this year. These awards were instituted during the platinum jubilee year of the academy and are unique for a science academy.

Dear fellow colleagues and members of NASI, I would like to thank you for your sustained engagement in a variety of activities of the academy. It is through your efforts that our academy has a distinctive place carved out for itself. Pursuing these efforts even more vigorously and follow the mission so clearly defined by our founder, Prof. Meghanad Saha is more relevant today than ever before.

We have a very distinguished set of eminent people to contribute to the discussion on the subject matter of the symposium. I would like to thank them for their being with us and sharing their ideas.

Finally, I must thank the office bearers and the members of secretariat for their untiring efforts towards all activities of the Academy.

Thank you.

Inaugural Address

Shri C. H. Vidyasagar Rao
Governor of Maharashtra

Dr. Anil Kakodkar, President of National Academy of Sciences India (NASI), **Dr. Kiran Kumar,** Chairman, ISRO, **Dr. Manju Sharma,** Convenor of the Symposium, **Dr N. R. Karmalkar,** Vice Chancellor, Savitribai Phule Pune University, **Prof Dilip Dhavale,** Chairman, NASI – Pune Chapter, **Dr. Veena Tandon,** Organizing Secretary, NASI, distinguished delegates, science leaders, researchers, teachers, students, ladies and gentlemen,

I am pleased to associate myself with the inauguration of the 87th session of the National Academy of Sciences India and the Symposium on **"Basic Research - its role in national development".**

The best brains in science from across the country, and some even from abroad, have assembled in this auditorium and I extend a warm welcome to each one of you.

I am particularly happy that the Academy is holding its annual session in Pune, the city known for its great tradition of scholarship. Pune had been home to many eminent thought-leaders, scientists and mathematicians like Anandi Gopal Joshi, Shreeram Abhyankar, D. R. Bhandarkar, V. V. Narlikar, P. V. Sukhatme, D. D. Kosambi, S. P. Agharkar and Banoo Coyaji to name a few. They have made pioneering contributions to their respective fields and to the society at large. The city has maintained the rich tradition and continues to contribute to the scientific growth and development in a significant way.

I congratulate the Academy and more particularly its dynamic President Dr. Anil Kakodkar for their efforts in hosting this session. I also congratulate the Chairman, Members and the Organizing Secretary of the Symposium on Basic Sciences.

Ladies and gentlemen,

The National Academy of Sciences India has been India's oldest and the largest science organization which has played a crucial role in popularizing and promoting science in the country. This is an occasion to remember with gratefulness eminent scientist Prof. Meghanad Saha who mooted the idea of setting up the Academy with a view to bringing the researchers and scientists of different disciplines and regions on a common platform to discuss and find scientific solutions to the problems of the country. Indians have made unique contributions to the realm of science in the ancient past. Some of our achievements in science have been spectacular.

Mathematician Aryabhata was the first person to create a symbol for zero and it was through his efforts that mathematical operations like addition and subtraction started using the digit, zero.

One of the notable scientists of the ancient India was Acharya Kanada who is said to have devised the atomic theory, centuries before John Dalton was born. He speculated the existence of *anu* or a small particle, much like an atom.

Sushruta Samhita is considered to be one of the most comprehensive textbooks on ancient surgery. Charaka authored the Charaka Samhita, on the ancient science of Ayurveda. Charaka's ancient manual on preventive medicine remained a standard work on the subject for two millennia and was translated into many foreign languages.

Mathematician and Astronomer Bhaskaracharya, who in the 12th Century meditated in the Sahyadri hills near Jalgaon, was the first to accurately calculate the time taken by the Earth to orbit the Sun, as 365.2588 days.

Unfortunately, long spells of foreign domination for centuries pushed Indian science in the background. It is quite reassuring that the Academy, led by such distinguished science leaders as Prof. M. G. K. Menon, Prof M. S. Swaminathan and now Dr. Anil Kakodkar, has been working for the propagation and promotion of science once again. I have no doubt in my mind that we shall reclaim our rightful place as a science leader among the comity of nations in the coming years. You must construct a bridge between our ancient past and the modern present.

Ladies and gentlemen,

The theme of the Symposium, namely **"Basic Research - its role in national development"** is extremely relevant in today's context when we are keen to leverage science for national development. India can address its challenges like poverty, hunger, ignorance, disease, sanitation, malnutrition, water - and energy security only through the power of science, technology and innovation.

During the last few decades, India has made spectacular progress in the fields of Information Technology, Space Science, Nuclear Science, Pharmaceuticals, Medicine and so on. These are indeed satisfying developments.

However the picture of basic science education, let alone research - in the country is worrying and should concern us all.

In the past, the best and the brilliant students invariably opted for science. Today, students have a wider choice of non-Science subjects. Further, there are various career options in other streams. As a result, there has been a steady yet noticeable decline in the number of students opting for science at the Under Graduate and Post Graduate levels. I sincerely feel that we need urgent intervention to reverse the trend and make science the preferred choice of meritorious students.

Teachers in primary, secondary and higher secondary schools have to play a significant role in popularizing science. It is equally important that science teachers teach the subject in an interesting manner. This will require capacity building of teachers and organizing regular workshops for them. This will also require a close rapport between our institutions of science on one hand and schools and colleges on the other.

India is suffering from a huge shortage of qualified teachers, more so in the stream of science. It is not uncommon to see science subjects being taught by history or art teachers. Our schools are incubators of tomorrow's science leaders. We cannot expect to produce scientists, innovators and researchers if we do not pay adequate attention to our schools.

In some cases, managements themselves are not keen to recruit qualified teachers for the simple reason that they will have to pay decent salaries to qualified teachers. There is a need to conduct academic audit of schools and colleges to ensure that schools have good number of qualified teachers, especially to teach subjects like science and mathematics.

As Chancellor of 20 universities having nearly 2.5 million students, I find a strange disconnect between our scientific institutions and our schools. I believe that our scientific institutions must not function in their solitary exclusion. There should be a regular interface between these institutions and our schools and colleges and the general public.

Many institutions of science were set up during the pre- Independence era. States have their own institutes of science. But many of these institutions are in a state of utter neglect and apathy. Our Institutes of Science and University departments of Science are functioning on barely 30 to 40 percent of sanctioned faculty strength. We need suggestions from you to tackle these crises and make our institutions and departments of science dynamic centres of learning, research and innovation once again.

Unlike in the past, today there is multiplicity of media available for propagation of science. There was only on television channel in the country for many years. Today we do not have the exact count of television channels available in the country. There are also radio channels and internet-based news portals. Social and digital media have made a revolution. And yet I find that science is missing from public discourse in the media.

Science is not succeeding in attracting the interest of the people or mainstream media. I read somewhere that even the readership of popular science magazines has declined.

It is necessary that we should have good science communicators. In fact I do feel that every science organization and universities should have a Cell exclusively for science communication and interpretation.

Such Cell should be constantly engaging society and students about its activities. Today, mobile and smartphone penetration in India has increased. In fact, we are among the top mobile data users in the world. Science communicators must take advantage of technology tools to reach out to every citizen with authentic information or articles on science.

Last year I had attended a programme of Marathi Vigyan Parishad on the invitation of Dr Kakodkar. I do feel that such organisations must be strengthened and empowered. We must have such organizations for all Indian languages. It will help scientific knowledge percolate and diffuse to the last person in his mother tongue.

Many countries have Science Festival in schools and colleges. I think every science institution and every University Science department must organize a Science Festival annually. These institutions must explain to the people what are they doing for the society with public funds.

In recent years, several measures, policy interventions and program initiatives for promotion of research and development have been launched by the Government of India. The government has launched the Startup India programme to encourage innovation and enterprise. The government is also creating technology incubators in academic institutions. Basic research should remain the cornerstone of strategy of transformation in all areas.

The Academy's initiative to organize this important discussion on the problems and prospects of basic research in India is therefore much timely.

I hope, the Academy will deliberate on the technical, scientific, as well as institutional and policy related issues in the context of the new programmes being launched by the Government. I have great expectations from this gathering of science leaders and I do hope that concrete and implementable recommendations would emerge from the meeting.

I congratulate the Academy for its excellent work and wish the delegates fruitful deliberations.

Thank you

Jai Hind !! Jai Maharashtra !!

Vote of Thanks

Prof. Veena Tandon
General Secretary, NASI

Dignitaries on the dais, our most valued invited guests, delegates, ladies and gentlemen! Very Good Morning to you all.

It's my privilege to propose a formal vote of thanks on this occasion.

- I, on behalf of NASI and the entire team including the Administrative crew and esteemed Fellows and Members led by the Honourable President, Dr. Anil Kakodkar, - let me call it the entire Fraternity of NASI here together- and on my own behalf, extend a very hearty vote of thanks to all present here.
- First and foremost- **Hon'ble Governor of Maharashtra & Chancellor of Savitribai Phule Pune University- Sri Chennamaneni Vidyasagar Rao,** we are grateful to you for gracing the event as Chief Guest and sharing with us your time and presence today! We are all inspired by your great words! We are also grateful to you Sir- for releasing the Compendium and for presenting the prestigious NASI-Reliance Awards- indeed, a great privilege experienced by the awardees!! Our congratulations to them!!
- Hearty thanks to Respected Dr. Anil Kakodkar, President of NASI, for delivering the excellent Presidential Address.
- Honourable **Dr. A. S. Kiran Kumar** - we are thankful to you for gracing the inaugural session as Guest-of-honour and delivering the theme address and sharing with us your thoughts and words of wisdom today!
- Respected **Professor Manju Sharma**, Convenor of the Session and the Symposium- our grateful Thanks to you Ma'am- for your untiring efforts towards initiating theprocess of planning and organization and for the valued guidance, constant encouragement, inspiration and support that you extended, as always before, to all of us and the organizers at this annual session of NASI.
- I would like to take this opportunity to place on record our hearty thanks to **Dr. Nitin Karmalkar, Vice Chancellor**, Savitribai Phule Pune University, and **Prof. Dilip Dattatray Dhavale, Chairman,**

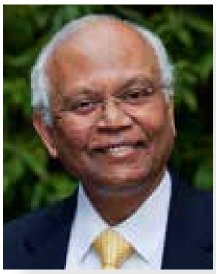
NASI - Pune Chapter- for providing the perfect logistic support and taking upon themselves and their institution the huge task of organising the event; **Dr. Soumen, Director IUCAA-** for providing the infrastructure and facilities.

- Well, Mr. Chairman, ladies and gentlemen, an event like this requires meticulous planning and a bird's eye for details. So, for the 87th session also, the wheels started rolling some 10 months ago. We have been fortunate enough to be backed by a team of very motivated and dedicated colleagues of Savitribai Phule Pune University. I cannot thank everyone enough for their involvement and their willingness to take on the completion of tasks beyond their comfort zones!
- I also extend our thanks to all members of the Local Organizing Committee, with a special mention of the team leaders: **the Conveners**-**Prof. Dilip Dattatray Dhavale and Prof. Shridhar Gejji, the Organizing Secretaries- Prof. Dipalee Malkhede and Prof. Kisan Kodam**, and **the Treasurer Prof. Kalpana Pai**, for their enormous effort and cooperation in the organization of this event.
- Our special thanks to **Dr. Purnima Sharma, MD BCIL**- for preparing the compendium in time.
- Economics forms the backbone of any endeavour and it is no different in the present one, too. I gratefully acknowledge the financial support rendered by our nodal agency- **DST**.
- And, we also would like to acknowledge our gratitude to the Media and Press for their efforts towards giving an excellent coverage to the proceedings of the Annual Session.
- Ladies and gentlemen, once again I want to state that we are all most grateful to all present here. We thank you for being with us this morning – it has been a great pleasure. We look forward to very productive deliberations of the 87th Annual Session and Symposium in the next 3 days. Please enjoy your stay in the Vibrant Knowledge Center- Savitribai Phule Pune University.

Thank you one and all!!

Game Changing in Indian Science Technology & Innovation

Dr. R. A. Mashelkar, FRS
National Research Professor



India has been making steady progress in science, technology and innovation, but it needs to change gears now. It needs to move into higher gears, accelerate the pace of growth and indeed create game changing innovation. Let's begin with some inspiring success stories.

Game Changer through a Mobile Revolution

One of India's early game changer was the mobile revolution. In the two decades from 1995 to 2014, about 910 million mobile phone subscribers were added – the numbers are incredible in themselves, but especially so if you consider that this was 18 times the number of landline connections in 2006 when landline subscriptions peaked at 50 million. The era of 'trunk calls' and ISD and STD booths had come to a definitive end. Thanks to liberalisation, the private sector rose to the occasion and innovation flourished in devices, processes and business models, among others. It represented a joint victory for the public sector, for private enterprise and for people.

Despite India's impressive achievements, the benefits of the digital revolution were not shared by all, thus creating the 'digital divide'. In spite of having a phone and a telecom connection, many could not afford to actually make calls. Some of you may have heard of the Indian term 'jugaad' – the Oxford dictionary defines it as "a flexible approach to problem-solving that uses limited resources in an innovative way." So Indian jugaad came to the rescue and people began using 'missed calls' to communicate. Many a parent, spouse and loved one signalled that they have arrived at their destination by giving a missed call to their anxious relatives and friends. Restaurants that catered to students started 'missed call ordering' – the students would place a missed call, and the restaurant would call them back and take their meal orders. In fact, an entire marketing field called Missed Call Marketing was born.

Look around yourself today and you will see that the situation has changed drastically. Competition in the Indian telecom sector reached a fever pitch in 2016 with the entry of Reliance Jio Infocomm Ltd., or Jio. Today, millions of Indians enjoy the benefits of free voice calling and extremely affordable (10 rupees per GB!) high-speed 4G internet using their Jio connections. Communication behaviours are changing across India as we speak, with the focus shifting from exchanging information to expressing emotion.

All these efforts have risen India's rank from #155 just one year ago to #1 today in global mobile internet usage and India now has one of the most competitive telecom networks anywhere in the world. More importantly, Jio has moved India from missed call to video call, a shift from *Jugaad* to systematic innovation. Jio is a true exemplar in game changing innovation.

Young Innovators can Change the Game too!

Now one might say, a company like Reliance has deep pockets, so they could do it. What about small businesses? What about start-ups?

Let me illustrate the point by talking about some winners of the Anjani Mashelkar Inclusive Innovation Award – an award I instituted in my mother's name for innovations that will do good to the society at large, not just a privileged few.

The awardees are those who believe in not just 'best practices', but 'next practices'.

In 2015, breast cancer replaced cervical cancer as the leading cause of cancer deaths among women in India. In India alone, almost 200 million women aged 35 to 55 do not undergo necessary annual breast exams which could potentially save their lives. Worldwide, this number is even higher. Late stage detection is the main reason behind breast cancer deaths. So how can we ensure that women in every corner of India – in fact, the world – undergoes breast cancer screening?

UE LifeSciences led by Mihir Shah has developed a handheld device that is used for early detection of breast tumours. It is simple, accurate and affordable. It is painless because it is non-invasive. Mammography and radiation are eliminated. Screenings are safe, pain-free and private. They have also deployed an innovative pay-per-use model – instead of targeting direct sales – which can empower doctors in every corner of the country to start screening women for breast cancer at the earliest. The device is US FDA cleared and CE marked. It is operable by any community health worker. And it only costs an amazing Rs. 65 ($1) per scan!

But UE Lifesciences is not only doing good, it is also doing well. In the last year or so, the device has earned nearly 1 million dollars in revenue and received purchase orders totalling nearly 2 million dollars. The company has also entered into a strategic partnership with GE Healthcare for marketing and distribution of iBreastExam across more than 25+ countries in Africa, South Asia and South-East Asia and benefit more than 500 million women. Most recently, it was launched in Botswana with a local partner.

This example is not a one-off success story. Here is another: cardiovascular diseases are predicted to be the largest cause of death and disability in India by 2020. Amidst the rising incidents of cardiac diseases – even among younger people – there is a pressing need to affordably, speedily and accurately monitor the heart health of Indians. This has been achieved by another awardee, Rahul Rastogi, who created a portable match box size 12- lead ECG machine. The cost is just Rs. 5 (8 cents) per ECG test. His company created a disruptive high-tech innovative solution for personal cardiac care – the 'Sanket' electrocardiogram (ECG) device.

Sanket is a credit card-sized heart monitor, which acts like a portable ECG machine, making it possible to monitor the heart condition, making it as simple as monitoring the body temperature. The high-tech 12-lead ECG recorder connects to a smartphone wirelessly and displays and records ECG graphs on a smartphone. The ECG report can be shared instantly with a doctor via e-mail, Bluetooth or message. The affordable device marks a dramatic shift in the way we approach cardiac care – doing away with expensive ECG machines, distant hospitals or laboratories and skilled technicians. Sanket has filed multiple patents and is all set to bring about a revolution in cardiac care and disrupt this space.

Most recently, they partnered with Tata Trusts to deploy 45 devices in clinics in Tripura for quick screening and diagnosis of cardiac diseases. In the remote and hilly state of Tripura, regular screening would have been virtually impossible.

Indian Game Changing Efforts in Technology that Failed

Simputer was an early game changing intent. Simputer was designed to be a low cost and portable alternative to PCs. The idea was to create shared devices that permit truly simple and natural user interfaces based on sight, touch and audio. Simputer was to read and speak in several Indian languages in its initial release. Simputer prototypes were launched by the Simputer Trust on April 25th, 2001.

It was hailed for its 'radical simplicity for universal access' Before the arrival of the smart phone in 2003, Simputer had anticipated some breakthrough technologies that are now commonplace in mobile devices. One of them was the accelerometer, introduced to the rest of the world for the first time in the iPhone. The other was doodle on mail, the ability to write on a phone, that was later a major feature on the Samsung Galaxy phones.

Bruce Sterling writing in New York Times magazine had said, "The most significant innovation in computer technology in 2001 was not Apple's gleaming titanium Power Book G4 or Microsoft's Windows XP. It was the Simputer, a net-linked, radically simple portable computer, intended to bring the computer revolution to the third world...."

Despite such game changing technology, India's Simputer failed to become game changing innovation. And by innovation we mean successful large scale use of a technology in society. What would have helped? A bold public procurement policy by the Government. Let me explain.

How can Public Policy help in Game Changing?

Innovations are products of creative interaction of supply and demand. Besides supply side initiatives, we need aggressive demand side initiatives – and public procurement is an obvious choice. With large procurement budgets, the government can not only be the biggest, but also the most influential and demanding customer of these innovations.

The government approach could be based on three pillars. First, government could act as the `first buyer' and an 'early user' for small, innovative firms and manage the consequent risk thus providing the initial revenue and customer feedback they need to survive and refine their products and services so that they can later compete effectively in the global marketplace. Interestingly, based on a survey of 1,100 innovative firms in Germany, it was found that public procurement is especially effective for smaller firms in regions under economic stress, a helpful lesson for India.

Second, government can set up regulations that can successfully drive innovation either indirectly through altering market structure and affecting the funds available for investment or directly through boosting or limiting demand for particular products and services.

Third, government can set standards that can create market power by creating demand for innovation. Agreed standards will ensure that the risk taken by both early adopters and innovators is lower, thus increasing investment in innovation. The standards should be set at a demanding level of functionality without specifying which solution must be followed. By not prescribing a specific route, innovation is bound to flourish.

Successful Indian Game Changer by Technology plus Policy

Our nation created history in 2014 when under the Pradhan Mantri Jan Dhan Yojna 1,80,96,130 bank accounts were opened in India in just one week, creating a Guinness World Record. It will provide access to various basic financial services for the excluded - basic savings bank account, need-based credit, remittance facility, insurance and pension. JAM combining J (Pradhan Mantri Jan Dhan Yojna), A (Aaadhar identification and authentication) and M (mobile telecommunications) created the fastest and largest financial inclusion in the world, with 300 million plus bank accounts opening up in record time. Before JAM, the disadvantaged sections of society were exploited by money lenders – both in rural and urban area. This bold policy innovation will allow for large-scale, technology-enabled, and real-time delivery of welfare services.

Just like India jumped from landline to mobile telephony, Jan Dhan, Aadhar & Mobile (JAM) will together allow us to leapfrog into the next phase of financial inclusion. It will allow millions of people to become a part of the mainstream economy and provide them access equality despite income inequality.

It is obvious that the tide of exponential technology, where performance is rising exponentially and costs are falling exponentially, will make many things previously considered impossible possible in entirely unbelievable ways and timelines, making the goal of achieving game changing innovation easier. Game changing innovation can greatly help any country in achieving multiple objectives. First, social harmony. It will help in creating access equality despite income inequality. Second, affordability. It will lead to scale, thus bringing equity to any population. Third, excellence. On one hand, excellence will meet the rising aspirations of local populace for high quality goods and services. On the other hand, excellence will open up opportunities for competitive exports to global markets.

Can we do Game Changing Science?

When Indian National Science Academy (INSA) celebrated its platinum jubilee, I had proposed[1] a five point agenda for raising the bar on making Indian science, technology and innovation (STI) original, innovative and creative. One of the challenges that I referred to was:***"........*** *It is time now that Indian science begins to make a 'big difference' to the world of science.*

But making big difference requires generating new big ideas. Richard Feynman had famously said, "The challenge is not to create new ideas, the challenge is to escape the old ideas. To escape the old ideas, we need irreverence." Therefore, at INSA's platinum jubilee, I had also raised[1] this issue – "*How do we create this culture of irreverence, where our young students will begin to challenge the established? A culture where irreverence will be tolerated and not demolished? Where there will be a tolerance for risk-taking and failure?*"

In fact I pursued the issue of irreverence in a guest editorial in Science[2], titled 'Irreverence and Indian Science'. And I have pursued the theme of Indian science, technology and innovation to a new height in my article in Current Scinece[3]. Let me recall some of these thoughts and take them forward.

Can we trigger a daring game changing spirit in Indian science by some bold and innovative funding? For whatever it is worth, I will share my own efforts to achieve this, first at a laboratory level, then at CSIR level, and then at a national level.

While I was the Director of National Chemical Laboratory (1989-95), we created a 'Kite Flying Fund'. A small budget was reserved for funding proof of concept studies on some truly out-of the-box ideas. The chance of success could be even one in hundred. Suddenly, there was an excitement in the air, since failure did not scare the scientists. Some top class research publications (e.g. in Science) emerged – but no great breakthroughs.

When I was the DG of CSIR (1995-2006), we created a similar 'New Idea Fund'. Again a small budget to support out-of-the-box ideas. Chandrakumar's early US patents on spin computing[4-5] were a good example of what could be done. But, in general, it turned out that the problem was not the lack of funding, it was the lack of breakthrough ideas!

At a national level, in the year 2000, we conceived and operationalized the New Millennium Indian Technology Leadership Initiative (NMITLI), the key word being 'leadership'. It was a bold public-private partnership, where grand challenges were taken up by the best brains in India in a `Team India' fashion.

One NMITLI grand challenge was to create 'two orders of magnitude faster liquid crystal display (LCD) device'. With NMITLI support, the Centre for Liquid Crystal Research did create new LCD materials which had two orders of magnitude faster response time. The invention was patented[6] but it did not lead to innovation, as India did not have the innovation ecosystem to capitalize on this breakthrough.

NMITLI posed a grand challenge on creating a new molecule that will clear tuberculosis (TB) in 2 months, rather than the conventional 6-8 months. Lupin and its NMITLI partners created an entirely new molecule having superior anti-mycobacterial activity for treatment of latent TB as well as treatment of multi drug resistant TB[7], while also achieving the 2 month target. It went successfully until phase II and then some issues have arien that need to be addressed. But the point is that Indian scientists did rise to the challenge and did discover a new TB molecule after Rifampicin, which was discovered 40 years earlier!

Was everything in NMITLI successful? No. There were failures too. But that is what happens when you wish to lead and not follow! NMITLI was not just a program, it was a new spirit, it was a bold message that Indian science will dare to try, unafraid of failure!

Concluding Remarks

For really game changing science, technology and innovation, we will need a fundamental change in our thinking. That will mean moving from current best practice to creating next practice, that will mean moving from slow reverse engineering to fast forward engineering, that will mean moving from the comfort of incremental innovation to discomforting disruptive innovation, that will mean not just being satisfied with adding small buckets of slightly differentiated new knowledge to the vast sea of already existing knowledge to creating huge waves with breakthrough new knowledge, that will mean not just being satisfied at looking through the new windows of breakthrough knowledge created by others, but creating new windows of breakthrough knowledge ourselves through which other will look at. That is a great transformation. My sense is that Indian science, technology & innovation is ready for such a game changing performance and sooner rather than later.

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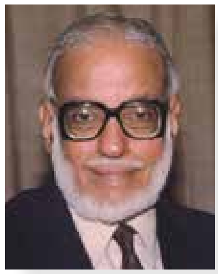
Basic Research as an Integral Component of a Self-Reliant Base of Science and Technology (Its Role, Relevance, Support, Areas of Thrust)[+ϕ]



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I am deeply grateful to the Indian Science Congress Association for the honour they have done me in electing me as President for the year 1981-82.

Dedication

This address is dedicated to two great Indian scientists who have been past Presidents of the Indian Science Congress: Professor Sir C. V. Raman and Dr. Homi Bhabha who presided over the sessions in 1929 and 1951 respectively; and to two other great scientists, Prof. Cecil Powell and Lord Blackett. Prof. Powell had visited India many times and addressed the Indian Science Congress at its Agra (1956) session. Lord Blackett had also visited India many times, the first time being for the New Delhi (1947) session of the Indian Science Congress presided over of Jawaharlal Nehru. I had the great privilege of knowing each of them personally and closely. They had very different backgrounds, personalities, and experiences, but each reflected excellence, and the distilled essence of science and scientific method, in all facets of their lives. It is from them that I have learnt a large part of the history, philosophy and method of science; and a great deal of what I have to say today will reflect this.

Focal Theme

I have chosen, as the focal theme for this Session of the Science Congress, the subject of "Basic Research as an Integral Component of a self-reliant Base of Science and Technology", covering aspects relating to its role, relevance, support and areas of thrust. I selected this theme intentionally, because for some time

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now, I have felt that, in response to meeting needs arising from the immediate and serious problems that we face as a society and a nation, understanding relating to the importance of basic science and research on fundamental aspects, and support for it, is gradually diminishing.

We are well aware of the many conflicting demands on our national economy. There is the already large population, which is continuing to grow, and there are obvious requirements of food and nutrition, health, housing, clothingand education and providing employment that have to be met. We are now facing major problems in the area of energy which was the subjects of the Presidential address of Prof. A. K. Saha at the 67th (Jadavpur) Session of the Indian Science Congress. In the current world situation, there are the growing and grim demands of national security. There are then the requirements of industrialization and of providing gainful employment. From time to time we are faced with natural calamities like floods, droughts, cyclones and the like, which constitute sudden and unexpected stresses on the national economy. All of these demand significant allocations from the national exchequer and call for immediate attention and solution. Indeed at the 1947 Session of the Indian Science Congress held at Delhi, the President of the Indian Science Congress Jawaharlal Nehru said "For a hungry man, truth has little meaning. He wants food. And India is a hungry, starving country, and to talk of Truth and God, and even of many of the fine things of life, to the millions who are starving is a mockery. We have to find food for them, clothing, housing, education, health and so on, all the absolute necessities of life that every human being should possess. So science must think in terms of the few hundred million persons in India." In the face of this, it would not be unusual for the decision makers to regard basic research as a non-priority item. But Jawaharlal Nehru, in spite of the connotation that might be put on what I have just quoted, supported science in the fullest measure; and as scientists we have cause to be deeply grateful to him for his abiding interest in science, and his vision and wisdom in creating the powerful base that we possess today; he understood fully that science is not cake but the bread and the butter of life of our type of civilization.

Having stated what is obvious, that we face immediate major problems that confront society on a day-to-day basis, I would ask whether these urgent priority tasks in the sectors of food, energy, health, employment and proper utilization of natural resources, etc. can be dealt with without recourse to a self-reliant base of science and technology in the country. And the answer is a definite No. To me it is clear that we are allowing problems of the present and immediate to overwhelm us, to such an extent, that the much smaller effort required to ensure that, in the long run, we can significantly ride above such situations, is being lost sight of.

The purpose of my address is to point out that there are certain philosophical, cultural and intellectual aspects of basic research that are not well appreciated, but which underpin in an essential manner the very concept of self-reliance. And for basic research to flourish, it needs an appropriate environment and climate as much as financial support.

S&T Component of the Sixth Plan

Last year, a major exercise was carried out to formulate the Sixth Five Year Plan of the country for the period 1980-85. I had the privilege of chairing a Working Group constituted by the Planning Commission to prepare the draft chapter on science and technology for the plan document. In starting on this task. I went back to the Scientific Policy Resolution adopted by the Government on 4 March 1958. (I have, for convenience of readers, reproduced this resolution in full, as an appendix to the written text of this address). This was a most remarkable document adopted by this country, through the visionary foresight of Jawaharlal Nehru. In its operative part, it says:

"Science has developed at an ever-increasing pace since the beginning of the century, so that the gap between the advanced and backward countries has widened more and more. It is only by adopting the most vigorous measures and by putting forward our utmost effort into the development of science that we can bridge the gap. It is an inherent obligation of a great country like India with its traditions of scholarship and original thinking and its great cultural heritage, to participate fully in the March of science, which is probably mankind's greatest enterprise today."

Indeed, with the great support given by Jawaharlal Nehru from the time of Independence, vigorous measures were taken for the development of science through larger financial allocations; from Rs. 20 crores for Plan and Non-Plan of the First Five Year Plan (1951-56), this allocation has gone up to Rs. 3367 crores in the Sixth Plan (1980-85). There has been a significant increase in the number of universities, institutes of technology, agricultural universities; a large number of National Laboratories have been set up under various agencies covering the entire spectrum of science, engineering, technology and medicine. There has been widespread application of science to national problems in the areas of agriculture, health, industry, energy, communications and so on; impressive returns have been obtained in many cases. There is today a significant infrastructure for science and technology in the country; a stock of scientific and technical manpower which also is large at first sight, being estimated at 2.5 millions; and many major achievements in the form of accomplishments of tasks that have been clearly assigned. Indian scientists are well recognized and regarded on an international plane.

In spite of all this, taking note of the spirit of the Scientific Policy Resolution, which I have just quoted in its operative part, the unambiguous and clearly laid down policy of attaining self-reliance and the large and important position that India has in the community of nations the Working Group asked itself: "how far have we gone bridging the gap and in participating fully in the march of science"; and it came to the conclusion that "while significant advances have taken place on the science and technology front in India over the past three decades, the gap between what is obtained in this country and in other advanced countries, in terms of infrastructure and capabilities, has significantly widened... There are many gaps in important fields and in the ranks of leadership and in excellence."

The Nurturing of Science

I am personally of the view which is shared by a large number of my distinguished colleagues in the scientific community of this country, with whom I have had extensive discussions, that the concept of excellence is being lost, that centres of excellence in the country are finding it difficult to survive because of lack of appreciation concerning issues of an administrative and financial nature and what might be referred to as personnel and labour aspects, particularly in terms of the laws of the land and the attitudes taken by our judiciary; our brilliantstudents have very few positions for training and further research at outstanding centres. Our educational institutions which have the responsibility for generating our scientific manpower have been sadly neglected in terms of support, even on a selective basis. Those who would potentially be the great scientists of the future are drifting to professions other than science, or are moving abroad where better opportunities exist. The Working Group on Science and Technology for the Sixth Plan has expressed its deep concern over all of these issues. There is, therefore, a need for a much wider appreciation and debate on these issues, since they are indeed fundamental and serious.

I have asked myself: "Under what auspices could questions of this type be publicly posed, leading to a greater debate on the problems and solutions". In terms of scientific bodies, there is the Science Advisory Committee to the Cabinet (SACC), the creation of which the Prime Minister announced at the last Indian Science Congress session at Varanasi; SACC has met several times over the past year, and has concerned itself with some of these basic issues. There are the academics of science and other professional societies. And then there is the Indian Science Congress Association which covers the broadest spectrum of scientific disciplines and whose membership today stands close to 7400. I believe that the issues we are considering are so important that they must be debated in all these forums.

I have noticed that the Indian Science Congress, in its sessions for quite some time now, has discussed many areas of national life where science has relevance and finds significant application. This is important. I also believe that the approach of selecting one broad area of national relevance and importance as a focal theme, on which scientists from different areas of science can focus their attention will lead to coordinated, interdisciplinary and integrated efforts. In all of this there is the basic assumption that the scientific base is strong, and itself needs no attention; and therefore our attention should be profitably concentrated on "applications of science". If, however, the base of science in the country is weak or unsound or not getting the support and climate that it needs for its own growth and development, then science as a force for development will obviously not be very effective. It is this question to which I wish to address myself: "how is science itself to be nurtured and developed in a manner in which it can be a successful component of development?"

It will be seen that the focal theme essentially covers three components: the concept of a base of science and technology; the concept of self-reliance; and within this framework the role and relevance of basic research; other aspects that we will consider are support and areas of thrust in respect of basic research.

Science and Technology: General Aspects

The world of today is largely the product of developments that have taken place in the field of science and technology; no doubt other social, cultural and economic aspects have influenced and made possible the self-sustaining exponential growth of science and technology that has taken place. These developments have occurred over the past few hundreds of years since the scientific and industrial revolutions took place. It must be remembered that science did grow but declined in many earlier civilizations, and did not attain the present self-sustaining character that we see around. The present developments were nucleated in the great industrial centres of the world today; as a result these areas were able to make rapid progress in the material sense, to become the highly developed countries. In monetary terms, 97% of the world's research and development is carried out in these developed countries and only 3% in the less developed countries.

At this point I am reminded of what Cecil Powell said when he was arguing in the early 1950s for support for basic research in Europe. At that time the United States was vigorously moving into the field of high energy elementary particle physics, and European physicists were trying to obtain support for a common European accelerator and high energy physics which today exists as CERN (European Council for Nuclear Research). Cecil Powell then said: "In the long run, it is most painful, and very expensive, to have only a derivative culture and not one's own, with all that it implies in independence in thought, self-confidence and technical mastery. If we left the development of science in the world to the free play of economic factors alone, there would inevitably result a most undesirable concentration of science and scientists in too few centres, those rich in science becoming even richer, and those poor, relatively poorer". This was as between Europe and America then. The disparity that exists is infinitely greater between the developing and developed countries. The UN Conference on Science &Technology for Development was held in Vienna in August 1979 precisely to seek ways to reduce this disparity, so as to lead to a New International Economic Order.

The spectacular, and highly visible, material developments that have taken place as a result of advances in science and the rapid succession of technological innovations in the areas of industry, agriculture, medicine, transportation, communications, energy, etc. are there for all to see. High speed jet engines and wide-bodied aircraft have resulted in mass transportation which has made the world a small place physically; the advent of the Space Age and of geo-stationary satellites, and the developments of modern electronic techniques have resulted in worldwide radio and TV broadcasting and telecommunications, which have made the earth a small place in terms of communications, transmittal of ideas and human expectations; advances in medical sciences, with modern antibiotics and other miracle drugs, as also our greatly increased basic understanding of biology at the molecular and cellular levels have had a profound impact on world population (with reduction in death rate and rapid rise in population), treatment of disease and the promise of an unending chain of new possibilities; modern high-yielding varieties have enabled food production populations; the developments in modern electronic techniques have made it an all-pervasive technology, affecting entertainment, industry, defence, communications, space technology, computer and information sciences and the like. All of this has resulted in rising expectations the world over, and a feeling of euphoria that science and technology is a magic wand to bring about development. The point that needs to be emphasized is that science and technology is not a magic wand. We must explode the myth that science is a great external solver of all problems. Lord Blackett in the first Jawaharlal Nehru Memorial Lecture given in 1967 had said: "Science is no Magic Wand to wave over a poor country to make it a rich one".

We have also to remember that science and technology should not be looked upon as a separate entity to be separately accountable for development. In this connection, Casimir has remarked "Science and Technology are an essential part of development. One does not apply one's lungs to respiration, nor one's heart to the circulation of blood nor one's legs to walking. If we regard science and technology as a crutch, it will at best provide a halting gait. If we regard them as a transplanted heart, they will sooner or later be rejected by the receiver". Science, and technology which is based on a basic understanding (in contrast to pure implementation of a well-defined set of technical tasks) cannot be imported nor be regarded as an external entity. It has to be an integral part of all our activities.

Self - Reliance

We have to recognize that India is a large country of sub-continental dimensions, with a population close to 700 million. The very size of our country, and the diversity and complexity of the problems we encounter, which are quite different from those of smaller developing countries, demand self-reliance. The Prime Minister, Mrs. Indira Gandhi, has remarked: "Self-reliance must be at the very heart of S&T planning. There can be no other strategy for a country of this size and endowments. While we all readily pay obeisance to this concept, there are too many and too frequent lapses. Considerations like security, the time factor, performance guarantee and costs often compel us to buy advanced technology from the international market. But in the ultimate analysis, neither true defence nor true development can be bought or borrowed. We have to grow them ourselves". She has further said: "Self-reliance does not mean making everything ourselves but acquiring the capacity to do so when things come to a head".

The pathway to self-reliance is not to set out to rediscover independently what has already been discovered, nor to invent what has analyse problems, and to define tasks and objectives; to obtain information/know-how etc. which is needed from wherever it is available, but on a specific basis; to have self-confidence to develop whatever needs to be developed; and most important, the ability to start from a base which may be a mix of indigenous and imported know-how, to move into the future on an internationally contemporary basis through innovation and original thinking. Self-reliance should also not be confused with self-sufficiency. Self-reliance demands national commitment and political will;

and involves many facets such as technology policy; management and technical skill etc. But clearly a cruicial element of self-reliance, in a world whose economy and life styles are dominated by scientific and technological advances, has to be a self-reliant base of S&T. And this base cannot be built without at the same time doing significant basic research; for that is the only way to generate basic understanding which is not restricted to specific knowledge in an area, but provides the ability to attack and solve problems over a wide spectrum: and it is this ability that basic research more than anything else develops to the highest degree. Aspects to basic research and the qualities that it demands are dealt with, a little later.

The Innovation Chain

I would now like to consider the place of science and technology within the overall framework of the productive sector. It was Lord Blackett who, in the first Jawaharlal Nehru Memorial Lecture, outlined the importance of ensuring the integrity of various links in what he referred to as the 'innovation chain', if investments at various points of the chain are to be fruitful. 'Innovation chain' is a term that has been used to signify the whole process from fundamental research (which is concerned with the discovery of new facts and the understanding of nature and hitherto unknown principles), through applied research (which involves definite practical objectives), to the development of a small number of items in batches on a pilot plant basis to test out production techniques (and analogous pilot plant operation for testing the feasibility and economics of process techniques), to devising processes to suit available skills and equipment and the use of items that are most easily and cheaply available, to the final emergence of marketable products or of services; in the fields of agriculture and medicine, the intermediate steps would be of field trails and liaison with the producers and users of the products. It is important to recognize that scientific research represents only the first few steps in this long and expensive chain. A high level of research and development alone is not sufficient to ensure successful innovation; the industrial and commercial elements of the chain are industrial and commercial elements of the chain are equally vital. Actually, research and development claims generally only a small part of the total costs of successful innovation. On the average, it is estimated that about 5-10% of the total launching cost of a successful new product goes into the research and development leading up to the basic innovation; and about 10-20% goes into the engineering development and design of the project. The remaining 70-85% is needed for the tooling costs for first production, and for the initial manufacturing and marketing expenses.

Thus, the British textile material "Terylene" was invented in a research laboratory running at less than $ 60,000 a year. When Imperial Chemical Industries obtained the UK commercial rights for this invention, it then spent the equivalent of around $ 11 million on pilot plant development; and for the first major commercial production, the new plant cost around $ 40 million. The economic factors involved in the various elements of this innovation chain have to be well understood if the investments on research and development are to be profitable, and not lead to frustration.

If on the basis of careful perspective planning, one can define end-requirements well in advance, particularly in the major economic sectors, then resources-human and financial-can be deployed wisely and in time on research, development and other aspects, with the clear-cut expectation that investments will be forthcoming in the later elements of the innovation chain in the productive sector, to make use of the scientific effort that has gone before. In the absence of such perspective planning, and linkages between the productive sector and the R&D, have often appeared to be unproductive, though the tasks defined for them had been accomplished; and this has been a frustrating experience for scientists. This has also led to the question that the scientific community is very often asked: "So much money has been allocated for science; what have we got in return?" It is essential to realize that returns will be forthcoming only if adequate investments are made in the different downstream steps of the innovation chain, and time elements that are relevant are kept in mind; we have to remember that long gestation periods are involved in the fructification of S&T efforts. And applied R&D, design and development work should not be initiated in areas where no chance of fruition exists, whatever be the reason.

There is often a tendency to use the wide umbrella term 'science and technology' under which many different facets are subsumed. This has resulted in a great deal of confusion in defining investments, efforts etc. that relate to the different components of Science and Technology. We have already seen that the largest resources-human and financial – in the productive sector, whether it be in agriculture, industry, transportation etc., have to be in the later stages of the innovation chain. Though these productive activities are based on science and technology, and they absorb the larger part of the output of trained technical personnel emerging from the educational institutions, they cannot be, (and are not), treated as the S&T sector. The latter is concerned with research (pure and applied), design and development. As already stated, applied research and development can fructify only when there are clear-cut end-objectives and needs, and appropriate guarantees and linkages to ensure utilization through investment in the productive sector. The largest part of the budget of the S&T sector in the country has so far gone into the areas of applied research and development, whether they be in the areas of atomic energy, space science and technology, defence or through the Councils dealing with Scientific and Industrial Research, Agricultural Research or Medical Research. In each of these areas, there is only a relatively small amount which goes into basic research. However, because of the overall allocations for science and technology, under which umbrella title basic research is also subsumed, it is generally assumed that it is also well looked after. But this has not been the case in real terms, and particularly in the context of the headlong advances that science and technology have been making and the completely new areas that are being opened out on an international plane.

A Restatement of the Background

In what I have said up to now I have covered several different facets of the scenario that a policy maker in the field of science and technology is confronted with. It would be good if I attempted at this stage to draw together the threads of my discussion into some simple statements. First, Indian planning since Independence has sought to work towards the objective of self-reliance; and this is the banner under which we have been marching all these years. Whilst we have individual achievements in science and technology to our credit, and today we produce a very significant part of all that we need for daily life within the country, yet we must admit that we still have a long way to go in attaining true self-reliance. In a world that has been fashioned by science and technology, and of which we are a part, it is quite clear that national self-reliance implies a self-reliant base of science and technology. For science and technology to fructify in terms of meaningful national development, it has to be ensured, on the one hand, that there are investments downstream, to ensure that know-how that is generated through applied research and development is transformed in a productive manner for the benefit of society; and on the other, that where large investments are involved in the science and technology sector, as is the case of applied research and development, this is done only in areas where, on the basis of long range planning, it is clear that there are needs and users. We are, of course, aware of many instances where users project their needs much too late for national S&T to respond or make any useful contribution; and usually these these instances relate to large projects. This should not be permitted.

The quality of excellence in all that we do can come about only if support is given to sectors such as basic research in the same manner as in sectors such as exports where the highest international standards alone will ensure competitiveness. I shall now pursue in the remaining part of my talk, the role and relevance of basic research in promoting innovation and excellence.

Basic Research: Its Role and Relevance

In January 1966, in the last speech that he gave in his life, HomiBhabha, addressing the International Council of Scientific Unions in Bombay remarked:

"What the developed countries have and the underdeveloped lack is modern science and an economy based on modern technology. The problem of developing the underdeveloped countries is therefore the problems or establishing modern science in them and transforming their economy to one based on modern science and technology. An important question which we must consider is whether it is possible to transform the economy of a country to one based on modern technology developed elsewhere without at the same time establishing modern science in the country as a live and vital force. If the answer to this important question is in the negative - and I believe our experience will show that it is - then the *problem of establishing science as a live and vital force in society is an inseparable part of the problem of transforming an industrially underdeveloped to a developed country*."

At this point, let us consider the important question Bhabha raised: Is it possible to transform the economy of an industrially underdeveloped country to one based on modern technology developed elsewhere without at the same time establishing modern science in the country as a live and vital force? Bhabha answered it in unequivocal terms on the basis of his experience in India for quarter of a century.

Bhabha had returned to India with an internationally established reputation as a theoretical physicist of the first order. Working during the years of the Second World War at the Indian Institute of Science, this outstanding theorical physicist began thinking of the need to establish modern science in India, of the needs of energy for economic development, the great potential that nuclear power was likely to offer in this regard within a couple of decades, and the enormous possibilities of leapfrogging in the process of development through modern sophisticated techniques. He did not, however, approach these possibilities in the manner in which foreign collaboration are normally embarked upon. He first proceeded to build a base of fundamental research by setting up the Tata Institute of Fundamental Research; he did this because he had become a ware of the shortcomings of science in India in some of the modern areas such as nuclear physics, high energy physics and so on, and felt that in these areas where so much fundamental and exciting work was going on, India should not be left out. He was also clear that in setting up such an institution, it would be necessary to introduce modern concepts of administration and research management, which would lead to an atmosphere and environment conducive to its being a pace-setter for the growth of science and self-confidence, and be the base from which major ventures could be undertaken. Loard Penney writing on HomiBhabha in the Biographical Memoirs of Royal Society has stated, “In the 21 years since the Institute was inaugurated in Bombay to Bhabha’s death in 1966, the Tata Institute of Fundamental Research has grown to be one of the finest research institutes in the world”. In the letter that he wrote to the Sir Dorab Trust outlining the proposal for setting up the Tata Institute of Fundamental Research, HomiBhabha showed that he was also clear about the long-range fall-out and the imperatives of self-reliance in a strategic area. In a visionary and prophetic sentence he remarked “Moreover, when nuclear energy has been successfully applied for power production, in say a couple of decades from now, India will not look abroad for its experts but will find them ready at hand”.

Since Bhabha conceived of the Tata Institute of Fundamental Research, many new area have developed right at the frontiers of science, for example in modern biology, with unambiguous indications of relevance, applications and growth. It is clear that we need to grow many more such institutions, and particularly in close coupling with the educational system.

Then Bhabha went on to develop the atomic energy programme; and he selected physicists, chemists, engineers and biologists who would work not on a purely imitative basis or by reverse engineering, but on the basis of an understanding of the basic elements in their areas, whether it related to materials, structures, heat transport, spectroscopy, chemical reactions and so on. It is this strength of basic understanding which characterizes the India nuclear programme, and which has enable it, in spite of many hurdles encountered more recently in the area of international cooperation, to stand on its own feet. At the dedication of the new buildings of the Tata Institute of Fundamental Research in January 1962 by Jawaharlal Nehru, Bhabha had remarked: "The support of such (basic) research and, of an institution where such research can be carried our effectively, is of great importance to society for two reasons. First of all, and paradoxically, it has an immediate use, in that it helps to train and develop, in a manner in which no other mental discipline can, young men of the highest intellectual caliber in a society, into people who can think about and analyse problems with a freshness of outlook and originality which is not generally found. Such men are of the greatest valueto society, as experience in the last war showed; for many of the applications of science, which were crucial to the outcome of the war, were developed by men who, before the war, were developed by men who, before the war, were devoting their time to the pursuit of scientific knowledge for its own sake. Radar and atomic energy are two examples of field in which a vast body of established basic knowledge was developed into technology of immense practical importance, largely through the application in war time of the efforts of those who might be called 'pure' scientists." Bhabha further said: "It is not an exaggeration to say that this Institute was the cradle of our atomic energy programme."

I have just conveyed to you what one of our great scientists Homi Bhabha, who made his reputation by accomplishing basic research of the highest quality, and who was responsible for promoting much else in national development in the fields of atomic energy and electronics, felt about the importance of basic research. I fully concur with all that he had to say.

Apects of Pure and Applied Research and Linkages between various concerned Institutions

I would now like to put down for clarity certain specific aspects concerning various forms of research activity, and their respective roles and relevance. Research is often categorized as pure research and applied research. The fundamental difference lies in the motivation. The motivation in the case of pure research is the desire to know something, whereas in the case of applied research it is the desire to do something. The words pure, fundamental or basic are often used synonymously.

Basic research is concerned with discovery of new knowledge and with increasing our understanding of natural phenomena. It ultimately leads to a clearer and sharper definition of the laws which govern nature. Basic research is not directed towards the solution of immediate practical problems. Basic research, by definition, is at the frontiers of our knowledge; and the quality of work and achievements have to be judged by the entire internationalscientific community. Quite clearly those who would accomplish such research have to possess capabilities necessary for work at the frontiers of science on a competitive international basis. In contrast, applied research has very definite practical objectives. It can and should be a highly creative process involving originality, imagination and inventiveness. In a desirable situation, these qualities, in the case of applied research, should be of the same magnitude as for basis research.

It is not the degree of creativity that distinguishes basic from applied research but the clear practical direction that applied research but the clear practical direction that applied research aims at. In contrast, design and development relates to the effective and economical execution of a task that has been shown to be feasible on the basis of applied research and past experience.

Another important aspect of fundamental research is its essential place in the system of education. In its broadest sense, education involves the totality of effort related to acquiring new knowledge, preserving it in suitable form, and transmitting it to future generations, together with the thought processes involved. Very often, with the obvious unfortunate consequences, the mere process of handing over knowledge as a dead, inanimate object is considered to be education; this happens in many of the educational institutions in India that stress uniformity and learning by rote. The only way in which teaching can be brought out of this rut of routine, pedantic transmission of facts is by ensuring the accomplishment of significant research that leads to a tradition of penetrating and independent inquiry. Such research may be pure or applied, but must be of high quality and encourage innovativeness.

Education is primarily the responsibility of the universities, and quite clearly there must be basic research at the universities if education has to have any quality. The question, however, can be asked whether all the basic research that needs to be done can be done within the universities; and I believe, the answer that question will be in the negative in today's context. The reason is that a lot of basic research today involves rather large expenditures, major facilities and infrastructural support, close links with technology and interdisciplinary efforts. This could involve accelerators, telescopes, major facilities for biological research and soon. These are best located and managed in separate research institutions, which will need autonomy and a culture necessary for them to manage large technical facilities and conduct interdisciplinary programmes. However, in my view, such institutions could be within, or should be co-located with educational institutions, so that the research institution participates, so that the research institution participates in the university activities and vice versa.

We must recognize that different kinds of institutions are appropriate for various categories of activities, and what is important is to establish associations and linkages between them for mutual benefit. For example, a university associated with a government or industrial laboratory may acquire thereby the stimulation of constant contact withapplied problems and also have available to it the large Scale facilities that are necessary and have been developed for a applied research Correspondingly, the government or industrial laboratory acquires increased contact with the very talented contact with the very talented enthusiastic young students and the openness of the of the university environment. What is required in such a linkage is not purely in terms of financing of research in the university by the government or industrial laboratory, but mutuality in participation. Mutuality cannot come about in wholly unequal relationships. It is for this reason that the weakening of our university research capabilities. Through lack of support, is reducing the possibilities of such mutually highly beneficial linkages.

I can now particularize the scenario to the national plane. We have a large number of universities throughout the country. In their vicinity there are major research institutions coming under the purview of the Atomic Energy and Space Commissions, the Council of Scientific and Industrial Research, the Defense Research and Development Organization, the Indian Council of Medical Research, Indian Council of Agricultural Research and Department of Science and Technology, the various surveys such as Survey of India, Geological Survey of India, Botanical Survey of India, Zoological Survey of India, as also major industrial units, some with excellent R&D facilities. There is, however, very little that is being done to establish strong interconnections between the University system and this infrastructure. There are a variety of schemes that I can think of which can be university staff as consultants by industry and national institutions. This must be made compulsory. Such consultancy provides the academic community with opportunities to get acquainted community with opportunities to get acquainted with important industrial research problems which challenge the scientific imagination. The consultants can be used for probing areas that are new and unfamiliar to the company or laboratory, as well as for giving lectures to the staff. (It is, in fact, my experience that very few lectures are given in most government or industrial research laboratories, which is a pity, since science thrives and grows only through open, critical discussion.) Through these interactions the academic community can be exposed to the industrial environment, its problems and its attitudes. Conversely, its problems and its attitudes. Conversely, it is important to provide visiting professorships, adjunct professorships, participation in university activities through advisory committee etc. to those from industrial and other national institutions. These provide opportunities for scientists from governmental or industrial laboratories to keep in touch with a broad spectrum of intellectual activity that a university represents and to widen their horizons.

There are a variety of such mechanisms to bring about better linkages that could be of mutual benefit; I have just indicated a few possibilities. Whilst some forms of collaboration have been worked out, it is nowhere near what can be achieved.

To my friends in the scientific community I would like to emphasize the point that basic research does not mean any research that is carried out which does not qualify as applied research. Basic research is characterized by high quality and innovation. It is subject to a system of peer review, and must arise from a deep inner urge to find out. It must, in the ultimate, be competitive at a truly international level. In this connection, I would like to recount a fable by Prof. Karl Popper: “Suppose that someone wished to give his whole life to science. Suppose that he therefore sat down, pencil in hand, and for the next twenty, thirty, forty years recorded in notebook after notebook everything that he could observe. He may be supposed to leave out nothing: today’s humidity, the racing results, the level of cosmic radiation and the stock market price and the look of mars, all would be there. He would have complied the most careful record of nature that has ever been made; and, dying in the calm certainty of a life well spent, he would of course leave his notebooks to the Royal Society. Would the Royal Society thank him for the treasure of a lifetime of observation? It would not. The Royal Society would treat his notebooks exactly as the English bishops have treated Joanna Southcott’s box. It would refuse to open them at all, because it would know, without looking, that the notebooks contain only a jumble of disorderly and meaningless items. "The reason is that as Paul Weiss has said: "The primary aim of research must not just be more facts and more facts, but more facts of strategic value".

I must confess that there is a considerable amount of so-called basic research done in this country, which falls in the category of that described in Karl Popper's fable; very large numbers of Ph.D's seem to emerge from our education system on this basis; reputations have been built up through the publication of hundreds of papers only to fool the untutored. All that is done is mere data collection on a routine basis without any urge whatsoever to really understand something new about natures. This is not to decry data gathering, because it is no doubt useful and necessary, for it is only on the basis of data that one can build up models, hypotheses, theories and so on. However, it is necessary that the data gathering process be treated as a means in an innovative manner, and must relate to analytical and interpretative research. It must be motivated by a deep desire to know.

Need for Centres and Schools of Excellence

It is quite clear that basic research is carried out by, and around, gifted individuals. This is true of any creative human enterprises such as music, art, dance and so on. It is well known that, apart from the innate gifts that an individual may possess, there is a very important component which an individual derives from the environment, particularly that close to him, and more particularly from a gifted teacher. It is this concept which has been the basic of the "guru-shishya" relationship in Indian education, and of the great "gharanas" of our country in music and dance. One can in our country and abroad, trace great accomplishments and individuals to great schools, and establish a genealogy based on teacher-pupil links.

This is certainly true of science. In the autobiographies of great scientists, one repeatedly comes across phrases which trace their own achievements to the influence of outstanding teachers. For example, Liebig was a pupil of the great French chemist Gay-Lussac, the discoverer of some of the fundamental laws of the behavior of gases, and Gay-Lussac was in turn a pupil of Berthollet. Liebig has remarked "The course of my whole life was determined by the fact that Gay-Lussac accepted me in his laboratory as a collaborator and pupil". Liebig, in turn told his student Kekule, who latter became famous for his contribution to the structure of organic compounds, specially the ring structure of benzene: "If you wish to be a Chemist, you must be willing to work so hard as to ruin you health". This was to emphasize the importance of hard work as a prime element in science. From Liebig one can trace several successive generations of scientist, containing more than 60 exceptionally distinguished name, and including more than 30 Nobel Laureates. The Deutsches Museum in Munich gives the genealogy of 17 Nobel Laureates who were members of a teacher-pupil family descended from Von Baeyer. One of these was Otto Warburg who has remarked "the most important event in the career of a young scientist is the personal contact with the great scientists of his time. Such an event happened to me in my life when Emil Fisher accepted me, in 1903, as a co-worker in protein chemistry". Warburg's student was Hans Krebs who also won Nobel prize and has remarked "If I ask myself how it came about that one day I found myself in Stockholm, I have not the slightest doubt that I owe this good fortune to the circumstance that I had an outstanding teacher at the critical stage of my scientific career. He set an example in the methods and qualities of first rate research". The essential point we have to keep in mind is that distinction develops if nurtured by distinction. It is attitude rather than knowledge which is conveyed by a distinguished teacher; as also enthusiasm which is the only basis on which exceptionally hard work that is ultimately required, does get put in. An important element of attitude that a great teacher imparts is that of humility,

And from it flows a self-critical mind and the continuous effort to learn and to improve. One can trace in the history of science great schools and certres as at Paris, Gottingen, Cambridge, Oxford, Berkeley and so on.

It is of course true that there are many individuals who are prodigies or genius in their own right, and do not trace their links with any existing school. In India, scientists like SrinivasaRamanujan, C.V. Raman, J.C. Bose fall in this category. However, such an individual, given the right opportunities, will very often be the starting point of a genealogy of excellence. One can trace many of the first rate scientists in India to schools nucleated by C.V. Raman, MeghnadSaha, S.N. Mitra, HomiBhabha and so on. However, it takes time and an appropriate environment with long-range support, to ensure full flowering of any such school. Unfortunately, in India, what should have been points from which whole generation of excellence came forth, dried up too early. HomiBhabha has remarked "It is the duty of people like us to stay in our own country and build up outstanding schools of research such a some other countries are fortunate to possess. "His other phrases, in this connection, were: "Build up in time an intellectual atmosphere approaching what we knew in Cambridge and Paris"; and again would have an electrifying effect on the development of science in India".

It must be remembered that very often an individual by himself tends to get lost, unless one was dealing with a genius like Einstein or Dirac or in India Ramanujan. We have to recognize the importance of an overall supportive environment and of team work. Jacques Monod has commented in his Nobel lecture on the importance to him of a Rockefeller Fellowship which gave him an opportunity to work at the California Institute of Technology in the laboratory of the Nobel Laureate Morgan: "This was a revelation to me-a revelation of what a group of scientists could be like when engaged in creative activity, and sharing it in constant exchange of ideas, bold speculations and strong criticisms".

It is very clear that most human beings never stretch themselves to the limits of their abilities. It is the outstanding teacher who attracts the finest students; and in the overall intellectual environment that the team represents, the individuals are pushed to the very limits of their intellectual capability, each deriving strength from the other we should aim at creating in the country. This, however, demands both the highest standards in selection and flexibility in management.

Under the banner of equality and democracy, circuses operate powerfully against the development of excellence in science; very often I fear we have too much of equality and too little promonon of excellence. This is not a matter which is the

responsibility of Government alone, though it also has some responsibility in terms of the rules and regulations that it frames for gerenal administration and makes applicable uniformly to scientific activities The primary responsibility is of the scientific community to cultivate through envy and jealousy, and for the petty considerations of individuals and groups

Louis Pasteur: The Opportunities for Basic Research in the Immediate Environment

I would like to spend a few minutes on what we could learn profitably from the life and work of a great scientist whose work I have always admired, since I have felt that it has so much relevance to our circumstances and for the choice of areas for research. The scientist I speak of is Louis Pasteur, who took his doctorate with dissertations in both physics and chemistry, and then carried out an impressive series of investigations on the relations between optical activity, crystalline structure and chemical composition in organic compounds. His work opened the way to a consideration of the disposition of atoms in space, and his early memoirs constitute the founding documents of stereochemistry. From crystallography and structural chemistry, Pasteur moved to the controversial and inter-related topics of fermentation and spontaneous generation. These were then empirical areas like cooking is today, but converted to areas of science through the work of Pasteur. This came about because he was appointed Professor of Chemistry at the Faculty of sciences at Lille, which was newly established with the objective of basic science; Pasteur strongly supported the goal of linking industry and the Faculty of sciences. His work in the area of fermentation (traced to the brewing industry in Lille) was based on his earlier interest in optical activity. He promoted specific living microorganism, and was responsible for the sterilizing procedures called 'pasteurization; he laid the foundation for the germ theory of disease, which was thereafter developed rapidly by others notably Joseph Lister. For a period of almost 30 years he worked in succession on silkworm diseases, where he achieved remarkable success, and on the etiology and prophylaxis of a range of infectious diseases, anthark, fowl cholera, swine erysipelas and rabies. He developed one treatment directly applicable to a human disease, namely for rabies. It is interesting that all of these problems that Pasteur encountered were in his immediate vicinity and interest in them evolved from his own basic research in which he displayed great experimental ingenuity. His approach was fundamental and resulted in the formulation of new biological principles. We have only to look at the range of problems that we encounter in our environment, whether in the area of population, meteorology, energy and so on to realize that there ae challenges to excite the keenest minds in our vicinity and in our surroundings. To meet these challenges one would have to devise new techniques, new instruments, new insights and approaches which could as easily open a window into the hitherto unknown areas of nature, leading to work pool of knowledge, without necessarily being dictated by fashions set elsewhere in the world. And there are areas of pure science such as astronomy in which we posses location advantages where work of the highest order is possible with relatively small investment. This is true of mathematical and theoretical areas.

Illustrative Areas of Thrust

I would now like to cover, on a broad illustrative basis, certain areas of thrust in basic research which are of great interest scientifically, and where one can also see very clearly, relevance in terms of possible tangible fruits in the not too distant future.

Let us look at the field of food production. The history of agriculture goes back cover a period of many thousands of years, since man shifted from his role as a food gatherer to a cultivator. Farming could be successfully carried out in the rich and fertile river valleys such as those of the Euphrates and Tiger, the Changjiang and the Indus. Based on a certain amount of logic, experience and common sense, coupled with knowledge concerning the movement of the sun and stars which define the seasons and weather, and which could be regarded as rudimentary science; agriculture developed in a rather empirical fashion since its earliest days upto relatively recently. However, the situation radically altered over the past century to make agriculture a highly science-based area of production. Remarkable success has been achieved in increasing yileds of many plants varieties, through an understanding of aspects of genetics and breeding, of nutrient requirement and of pest control. This success owes very significantly to the inputs that could be provided in the form of water and fertliser which were available cheaply so long as energy was available cheaply. Which the production outputs grew significantly this had not been the case with production efficiency in terms of energy. India had a good base in the agriculture science when the process of modernization to increase yields in Indian agriculture was initiated around two decades ago, forced largely under the pressures of a large and growing population and the need to produce adequate food to avoid very heavy imports that would otherwise be needed, with consequent problems of both availability and high foreign exchange outflow. This modernization and increase in food production depended on an agricultural strategy similar to that adopted in the Western countries, which was essentially strategy at that time before the energy crisis of the 1970's. It was essential to tide over the immediate problem of raising food production to a level of food grains. India had no choice but to initiate the energy-intensive agricultural, so called greend revolution. As the Prime Minster, Mrs. Gandhi, has stated:

"It was a time of acute grain shortage, and the point was how do we immediately double the production of wheat. And so we went all out, and that is how we have been able to survive all this time, even through drought"

This strategy and similar improvements in many cash crops will and must continue, to enable us to meet the immediate problems of demand and to avoid or reduce imports. The question, however, is what should be the strategy in the long run.

First and foremost there is the question of energy. Oil is still a significant items of import, and has been subject to several increases in price in recent past, making a total price increase of twenty-fold over the last 8 year. Oil is a non-renewable source, and with expanding world population and human expectations, one must accept the fact that it will become more scare with time and more expensive; and dependence on it in any major way can only make us vulnerable. It is, therefore, important to see whether agricultural strategies cannot be developed which will make lesser demands on chemical fertilisers which are oil-based, and lesser demand on energy for agricultural operations. In the short run we must certainly produce more fertilizer. Even though India today is the fourth largest producer and consumer of feriliser nitrogen in the world, the country is faced with a gap which will increase to 4 million tonnes by the end of the Sixth Five Year Plan and to a much large figure by the end of the century. The imports of large qualities of oil, food grains, edible oils and fertilisers can be supported in the short-term through loans and have to take place to meet immediate needs. But what of the long-term; Consider the case of fertiliser. The question is whether we can turn to methods of providing nitrogen to plants without depending wholly on chemical fertilisers, where nitrogen is fixed through the intensive use of energy. We must remember that until recently our agriculture has survived for thousands of years depending on the renewable sources for nitrogen existing in our soil. Can we extend the host range of nitrogen fixing organisms and identify new bacteria and other microorganisms which will fix nitrogen; Can we transfer the nitrogen fixing genes to a wide range of microorganisms through the process of genetic engineering; These could then from symbiotic or non-symbiotic association with crop plants like cereals, in addition to the pulses. This immediately takes us into problem of genetic engineering microbiology and soil science using nitrogen fixation concepts right at the frontiers of modern life sciences.

Another extremely important area of basic science from the viewpoint of agriculture, and of energy, is the area of photobiology. All biomass on the earth is produced through the produced through the process of photosynthesis, in which using the sun’s energy, carbon dioxide and water can be converted to carbohydrate and oxgen; and additionally nitrogen, sulphur and so on can be incorporated. The final efficiency of the process, when one considers large scale biomass production, tends to be only of the order of 0.02%. The question is:can we improve this efficiency? And this takes us into areas of “whole plants physiology and biochemister”. Further a detailed study of the various elements involved in photosynthesis might enable us to mimic some of thereactions artificially, so that one can photo chemically produce hydrogen from water. It is expected that in time this will become an important source of energy.

Energy today has assumed very important dimensions from the viewpoint of both availability and cost.

In India, half of the energy used is non-commercial energy, which means burning up of wood agriculture residues and animal dung. This is leading to serious deforestation and desertification possibilities exist for improving the whole area of forestry through the techniques of issue culture fixation techniques, as discussed earlier in the case of crop plants. We can also consider production of varieties like sugarcane and tapioca, which make extremely good use of the sun's energy and these could then be converted to produce ethanol which is a basic chemical building block.

We are aware of the problems of diseases in plants, and that these are larger by a factor of ten in the tropics compared to the temperate zone. Pesticides are being used but have their own problems relating to the environment and health. Strategies relating to integrated pest management are called for and these will involve work in insert physiology at the frontiers of our present knowledge.

There is no question that the success of the green revolution owes significantly to the farmers and peasants who were responsible to recognizing the potential of the new strategies and implementing these with success. However, it is important to point out that the so-called green revolution could never have come about but for the scientific discoveries and scientific data accumulated over the period of time prior to the breakthrough. As I have already mentioned these strategies will and must continue; and there will be many aspects of research that will need to be conducted in the agricultural institutes and universities which will relate to practical aspects to meet the felt needs of the farmer. But these by themselves are not going to solve the complex problems that we are going to encounter in our Seventh Plan and beyond. To solve these problems we need new approaches.

There was a symposium on "Basic Sciences and Agriculture" organized under the auspices of the Indian National Science Academy in 1975. The proceedings of this Symposium bring out in great detail the variety of possibilities for new quantum jumps in productivity in the field of agriculture. These possibilities are based on basic on basic research in varied fields such as plant physiology and photosynthesis, biological nitrogen fixation, new work in genetics and genetic engineering and so on. New institutions, centres and programmers need to be supported in these areas; and the potential rewards from this basic research are likely to be so great that we must go ahead even at the risk of failure. But whilst such symposia are held, and valuable and feasible recommendations are made, the follow-up tends to be not commensurate with the importance and urgency of the problems. In my view, this is the opportune time when we should be thinking and planning for the new agriculture that we require in a decade from now and undertake the basic researches that will enable this to happen.

In recent decades we have been witnessing a major revolution in the field of life sciences. This has primarily been brought about through an increased understanding of biological systems at the cellular and molecular levels. This would not be the place to go into the details of these spectacular changes that have come about in our understanding and in our capabilities. These capabilities, coming under the broad heading of biotechnologies, relate to the fields of tissue culture, developments in the field of recombinant DNA technology or genetic engineering, plasmid and gene transfers, developments relating to hybridomas and aspects relating to enzyme engineering, immunology, photosynthesis etc. Apart from the fact that these are areas of science where there is great excitement and significant new developments are taking place continuously, it also turns out that these are areas with great practical applications.

We are now aware of the formation of companies based on biotechnologies, originally started by life scientists who had developed and worked out these techniques, and now significantly backed by major oil companies and pharmaceutical and chemical companies; these new companies are in the several hundred million dollar category. The beneficiary areas are those of agriculture, medicine, energy and industry. For example, in agriculture one is considering the possibility of genetically changing plants to give them resistance to pests, drought and saline soils; to make them convert sunlight more efficiently; and to persuade them to fix nitrogen from the air rather than relying on expensive fertilisers. Even without going as far as genetic engineering, considerable developments are taking place through conventional plan breeding and protoplast fusion. In forestry, there are new efforts relating to large scale propagation of trees from cells taken from leaves and growing baby trees in test tubes. Biological processes are being developed for a whole range of chemicals such as ethanol, ethylene glycol, ethylene oxide, lubricants, olefins and paraffins, various fine and ultra-pure chemicals etc. In the area of medicine many products are likely to be extracted from blood by genetic engineering including albumin, urokinase etc.; and this technique may be used to produce a number of vaccines such as those for animals for swine dysentery, and safer foot-and-mouth vaccine; and vaccines for human use against hepatitis and possibly malaria. Hormones such as human growth hormone (HGH) and insulin which control various activities in different tissues of the body, and interferon which is part of the body's immune system, are all products being worked on for production through genetic engineering techinuqes.

It is clear that with the range of problems that we have in the areas of agriculture, animal and human health, population control, energy and the production of a range of interesting chemicals and pharmaceutical products, the new biotechnologies will play an increasingly important role. These technologies are science-based, and if one is going to embark on them and to participate in their development, particularly for applications of great interest to our country, we will have to encourage and support significantly research and development in educational institutions which alone can generate the needed scientific manpower, as also in major national institutions of research which will need to be set up where major facilities for work in such areas can be well provided. I shall now cover briefly some areas of basic science that are relevant to high technologies. There is today, a large gap between basic science and engineering in our county. We have to recognize that with regard to areas of high technology, our industry is behind that of the advanced countries by at least a decade in terms of Sophistication. In the advanced countries, sophisticated industries operating in the areas of high technology are able to interact rapidly with research scientists working in their fields in educational institutions and various research laboratories to make rapid use of the discoveries that are taking place. What are these areas of high technologies? They are primarily the areas of lasers; cryogenics (up to liquid helium temperatures); micro-technologies going down sub-micron levels; high temperature technologies; high pressure technologies; electro-optics and opto-elecronics; new materials and so on. It is important to recognize that in all these technologies the innovative capabilities relating to work in science at the frontiers are required. If one does not have ongoing basic research to cover these areas, it would be very difficult even to identify meaningful areas of application, to define what can be indigenously developed and that which needs to or could be imported equipment and systems for use as black boxes, or makes some of these under license in the country. But the rate of change in these areas is so significant that one will be permanently trailing in cost and economics of production, and in international competitiveness, in many areas where we have advantages otherwise. These also happen to be areas on which a very large number of Indian scientists and technologists are working abroad and it is unlikely that one can bring them back except through opportunities for similar work of India.

In more concrete terms let me illustrate the scenario in the fields of electronics and material science:

In electronics particularly since the Second World War, a continuing revolution has been taking place, the origin of which was basic scientific research relating to the applications of quantum mechanics to understand solid state phenomena. This resulted in the invention of the transistor, and thereafter through a series of integrated circuits in common use today where one talks of 256,000 bit memory chips, and achieving by the end of the decade million bit memory chips.

What is clear is that many apparently separate fields are merging together to form an enormously new and powerful whole. Advance in computer and communication technologies are bringing about an inseparable union of these two fields. The development of these technology is now mutually dependent. Large volume data to and from computers are transmitted over communication lines. Equally, telecommunication systems are becoming increasingly electronic with the introduction of electronic switching systems; it is the switching side which had remained largely mechanical and electromechanical up to now. In addition, a new development of great importance for high density traffic will be the use of optical fiber based telecommunication, where the light source will be solid state laser. A further important development is that the communication format will become mostly digital. The shift from analog to digital system will further merge the computer and communication fields.

The electronic revolution is bringing about an information revolution. Computer which were once considered to be large central machines meant primarily for large volume routine computation or for advanced research, are now becoming all-pervasive, with a continuous spectrum ranging from the pocket or hand-held calculator up to the largest computer. A major development has been the advent of the microprocessor. It is the evolution of the silicon chip technology that has enabled this progress in capability, lowered cost and increased areas of application; and as this chip technology continues to evolve, the distinction between micro, mini and large computer will depend less on size have diminished over the years while computation speed has increased substantially; further increases in speed are expected. Computers now under development will store much greater amounts of information at less than one par cent of current costs. One of the major areas to work over the future will relate to software. As a result of all these, the information revolution will permeate society on a very general basis.

Information is the key to development and progress. Until recently transfer of information had been effected mechanically through persons, through mail and printed matter; and communication systems were largely mechanical or electro-mechanical. These involved bulk transport of matter; and mobility in physical space obviously had its limitation. In the future, information transfer will essentially be through electrons or coded electromagnetic waves. What will be needed are appropriate terminal device at the points from where information is sent out and where it is received.

A part from the aspects that I have already mentioned, major advances have taken place in microwave technology, radars, lasers, video systems and broadcasting, transducers, industrial control, inertial guidance and many other areas in electronics.

Let us now consider the area of materials. In the past we were content with making use of materials that were readily available. Present industrial needs demand new materials, with specific properties; this is particularly true for the high technology areas such as aerospace, nuclear and electronics engineering etc. The availability of suitable materials will define the progress possible in these fields. Factor that have to be taken into account are restricted availability and

Increasing costs of energy, as well as of many relatively scare non-renewable resources.

In the area of discovery and extraction of raw materials, the new developments will be based on increased scientific knowledge about the earth, particularly based on the theory of plate tectonic, new systems for airborne profiling of the terrain, new technology in marine geology and geophysics to explore the ocean potentials (for gas, oil, minerals) particularly in the continental margins, and the use of remote-sensing techniques.

A substantial effort is needed to develop substitute materials, such as high strength polymers and ceramics in place of energy-intensive or scarce materials. Similar substitution efforts will cover replacement of stainless steel by iron-aluminium alloys, or whole platinum by platinum-coated parts; use of recycled material in asphalt pavements etc. Composite materials are often stronger, lighter and more durable than conventional materials, and their use can lead to significant savings; examples are of fibre reinforced plastics, carbon fibre which is stronger than steel, and ferroics with 3-dimensional or 2-dimensional connectivities; in the case of these new materials, aspects relating to their life and of failure (under stress and environmental conditions) need careful investigation. In view of the problems relating to the high cost and decreasing availability of oil-based raw materials, possibilities need to be explored of organic materials extracted from plants, and particularly those that grow well on poor lands. In many cases, instead of new classes of alloys, material scientists hope to meet specific requirements by modifying the internal structures in metals through precise control of the steps in fabrication. Thus high-strength micro alloy steels may be increasingly used in automobiles because they save weight. It is now known that all materials can be made amorphous. Amorphous materials have unique properties (distinct from those of crystalline materials), and these properties can be exploited to advantage; examples are the use of amorphous semiconductors such as silicon, and of metallic glasses, that will find important applications for transformer windings etc. Mention should be made of the challenges in the area of superconducting materials, particularly the possibility of high temperature superconductors. Diamond is the hardest metal known; can we develop super-hard materials? Other possibilities in the field of materials include: synthetic polymers (plastics and synthetic rubber); low cost polymer materials with improved properties; ceramics, particularly silicon ceramics; materials based on directional solidification; powder metallurgy techniques to get near-net shapes; new methods for detecting wear; and new surface treatments particularly using laser and electron beams. This is only an illustrative list, but indicative of a high temp of development that will continue to yield materials of interest for transportation, aerospace, electronics and other high technology applications. But these are areas that can be developed only through an understanding of the physics and chemistry of condensed matter, and the most advanced multifaceted instrumentation to probe compositions, structures, surfaces and so on.

In this part of my talk I have attempted to give both the philosophy as well as details of some fields which could be regarded as areas of thrust in agriculture, biotechnology, and in high technology areas such as electronics and materials. It would be a very claborate exercise to do this in detail to cover all areas of science; and I shall, therefore, not attempt this in this talk. I would like to stress that my list is illustrative and not comprehensive.

Selection of Areas of Thrust

It would be of some interest to consider the rationale that one could employ for selecting areas of thrust for basic research. Firstly, the area must be one which is clearly regarded as in the front line of development, or likely to be so. It must be an area where one can build an effort which is viable and critical on the basis of resources that can be provided by a country such as ours. It should also be an area where there already exist interested individuals who are deeply motivated and of the highest quality, whose work should be supported and strengthened; it is always necessary to ensure a minimum size for research groups so that advantage can be taken of a high level interactive community; it is also desirable to have several groups working in the field in the country, who could interact amongst each other by exchange of personnel, through discussions, and for whom major and expensive facilities can be provided on a common basis. Finally, it would be desirable if the concerned area has clear possibilities for relevant application, that would be supported by other work in complementary areas of applied research and development, where larger sums of money are generally available for infrastructural aspects. In the absence of such criteria, the tendency is to look at each project or programme on its own merits, as it is put forward, and to spread the available resources over a wide range of projects that get approved, without leading to a critical mass or thrust in any particular set of areas. It is the responsibility of the scientific community to discuss these issues and put forward its views on how the scientific effort should be focused so as to make the greatest impact at a select number of points across the whole scientific front. It is, of course, clear that resources must be available for the support of individuals of the highest quality, who may wish to put forward programmes of their own, which do notCome within any such planning exercises. The system must have the capcity to recognize such situations, and the flexibility to ensure that such support is provided.

It is worth while to emphasize that there have been spectacular advances in the filed of instrumentation that have transformed the entire experimental approach in science. The days have gone when scientist had to take readings, record them and make graph etc. using the data. Today, practically every instrument is a "smart" instrument with attached microprocessors which enable the data to be automatically reduced to desired formats and then display or print them. Interactive displays are also in use in a variety of situations. There are a whole host of new techniques for analysis of minute quantities of materials at the levels of parts per billion or parts per trillion impurities in solids. We can look at atoms directly with high voltage high resolution electron miscroscopy, under realistic conditions including dynamic changes. A veriety of techiques can be brought to bear simultaneously on a single problem giving insights from different angles. A laboratory equipped with these modern instrumentation facilities is capable of obtaining data of a highly complex nature and proceeding then to the building up of hypotheses to enable further planning of experiments, all in a matter of a few hours or a few days, whereas working with the older approaches that many of us used two or three decades ago, and that are available in our laboratories, one would need time periods of half-a-year or a year for this. It is extremely Important the instrumentation facilities right at the front line be provided on a selected basis in the country.

Role of the Professional Bodies such as the Academies and Indian Science Congress in Postering Basic Research

Scientific academies, professional societies and those concerned with publication of scientific and those concerned with the publication of scientific and technical journals have an exceedingly important role to play in setting standards of excellence for scientific research. This is primarily because science can only advance through open critical discussion and debate. Scientific work must be presented to the widest possible audience. Indeed in the earlier period, scientists made serious efforts to communicate with each other by extensive correspondence so as to get different views to bear on their own work and thinking. Today, this is largely accomplished through meeting and publication of scientific results in journals. It is not surprising that the tremendous growth of science that has taken place over the past few hundred years is also related to the advent of printing and the increased ability to travel and interact. A principal objective of scientific academics and professional societies/institutions should be to arrange for such scientific discussions. Indeed, in all scientific institutions, there must be a conscious effort to have regular programmes of lectures, seminars and discussions, where the work being carried out is presented and critically assessed. Science does not believe in secrecy. Science also does not believe in hierarchy and the youngest listener has the fullest right to question and criticize what may have been put forward by senior and distinguished scientists. Indeed, this must be encouraged, for it is more than likely that the younger colleague has the more original approach, whereas it is the more senior scientist who has greater experience, information and skills. In the case of papers sent to scientific journals they ought to be objectively and critically referred so that only sound work gets published. In the absence of good journals of science in the country, the tendency is to publish a broad; this has in any case been so beacause of the undue importance attached within the country to publications in journals aborad. The scientific and professional societies of the country must come together to ensure that the major part of the scientific work done in India, and certainly the best work, is published in this country. Professor Raman has remarked: "While the foundation of the scientific reputation of a country is established by the quality of work produced in its institutions, the superstructures is reared by the national jounals which proclaim their best achievements to the rest of the world. Manifestly the edifice of science in India is incomplete... It is true that the spirit of science and its service are international, but it is not also true that every nation has its own Academies, learned societies, magazines and journals? India will have to organize and develop her national scientific institutions before she can enter into the comity of international scientists."

It is for this reason that a special effort is being made during the Sixth Plan period to consolidate and strengthen the professional academies and societies in India to play this role.

On this occasion, let me say something more particular about the Indian Science Congress.

The India Science Congress was established in 1914 with the first objective being defined as "to advance and promote the cause of science in India". In fact, in the detailed account relating to the Indian Science Congress Association it is stated that it was "Established in 1914 to convince people and Government that science plays a vital role in the life of the nation. "It is very clear from these objectives and the manner in which the Indian Science Congress is structured, that it is largely patterned on the British Association for the Advancement of Science which had its first meeting in York 150 year ago. It may be of some interest for those of us concerned with the Indian Science Congress to go back to the origins of the British Association which can be traced back to Charles Babbage, credited as the father of the computer, and to David Brewster, the well-known optical physicist and the inventor of the laleidoscope. I recount this background intentionally for the reason that it throws light on the manner in which science has changed with time and also on how we should organize ourselves in the future to promote the cause of science.

Babbage who was on a visit to Germany in 1827, at the invitation of the great Alexander Von Humboldt attended a meeting in Berlin of the DeutscherNaturforscherVersammlung. This society had arisen from the idea of having "a great yearly meeting of the cultivators of natural science and medicine from all parts of the German fatherland". Babbage was greatly impressed by the meeting. At that time he was, infact, very depressed about the state of science in his country, and had written a book entitled "Reflection on the Decline of Science in England". On return from Germany, Babbage wrote an article in the Edinburgh Journal of Science, edited by David Brewster, on the German meeting which he had just attended. This struck a sympathetic chord amongst many in Britain. Brewster worked up the idea of having such a meeting in Britain and what it could do. He stated that it would make: "the cultivators of science acquainted with each other, to stimulate one another to new exertions-to bring objects of science more before the public eye and to take meausres for advancing its interests and accelerating its progress" and further "to revive science from its decline, and the scientific arts from the depression; to instruct the government when ignorant, and stimulate when supine; to organize more judiciously our scientific institutions, and the public boards to which scientific objects are entrusted,..... to raise scientific and literary men to their just place in society". These views would hold good as the objectives of the Indian Science Congress today.

I would also like to remind you that some of the great discoveries of science were reported originally at the British Association for the Advancement of Science. These Included. J.J. Thomson's announcement of his discovery of the electron (1899); the demonstration by crookes of the properties of cathode rays (1879); the discovery of a new gas argon by William Ramsay (1894); the ideas of James Joule on the mechanical equivalent of heat (1843); Clark Maxwell's first reports on molecular physics, and ideas on the Maxwell first reports on molecular physics, and ideas on the Maxwell distribution (1873); Clark Maxwell's first reports on molecular physics, and ideas on the Maxwell distribution (1873); Fitzgerald's report on the discovery by Hertz of the electromagnetic waves predicted by Maxwell (1888); Millikan's measurement of the unit charge on the electron (1909); etc. Additionally, many of our scienctific units originated with the British Association: the joule; the ohm, the dyne and the erg; the CGS system of measurement etc. I am more than a ware that all this occurred in the historical, just when science started on its present dizzy exponential growth. Today most discoveries are reported over the radio and in the daily press, and discussed at highly specialized thematic meetings. They are no longer reported at the British Association for Advancement of Science, nor will they be at the India Science Congress. (We should of course remind ourselves that Prof. Raman reported at the January 1929 (Madras) Science Congress, in his Presidential Address, the work done in Calcutta over the previous year which resulted in the discovery of the Raman Effect.)

There is no reason, however, why topics of major scientific interest and excitement should not form part of our discussion at the Indian Science not form part of our discussion at the India Science Congress which happens to be the largest single gathering of scientists in the country, covering the whole range of sciences. The Indian Science Congress should not be a place for reporting of routine measurements or for discussing pedestrian details of science policy. It should be a forum to generate a sense of enthusiasm and elan in the scientific community. With its coverage of a wide spectrum of scientific disciplines it can arrange for panel discussions on interdisciplinary aspects where some of the major thrusts occur for as C.V. Raman has remarked: "History of science has shown that real fundamental progress is always due to those who had ignored the boundaries of science and who treated science as a whole". This was a man interested in the colour of the sky and of the sea, in crystals and diamonds, in the theory of vision and of hearing; in the theory of musical instruments and much else.

Basic research always happens to be an area of innovation, originality and excitement. And the Science Congress should attempt to focus in this direction if it is to be dynamic and relevant and excite the young minds.

An aspect which the scientific community must always keep in mind is that, if science is to grow and flourish, it must attract to science some of the finest minds of the country. This can happen if one can convey to the potential young scientists a sense of excitement and the possibility of new discoveries. It is the young minds who are characterized by the greatest originality, and it is this generation which is capable of putting in exceptionally hard work. A very important reason for strong support to research in the educational system is that it is here that we find the truly young generation, in the student community. Some deliberate measures are called for to see that the best and that well trained amongst them are provided adequate incentives to take up research as a career, and that areas are defined and supported that best serve national interest and priorities towards which such talent can be directed or encouraged to work on. The Indian National Science Academy awards each year the Young Scientists Medal, which is presented by the Prime Minister at the Indian Science Congress Session. This is an attempt to focus attention on work of high quality accomplished by very young Indian scientists. Particular efforts are also being made in the Sixth Plan to involve young scientist directly on a more active basis in scientific research and development.

Concluding Remarks

In conclusion, I would like to restate some of the aspects that I have covered in this address that I regard as important, and also which call for action both on the part of the scientific community as well as decision makers at various levels.

Indian science and technology have been placed on a relatively firm footing through major efforts since independence. We are now at a take-off point, but the question is whether we will seize this opportunity. A large part of the resources allocated have been in the areas of applied research and development, and in these, wherever clear-cut tasks have been assigned. Indian science and technology has invariably produced the results expected of it. What is important is that, on the basis of perspective planning, the needs and investments in the productive sector are clearly defined, well in advance, so that the appropriate scientific effort can be initiated right now to meet those requirements. Furthermore, there is no point in undertaking applied research and development on an ad hoc basis, without a clear appreciation that investments will take palce downstream which can make use of the scientific effort.

The world of today is quite clearly a world characterized by science and technology. In the future it will be characterized even more so. Technologies relating to areas across a whole spectrum of agriculture, health, energy, industry and so on are becoming increasingly science-based, and for any meaningful efforts in applied research and development it is essential that we have in the country the appropriate background of basic understanding. This, as well as its role in the system of education and the creation of manpower in the country with innovative capabilities, demands the execution of basic research across a wide spectrum. Applied sciences and technology are forced to adjust themselves to the highest intellectual standards that are developed in the basic sciences. This influence works in many wyas; for example, some students trained in basic research come into industry; again, the techniques which are developed and applied to meet the most stringent requirements of basic research at the frontiers of human capability serve to create new technological method for industry.

There is total national agreement on the importance of self-reliance. The problems we encounter are large in magnitude, and many are locale specific; we have to find solutions for these ourselves, and it is for this that innovative thinking, characteristic of basic research, acts as a pace setter. All of this is inherent in the Scientific Policy Resolution. What we need to do is to aim steadfastly at implementing this Resolution in its true spirit.

Basic research needs to be supported first in the educational institutions which have been allowed to run down sadly in recent years. Much greater support is required to build up the infrastructural capabilities, at least on a selected basis, in educational institutions. Apart from this, basic research bodies. In many areas of agricultural, industrial and defense research, faced with the problems of the immediate, there is a tendency for decision makers to insist that everything is directed at solving felt needs of the users. I have very often emphasized that in the case of the Council of Scientific and Industrial Research, the word 'scientific' precedes the word 'industrial'; and in fact the organization can be effective for industrial research only by carrying out scientific research. This is equally true in areas of agriculture, of medicine, of defence and so on.

We have to recognize that basic research has to comply with international standards of performance and excellence; and is centredaround the most gifted individuals. The environment under which such individuals work, and attract outstanding pupils and create centres of excellence, is not the environment of factories or of Government departments. Apart from the financial support needed for nurturing such centres of excellence, there is the need to support them in generating the culture where such growth can take place. In this respect, the situation has deteriorated in recent years.

Many of our activities today on the scientific scene relating to the educational sector, the national laboratories, the industrial sector and Government departments are largely linkages amongst these, which are not difficult to implement but are largely missing because of administrative and financial bottlenecks.

The future of science will depend on attracting some of the finest minds of the country to scientific research. The importance of enthusing and nurturing the potential young scientists of the country needs no emphasis. Professional bodies have an important role to play in this regard as also in that of popularization of science.

It is clear that resources both human and financial will not be available to cover that total spectrum of science and technology on a viable basis. We have to be selective in the thrust areas that we choose to concentrate on. Many of these can and will relate to problems in our immediate environment, which offer opportunities not only for work at the frontiers of science but also for work that could have relevance for large sectors of national development.

The value of basic research does not lie only in the discoveries it leads to which are international. There is more to it. It affects the whole intellectual life of a nation by determining its way of thinking, and the standards by which actions and intellectual production are judged; an atmosphere of creativity is established which penetrates every cultural frontier. It is fundamental research which sets the standards of modern scientific thought. As C.V. Raman has remarked: "Unless the real importance of pure science and its fundamental influence in the advancement of all knowledge are realized and acted upon, India cannot make headway in any direction and attain her place among the nations of the world. There is only one solution for India's economic problems and that is science and more science and still more science.

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Annexure

GOVERNMENT OF INDIA SCIENTIFIC POLICY RESOLUTION

New Delhi, 4th March 1958

No. 131/CF/57. The key to national prosperity, apart from the spirit of the people, lies, in the modern age, in the effective combination of three factors, technology, raw materials and capital, of which the first is perhaps the most important, since the creation and adoption of new scientific techniques can, in fact, make up for a deficiency in natural resources, and reduce the demands on capital. But technology can only grow out of the study of science and its applications.

2. The dominating feature of the contemporary world is the intense cultivation of science on a large scale, and its application to meat a country's requirements. It is this, which, for the first time in man's history, has given to the common man in countries advanced in science, a standard of living and social and cultural amenities, which were once confined to a very small privileged minority of the population. Science has led to the growth and diffusion of culture to an extent never possible before. It has not only radically altered man's material environment, but, what is of still deeper significance, it has provided new tools of thought and has extended man's mental horizon. It has thus influenced even the basic values of life, and given to civilization a new vitality and a new dynamism.

3. It is only through the scientific approach and method and the use of scientific approach and method and the use of scientific knowledge that reasonable material and cultural amenities and services can be provided for every member of the community, and it is out of a recognition of this possibility that the idea of a welfare state has grown. It is characteristic of the present world that the progress towards the practical realization of a welfare state differs widely from country to country in direct relation to the extent of industrialization and the effort and resources applied in the pursuit of science.

4. The wealth and prosperity of a nation depend on the effective utilization of its human and material resources applied in the pursuit of science.

5. Science and technology can make up for deficiencies in raw materials by providing substitutes, or, indeed, by providing skills which can be exported in return for raw materials. In industrializing a country, a heavy price has to be paid in importing science and technology in the form of plant and machinery, highly paid personal and technical consultants. An early and large scale development of science and technology in the country could therefore greatly reduce the drain on capital during the early and critical stages of industrialization.

6. Science has development at an ever-increasing pace since the beginning of century, so that the gap between the advanced and backward countries has widened more and more. It is only by adopting

the most vigorous measures and by putting forward our utmost effort into the development of science that we can bridge the gap. It is an inherent obligation of a great country like India with its traditions of scholarship and original thinking and its great cultural heritage, to participate fully in the march of science, which is probably mankind's greatest enterprise today.

7. The Government of India have accordingly decided that the aims of their scientific policy will be:

i) To foster, promote and sustain, by all appropriate means, the cultivation of science of sciences, and scientific research in all its aspects-pure, applied and educational;

ii) To ensure an adequate supply, within the country, of research scientists of the highest quality, and to recognize their work as an important component of the strength of the nation;

iii) To encourage and initiate, with all possible speed, programmes for the training of scientific and technical personal, on a scale adequate to fulfill the country's needs in science and education, agriculture and industry, and defence;

iv) To ensure that the creative telent of ment and women is encouraged and finds full scope in scientific acitivity;

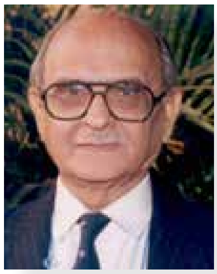
v) To encourage individual initiative for the acquisition and dissemination of knowledge, and for the discover of new knowledge, and for the discovery of new knowledge, in an atmosphere of academic freedom; and

vi) In general, to secure for the people of the country all the benefits that can accrue from the acquisition and application of scientific knowledge.

The Government of India have decided to pursue and accomplish these aims by offering good conditions of service to scientists and according them an honoured position, by associating scientists with the formulation of policies, and by taking such other measures as may deemed necessary from time to time.

Basic Science: A Clinician's Perception

Prof. P. N. Tandon
National Research Professor
Former President, NASI



"If however the base of science in the country is weak or unsound or not getting the support and climate that it needs for its own growth and development then science as a force for development will obviously not be effective."
Late Prof. M.G.K. Menon

First, I must congratulate the Academy for a timely selection of a topic of great contemporary significance: "Basic Research – It's Role in National Development" for its annual symposium. It is important for a variety of reasons. Recently, there has virtually been a national hue and cry, lamenting on the state of Indian Science. This includes directly and indirectly, comments by the (former) Hon'ble President, Vice-President and Prime Minister of the country, echoed by some of the most outstanding scientists including Bharat Ratna Prof. C.N.R. Rao, who themselves have been responsible for guiding the destiny of Indian S&T (Tandon 2016). At the same time, the term 'science' in the perception of our people and policy makers alike includes technology.

Though the two are to a certain extent inseparable and have ill-defined boundary, for a variety of reasons (to be discussed later) it is important to point out some practical distinctions between the two. 'Basic Research', 'fundamental research', 'blue-sky research' and 'curiosity-driven research' are terms interchangeably used for basic science'.

Scientific research is no doubt, a seamless continuum consisting of knowledge generation, acquisition and utilization. It thus includes all elements including fundamental/basic/blue sky research on one hand and engineering and technology research on the other. However, as Prof. Menon pointed out "...there are certain philosophical, cultural and intellectual aspects of basic research that are not well appreciated, but which underpin in an essential manner the very concept of self-reliance. And for basic research to flourish it needs an appropriate environment and climate as much as financial support (Menon 1982).

Years ago Prof. C. V. Raman argued, "Unless the real importance of pure science and its fundamental influence in the advancement of all knowledge are realized and acted upon, India can not make headway in any direction and attain her place among the nations of the world. There is only one solution for India's economic problems and that is science and more science and still more science."

Addressing the General Assembly of ICSU in Bombay in 1965, Homi Bhabha pointed out that, "what developed countries have and what developing countries lack is modern science and an economy based on modern technology". He therefore advocated that "establishing science as a live and vital force is inseparable part of transforming an industrially underdeveloped country to a developed country." More recently Prof. C.N.R. Rao stated, "Science has to be protected for its own sake. Countries interested in technological development have to support scientific research of the purest kind as an essential element. The funds spent for 'blue sky' research may vary from country to country yet it seems that unless some creative science activity is promoted it would be difficult for a country to cope with advanced technologies and new developments in industry in the long run. Futuristic science is an essential ingredient for futuristic technology." Fundamental research is an investment in future. From it arises the unexpected, the discontinuities which the economic forces can never conjure up. Alexander King addressing the TWAS Conference in 1992 pointed out, "Despite the absence of direct economic gain from nation's fundamental research, it is essential for each country to cultivate it to a certain degree. It imparts a sense of contemporary flavor to the educational process, contributes to the level of scientific and hence technological awareness and is a basis for the training of applied research workers and development engineers."

Further details of a thought provoking discussion on the subject "The essential role of science in technological progress and economic development" may be seen in the Proceedings of the Conference on the subject held at TWAS in 1992.

While most scientists and technologists appreciate the difference between the various aspects of scientific research, it is desirable to clarify it here. Since lay people, bureaucrats and policy makers, not acquainted with these mix up science and technology as the same. This has its implications in respect to the expectations from their outcome, which will be elaborated later.

It is not commonly recognized that however strong the interaction between science and technology it is not linear. None of the scientific discoveries that have changed our life, electromagnetism, discovery of double helix, Newton's third law of motion, the second law of thermodynamics, the equations of relativity and quantum mechanics, the periodic table of elements, the genetic code, were all results of basic research. Neither their discoverers, nor their contemporaries had any idea of their apparent application value, yet most of our day to day existence today is dependent on it. It is not surprising that Rutherford the founder of nuclear science called prospects of releasing atomic power moonshine; Roentgen failed to realize that his basic discovery will revolutionize medical diagnosis and is the basis of all recent developments in the field of medical imaging. It often takes decades and even more for any practical application of results of basic research. It was not C V Raman who converted Raman Effect for its use in Raman Spectroscopy which today is a valuable investigation tool.

Basic research is an intellectual journey into the unknown. Unpredictability is the essential in search for new knowledge – the primary objective of all science. Thus it was in 1950's that scientists found that heredity (already discovered a century ago) was controlled by a simple code written in DNA. In 1960s the code was deciphered. In 1970s they found how to insert new genes into the code of bacteria. In 1980s it was achieved and gave birth to a new industry – Biotechnology – which is now a multi-billion dollar enterprise globally. Many more such examples can be quoted but I may add a more recent one from personal experience (Tandon 2001). The notion of stem cell *stammzelle* was initiated in Imperial Germany in the late nineteenth century by Ernst Haeckel. Theodore Boueri introduced the term in embryological studies and early genetics around 1900. A little later Ernst Neumann and Arthur Pappenheim discovered the role of stem cells in the physiological hematopoiesis (Maehle 2011). It was only towards the end of the twentieth century that human embryonic stem cells were isolated (Thompson et al 1998). Based on rapidly accumulating evidence from diverse sources the use of such isolated cells were successfully transplanted in the rodent and monkey brain to replace damaged and lost brain cells (Auerbach et al 2000). Much progress has been achieved in this direction during the last two decades. Their potential use for treatment of a host of diseases of the human nervous system has been found to be very promising. Notwithstanding many recent advances, it is generally acknowledged that much more basic research is required before routine clinical application of this knowledge would be possible (For other such examples in the field of neurosciences, see Tandon 2002 and 2004).

In general, it is true that notwithstanding significant contributions to translational and clinical research in the field of medicine and health research, basic science research has remained neglected and continues to be so in India (Tandon 2018). As a matter of fact, the concept of basic sciences among medical professionals has been restricted to research in the field of anatomy, physiology, and pharmacology. The newer disciplines like molecular biology, immunology, genomics, cell sciences and neurosciences which have been responsible for the most spectacular advances in biomedical field are not even included in the medical curricula in most medical colleges. There is hardly any interaction between national institutes in these fields and the medical colleges. It is worth pointing out that these fields of Biomedical research were originally founded by non-medical scientists – physicists and chemists, biochemists (Delbruck, Khurana, Watson and Crick to name a few) and yet the prospective medical students are inadequately exposed to these fields before or during their medical education. Unless this is remedied, we are unlikely to acquire leadership status in overall field of health research nor successfully solve our unique health problems.

It is said that basic research is often motivated by a question no one knew needed to be answered, answer it and move on, leave the technologists to turn the answer into a machine, a drug or a computer program. It is not possible to prescribe a fundamental discovery. The greatest deterrent for basic research is the belief among the public and policy makers that only what is capable of solving immediate problem, and what is immediately and directly 'relevant' is worth researching. This is reflected in Hon'ble Prime Minister's Shri Modi's address at the 105th Indian Science Congress held at Manipur 15-20 March 2018, "This year the time is ripe to redefine "R&D" as Research for Development" of the nation" – "that is R&D in the real sense. Science is after all, but a means to a far greater end – of making a difference in the lives of others of furthering human progress and welfare." He added, "Science and technology could help facilitate 'ease of living' for the people". He said, "Scientific knowledge should be applied to solve day-to-day problems in various sectors such as housing, malnutrition, clean energy and elimination of diseases."

The objectives and expectations from S&T referred by him cannot be disputed and in principle, should be a matter of concern for scientists and more so to the technologist. Nevertheless, it unwittingly undermines the importance of basic research which provides the base or foundation for all S&T. As a matter of fact, the need for scientists to pay attention and even give priority to issues of societal relevance has been a matter of equal concern to leaders of the developed world also. Hence it is the responsibility of scientists themselves, and even more so of the science academies, to inform and advise the public and policy makers that without strong basic research the necessary applied or translational research is unlikely to bear fruits. Homi Bhabha addressing the ICSU General Assembly in 1965, reiterated, "establishing science as a live and vital force is inseparable part of transforming an industrially under developed country, to a developed country." Obviously this referred to development and support to basic science/research. As recently as 2016, addressing the Indian Science Congress Nobel Laureate in Physics David Gross remarked, "…. attempts at manufacturing high end products in India won't yield the desired benefits unless backed by sustained investments in basic science – right from school to higher education".

It may be of interest for our policy makers to pay heed to a studied statement by Frank Press, a former President of the US National Academy of Sciences, "Money spent on fundamental science research has a rate of return of 28 percentage a year and technical innovation accounts for 4 to 7.7% of productive increases". In this connection he pointed out that, "Science has come a long way from Bunsen with his burner. Chemists have worked in teams since the nineteenth century, physicists since Rutherford, and biologists began to do so more recently. A single experiment on the supercollider being built in Texas will employ 1000 people. Even in Biology, a typical American University laboratory has an annual budget of one million dollars". To quote Prof. Menon once more "……. Science can only grow if it has the right milieu. Science is not a stand-alone system; it derives its strength from the society and its value systems that are part of the society."

The unit for Policy Research in Science and Medicine of the Wellcome Trust, London arrived at a similar conclusion, "On the face of it investment in basic research may not be justified by economic reasons alone as its benefits are not obvious in the short-term. But futuristic science is an essential ingredient of futuristic technology. Recent developments in the field of information technology, biotechnology or the emerging field of nanotechnology provide enough evidence to support this contention."

The global economy is experiencing a period of rapid technological change in which the dominant feature is the growing science content in technology. The modern world is characterized by the emergence of the “knowledge economy”. To survive in this economy, a much higher knowledge base is necessary than what was required till recently. Even if the developing countries are unlikely to generate comparable or competitive technologies, it requires a strong base of endogenous S&T competence to select and adapt the relevant technologies for their effective utilization. It is therefore important to recognize that for successful application of S&T for developmental objectives, there must be a proper balance in the endogenous S&T capabilities at all levels.

The vast range and deep sophistication of contemporary science and the diversity of technologies based on it dictates the need for creating a critical mass of scientific activity i.e. the creation of an endogenous problem. There is a failure to recognize science as a public good amongst the political leaders in many developing countries, who while paying lip-service to the value of S&T have failed to provide the necessary resources to develop it.

Science and fundamental research are thus essential first of all for inspiring education and training, secondly for tapping into world research, and thirdly to stimulate creativity of the individual. Unlike in the earlier years of industrialization today technology is generally driven by science and in turn, technology drives science. It is what seems to have prompted Fredrico Mayer, Director General, UNESCO, to advocate at the World Congress on Science, at Budapest in 1999 that, “Capacity building in the developing world must put emphasis on basic science more than technology transfer. Only this can put each country in-charge of its application of science and technology”. Abdus Salaam, an outstanding leader of science from the developing world, exhorted the members of the Third World Academy of Sciences thus, ”A country to become less dependent technologically must create its own science.”

In addition to the intrinsic values of scientific research it must be realized that just as scientific competence is dependent upon a sound educational base, similarly technological development requires sound scientific competence. The interrelatedness/dependence of science education, scientific research (basic), technological development (applied research), industrial development (R&D) and commercial (market) opportunities makes it imperative for attention to all these by national policy makers if they hope to raise the standard of living of their people.

Who should support Basic Research?

It is quite understandable that most governments, specially in the developing countries, in their eagerness to promptly deal with the pressing societal problems are reluctant to invest in programmes not likely to result in predictable outcome in a time bound fashion – an inherent limitation of basic research as illustrated above. This is also true to some extent even in the developed world where a large amount of scientific research is supported by the industry and philanthropic organizations. A recent conference in Australia on “Nurturing Creativity” testifies to this fact. The deliberations revealed, “Some extreme examples of growing tendency of governments to drive research towards strategic socio-economic goals at the expense of basic research." Prof. Philipa Black, President of the Royal Society of New Zealand gave the most stunning examples of harm done to basic research through strategic planning. The conference concluded, "Why be apologetic? Let's argue very strongly that blue-sky research is very much in national interest." And "Basic Research, it seems, provides a base for development of new technologies and economic growth". (Swinbanks 1996). Compared to the developed countries support for basic research from industry and philanthropists is very rare in developing countries. However, there are exceptional examples like that of JRD Tata who not only made personal and Tata's son's contributions for the establishment of the Tata Institute of Fundamental Research (TIFR). But it is even more important to recognize what an industrialist of his stature and standing had to say on the subject of fundamental research. Soliciting funds for TIFR from one of his industrialist friend, he wrote, "You may perhaps feel that advanced physics, mathematics, astrophysics are particularly abstract subjects, research in which is unlikely to produce material or practical results within a reasonable period of time. I should, however, like to point it out that most of the great practical advances in science, and therefore in industry, have had their origin in fundamental research without which they would have been impossible or would have been long delayed."

(Quoted by Prof. MGK Menon in his public lecture at TIFR on 28th July 2004).

It is interesting to note that even Margret Thatcher acknowledged that," the majority but not all of basic research, is rightly funded through the public purse by way of universities and scientific institutes." A report, "Rising above gathering storm" by the U.S National Academy of Sciences recently concluded that the two highest priorities to preserve American Competitiveness are repair our K-12 education system and to increase our investment in basic research" (emphasis by the author). Nature in an editorial pointed out that it is essential to recognize the need to safeguard the status of scientific knowledge as a public good in an era of rapidly spreading privatization (Nature 1998). By implication 'public good' needs to be served by public finds. World Conference on Science (1999) in Budapest unanimously acknowledged the need for supporting S&T development to minimize the existing gap between the developing and developed countries. It may be pointed out that the Government of India is a signatory of this UNESCO declaration. This was unequivocally highlighted in the Inter Academy Council report, "Inventing Future" in 2004.

In India, unlike in developed countries, most of the budget for S&T comes from the state, primarily the Central Government. While the overall S&T budget has increased over the years, but not as a percentage of the GDP. It has remained below 1.0 percent of the GDP for several decades. In addition, as pointed out by Prof. Menon in 1982, " The largest part of the budget of the S&T sector in the country has so far gone into areas of applied research and development, whether they be in the areas of atomic energy, space science and technology, defence or through the Councils dealing with Scientific and Industrial Research, Agriculture Research, or Medical Research. In each of these areas, there is only a relatively small amount which goes into basic research" (Menon 1982).

It is unfortunate that not withstanding promises to the contrary, the situation remains unchanged, as revealed by a NISTAD study in 2008. During the same period, there has been a substantial increase in S&T budget allocation in China, South Korea, Taiwan and Singapore (For further details see tables 4 & 5; Tandon 2016).

A recent report from NITI Aayog – Three Year Action Agenda – recognizing S&T as one of the 'growth enablers' and need for a strategy for 'spurring it'. It acknowledges that "With economic growth India's contribution to S&T has gained momentum but it still lags behind the other major economies in the world. (Underlined by the author). It states that India spent only 0.82% of its GDP for S&T in 2011. In this detailed report, there is no specific reference to basic research though it observes that there is a "lack of focus on research in the universities, industry- academia research link". Obviously, the critical role of basic research for development remains understated.

It is universally recognized that the universities are the real home for basic research. Yet, the state of Indian Universities has remained dismal as is highlighted in a number of detailed studies reported recently (Pawan Agarwal 2009, Beteille 2010, Patel 2012, Tandon 2016). As recently as 2016, (former) Hon'ble President of India Shri Pranab Mukherjee delivering a Convocation Address at BITS, Mesra, called for "the need to arrest the declining standards of education in the country". The poor contributions to basic research by our universities is reflected in the fact that an analysis done by UGC in 2009, only 20 of the 120 traditional Universities have a Fellow of one of the three science academies. In 2013, the author found that during the last decade, among the 287 Fellows elected to the Indian National Science Academy, there were only 60 from the Universities that included IISc, Delhi University, BHU etc. (Tandon 2013).

Conclusion

It is now universally accepted, even by hard-core economists, that S&T contributions are an essential component for national development. Basic Research is the foundation for all S&T activities. The S&T community is aware of the differences between the various constituents of S&T i.e. basic or fundamental research, applied research, translational research, technology and engineering and industrial research and it application for product development. However, the lay public, the administrators and policy makers generally use S&T to cover all these sub-divisions of science. Even though there are no clear cut demarcations between these different sub-divisions of S&T, it is also true that there are certain differences in philosophical, cultural and intellectual aspects of these. There are also different motivations and specific infrastructure, technological and financial and eco-system requirements for successful implementation of basic research. Lack of appreciation of these factors often results in sub-critical support and undue expectations specially in case of basic research. Unpredictability of outcome, high risk of failure, need for repeated confirmation are inherent features of basic research. More often it is search for knowledge for knowledge sake, guided by an instinct to explore the unexplored knowledge without an obvious application. Yet surprisingly basic research constitutes the real foundation of all scientific endeavor necessary for development. The inherent characteristics of basic research result in low priority for support in the mind of the administrators and policy makers as is obvious on close scrutiny of budget allocations. It is therefore the responsibility of the S&T community and specially the science academies to inform the public and policy makers of the importance of basic research in the overall strategy for application of S&T for development. I hope the deliberation of this symposium will serve this purpose.

Let me conclude by a quotation from Swami Vivekananda, "Knowledge has to be acquired for knowledge's sake.........knowledge also has utility." Knowledge acquisition and advancement are the primary objectives of basic research, no doubt knowledge itself is the basis for development.

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II. PRESENTATIONS FROM INVITED SPEAKERS

Indian Science, its Competitive Strength & its Relevance to National Needs

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Based on a NASI study group report made by Prof. Rohini Godbole, Dr. Chandrima Shaha, Prof. K.V.R. Chary, Dr. S. L. Hoti and Dr. Sampat Kumar Tandon, with data compiled by Prof. Jayant Modak.

A. Preamble

In the 70 years since independence, Indian science has had a significant impact, so much so that *"India now ranks 5th in global research publication output where countries from North America, the European and Pacific dominate, both in terms of quantitative and qualitative research"*, as revealed by a joint study by Council of Scientific & Industrial Research – National Institute of Science Technology and Development Studies (CSIR-NISTADS) and Indian Institute of Science Education and Research (IISER) (ref. 1). A significant amount of basic research has been and is being carried out at several academic institutions as well as at a number of research laboratories in India. This has been possible since various funding agencies have been giving research grants for basic research. The Government of India supports several autonomous institutes and organizations under various Ministries and Departments. The budgetary support for selected Autonomous and Grantee Bodies in the domain of Science and Technology for 2017-18 was Rs. 69422.54 crores and the budget estimate for 2018-19 is Rs. 66926.60 crores (ref. 2&3). Further, the Government of India has several central sector schemes under various Ministries and Departments. The revised budget estimate for select Central Sector schemes in the domain of Science, Engineering and Technology during 2017-18 was Rs. 38685.26 crores while the budget estimate for 2018-19 amounts to Rs. 52067.40 crores (ref. 4). These are very significant numbers that our government spends in this domain. It is important to spend on research and development since the development of fundamental knowledge is critical for the growth of science and technology in India.

The alignment of fundamental knowledge with the needs of the globe or a country is quite critical for the growth of science and technology of that country. All leading developing countries have practiced this and the results are there for all of us to see. Even in developed countries, funding for basic research comes mainly from the Government. However, to a smaller but growing extent, research funding comes from Industry Venture Capitalists, since risk is significant and private sector would not like to risk its capital. Whenever applied research is being done and project formulation is with involvement of Industry Partner, funding from Industry is likely. In recent times, the proliferation of technology parks and incubators has drawn research towards applications. In parallel, the glamour of big science projects like Mangalayan has caught international attention as well as public enthusiasm. It is a bright picture to see that co-operation as well as competition between groups and countries has led to mega projects in basic sciences. India has benefited by competitiveness in the international context due to the perception that investment goes a longer distance and is done more frugally, a proven concept in certain fields like space launches. This leads to an important question: how competitive is Indian science in the context of National Development? The Science and Technology Institutions should also introspect before starting a research programme: the proposed research is being done for whom? And for which application? They should avoid duplicating research done in advanced countries and if it must be done, it should go beyond the level achieved by advanced countries, so that India creates Intellectual Property in the competitive areas. Research in basic sciences has always been the foundation of transformational technology. Basic sciences sits at the base of the national progress pyramid, followed by applied sciences, engineering, technology, business, market and wealth of the nation at its apex as depicted in the pyramid. Clearly fundamental science is the key to technology development and in turn, wealth creation and increase in GDP.

Scientific Academies can be a beacon of this development policy, and the National Academy of Sciences (NASI) has taken a lead, deliberated and wishes to take a lead on this issue. This subject is close to the basic tenets of NASI, India's first and hence oldest Science Academy, which has taken on a mandate of Science and Society. This subject is also a matter of personal conscience of the fellows and members of NASI. Therefore, it was decided that the Academy should look at:

i Potential for technology development and applications, particularly those addressing National needs, arising from contemporary basic research being pursued in the country.

ii Leveraging basic research for demand driven technology programmes.

iii Linking the basic research community for assimilation of imported technology.

iv How basic research can address and solve national problems?

A group was set up to look into and give their views to the Academy in due course. The group consists of the following: Prof. Ashok Misra, Prof. Jayesh Bellare, Prof. Rohini Godbole, Dr. Chandrima Shaha, Prof. K.V.R. Chary, Dr. S. L. Hoti and Dr. Sampat Kumar Tandon. The terms of reference set for this study were the following:

1 Identify the major areas of basic research in India and related technology and their potential.

2 Analyse the feasibility potential for translation of these into applied work and in turn their applicability to technology transfer.

3 Determine the technology and innovation needs in national context and the extent to which inventions and innovations nurtured in India can be leveraged.

4 Critically review the status of the intellectual property canvas and its growth.

5 Examine if the systems for invention, innovation and Intellectual Property development are adequately addressed.

6 Analyse the impact of basic research leading to technology development and in turn leading to technology transfer for addressing the national needs.

7 Assess areas of science of high technology importance and bridge gap areas, if any.

B. Current Status

Scientifc discoveries and technological advances are drivers of nation's economic growth. In the present scenario in India, the development of premier universities and educational centres is struggling to match up with the burgeoning population. At the time of independence our population was 320 million and today we are a nation of about 1320 million people. Those who were born in the 21st century (270 million; 5% of the total population) will soon start turning 18 years of age. To open up bright career opportunities for these young men and women, there is a need to build a research environment wherein science education directly correlates with the state-of-the-art research and thereby stengthen the base of the nation thus meet the demands and aspirations of our country.

Many of our older universities with a rich scientific heritage (e.g. Allahabad University) have ceased to be centers of excellence mainly due to dearth of quality faculty, lack of good facilities for experimentation as well as state-of-the-art scientific research and administrative lethargy. Even some of the largest and historic universities like Mumbai University and Banaras Hindu University have not been spared this downturn. Of the established institutions, a few have acquired a powerful global brand name and are performing reasonably well on the science and technology front. Among them are Indian Institute of Science, Bangalore (IISc), Indian Institutes of Technology (IITs), Indian Institutes of Science Education and Research (IISERs), Tata Institute of Fundamental Research (TIFR) and its sister institutions, All India Institute of Medical Sciences (AIIMS), Tata Memorial Centre-Advanced Centre for Treatment, Research and Education in Cancer (TMC-ACTREC), Inter-University Centre for Astronomy and Astrophysics (IUCAA), Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Indian Association for the Cultivation of Science (IACS), National Institutes of Technology (NITs), Indian Statistical Institutes (ISIs) and several Institutions under the GOI agencies and departments like Department of Atomic Energy (DAE), Department of Science & Technology (DST) and Department of Biotechnology (DBT). The above is a representative list and not an exhaustive one. However, the emphasis on basic science is given its due place only in a few of these institutions. The mandate of the science departments in a handful of these institutions is not enough to meet the aspirations of the nation. Enthusiastic students wanting to pursue science are not able to find a place that can satisfy their zeal. Coupled with this is the lack of enthusiasm amongst the great majority of youth to pursue higher level studies in the fields of science.

During the last two decades, a number of distinguished scientists have put in a lot of effort in setting up Centres of Excellence in basic sciences to reverse the declining trend of young people joining basic sciences. Their vision was to enable students and faculty to pursue science education and research at the highest level of excellence in ways that reinforce and elevate each other and set new standards of sustainability, functionality and aesthetics in our country. The environment in these institutions were designed to foster interaction and creativity and break compartmentalization of traditional disciplines of biology, chemistry, computer sciences, mathematics and physics. The concept of inter-disciplinary research is still in its infancy – Engineering departments and Science departments have to break this barrier and this will be for mutual benefit. The fundamental concepts of science and engineering education need to be reassessed vis-a-vis high impact research, and big projects nationally and internationally. New policies need to be framed and looked into.

The urgent need of the hour is to understand and realize that translational coherence between these levels can be made stronger only when opportunities in basic sciences change from a handful to many. Accelerating scopes wherein such fruitful correlations can be achieved is something which needs to be initiated and pursued on a war footing. There are several dimensions to this, such as accelerating excellence in research; enhancing capability to translate a new scientific idea into a new technology; sustaining a conducive ecosystem for academic excellence, scientific competitiveness, innovation, nurturing entrepreneurship and human development. There is a historic opportunity here of taking advantage of the Indian demographic boom of the millennials entering the work force in the next few years. We can be their "bhagya vidhatas".

Nevertheless, education and research in basic sciences has to remain our nation's highest priority and it should go hand-in-glove with education and research in applied research and technology development. Science is search for knowledge for knowledge's sake alone, without regard for any application (a.k.a. blue sky research, thirst for knowledge, individual craving, creativity, seeking truth). Technology is the application of knowledge for an economic or social good. Directed and applied science comes in-between. It is fundamental knowledge that in itself does not translate to applications but is essential to translate a basic science into innovation and then into useful products and applications. The synergy between science and technology is influenced by directed basic research.

Our historic achievements based on science include hydrology, sanitation, number system, medicine and surgery, perfume and distillation, dyes and indigo. Our current progress and successes include medicines, infrastructure, aviation, electricity, information technology, education, communication, agriculture, industry, transportation technology, smart cards, better health care, PARAM supercomputer, Kaveri cryogenic engine, Polar Satellite Launch Vehicle (PSLV), milk revolution, Aadhar, Bhim card-less payments, renewable energy (PV), solar-thermal, generics, biosimilars, better weather and monsoon prediction, nuclear reactors and nuclear submarines, giant telescopes, satellite launching vehicles, spacecrafts, missiles, jet fighters, battle tanks, LIGO, AstroSAT, LHC, GMRT, tsunami warning system, square kilometer array telescope, and even a planned neutrino laboratory deep inside a mountain (INO).

There is a great amount of scope to enhance collaboration between the industry and the research/ academic institutions. If industry involvement is there at the conceptualization stage of projects then it can bring fruitful result and industry can provide funding. However, it was pointed out that in most cases, industry is asked to fund when half of the work is done and at that, the relevant Industry may find it not to be useful. Clearly much more is still needed to be done, particularly at early stages of problem identification.

Competitiveness cannot come at the price of safety or compromise in research integrity and ethics. The issues of safety and ethics are central to the practice and excellence of science. There is a need to provide appropriate equipment and safety devices at all levels of education and research institutions of different disciplines. Unethical research practices, especially scientific misconduct, is a major challenge for sustaining of institutional excellence. The institution heads need to ensure compliance. A close watch on violators and penalizing them is very essential. This calls for framing and institution of appropriate guidelines to curb unethical practices. The highest level of ethics is to be used in animal and human experimentation. Animals are increasingly used for education, research and pharmaceutical production purposes, for which billions of small and large animals are used every year. There is growing awareness about adopting ethics in animal experimentation, in view of the guidelines framed by CPCSEA (Committee for the Purpose of Control and Supervision of Experiments on Animals) and establishment of institutional ethics committees wherever animal experimentation is performed. Strict vigilance needs to be in place for ensuring total compliance. Wherever possible, alternate systems such as use of models in educational institutions and cell lines and other biological systems in research and manufacturing units should be used. Further, when animal use is absolutely necessary the animals being used are to be treated in the most humane manner. Unethical practices in the use of human subjects both in research and clinical trials by institutes and pharmaceutical industries are major issues and strict vigilance regarding the compliance of the ethical guidelines need to be ensured.

C. Salient Features to Address

It is recognised that the competitiveness of Indian science with respect to basic research, as well as its speedy translation to technology, needs attention in the context of growing importance of basic knowledge in economic and other activities of national importance. Some of the dimensions of this multifaceted issue that we need to address are:

1 **Nurture excellence in research**: Basic research should lead to inventions that feed innovations. Enabling systems should be put in place for this to happen as mentioned in subsequent points.

2 **Aims of Research and Educational Institutions:**

a Provide high quality Education in order to develop quality manpower.

b Conduct Basic Research and Development and develop new knowledge.

c Carry out Applied Research and Development and develop advanced technologies.

d Create Inventions, Innovation and Intellectual Property.

3 **Influence research direction**: National Academies (Science and Engineering) should promote advocacy through policy documents and guidelines that outline the systems that are needed scientifically and how to achieve it. The study group proposes a ***Science Policy Task Force*** to fulfil this need at the earliest.

4 **Translate basic research into new technology products**: This would be done through entrepreneurship, licensing to industry, and co-development with industry. It is highly recommended that there should be sufficient **Technology Incubators** that can take the basic research to a new level of forming enterprises. There are several efforts in this direction, like Society for Innovation and Entrepreneurship (SINE) at IIT Bombay, Society for Innovation and Development (SID) at IISc, Venture Park at National Chemical Laboratory, Technology park of IIT Madras, Biotech Park of Swaminathan Foundation (with emphasis on women), AMTZ, etc.

5 **Enhance industry-academia interaction**: This would include interactions with the micro, small and medium enterprise (MSME) industry, particularly receptiveness of industry to new and/or indigenous technology, through awareness, education and joint research that gives rise to meaningful collaboration and ability to absorb inventions. Industry investment in science can be a good measure of excellence in translational research along with parameters like: i) number of start-ups bigger than a threshold level of investment, ii) investment attracted by domestic technology developed and IP generated through research, iii) first of kind technologies with user impact developed, and iv) significant strategic advantage for the country.

6 **Reverse the growing trend of a lack of industrial support for basic sciences**: After solid-state devices such as transistors made possible the expansion of switch-boarding in telephone services, industrial laboratories such as Bell Laboratories lavishly financed solid-state physics. In India, TIFR, IISc and Tatas once encouraged basic science too. But today, Bell labs is gone, Tatas have moved to philanthropy. Many private universities have ventured into research, but their research record is mostly questionable.

7 **Translation of basic research to technology development**: We may have missed the silicon foundry, but we should build the mechanism to absorb the micro/nano-electronics inventions and innovations. This is a very important and critical aspect for the translation of basic research to technology development. This needs the involvement of the concerned industry as partners in the

research projects from an early stage. Such an interaction would provide researchers directions to their research to address industrial needs. On the side of the industry, they need to develop an appreciation of basic research to address their problems. Initially it would make more sense to tap the industry demand to start directed research projects.

8 **Balance foreign investment policies for high technology industry**: Example of cell phone – India allowed a multinational, Nokia, to set up its plant in India but China had home-grown cell phone manufacture that is thriving today, whereas Nokia's plant here was closed and the company itself is taken over. Similarly with technology: such as in wireless communications compare between LTE vs. WiMax for the advantage of India.

9 **Nurture collaborative alliances in science between industry and academia**: The result of such alliances can be seen in the biotech industry in India which is worth almost INR 23,000 crores with India being the largest producer of vaccines in the world. Here basic science and industry alliance has made a major impact in the global scene. Some other examples include BT cotton, prostaglandins, and generics. Such examples need to be developed in other areas also.

10 **Set up translation institutions**: like the Faridabad health cluster of DBT for validation and improvement of technology readiness levels (TRL) of basic science being translated to technology. Agencies like CSIR and ICMR should be proactive in this direction. Their labs should be re-dedicated to the task of technology innovation and translation rather than solely on teaching or pursuit of blue sky research.

11 **Nurture end-to-end innovation ecosystems**: Like the AP MedTech Zone that facilitate hassle free engagement of stakeholders across the research translation chain.

12 **Sustain a conducive innovation ecosystem and nurture entrepreneurship within institutions**: Many new eco-systems like incubators have been set up in the country, like the SIB at AIIMS-IITD, but there is scope for even more.

13 **Nurture IP awareness**: Many incoming students of IITs, AcSIR, IISc, IISERs, TIFR, NCBS, AIIMS, TMC-ACTREC, IUCAA, JNCASR and NITs and some other institutions have short courses on this. The faculty and students across all institutions need to be sensitized to the IP awareness and the systems required for it. In Bangalore there is company, FormulateIP (Founded by an IIT alumnus), which provides full service for intellectual property consulting and can help in this area. There are several other companies that help in writing and filing patents.

14 **Encourage and inculcate the scientific temper and method in the public at large through programmes / curricula at school and for lay public**: There is a need to train the trainer at all school and college levels. Public advocacy should be there through Information, Education and Communication in local communities and through massive online courses. There should be advocacy to 18-year olds. To encourage students from school upwards, the scientific method of inquiry and

questioning should be encouraged at home and at school. As a part of learning science, there should be emphasis in STEM for developing and rewarding experimental skills and innovativeness such that student's experience, apart from excitement of doing science, offers multiple exciting career opportunities that makes taking to science more popular.

15 **Establish special schemes for inclusiveness in science and to promote diversity**, particularly gender and geographical diversity.

16 **Develop systems to transform institutions of lower strata to help them grow**: They are the ones needing more handholding, after which they would have much greater impact due to their reach and catchment area.

17 **Improve trained scientists in terms of number and quality**: This is a critical issue as we have to have scientists for the future. How can the students in these institutions be excited for pursuing basic sciences and be innovative? Although there is a lot of interest and enthusiasm for science, but insufficient exposure to role models or clear prospects in science, added with struggle for access to appropriate infrastructure / facilities, discourages many potential science graduates to veer away from pursuing scientific careers. There is a need to attract good graduate students into project-mode R&D. For example, success of large science projects like GMRT / LIGO / Astrosat / LHC, can be leveraged to draw-in students and sustain their careers. For this, more job opportunities through long-term schemes need to be created.

18 **It is increasingly recognized that project-mode schemes have been more successful in basic research**, e.g., GMRT, LIGO, Astrosat, LHC, space missions, etc., hence more such projects must be planned. Participation in global and local mega science projects benefits the country. It brings into the country advanced, cutting edge technology. This in turn propels 'cutting edge' science in the country. These give fourfold expertise: in theory, in detectors, in IT and in engineering. Frontier research often requires building new experiments involving cutting edge technology. International co-operation in such areas invariably facilitates first hand exposure to building technologies of tomorrow. Participation in such programmes when linked to a domestic programme brings in large technology dividends.

19 **Involve more undergraduate students in research**: Especially in *high-risk* research (*high-risk* is with respect to uncertain scientific output and career advancement as opposed to safety). The UG students are really very bright, especially at the IITs, NITs and IISERs in the higher educational arena. They can be brought in the fold of UG research programs by changing the curriculum and making it more projects oriented. IISERs are already doing it. More institutions should do the same. Other bright students should be encouraged into these programmes.

20 **Establish linkages between CSIR and academic institutions** (like IITs, AcSIR, IISc, IISERs, TIFR,

NCBS, AIIMS, TMC-ACTREC, IUCAA, JNCASR and NITs). This would synergise their expertise. There should be greater engagement between basic science institutions and technology institutions.

21 **It is necessary to encourage inter-disciplinary collaboration across multiple institutions working on the same problem in co-operative mode**: An example is the Nano electronics centre at IITB and IISc, which are working together, which has worked extremely well. Another is the School of International Bio design between AIIMS and IITD. In some cases, this can be done in competitive mode rather than cooperative mode.

22 **To develop facilities for advanced instrument development**: Access to equipment (like IITB's central facility model for advanced shared facilities) and setting up of Tinkerer's Labs to foster hands-on capabilities.

23 **Advanced components and equipment needed by basic research has encouraged industry to produce them**: How to best leverage this to foster better industry? One could aim at significant engagement between industry and institutions at academic/research/technology co-development level centered on industry / user needs. Science pushes tool building, which eventually leads to wider applicability of the tools. India had a history of tool building, but where is it today? Demand driven competitive research involving industry-institute consortia is possibly a good model to pursue for tool building. (For example, DARPA or eARPA in USA). There is an urgent need for the creation of an industry that supplies fundamental research groups all over the country with advanced components and equipment. These could even be spin-offs from university or institutional research. **India needs an Oxford instruments (first start-up from Oxford University, a leading supplier of superconducting magnets that are a crucial component of a number of experimental research areas) or a Leiden cryogenics (start up from Univ. of Leiden, leading supplier of dilution refrigerators (~10 mK temperatures) that are heavily used by condensed matter experimentalists world-wide).** These could also extend to more routine products such as basic electronic components, mechanical fittings, electrical measurement equipment, fume hoods, etc. that are actively used by a plethora of research groups, in labs all across the country. In addition to reducing the reliance on foreign suppliers and cutting down costs, building such an eco-system would be very beneficial for availability of spare-parts and prompt service and repairs, which are currently a critical roadblock to research in India. **One example of a successful Indian company that supplies custom designed high vacuum deposition systems (which are a mainstay of several materials science, condensed mater physics and engineering labs across the country) is Excel Instruments, with clients in India and worldwide (http://www.excelinstruments.biz/Clients.php).**

24 **Government should have more of the DBT - BIRAC type small business funding models, for start-up, proof-of-concept, industry-institution collaboration and more**: BIRAC has been a good model that can be pursued in other areas. Uchhatar Avishkar Yojna type schemes have been

good, but they should begin with industry-led problem definition; Government should ask industry first for a wish-list, then fund institutes. Some industries have funded master's and other students and academic programs, e.g., NTPC at IIT Delhi; Bharat Forge and BPCL at IIT Bombay and Steel Industry at IITB.

25 **Encourage safe practices in science, including hazard and risk mitigation and safety**: Approvals like biological, radiation, environmental and chemical safety through appropriately constituted committees.

26 **Encourage integrity and ethics in all scientific endeavours**.

27 **Develop measures to quantify the return on investment of basic science**: Some possible measures: i) GDP increase / science spend, vs. ii) GDP increase / technology spend, vs., iii) Competitive domestic value addition / S&T spend. Here we need to differentiate between science and technology; this may be difficult to do. GDP is not a good measure of productivity of science. Other measures like number of Start-ups, Patents, Technology transfers, and Papers need to be factored in. We should use health improvement measures like: infant and child mortality, DALYs (disability-adjusted life year). Some of these measures are surrogate measures. There is a need to develop direct measures to quantify **basic research leads** that make way for **innovations** which eventually lead to **translated products**. We need new indices like Health Technology Index and ratio of number of patents filed vs. number of technologies transferred. We need to assess these measures at individual, society, national and international level separately and compare competitiveness.

28 **To gauge the value of national investments, we can compare various countries**: Countries like South Korea and China have increased their expenditure in science steadily over the last decade whereas in India it has remained almost constant; India and China have similar population but the number of scientifically trained people in China is about 6 to 7 times that in India. USA has 18 out of every 10000 involved in Science, in China it is 20 out of 10000 and in India 4 out of 10000 are involved in science. China, which was poorer than India 30 years ago, but now the situation is flipped and experts like Prof. David Gross credit doubled spending on scientific research for the country's growth. Countries which have a strong base in science and technology are the ones that developed faster. Examples: Russia, Japan, Brazil, China, India and more. USA which invests a large amount for research and development is in the highest stratum of development whereas countries like Nepal who invest less remain in the lowest ladder of development.

D. Executive Summary of Recommendations:

1 Identify and setup systems to transform basic research into inventions that feed innovations. Government to fund basic research and keep the industry in the loop. This can be facilitated by industry groups and organisations like CII.

2 Constitute a Science Policy Task Force to identify what exactly is needed scientifically, how to prioritize it, and how to achieve it. Yet allow for blue-sky research, here again with the active participation of the industry.

3 Partner with policy institutions to flesh out this report by putting numbers to quantify parameters identified in this report and to develop new and better measures of the impact of science because GDP is not a good measure. To convince policy makers to provide economic value of some scientific / technological discoveries or innovations made by Indians in India.

4 Set up a large number of technology incubators and translation institutions that can take the basic research to a new level of forming enterprises. For this involve Venture Capitalists and relevant industry to provide timely "Invention Capital" and avoid the proverbial Death Valley syndrome.

5 Have a scheme to link industries to scientific institutes through projects for specific long term deliverables identified by industry and funded by Government.

6 Promote tool building (including advanced tools like those used in GMRT, LIGO, etc.) at various levels, like through hardware hackathons at school/college level, to funding of large-scale projects.

7 Have better publicity of the impact of basic research through traditional media (print, TV) and modern media (Facebook, Twitter, etc.).

8 Nurture IP awareness amongst students at all levels, including Ph.D., Masters, and Bachelors as well as in high schools.

9 There should be significant sustained pursuit of research. As an example, it should be ensured that the research output does not die when a Ph.D. is completed or a Professor retires.

10 Develop means to excite students into science through mentorships, internships (expand National Academies' internship programmes). Emphasize science teaching with modern labs in metro schools as well as remote area schools, since scientific talent can come from anywhere.

11 Use health improvement measures like: infant and child mortality, DALYs (disability-adjusted life year), child nutrition status, social and mental health, quality of life indicators or even socio-economic indicator to publicise program benefits like polio mission, Asha, etc.

12 Establish network amongst basic research groups to prevent duplication of efforts. Further, the institutions should avoid duplicating research done in Advanced Countries, and if done it should go beyond the level achieved so that India creates IPR in the competitive areas.

13 Reduce number of decision making bodies. In today's context, technology development requires speed but in India sometimes there are multiple partners and the speed goes down proportionate to number of decision making bodies.

It conclusion, it is proposed that NASI along with the other Science Academies in India as well as the Indian National Academy of Engineering should play a leading and pivotal role to facilitate the recommendations made above. NASI should also actively play a role of advocacy with the Government of India, its research funding agencies, MHRD and the industry organisation for the overall benefit of the nation. ***We have a huge opportunity for India to make an impact. A national science policy and vision should be developed for India to make significant disruptive changes. This needs to be done on a war footing in Mission mode.***

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Science Based Innovations for Agricultural Transformation in India

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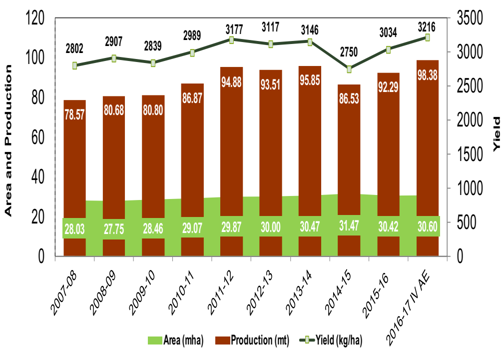
Indian agriculture has witnessed transformational changes through progressive science based innovations. The National Agricultural Research System (NARS) has played the key role in this process through systematic and collaborative agricultural research, technology development and technology transfer to the stake holders particularly the farmers. Indian Council of Agricultural Research (ICAR) acted as the catalyst to accelerate collaborative development and application of agricultural innovations involving the public, private and non-governmental research organizations, and farmers. The ICAR has developed several location specific technologies due to which the country could produce enough to become self-sufficient, with marketable surplus in majority of the commodities. The science led saga of success of Indian agriculture is worth documenting for drawing lessons for future.

From Shortage to Surplus

During the early nineteenth century, with the establishment of crop based research institutes such as the Indian Agricultural Research Institute (IARI) in 1905 and Indian Council of Agricultural Research in 1929, agricultural research got a boost. One of the bright examples of innovation led growth in Indian agriculture is the use of dwarfing genes in 1960s for significant yield increase in wheat and rice that enabled realization of Green Revolution in the country. India's food insecurity problem was resolved. In other areas of agriculture and allied sectors, innovations did play their part. In case of cereals, pulses, oilseeds and vegetables, our major emphasis has been on developing varieties using conventional breeding and Marker Assisted Selection Technology (MAST) along with best management practices. While in horticultural crops, selection of superior cultivars, improvement in production technologies such as high density planting, and canopy and nutrient management have been implied. Improving the animal breeds and nutritional status of animals and poultry for obtaining more milk, meat and eggshas been the priority of ICAR. Major emphasis on aquaculture, marine fishery, fish breeding, product development from fish and sea weeds have enhanced the fish production benefiting farmers as well as consumers. Emphasis on sustainable agriculture practices through developing integrated and organic farming models and addressing climate issue through climate resilience smart villages concept has benefited the farmers and ensured conservation of our natural resources. Innovations in developing modern farm machinery and implementations and post-harvest processing technologies have immensely contributed to the growth of Indian agriculture. Scientific and technological innovations have strengthened almost all the spheres of Indian agriculture. Consequently, food grain, milk, egg, fish and meat (level 1998-99), production increased by 5.5, 9.5, 48, 15 and 3.38 times today as compared to 1950-51. Similar gains have been realized in the production of sugar, oil seeds, pulses, fruits, and vegetables. The country is exporting many agricultural items including rice, spices, seafood and meat. Spice and spice products export touched all time high with 1.03 million tons in 2018 at about Rs 17,930 crores, similarly our sea food export has grown by 21% in 2017-18 to touch 13,77,244 tons and earned $7.08 billion (Rs. 45,106.89 crore).

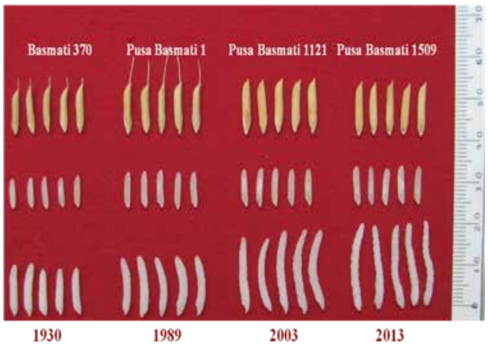
Brimming Bread Basket

It was in 1940s and 1950s, Dr. B. P. Pal carried extensive basic research on the devastating disease call rust caused by the fungal pathogen *Puccinia* in wheat. He studied the disease pattern, symptoms and genetic inheritance using wheat germplasm, identifying thereby the sources of resistance to all the three forms of rust (Black, brown and yellow). The identified resistant sources were then used in cross-hybridization strategically to develop the first wheat variety NP809 in 1954, which was resistant to all the three rust types. This exemplified science based innovation leading to a technology that has been subsequently modified as per the need to sustain growth in wheat production in the country. Over the decades, new races of the pathogen have evolved but systematic and innovative gene identification and development through breeding has safeguarded India’s wheat crop against major outbreak of diseases to ensure sustained food security. Major threat of Ug 99 strain of *Puccinia graminis tritici*, causing stem or black rust disease could be successfully averted in India due to the development of several resistant wheat varieties. The recent recognition by Borlaug Global Rust Initiative (BGRI) to ICAR scientists by conferring Gene Stewardship Award for the outstanding work done by the Indian Wheat Programme in development and constant release and dissemination of agronomically-superior rust resistant wheat varieties is worth mentioning. The flagship variety HD 2967, is currently occupying about eight miilion ha area across the country. An unprecedented breeder seed demand for this variety has been witnessed which has touched 3600 quintals during 2017-18, highest ever demand for a single variety in the history of Indian agriculture.



Rich Returns from Rice

Rice crop also underwent similar transformation process in the country using innovative technological research. In 1950s, it was realized that the indigenous varieties being tall, did not respond to chemical fertilizers well and yielded poorly. Use of *japonica* type germplasm in hybridization with tall *indica* types was initiated as an innovative programme to combine desirable traits. Prof. M.S. Swaminathan, on his return from abroad participated in this mammoth task at the famous, Central Rice Research Institute (now, National Rice Research Institute), Cuttack. A set of excellent varieties were developed through this programme, which included "Mahsuri", one of the parents of the present day mega rice variety "Swarna". Realizing the strength of semi-dwarf *indica* types (e.g. TN1) developed elsewhere, they were introduced and crossed with local varieties (e.g. T141). From one of such crosses involving TN 1 and T141, the variety Jaya was bred and popularized. The rice production continues to grow outpacing the demand due to the new-bred varieties. Basmati rice variety, Pusa Basmati 1121, a landmark variety developed by Indian Agricultural Research Institute, New Delhi has great demand in domestic and as well foreign markets. Export of this variety alone earns the country foreign exchange equivalent to more than Rs. 15,000 crores annually.

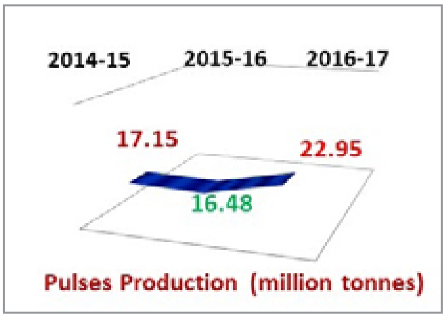


Progressive improvement in grain and cooking quality in Basmati rice

Breeder Seed Production of Pusa Basmati 1121 at ICAR-IARI

Knowing the Pulse of Pulses

India is the largest producer as well as consumer of the pulses. Pulses promote long-term sustainability to the Indian Agriculture; it needs less water, grown on degraded and rainfed lands. Through concerted and systematic breeding efforts coordinated by ICAR, more than 132 varieties in chickpea, 110 in pigeon pea, 102 in mungbean, 84 in urdbean, 41 in lentil, 37 in field pea and 13 in rajmash have been developed since 1970's. Major emphasis was given to developing short duration, high yielding, biotic and abiotic stress resistant varieties. However, to meet the domestic demand, pulses were imported during the last several years. To overcome this, ICAR initiated cluster frontline demonstrations on several pulses crops. Krishi Vigyan Kendras (KVKs) of ICAR organized cluster frontline demonstrations and also produced adequate quantity of seeds through seed hubs. Due to this innovative extension planning, India could reach to the level of near self-sufficiency with total pulse production reaching 23 mt during 2016-17.



Sweet Revolution

Sugarcane is the second important commercial crop grown in about 5 million ha area in the country. India is the second largest sugar producing country in the world after Brazil. India's share in world sugar production is 13.34 per cent (22.5 million ton) during 2016-17, while in 2014-15, India set a record high sugar production of 28.31 million tonnes. Dr. C.A. Barber and Sir T.S. Venkatraman initiated inter-specific hybridization at the Sugarcane Breeding Institute, Coimbatore in early part of nineteenth century and presented to the world the first high-yielding inter-specific hybrid Co205, released for commercial cultivation in 1918 that revolutionized cane farming, and ultimately the cane industry in the country. Inter-specific hybridization has become the rule in cane breeding programmes ever since Co205 was released. Our varieties exhibited remarkable adaptability and at one point of time were grown in over 30 countries. More recently, the sugarcane variety Co 0238 with average sugar recovery of upto 12% and released for commercial cultivation in North West Zone (Punjab, Haryana, Rajasthan, Uttarakhand, Central and West U.P.) has revolutionized sugarcane cultivation in subtropical part of the country. Economic impact of Co 0238 was assessed based on its area during the period from 2013-14 to 2016-17. During this period, Co 0238 produced 147.81 million tonnes cane and 16.19 million tonnes sugar of value Rs. 965.07 billion in five sub-tropical states (UP, Punjab, Haryana, Bihar and Uttarakhand). In addition, Co 0238 also produced 44.34 million tonnes bagasse, which is sufficient for generating 18,193.2 million units of electricity and 6.654 million tonnes molasses sufficient for producing 1,773.39 million litres of ethanol. The total economic worth of Co 0238 is estimated to be Rs 1,130.47 billion. During 2017-18, sugar production in India is reported to reach 32 million tonnes which is more than the domestic requirement of about 25 million tonnes.

White and Blue Revolutions

India's milk revolution is a bright example of innovation in cooperative system of production and marketing. Credit goes to Dr. Verghese Kurien who led the Kaira District Co-operative Milk Producers' Union (KDCMPUL), now famous as Amul. He built this organization into one of the largest and most successful one. Seeing the success of the Amul pattern of cooperatives, the then Prime Minister Shri Lal Bahadur Shastri created the National Dairy Development Board (NDDB) in 1965, to replicate the program on a nationwide basis. 'Operation flood' started by NDDB in 1970 made India the largest producer of milk in the world. The white revolution thus happened and the trend still continues. Today, India tops in milk production, which stands at 165.4 million tonnes, with per capita availability of 355 grams per day. Besides cooperative model, developments on the technology front including cross breeding involving exotics, artificial insemination, vaccination, disease diagnosis using modern tools, use of nutrient supplements and healthcare did play their part. Similarly, the fishery sector has grown significantly. From less than one million tonne in 1950-51, the fish production has increased to 11.4 million tonnes today that has enabled export of about one million tonne. Science based innovations in breeding, seed and feed production, health management etc. have played significant roles in this development.

Challenges to Indian Agriculture

Indian agriculture is facing multiple challenges that threaten the country's food and nutritional security. As per the recent OECD-FAO Agricultural Outlook 2017-2026, the world's population will increase from 7.3 to 8.2 billion during this period. Almost all of this population growth will occur in developing countries. The population of India will grow from 1.3 billion to 1.5 billion, an increase of almost 150 million, thereby overtaking China as the world's most populous country. As the human population in India would touch 1.6 billion by 2050, ensuring food and nutritional security for such a large population would be the greatest challenge. Another major challenge impacting most would be climate change. Recent report of World Bank (2018) on "South Asia's Hotspots: The Impact of Temperature and Precipitation Changes on Living Standards" indicated the South Asia as highly vulnerable to climate change and by 2050, the temperature would rise by 1-2%. This is going to impact highly climate sensitive occupations such as agriculture and fisheries. Reports also highlight that inland areas, comprising northern and north-western parts of the India will be the most affected by climate change. The quantity and quality of water available for irrigation will decline further. The per capita water availability is estimated to decline from the current level of about 1540 cubic meter to 1140 cubic meter by 2050. About 104 million hectares (out of 142 mha) of our cultivated land area is now considered degraded. With more heavy downpours, as predicted to occur in future, the soil erosion rates will further increase. Sea level rise is apprehended to result in inundation of coastal areas with saline water. India has to face these challenges more aggressively by developing and using sustainable food systems and smart-modern technologies. Innovations are the key to meeting these challenges. Besides, we need to make our farmers tech savvy, retain our youths in agriculture profession and develop more attractive support systems. In USA, the share of agriculture in GDP was 47% in 1840; today it is 1.1%. Dependency on agriculture was 68% in 1840, today it is 1.7%. However, in India, if business-as-usual continues, the share of agriculture in GDP will be around 1% by 2026 but still the dependency will be about 37% (OECD-FAO, 2017). Therefore, we need to treat agriculture as an industry in future ensuring profitability of farming to be kept in mind. Attaining the targeted growth will entail increase in total factor productivity (TFP) from current level of 1.4 to more than 1.75. Another challenge is doubling the income of the farmers by 2022. This calls for reducing the cost of cultivation, enhancing productivity, diversification, post-harvest processing and value addition and effective market linkage. Use of innovative technologies in all these areas holds the key to doubling the farmers' income.

Future Agricultural Innovation Pathways

Germplasm resources have been used to enhance productivity and impart stability to production in the past. But less than 5% of the available germplasm in different species could be used effectively, since a large part of the conserved germplasm are not evaluated. Future use of germplasm to meet the food, feed, fiber and fodder needs demands systematic trait discovery. High throughput image based precision phenotyping will guide trait discovery and thus efficient germplasm use as well as gene discovery. Speed breeding and elaborate gene editing are expected to be used extensively by the national agricultural research system. The under-explored microbial world needs to be examined more critically for deriving agronomic benefits. The insect resources in the form of predators and parasites will be an important component of organic agriculture. Huge information resources collected over decades pertaining to agro-ecology, weather parameters, land resources, soil properties from long-term experiments, plant responses under varying management practices, water management etc., are to be treated using appropriate data analytics, for effective artificial intelligence system to operate thereby enabling precision agriculture. Nano-science and sensor research will guide development of new precision agriculture technologies. Indigenous breeds of animals, birds and fishes will be characterized and improved further using tools of genomics. Semen sexing in cattle will have to be routinely deployed for increasing the productive animal population. Large-scale cloning of most fertile plus bulls coupled with artificial insemination is expected to provide impetus to animal productivity. Given the limitation of water for extensive in-land aquaculture, innovative breeding, seed production, feed system etc. for cage culture of diverse marine fish species are to be pursued vigorously. Solar energy harvesting and robotics will play key roles in future Indian agriculture.

To keep pace with these technological advances, we need to develop world class laboratory infrastructure, train our manpower and invest more in basic and multidisciplinary and multi-institutional agricultural research and development. ICAR has already taken up some initiatives in this direction. However, we need to be more proactive to keep pace with international research initiatives. When we compare with other countries our investment in this sector appears much lower. Overall, the US allocates close to 2.7%

of its GDP for research and development, while India allocates only 0.85%. Even when we compare among the BRICS countries where India is a proud member, India's expenditure on Research and Development has been the least. It clearly points towards more public funding for basic and strategic research in order to achieve the desired goals of sustainable and profitable agriculture.

Insights into the Molecular Mechanisms of MADS29, A Major Regulator of Seed Development in Rice

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The molecular program leading to seed development in most angiosperms initiates as a result of a plant-specific mating event, known as double fertilization. In this process, two spermss imultaneously enter the 7-celled embryo-sac. One sperm fuses with the haploid (1n) egg cell resulting in a diploid zygote that eventually develops into the embryo. Whereas, the other sperm fuses with the central cell that contains two polar (1n) nuclei. This second mating leads to the development of a triploid (3n) nutritive tissue, the endosperm (Sreenivasulu and Wobus, 2013; Lafon-Placette and Köhler, 2014). In most dicotyledonous plants, the endosperm is consumed by the developing embryo, whereas in monocots (especially cereals) the endosperm persists and constitutes major portion of the mature seed. The endosperm cells in rice and other cereals, like wheat, maize, sorghum and pennisetum are tightly packed with starch granules, which are degraded into soluble sugars at the time of seed germination, providing essential nutrition to the developing seedling.

Role of OsMADS29 in Hormone Homeostasis

By using high-throughput microarray-based transcriptomic analyses, our group has identified a novel MADS-box transcription factor, *OsMADS29,* that plays multiple regulatory role during embryo development and grain filling by affecting hormone homeostasis during seed development in rice. *In situ* immunolocalization experiments revealed that OsMADS29 protein accumulates mainly in the embryo and aleurone and sub-aleurone layers of the endosperm. Suppression of OsMADS29 expression by RNAi severely affects seed set. The surviving seeds are smaller in size, with developmental abnormalities in the embryo and reduced size of endosperm cells. The packaging of starch in the endosperm is also not as compact as in the wild type. It has also been suggested that OsMADS29 contributes to seed development by regulating cell degeneration of maternal tissues (Yin and Xue, 2012; Yang et al., 2012). Our data, however, is in the favor of a more generic role of OsMADS29 in changing the hormone homeostasis in favor of cytokinins (Nayar et al., 2013).

The most intriguing insight into its function was observed when OsMADS29 was ectopically expressed in rice transgenics under the control of maize ubiquitin promoter. The resultant plants were severely stunted; however, their innate developmental program was not compromised. Similar to the wild-type plants, the OsMADS29 over expressing (OsMADS29OX) plants had 9-10 leaves and could occasionally develop rudimentary panicles as well. We discovered that these plants accumulated very high level sofcytokin in (i.e., trans-zeatin; tz) along with 2-3 fold reduction in the level so faux in (IAA) (Nayaretal., 2013). The effects of auxin and cytokin in homeostas is have been well studied during root development, where it has been postulated that in the root meristem a predetermined ratio of auxins and cytokinins is required for optimal growth and development. When this balance tilts in favor of auxins, the meristem size increases because reduced rate of cell differentiation leads to enlarged organs, hence, a larger number of meristematic cells are available for organ formation. On the other hand, increase in the levels of cytokinins leads to higher rates of differentiation, leaving fewer undifferentiated cells in the meristematic region. This results in reduction in the size of the meristem, and thereby, miniaturization of the resultant organs (Moubayidin et al., 2009). To our surprise, the intercalary meristem that contributes newer cells to the leaf blade as well as leaf sheath was found to be severely compromised in *OsMADS29*^{OX} transgenic lines, it was reduced to a fifth of its size in wild type leaves of the same age. These data suggested that *OsMADS29*, when expressed outside its natural domain of action, is able to regulate cytokinin biosynthesis pathway to achieve higher cytokinin levels in the target cells (Nayar et al., 2013). Transcriptome analysis of overexpression and knockdown lines have indicated genes involved in plastid biogenesis, starch biosynthesis, cytokinin signaling and biosynthesis pathways as probable targets of *OsMADS29* (Nayar et al., 2013).

Relationship between OsMADS29, Cytokinin and Starch

Based on its indicated association with cytokin in and starch biosynthesis, we were looking for a system where the relationship between *OsMADS29*, higher cytokin in levels and starch accumulation could be established. Interestingly, a series of papers from Japanese groups of Shigeo Yoshida and Tsuneyoshi Kuroiwa clearly established a link between exogenously supplied cytokinin levels and differentiation of proplastids into starch bearing amyloplasts (Miyazawa et al., 1999; Sakai et al., 1999; Miyazawa et al., 2002). To test our hypothesis that *OsMADS29* could influence endogenous cytokinin levels and thereby starch accumulation, we transformed tobacco BY-2 cell line with *OsMADS29*cdsexpressed under the control of maize ubiquit in gene. The results showed marked enhancement in starch accumulation mimicking the effect of exogenously supplied Benzyl-aminopurine (BAP) (Nayar et al., 2013).

Multiple level Control of OsMADS29 activity

As far as regulation of *OsMADS29* expression is concerned, there are multiple levels at which it seems to be regulated. The control at the level of transcription is evident from the microarray data and its subsequent validation by quantitative real-time PCR. These studies have confirmed that *OsMADS29* expresses specifically in seeds and its mRNA starts to accumulate few hours after pollination and within a day increases by several hundred folds. The factor that causes this upsurge in *OsMADS29*'s mRNA accumulation has not been identified as yet. Our studies have also revealed that although significant levels of *OsMADS29* mRNA accumulate in the first two days of seed development, the synthesis of the corresponding protein is delayed by at least four days. This observation strongly points towards the existence of a temporally regulated translational block that does not cause degradation of the mRNA (Nayar et al., 2013). More work is needed to identify the nature and/or components of the underlying mechanism. Our data has further revealed that even though OsMADS29 is a transcription factor, that would require to move into the nucleus to regulate its downstream targets, its monomers are incapable of localizing in the nucleus. However, when a OsMADS29 monomer interacts with another monomer of OsMADS29 or with any of the11other seed expressing MADS- box proteins, the resultant dimers localize very specifically in the nucleus (Nayar et al., 2014). This in dicates that there could lie another level of control at the post-translational level that might influence OsMADS29's activity.

Evolution of OsMADS29 function and Starch Biosynthesis

The phylogenetic analysis of OsMADS29-related proteins in monocots and dicots suggests that this transcription factor should have evolved after the divergence of monocot lineage from that of the dicots (Nayar et al., 2013; Yang et al., 2012). Coincidently, cereals like, rice, wheat, barley, sorghum and pennisetum that store starch in their endosperms also show high level of conservation in the OsMADS29 protein sequence. Consider in gits role in regulating cytokin in levels, differentiation of proplastids into amyloplasts and starch biosynthesis, *OsMADS29* could very well be the master regulator that directs manufacturing and storage of nicely packed sacks of starch in cereal grains.

Now these observations bring us to an interesting question, whether *OsMADS29* could convert any cell into a sink cell that is capable of channelizing all available simple sugars in to starch? And if yes, could this feat be achieved at cellular level rather than the organ or organism level? Finding answers to these questions would be the quest of our group into the foreseeable future. Besides affecting the starch industry on earth that solely depends on potato and cereal crops for starch, any leads obtain from these initiatives would have direct impact on food research for space exploration.

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Research - its Role in National Development: Value conscious Innovations

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The development of medical school illustratively and the action medicine on the other citing the examples from the fast growing biomedical research in India, presently the focus of which is mainly diagnostic tools and a few devices has been highlighted. Prof. Bhargava referring to various achievements and contributions made by our country-men in different sectors since independence viz. Science & Technology, IT sector, computers and mobiles, emphasized the glorious achievements in the areas of nuclear and space science; as well as the path breaking role of Green Revolution, White Revolution, Healthcare and Pharma Industries in changing the grim scenario to the status of rank country in these fields. Further, focusing on the health care, he expressed that this is one such area in which we have done phenomenally well and this is one of the reasons the people of this country are satisfied with the kind of treatment and diagnostics for different ailments. He told that there are 40 million people falling below poverty line because of health related expenditure in India and India also ranks low so far as the infant mortality rate is concerned; approximately 41,000 children/infants die annually, an exceptionally higher rate in comparison to USA and other developed countries.

But the state of health research is gradually gaining strength with the evolution of state of art technologies; and the national institutes/laboratories/medical hospitals are now putting a lot of human resource and money to the field of Bio-medical Research, which is evident in the Fig. 1 & 2.

Fig. 1

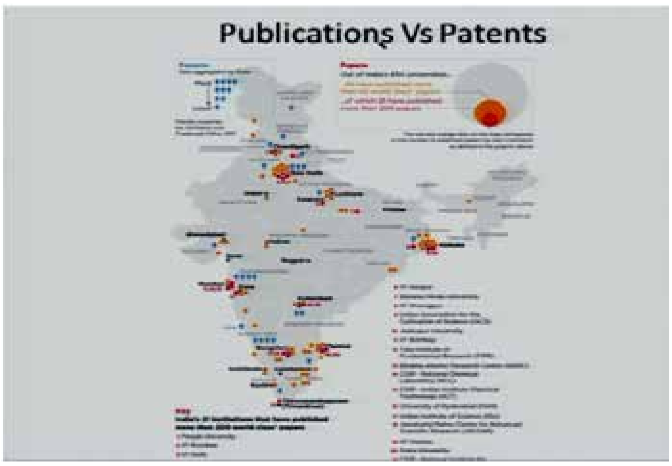
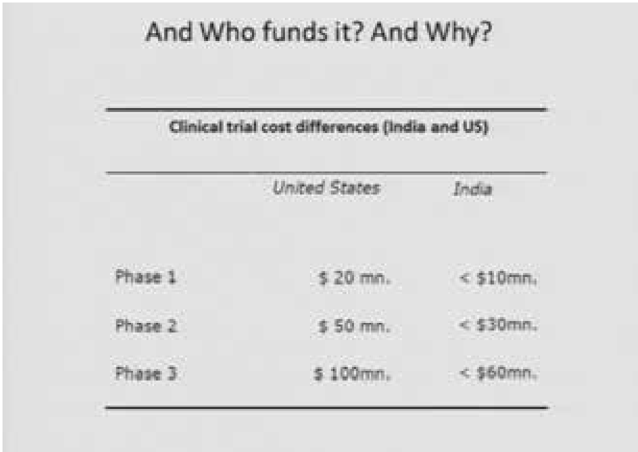


Fig. 2

More efforts are needed in this direction with attitudinal change in the paradigm. The biomedical research be focused on social inclusion of Gandhian practice (Fig. 3) as emphasized by Dr Mashelkar in his paper recently published in a reputed journal. There must be a fine balance in innovation and cost effectiveness to make our medical practices more oriented towards social health care. India is a clinical hub, with more opportunity of clinical trials (Fig. 4) and better incubation periods for drug trials, which could evolve better, tried and trusted medicine with low cost to serve the humanity.

Fig. 3



And Who funds it? And Why?

Clinical trial cost differences (India and US)

	United States	India
Phase 1	$ 20 mn.	< $10mn.
Phase 2	$ 50 mn.	< $30mn.
Phase 3	$ 100mn.	< $60mn.

Fig. 4

India could soon become an innovation giant by cracking the iceberg of transformational technology to provide complete bio health coverage and universal health coverage (including emergency medicines). Appreciating the Indians with innovative bent of minds, there is no dearth of talent in our country with large science pool engineers having knack to solve problems elegantly in cheaper and pragmatic way. It has been recognized that the contributions made by Indian scientists to various nuclear programmes, metro system, resilience banking systems as well as various government schemes assuring the growth and development of the Biomedical diagnostics and devices in India have been very encouraging. Some statistics and patterns with high impact publications in Biomedical Research in India depict that. Most of the research is industry funded, Indian public or foreign public funded. In India, the speed as well as the cost of research is very low.

By addressing the locally relevant diseases, the quality of research could be improved. Accordingly, the paradigm of research should be social inclusion, affordability and accessibility. AIIMS has set such examples by creating 13 innovative devices and 8 start-ups. Several patents have also been filed. The young researchers to take up this baton ahead for ensuring India as the leader in Biomedical Research.

Basic Research for Decision Making in Control of Vectors of Malaria and Dengue in India

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Abstract

The burden of vector borne diseases (VBD) at global level as well as in India is of considerable public health importance. There has been significant achievement in reducing the burden of malaria, visceral leishmaniasis and lymphatic filariasis, eventhough there is persistence of VBDs in some foci, while dengue, chikungunya and Japanese encephalitis are on increase. In the era of socio-technological development, the changes in bio-ecology of vectors thwart the intervention efforts. Therefore, some basic aspects of biology and ecology of vector species related to intervention strategy of vector control need to be revisited for analysing the reasons of persistence of VBDs and devising evidence based strategies. In the present communication, the aspects of basic research which affect intervention strategies eg. knowledge of preferred breeding habitats of vectors of malaria and dengue, outdoor resting, host preference, ecological changes due to social development and climate change, which keep on changing with change in economic development and life style, has been emphasized. The scope of cutting edge tools like genetically modified insects, use of Wolbachia bacteria and CRISPR/Cas9 has also been discussed.

Introduction

India is endemic for several vector borne diseases (VBD) which pose a considerable public health problem. The National Vector Borne Disease Control Programme (NVBDCP) of the country formulates guidelines and policies for control of six major VBDs, i.e. malaria, lymphatic filariasis (LF), dengue, chikungunya, visceral leishmaniasis (VL) and Japanese encephalitis (JE). Of six major VBDs, lymphatic filariaiasis, VL and malaria are set to be eliminated by the year 2018, 2020 and 2030 respectively. The goal of elimination of VL and LF was 2015 but the target could not be achieved. With the available tools of intervention like affordable diagnostic kits, Long Lasting Insecticidal Nets (LLN), synthetic pyrethroids for Indoor Residual Spray (IRS) and combination therapy for treatment of malaria patients, there is overall reduction in malaria cases, however, there are still hard core foci in tribal and forested areas in the country. The incidence of Dengue is gradually increasing spatially as well as temporally. The reduction in disease incidence is not commensurate with available tools, warranting the need of revisiting strategies of control and need of research. A recent publication by WHO reveals that major gains in malaria control are due to vector control tools [1] (Fig 1), emphasizing the need of attention on vector control tools for malaria control. There is growing interest in developing high end tools like genetically modified mosquitoes, use of Wolbachia for control of dengue. However, the strategic plan of malaria elimination in India [2] still recommends the need of some basic issues to be addressed for vector control. The present communication highlights the need for basic research required for vector control of malaria and dengue in India. The review is not exhaustive, it rather covers the most-felt aspects of research which affect decision making in vector control.

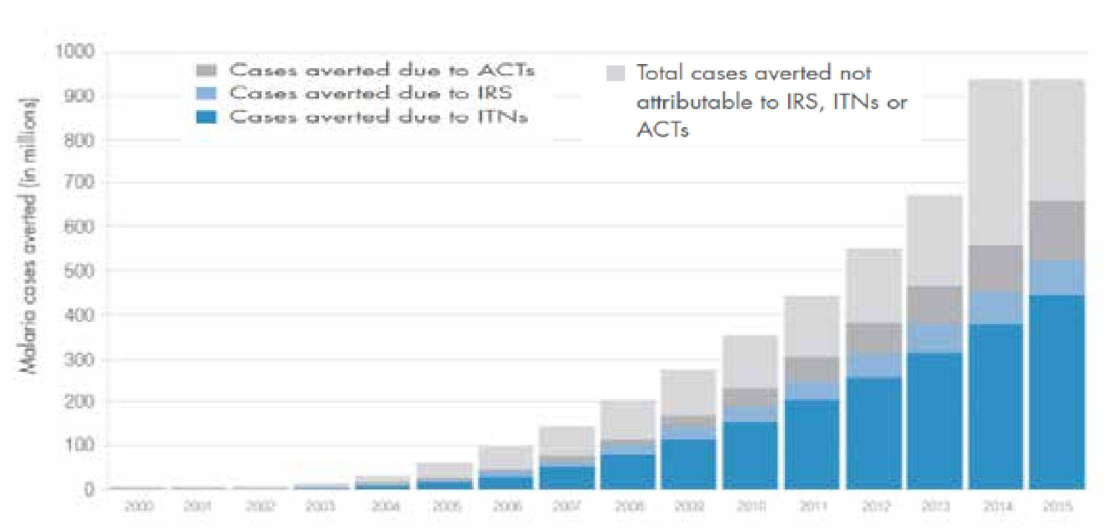

Figure 1 Major gains made against malaria through vector control

(Source: Cibulskis et al. Infect Dis Poverty. 2016; 5:61)

Overview of basic research aspects worth attention

Interventions in breeding habitats of vectors: Knowledge of preferred breeding habitats of vector species is essential for extermination of their progeny before they emerge into adults. For control of mosquito vectors of malaria, the strategy of NVBDCP is to undertake larval control in urban areas only [3]. In recent years it has been observed that even confined breeding habitats like irrigation tanks and wells in rural areas also need to be treated with biological agent like *Bacillus thuringiensis israelensis* and even release of larvivorous fishes [4].

Targeting for larval source management, it is essential to know whether the breeding habitats are temporary or permanent; whether source reduction by environmental management will be possible or minor engineering intervention would be required.

Surveillance of immature stages of Aedes mosquitoes: *Aedes aegypti* and *Ae. albopictus* are the main vectors of dengue in India**.** Survey for immature stages of Aedes mosquito is essential in understanding the risk factors for breeding of Aedes mosquitoes. Based on year long fortnight survey, the most preferred breeding habitats are determined and based on below given indicators the low/high risk of dengue transmission is determined.

- House Index(HI)= No. of houses infested x100
  No. of houses inspected
- Container Index(CI)= No. of containers positive x100
  No. of containers inspected
- Breatau Index (BI)= No. of containers positive x100
  No. of houses inspected
- Pupal Index (PI) = No. of pupae collected x100
  No. of houses inspected

BI of > 50 indicates high risk of Dengue transmission while <5 BI indicates low risk of transmission.

As regards the breeding grounds of Aedes mosquitoes, over-head tanks, underground tanks, coolers, flower pots, junk material, garbage, discarded tyres in open, bird feeding earthern pots, outdoor water containers beneath shrubby places etc. in the vicinity of peridomestic areas etc. have been reported from Delhi [5-7], but the strategy of search and control of breeding grounds of Aedes has been limited mainly to domestic breeding by Domestic Breeding Checkers. Therefore, focusing only on indoor breeding grounds of Aedes is not adequate. In addition to domestic breeding, control of breeding in peri-domestic habitats is also essential. In changing ecological and socio-developmental scenario, there is periodic need of determining the preferred breeding grounds for effective containment of breeding particularly for Aedes mosquitoes, where larval control is the only strategy for control of dengue transmission. Further, the usefulness of the indices mentioned above need to be reaffirmed through case studies so that the usefulness of these indices may be applied in averting outbreaks.

Importance of resting habitats of vectors: The strategy of IRS is based on the principle that mosquito vectors rest indoors and if they sit on indoor surfaces, their longevity is reduced so that they do not survive long enough to transmit the disease. If the vector species does not rest indoors, there is no point of undertaking spray. *An. baimai* (*An. dirus*), the vector of malaria in northeastern parts of India is reported to rest outdoors except a brief visit to indoors for taking blood meal [8]. In such situation, IRS will not be effective against *An. baimai* .

Density of vectors and Entomological Inoculation Rate (EIR): In most of the entomological surveys for malaria vectors, man hour density of vector species is determined at fortnightly interval, but is rarely used for decision making in vector control as the critical density which results into outbreak, is not known fairly. As per current strategy, decision of undertaking IRS is taken based on Annual Parasite Incidence (API) at subcentre level in the preceding year. If the threshold of critical density of a particular vector is known, the decision for IRS can be evidence based and will be a proactive approach.

Further, a better indicator, which takes into account the density of vector, biting rate and infectivity of vectors with Plasmodium parasite, is EIR (MaS: M is a product of number of vector species per person, a is number of persons bitten by vector in one night while S is sporozoite rate) [9], indicates the intensity of transmission of malaria in a given area, is also rarely used for decision making. Reduction in any of the parameters of EIR mentioned above, reduces the transmission rate. Therefore, EIR may be used for assessing the impact of vector control particularly in the wake of malaria elimination goal.

Host preference and biting rhythm: Host preference has very important bearing to determine whether the particular species of mosquito is a vector or not. If the vector species does not feed on human beings, there is no possibility of transmission of disease to human beings. *Anopheles fluviatilis* species which is a vector of malaria in foothill areas, is available in most parts of India [10], but does not act as vector as the species resting in cattle sheds does not feed on human [11].

Knowledge of biting rhythm of vector species is very crucial in advising the community when to use Insecticide treated net/Long Lasting insecticidal Net for prevention from mosquito bites and malaria. In several areas, the time for sleep of users does not match with biting rhythm of vector species resulting into ineffectiveness of Bednets. *Anopheles culicifacies*in Amravati/Gadchiroli has been found to start feeding with sunset while the communities start using nets at 21:00 hrs. (personal observations). The biting rhythm of vectors species vary from area to area and season to season, therefore, studies should be undertaken accordingly.

Susceptibility to insecticides being used for Indoor Residual Spray: Studies on determining the susceptibility of vector species to the insecticide being used for IRS or larvicide is essential to guide the National programme/Municipal Corporations in deciding the insecticide to be used for vector control. Development of resistance in vectors is the reason of most of the outbreaks of malaria, therefore, such studies are required at district level and at periodic interval.

As regards the management of insecticide resistance in vector species, rotation of insecticides is the only option available. Though advanced research has been undertaken to understand the mechanism of development of resistance in vectors demonstrating Kdr mutations in *An. stephensi* and *An culicifacies* vectors of malaria [12-13], but there is no insecticide resistance management strategy so far.

Ecological Change detection: Changes in ecological conditions due to deforestation, afforestation, urbanization, developmental projects particularly irrigation projects alters the habitats of mosquito vectors. Periodic monitoring of ecological changes leading to alteration in habitats of vector species should be made. Recently succession of *An. culicifacies* by replacing *An. minimus* has been reported from Sonitpur, Assam [14]. With the availability of satellite images at finer resolution, it is possible to detect ecological changes at microlevel.

Climatic change as a threat in hitherto VBD free areas: Climate change is an emerging issue which has started affecting the spatial and temporal distribution of vector borne diseases particularly malaria [15-16]. As India has launched malaria elimination programme in the country, it is imperative to monitor vulnerable areas projected to have new foci of transmission [16]. The areas under zero category of malaria elimination strategy [2] would require more attention so as to keep them free from re-introduction/establishment of new foci. The already endemic areas which are projected to have extended transmission windows, the time of IRS is likely to alter.

Cutting Edge Tools for Vector Control

a. Genetically Modified Mosquitoes: The science of genetically modified (GM) mosquitoes was tried in India for control of Culex mosquitoes long back [17] but failed due to various reasons. Recently, Oxitech, a UK based company (taken over by Intrexon, U S A in 2015) has produced GM male *Aedes aegypti* mosquitoes which have been trialed in field conditions in Cayman Islands, Malaysia, Panama and Brazil and claimed 90% reduction in Aedes population [18].

However, keeping in view that "the method has not been conclusively tested for its safety or efficacy to control wild populations of the insect vector" [19], the logic of success of GM mosquitoes for control of vector species or respective disease does not hold promise. A recent review by Genewatch UK [18] concluded that "the method was not practical besides involving high costs", and "there is no direct evidence of a fall in the population of biting female mosquitos, which transmit disease", appears to be the final word in this direction.

b. Use of Wolbachia bacteria: Recently Wolbachia bacteria has been found useful in suppressing population of Aedes mosquitoes as well as reduced vector competency by cytoplasmic incompatibility [20]. The first field trial was undertaken in Cairns, Australia in 2011 which extended gradually to Singapore, Vietnam, Colombia and Indonesia. In Singapore also the field trials have proved successful in reducing dengue transmission [21]. The World Health Organization has permitted carefully designed field trials to see the effect of Wolbachis for reduction of dengue [22]. In Brazil, a biggest release of Wolbachia infected Aedes mosquitoes were released in Rio de Janeiro, Brazil, and Medellín, Colombia to fight Zika, dengue and chikungunya viruses [23]. More and more areas are undergoing field trials and this approach is being regarded as a successful biological control strategy [20]. A Mathematical Modelling study by Dorigatti et al [24] found that Wolbachia has exciting potential for spread amongst Aedes population and suppress dengue transmission. The Indian Council of Medical Research has also signed a Memorandum of Understanding with University of Monash (Australia) on 7th February

2017 for undertaking trials for control of Dengue in India (http://pib.gov.in/newsite/photoright.aspx?phid=98795) wherein Monash University will help set the laboratory for study and provide technical support before undertaking field trials.

c. Clustered regularly interspaced palindromic repeats (CRISPR) and CRISPR-associated (Cas) gene: CRISPR/Cas9 is a technique to edit a gene in mosquito so as to prevent the development of Plasmodium parasite . Dong et al [25] found that gene edited *Anopheles gambiae* were less likely to carry human or rodent Plasmodia and they were less fit than normal population. This tool also has potential to prevent malaria transmission.

Conclusion

The strategies of vector control using larvicides, IRS, use of ITN rely on the preferred breeding habitats by a vector species, place of resting, biting rhythm and susceptibility to insecticides which change with the change in social-development and exposure to insecticides. There is constant need to undertake research on these basic aspects for getting impact of vector control interventions. With the advent of new tools and technologies, determination of EIR in problematic foci of malaria for planning IRS and assessing the impact of intervention, use of space technology for ecological change detection, and Wolbachia for control of dengue by reducing Aedes populations are warranted.

As our country has launched malaria elimination, gradually more and more areas will come from category three to 2 and 1 (API <2). Such areas with very low transmission are likely to witness outbreaks particularly in western side of India. Need for early warning system using rainfall, Vegetation index, Sea surface temperature or Temperature Condition Index [26-29] would be felt, warranting the need of a Web based system which can be used at district level. Notwithstanding, the need for evaluation and development of new products/tools of vector control should always be there.

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Dengue Fever Epidemiology Prevention and Management

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Epidemiology

The first recognized epidemic of dengue was in the 1780s and Benjamin Rush, a Philadelphia based physician and signatory of the Declaration of the United States, was the first one to report a confirmed case, giving it the name of "break-bone fever" after the terrible back pain these patients used to have.

Dengue is endemic to around 100 countries of the world. Before 1970, only 9 countries had suffered from dengue epidemics, but with rapid globalization, there is a fast spread of mosquito-borne illnesses in regions hitherto free of those diseases. Around 40% of the world population living in tropical and subtropical areas is at risk of disease.

Since most dengue infections are asymptomatic and there is gross underreporting of cases, actual incidence is difficult to calculate. There is no doubt however that global incidence is increasing and an estimated annual incidence of infection is 390 million (95% CI 284-528 million) with 96 million (95% CI 67-136 million) having clinical manifestation(s) [Figure 1]. In India, in 2017, there were 0.15 million cases reported with 250 deaths.

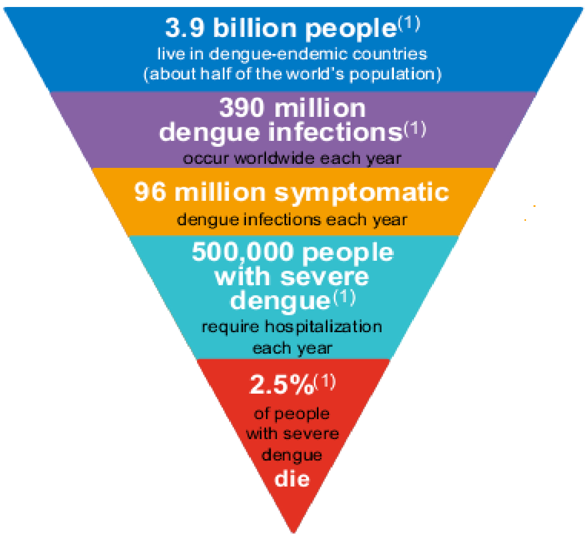

Figure 1: The Dengue Fact-Sheet (World Health Organization, 2015)

Epidemiological Determinants

Agent: The dengue virus belongs to the *flaviviridae*family. There are four serotypes DENV1-4, and all four serotypes are present in India, causing epidemics of dengue.

Vector: *Aedes aegypti* and *Aedes albopticus* are two main vectors. *Aedes aegypti* is highly domesticated, anthropophilic and nervous feeder and feeds on more than one host; therefore is highly suited for spreading the infection. *Aedes albopticus* is usually involved in transmission in forested areas.

Pathophysiology

The incubation period of dengue infection is usually 3-14 days. The severity of infection depends upon the immune response mounted by the host. Patients with prior infection tend to mount a heightened immune response, leading to mast-cell degranulation and vasodilation with enhanced antibody-dependent replication (Halstead Theory), ultimately leading to a cytokine storm and septic shock.

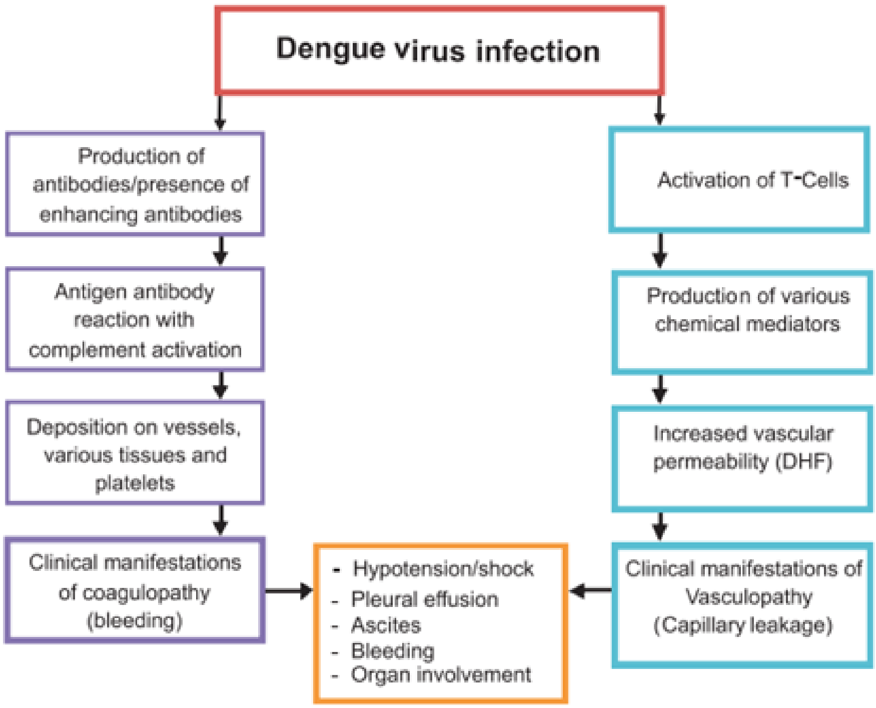

Figure 2: Pathophysiology of Dengue Infection (NVBDCP National Dengue Guidelines, 2014)

Clinical Features

Most of the infections do not cause any symptoms and these patients are diagnosed to have prior asymptomatic infection through IgG seropositivity in routine tests. Dengue fever passes through the following 3 phases:

1. Febrile phase
2. Critical Phase
3. Convalescent Phase

1. Febrile Phase

Sudden onset high-grade unremitting saddleback fever lasting for 2-7 days, commonly associated with a headache (predominantly retroorbital), flushing and rash.

2. Critical Phase

3-4 days after onset of fever, plasma leakage happens with hemoconcentration and hypotension. There is third space fluid loss with Gallbladder wall edema, pleural effusion, and ascites. This phase lasts for 1-2 days.

3. Convalescent/ Recovery Phase

The fluid lost to extravascular compartment due to plasma leakage comes back into the circulation, leading to improvement in symptoms and signs. Lasts for 2-3 days. Optimal fluid management necessary to avoid fluid overload.

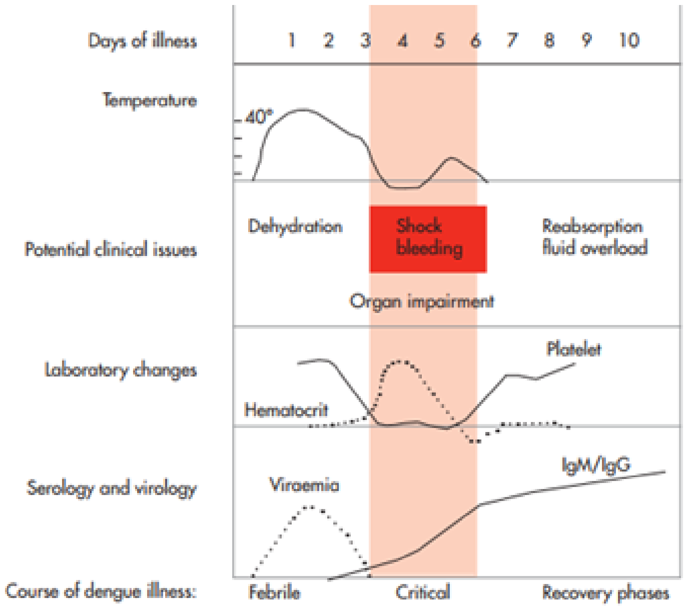

Fig. 3: Phases of Dengue Illness (Source WHO 2009 Dengue Guidelines)

For purpose of stratifying patients into those who require emergent hospital care or can be safely discharged home, dengue infection is divided into (Figure 4):

1. Mild Dengue
2. Moderate dengue
   - With high-risk features and comorbidities
   - Without high-risk features and comorbidities
3. Severe Dengue (Includes Dengue hemorrhagic fever and Dengue Shock Syndrome)

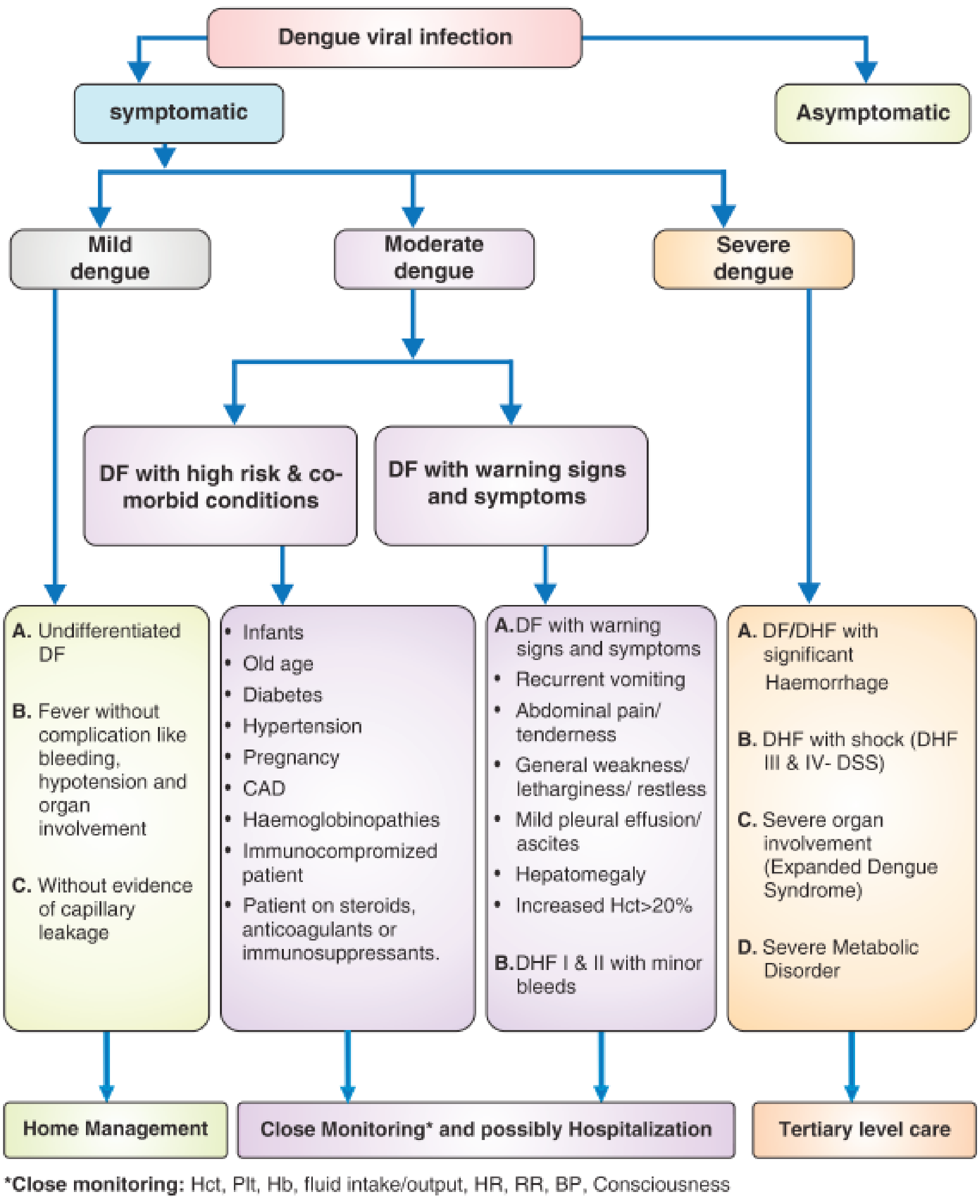

Figure 4: Dengue Case Classification for purpose of Management (NVBDCP National Dengue Guidelines, 2014)

Diagnosis

< 5 days NS1 Antigen detection helps in early detection during viremia while antibody response is poor.

> 5 days IgM antibody detection using Enzyme-Linked Immunosorbent Assay (ELISA)

Management

1. Aim

- Control of fever during febrile phase with supportive management
- Adequate fluid resuscitation during critical phase
- Supportive management and observation during recovery phase

2. General Principles

i. Bed Rest

ii. AVOID NSAIDs and Over the Counter Pain Killers

iii. Cold/tepid sponging to keep temperature <38.5^{o}C

iv. Acetaminophen: Adults 500mg/dose, can be repeated every 6 hours

v. Oral fluids, ad libitum

vi. Observation for 24-48 hours till afebrile

vii. Patients with Severe Dengue require intravenous fluid resuscitation and may require blood products as well, mandating hospital admission

viii. Crystalloids are favored over colloids, with normal saline being the preferred fluid.

ix. Patients with moderate dengue must be managed on an individual basis, depending upon co-morbidities and risk factors.

x. Platelet transfusion:

➢ Primary Prophylaxis: Platelet count <10,000/ul

➢ Secondary prophylaxis: Hemorrhage with/without thrombocytopenia

Prevention

1. Mosquito Control: Thoroughly integrated vector management and source control.

Action	For individual & family protection	For community protection
Source Reduction	Prevent water collection in and around household	Environment sanitation an drainage
Anti-Mosquito measures		Space spray of insecticides
Anti-Larval measures	Peri-domestic sanitation	Biological control Chemical Control
Reduction of human-mosquito contact	Insecticide treated bed nets Insect repellant creams Preventive clothing	

2. Vaccines:

CYD-TDV®, marketed by Sanofi-Pasteur has been tested in large randomized trials, in South America as well as Asia. It showed a significant reduction in dengue hospitalization (67-80%) and was found to be more efficacious in subjects having seropositivity for dengue at baseline. It is not recommended in children < 9 years of age due to increased severity of illness and risk of hospitalization in 2-5year age group with the vaccine. It is recommended for use only in those regions and population sub-group where the prevalence of seropositivity is ≥70%. The vaccine is currently not approved in India.

Global strategy 2012-2020 for dengue prevention and control (WHO 2012)

- Reduce dengue mortality by ≥ 50% by 2020
- Reduce dengue morbidity by ≥ 25% by 2020

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The Relevance of Experimental Evolution Studies in Times of Rapid Anthropogenic Change

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Abstract

There is a general misconception, particularly so in Indian biology, that evolution and ecology, especially experimental laboratory studies of evolution and ecology, are areas of largely basic interest, generally lacking in applied significance. This could, however, not be farther from the truth. In an area of rapid anthropogenic change in environment, whether it be climate change, habitat fragmentation, or the increasing antibiotic load, there is much that experimental evolution studies can contribute to how we conceive of, understand and tackle a variety of pressing societal problems. It is also not very well known in India that well over half the research groups using long-term experimental evolution laboratory studies are based in our country and are making significant contributions to basic understanding, contributions that also have far-reaching implications for practical issues. In this paper, I first introduce the range of societal problems that need an evolutionary biology input for their successful tackling, then briefly discuss the range of experimental evolution and ecology researches done in India, and finally outline results from three such long-term studies that have particular applied significance. Finally, I discuss the state of evolutionary research in India in this context and suggest some corrective measures.

Key-words: experimental evolution; laboratory selection; fluctuating environments; antibiotic resistance; dispersal ability; habitat fragmentation; population stability; metapopulation dynamics; extinction; environmental change.

Introduction

There is a fairly pervasive misconception, especially in India, that evolutionary biology is a field of study primarily of academic interest, and one that has few applications or implications for solving important societal problems (Joshi, 2018 a,b). Of course, historically speaking, Darwin (1859) built up his evolutionary world-view in large part by analogy to the time honoured and successful technique of plant and animal breeding. Darwin (1871, 1872) also believed that an evolutionary viewpoint would shed great light on human social behaviour, an insight that came to full fruition only after a century or so, with the establishment of evolutionary psychology (Barkow *et al*. 1992) and sociobiology (Wilson, 1975) as full-fledged areas of biological inquiry. However, while the foundational role of evolutionary biology in scientific plant and animal breeding has been well recognized for most of the twentieth century (*e.g*. see Kearsey and Pooni, 1996), the other varied applications of evolutionary biology have largely been ignored by all except practitioners in those niche areas, although this situation is beginning to change, especially in the developed world (*e.g*. see Hendry *et al*. 2011).

The reality is that evolutionary biology is not a sub-discipline of biology the way, say, embryology or biochemistry are. Evolutionary biology is a perspective that provides a logical framework for understanding biological patterns and processes at structural levels ranging from molecules to ecosystems. Consequently, an evolutionary perspective is crucial to understanding most of the major problems we face as as a society and can often suggest interventions that more reductionist forms of biology will not. In the present era of rapid anthropogenically driven environmental and lifestyle change, societies world-wide are facing challenges of unparalleled magnitude and impact. A variety of so-called lifestyle diseases are reaching epidemic proportions, multi-drug resistance in microbes and new viral diseases are on the rise, habitats are getting fragmented or are disappearing, and species distributions and interactions are being drastically altered by changes in climate, habitat availability and global mobility. All of these changes create challenges that require an evolutionary perspective to tackle.

Even a quick look at the range of problems for which evolutionary biology provides the foundations for possible solutions illustrates eloquently how relevant evolutionary biology is to societal concerns. Understanding multi-drug resistance in microbes, the complex progression of cancers and their responses to interventions, the phenotypic, genetic and environmental correlates of complex diseases, the diverse mechanisms of ageing and its slowdown very late in life, the emergence of new viral diseases by host-switching and how it is exacerbated by habitat alteration, the epidemiological consequences of climate and environmental change, and the challenges to vaccine production in certain kinds of rapidly mutating microbes, are all of crucial importance to tackling bio-medical problems in the present times, and all of these are classic problems in evolutionary biology. Darwinian medicine (Daszak *et al*. 2001; Nesse, 2001; Greaves 2007; Rauser *et al*. 2011), has grown in the last few decades to become a major part of bio-medical science in the developed world. In India, except for work on developing a Darwinian framework for understanding metabolic disease and Type 2 diabetes (Watve, 2013), Darwinian medicine is yet to make significant inroads. Similarly, habitat and climate changes, as well as pesticide and herbicide use, are affecting species distributions and ranges world-wide, often bringing new species into contact, resulting in new interactions between them that can have profoundly damaging effects on ecology in general, and agriculture in particular (*e.g*. see Hautier *et al*. 2015). In this area, as in the realm of assessing the eco-evolutionary risk of genetically modified organisms, Indian research is lagging behind the developed world. On the explicitly societal side, evolutionary psychology and sociobiology have important insights to offer on diverse questions such as whether rape is primarily about power or sex, why are nepotistic and despotic societies (rather than egalitarian ones) so common in humans, why intra-family (among spouses or between parents and offspring) violence shows certain asymmetric patterns across cultures, why is there parent-offspring conflict which is often differentially expressed by gender of the offspring, who exactly (*i.e*. males or females) benefits from monogamy and how, why do males in most mammalian species (as in humans) court females and not vice versa, and what explains the extreme, and often self-damaging, destructive behaviour of adolescent males. Once again, these are important questions, and evolutionary biology often offers explanations that differ significantly from those of sociologists. These differences, in turn, have non-trivial consequences for how we tackle some of these issues as a society (Wright, 1994). This form of analysis of problems in human social behaviour is largely non-existent in India. Similarly, the use of DNA data for forensic purposes is fraught with pitfalls in the absence of a deep knowledge of molecular population genetics (Mueller, 1993; Gilder *et al*. 2009; Krane *et al*. 2009), but in India is being used largely without such expertise being available for interpretation of the test results.

Experimental Evolution and Ecology

Experimental evolution and ecology are old areas of research, which got sidelined in the mid-twentieth century, but then made a comeback in the 1980s and 1990s. The basic idea of these studies is simple – it is to impose a well-defined environmental challenge on a population, or set of populations in the laboratory, and then observe their evolutionary and ecological responses to that challenge in real time, relative to ancestral control populations treated identically except for the specific ecological challenge. Thus, rather than observing the end-points of an evolutionary process and inferring the pattern of evolutionary change they underwent, one can empirically observe the evolutionary trajectory, as in any other branch of experimental science. The very first experimental evolution study was done by William Dallinger (Dallinger, 1887) in the 1880s. He cultured protists that could initially not survive beyond about 35ºC in the laboratory, gradually increasing the rearing temperature from 16ºC to 70ºC, thereby evolving a population that could grow comfortably at 70ºC. The high temperature adapted population also lost the ability to survive at lower temperatures, thus providing the earliest example of a trade-off in adaptive evolution. Some of the early experimental ecology studies on single population dynamics (Pearl, 1927; Chapman, 1928) and species interactions (Gause, 1934) were likewise carried out early on in the history of ecology, in the first few decades of the twentieth century. Experimental evolution in the modern sense of using well-replicated large populations for long-term selection studies really began in the late 1970s to early 1980s, with (i) Laurence D Mueller's work on adaptation to crowding using fruitflies, (ii) Michael R Rose's studies on the evolution of aging using fruitflies, and (iii) Richard E Lenski's very long-term evolutionary dynamics studies using bacteria (reviewed in Garland and Rose, 2009). Long-term, well replicated experimental studies on population ecology, likewise, picked up again in the 1970s and 1980s, with work on fruitflies and flour beetles, and were extended to laboratory studies on stability and dynamics of metapopulations from the 1990s on (reviewed in Mueller and Joshi, 2000). These experimental evolution and ecology studies over the past few decades have yielded fundamentally important insights into phenomena as diverse as speciation, sexual selection and sexual conflict, aging, the evolution of competitive ability, the evolution of developmental rates and fecundity schedules, the evolution of antibiotic and insecticide/pesticide resistance, the evolution of population stability and the impact of dispersal on the dynamics and stability of spatially structured populations and small populations. As we shall see in the next section, Indian research groups have made significant contributions to this corpus of work.

Experimental Ecology and Evolution in India

In India, long-term experimental evolution studies on the cytogenetic and other correlates of the early stages of speciation following hybridization between species of *Drosophila* were initiated at the Department of Studies in Zoology, University of Mysore, in the 1980s (Ranganath and Aruna, 2003). Subsequently, experimental evolution studies aimed at understanding life-history evolution in fruitflies and experimental studies of dynamics and stability of metapopulations were initiated in the 1990s in the Evolutionary and Organismal Biology Unit of the Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru, and soon extended to experimental evolution work on aspects of circadian organization in fruitflies. All the laboratories presently carrying out long-term experimental evolution and ecology studies in India (with the exception of Deepa Agashe's group at NCBS, Bengaluru) are direct or indirect offshoots of the Evolutionary Biology Laboratory at JNCASR, Bengaluru.

At present, experimental evolution and ecology research in India covers diverse areas of the field (Table 1) and, in many of these areas, Indian research groups are among the world leaders. This is particularly true of experimental evolution studies of (i) adaptations to crowding, (ii) sexual selection and sexual conflict, (iii) adaptation to fluctuating environments, (iv) evolution of dispersal ability, (v) the evolutionary relationship between developmental rate and competitive ability, (vi) immunity and life-history evolution, and experimental ecology studies of dynamics, coherence and stability in small populations and metapopulations. Unfortunately, this fact is not widely appreciated in India and when we talk about why Indian biologists are not among world leaders at various brainstorming sessions, it is hardly ever recognized that we do have such world leaders in experimental evolution. Indeed, the vast majority of research groups world-wide using long-term experimental evolution and ecology approaches to investigate fundamental questions in the fields are in India!

Table 1. Research groups in India that primarily use long-term experimental evolution and ecology approaches in their work.

PI	Institution	Organism(s)	Major Areas	Representative Publications
H A Ranganath*	University of Mysore	fruitflies	Hybridization and speciation	Ranganath and Aruna (2003)
Amitabh Joshi	JNCASR	fruitflies	Life-history evolution, adaptation to crowding, evolution of popualtion stability, metapopulation dynamics.	Dey and Joshi (2006); Ghosh and Joshi (2012); Sarangi *et al*. (2016)
V K Sharma**	JNCASR	fruitflies	Evolution of circadian organization.	Vaze and Sharma (2013)
N G Prasad	IISER Mohali	fruitflies	Sexual selection, sexual conflict and life-history evolution.	Syed *et al*. (2017)
Sutirth Dey	IISER Pune	bacteria, fruitflies	Evolution in fluctuating environments, evolution of dispersal ability, metapopulation dynamics.	Karve *et al*. (2015); Tung *et al*. (2018)
Mallikarjun Shakarad	Delhi University	fruitflies	Life-history evolution, nutritional status and ageing.	Sageena *et al*. (2014)
Deepa Agashe	NCBS	bacteria, beetles	Evolution of codon usage, evolution of insect immune function.	Khan *et al*. (2018); Mahajan and Agashe (2018)
Bodhisatta Nandy	IISER Berhampur	fruitflies	Sexual selection and the evolution of mating behaviour.	Nandy *et al*. (2016)
Imroze Khan	Asoka University	beetles, fruitflies	Evolution of insect immune function and life-history evolution.	Khan *et al*. (2017)

(*: retired; **: deceased)

Some Case Studies

In this section, I briefly outline three long-term experimental evolution or ecology studies from India that have significant implications for some of the pressing problems we face in the present era of rapid anthropogenic environmental and habitat change.

Multi-drug Resistance in Microbes

Microbes that are resistance to multiple drugs, including very recently developed ones, are now widely recognized to constitute a bio-medical crisis of the greatest import (Powers and Kesselheim, 2018). Even more worrisome are reports of microbes from human microbiota that are already resistant to recently developed antibiotics to which they could not possible have had any exposure (*e.g*. see Clemente *et al*. 2015). A possible explanation for why microbes from pristine high-altitude streams, or primitive tribes from the Amazon rain-forest exhibit resistance to antibiotics not even in wide use yet comes from long-term studies of adaptation to fluctuating environments in the bacterium *Escherichia coli*, carried out by Sutirth Dey and his students from the Population Biology Lab at IISER Pune (Karve et al. 2015, 2016 a,b). Traditional experimental evolution studies have typically involved adaptation to a constant, single selection pressure, like a stressful temperature or density, or constant light, or the need to reach adulthood fast, or to reproduce late in life (reviewed in Prasad and Joshi, 2003). In the above-mentioned studies, *E. coli* populations were subjected to environments in which three novel stresses – extreme pH, high salt concentration and high oxidative stress – were experienced in randomly occurring combinations, over a long timespan. In parallel, other populations were also subjected to each of these stresses singly, in a constant manner. In all the cases, populations evolved to adapt to the novel stress(es) and became better at surviving in those stressful conditions, over many generations. However, populations adapting to one stress at a time often showed tradeoffs with the ability to deal with the other stresses, whereas populations adapted to dealing with environments involving randomly fluctuating combinations of the three stresses did not exhibit any such tradeoffs. Moreover, the populations adapted to fluctuating combinations of the three stresses also evolved the ability to deal with novel stresses that they or their ancestors had not experienced for thousands of generations of laboratory rearing. In particular, these populations exhibited resistance to multiple antibiotics that they or their ancestors had never been exposed to. Further investigations revealed that the mechanisms of stress resistance in the populations adapted to the fluctuating combinations of three stresses were different from, and more generic than, those evolved in the populations challenged with one stress at a time. Specifically, these populations evolved greater efflux pump activity, that also yielded multi-drug resistance as a by-product. These studies, thus, suggest that resistance to multiple antibiotics can evolve even in populations not exposed to any of those antibiotics, merely as a by-product of adapting to a complex environment with multiple fluctuating stressors. Moreover, such evolution in a complex environment seems to avoid the emergence of tradeoffs between the ability to deal with different specific stresses. This finding, again, suggests that relying on such tradeoffs to manage problems like antibiotic resistance, by cycling patterns of antibiotic use, may not be of much use, and also has cautionary implications for the outcomes of selection for tolerance to single stresses, as commonly practised in agricultural breeding. The point to be noted here is that these studies were not done to investigate antibiotic resistance *per se*. Rather, a study of a basic evolutionary question – how populations adapt to multiple fluctuating stresses – led to insights that are relevant for our understanding of the evolution of multi-drug resistance in microbes.

Evolution of Dispersal Ability

With growing habitat fragmentation, and hitherto habitable areas becoming inhospitable due to climate change, the importance of dispersal as a potentially adaptive trait in times of anthropogenic environmental change is increasingly being appreciated (Clobert *et al*. 2012; Travis *et al*. 2013). Till recently, while it was recognized that dispersal is a complex trait made up of many components, it was not clear for any system what all these component phenotypes are and how they interact with one another, whether there are tradeoffs among them or with other life-history traits, and how dispersal responds to selection on the various components (Tung *et al*. 2018). A long-term, multi-generation study by the Population Biology Lab at IISER Pune (Mishra *et al*. 2018; Tung *et al*. 2017, 2018), selecting populations of *Drosophila melanogaster* for increased dispersal ability by making them disperse for increasing distances each generation in order to be chosen to breed, has shed considerable light on these important questions. After over fifty generations of selection for increased dispersal distance, selected populations showed large changes in the dispersal kernel, exhibiting greater propensity and ability to disperse, as well as an increased frequency of long distance dispersers. The differences between selected and ancestral control populations persisted even in the absence of proximate drivers of dispersal, such as lack of food. There were no major tradeoffs with longevity or fecundity, and the evolution of higher dispersal was accompanied by evolved increases in exploratory behaviour and aggression levels, and by physiological changes towards higher energy metabolism. Sex and density exhibited complex interactions with regard to sex-biased dispersal patterns, suggesting subtly different effects on components of dispersal-related behaviour or physiology between the sexes. The experimental demonstration of rapid evolution of dispersal propensity and ability, accompanied by increased aggressive and exploratory behaviour, has important implications for assessing the consequences of habitat fragmentation or reduction on invasive species, or host-range expansions of pathogens and other antagonists (Tung *et al*. 2018). Again, it should be stressed that it would have been very difficult to gain such clear insights into the evolutionary dynamics of dispersal using field studies, as opposed to an experimental evolution approach.

Effects of Dispersal or Immigration on Metapopulation Stability and Persistence

Increasing habitat fragmentation has also meant that many more populations than before are now found as metapopulations, or sets of small populations linked by dispersal. A major conundrum among theorists in the area of metapopulation ecology has been about the effects of dispersal (earlier called 'migration') among subpopulations on overall metapopulation dynamics and stability (reviewed by Abott, 2011). The issue has been that theoretical studies suggest that the impact of increased dispersal among subpopulations can be destabilizing or stabilizing at the global level, depending on the degree of coherence among the dynamics of the subpopulation sizes, especially when the subpopulations have unstable or cyclic dynamics. Another problem has been that theory has often bothered about stability of population dynamics in the sense of constancy, whereas ecologists and wildlife managers are often more concerned about stability in the sense of persistence (reviewed in Dey and Joshi, 2018). The relationship between local dynamics, global stability, dispersal rate and coherence is almost impossible to study in the wild, but is amenable to experimental examination using model systems in the laboratory (Mueller and Joshi, 2000). Once again, Indian labs – at JNCASR Bengaluru, and IISER Pune – have been at the forefront of such empirical studies. In fact, the use of *D. melanogaster* metapopulations in the lab for addressing such questions arising from theoretical studies was pioneered in the late 1990s at the Evolutionary Biology Lab at JNCASR (Mueller and Joshi, 2000). Over the past two decades, a series of studies from these two labs have added greatly to our understanding of the subtleties of how dispersal and local dynamics interact in their effects on global stability in metapopulations, and also to our appreciation that constancy and persistence can often respond independently to ecological or evolutionary pressures. Given the potential use of dispersal corridors or controlled immigration from a neighbouring or captive bred population in managing fragmented populations of wild species (*e.g*. see Gusset et al. 2009), this understanding is highly significant to planning such management interventions in conservation biology.

These studies on *D. melanogaster* populations provided the first empirical verification for the prediction that low rates of dispersal among unstable local subpopulations will be stabilizing at the global level by mediating negative synchrony among subpopulation sizes (Dey and Joshi, 2006). Subsequent studies, reviewed by Dey and Joshi (2018), showed that low dispersal mediates negative synchrony only when subpopulation dynamics are unstable or cycling, not when they are relatively stable. Higher rates of migration increase coherence (positive synchrony) among subpopulations and can, therefore, be globally destabilizing when local dynamics are unstable. Moreover, these studies also revealed interesting patterns of interactions between dispersal rate and local dynamics on both constancy and persistence, and yielded the first empirical demonstration of greatly increased global extinction rates due to a combination of low subpopulation persistence and constancy, and high coherence induced by high dispersal, together with targeted immigration into a few subpopulations every generation. Taken together, these studies clearly indicate that it is important to have some knowledge of local dynamics and likely dispersal rates when planning interventions involving dispersal corridors between habitat patches, as well as interventions involving the targeted release of captive bred individuals into subsets of local populations within metapopulations, in attempts at stabilizing metapopulations with an intent to enhance global persistence.

Conclusion

The present state of evolutionary biology research and education in India is ironic. On the one hand, our curricula largely neglect evolution and what little is taught of it is often a half century or more out of date. There are no post-graduate departments of evolutionary biology in any Indian university, and evolutionary biology is not among the very numerous under-graduate specializations possible in biology in India. The single, small post-graduate training programme in the field – an Integrated PhD course in Evolutionary and Organismal Biology at JNCASR, Bengaluru – was abruptly terminated after a few years, despite very appreciative student responses. Yet, on the other hand, Indian evolutionary biologists, though few in number, have, on an average, contributed to the growth of knowledge in their field to an extent quite possibly unmatched by those working in other areas of biology (DST, Government of India, 2017). More to the point, as the preceding sections have shown, evolutionary biology is very relevant to devising ways and means of tackling a whole range of problems facing our society, from public health issues to concerns about sustainability, conservation and wildlife management, and increasing levels of domestic and sexual violence. In order to produce professionals who are well placed to tackle such problems, we need a solid grounding in evolutionary biological concepts and phenomena to be part of the basic training in diverse areas of applied science, from health and agriculture to psychology and sociology.

There are several things that can be done to address this imbalance in our need for and possession of adequate numbers of people in diverse fields who have a deep understanding of evolution. At the school level, we need far greater representation of evolution in biology curricular, with adequate and up to date treatment of concepts and phenomena, as well as a proper emphasis on the myriad applications of an evolutionary perspective in tackling pressing societal problems. At the undergraduate level, we need to have B. Sc. (Hons.) degrees in ecology and evolutionary biology. At the post-graduate level, we need full-fledged degree programmes and departments of ecology and evolutionary biology, including M. Sc. Programmes in applied ecology and evolutionary biology. Major research institutes that have a focus on various aspects of bio-medical science or agriculture should also have thriving departments of ecology and evolution to enable proper multi-disciplinary strategies to be brought to bear on problems of societal importance. And, finally, there is a pressing need for at least one large national-level research cum training institute focused on evolutionary biology in its broadest sense, covering ecological and evolutionary dynamics, evolutionary genetics, phylogenetics, social evolution, coevolution, eco-evolutionary epidemiology, Darwinian medicine, evolutionary psychology, palaeontology, human ecology and evolution, and applied evolutionary biology.

If India wishes to effectively leverage scientific understanding to address problems of public health, environment, agriculture and societal breakdowns, it cannot be done without greatly enhancing our appreciation of the importance of an evolutionary perspective to attacking these problems. In fact, in many areas, it is folly to imagine that reductionist biology will be able to provide solutions to multi-faceted and complex problems on its own. In some areas, reductionist biology has actually contributed to creating the problem in the first case. Similarly, in many technologically intensive and expensive areas of reductionist biological research, it is difficult for Indian research groups to be globally competitive unless they are located in a small handful of elite institutions. In most sub-areas of evolutionary biology and ecology, however, even researchers in state universities could do world-class research, provided they had the requisite background in the field. Given the lack of a technology gap, and our tremendous resources in terms of habitat variety and biodiversity, large numbers of Indian evolutionary biologists could very easily be competitive globally if their exposure to, and grounding in, the subject were improved through far-reaching changes in biology education. Indeed, in several areas of evolutionary biology, including social evolution, coevolutionary dynamics, evolution of competitive ability, sexual selection and sexual conflict, evolution of population stability, *etc*., Indian researches are already among the world leaders. A massive up-scaling of our investments in evolutionary biology research and training would, thus, help us attain two goals: a better ability to tackle a wide range of societal problems, and a greatly enhanced profile of our nation in biological research world-wide.

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Alternative Alert Systems for River Health: Need for Ganga River Basin Management

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Abstract

During recent years, a number of diagnostic criteria have been identified to mark the state of river health and the magnitude of anthropogenic perturbations. However, despite being critical in predicting changes, there exists a wide gap in bridging these narrative criteria to geographical scale policy implementation. The primary objective of this study was to explore cost effective alternative alert systems to address changes in water quality, status of eutrophy and associated feedbacks in the Ganga River. This multi-year and multi-scale study considers: (a) basin-scale investigations covering 2525 km river stretch between Dev Prayag and Ganga Sagar; (b) middle segment of the river covering 518 km between Kanpur upstream and Varanasi downstream; (c) Varanasi region representing 37 km long stretch between Sitalamata upstream and Varanasi downstream; and (d) a 1.5 km trajectory analysis downstream a point source along the Varanasi city. The study identifies N:P:Si stoichiometry and associated shift in diatom dominance and production of transparent exopolymeric particles (TEP) as a potential indicator of self-purifying capacity of the Ganga River. Activities of β-1,4-glucosidase, protease, FDAase and alkaline phosphatase in riverbed sediment can be used as indicators of carbon and nutrient pollution, status of eutrophy and ecosystem feedbacks in the river. This has relevance from a river conservation/rejuvenation perspective.

Introduction

During recent years, a number of diagnostic criteria have been identified to mark the state of river health and the magnitude of anthropogenic perturbations. Among these, determinants such as diatom indices (Potapova *et al*., 2004; Ponadar *et al*., 2008; Rimet and Bouchz, 2012), chl **a** biomass and biological oxygen demand (Gholizadch *et al*., 2016), phycocyanin (Ahn *et al*., 2007) and micro-invertebrate communities (Turley *et al*., 2016) have been identified as important bio-indicators, and are accepted globally. Biological oxygen demand (BOD) is one of the most commonly used diagnostic criteria for assessing river health for management purposes. This variable, however, has its own limitations specially in addressing eutrophy, contributions of autotrophic and heterotrophic factors, allochthonous inputs and ecosystem feedbacks. Additionally, short term variations in the concentrations of critical nutrients interfere in the assessment of the long term changes in the trophic status. The BOD reflects the proportion of labile organic carbon in an aquatic system. Rivers are important repositories and transporters of carbon (C) where autotrophic-heterotrophic balances together with allochthonous-C regulate fluvial-C cycle. Allochthonous-C of terrestrial origin is added into the system mainly through rain-driven land surface runoff. The quality and quantity of surface runoff depend on watershed characteristics and, on the nature and magnitude of human interferences. River discharge during surface runoff flushing is very high, transporting a major share of allochthonous C to the coastal areas. Recalcitrance of this carbon, and therefore a proportion of BOD, depends on the type of land use and land cover (LULC) in the sub-watershed (Pandey *et al*., 2014a).

Diatom based indices have gained global momentum as a narrative criteria in bio-assessment of water quality. According to the US Environmental Protection Agency (U.S.EPA, 2000), indices based on benthic diatoms are more stable indicators because they respond directly to nutrient enrichment. Presence of diatoms in all geographic areas/habitat conditions are considered as one of the major advantages in using diatom indices as monitoring tool. Diatom based predictions follow the concept that, their functional attributes respond directly to environmental variables that represent conditions during diatom growth (Potapova *et al*., 2004). However, studies conducted by some other authors suggest that the diatom indices developed in a specific geographic region may be less suitable when applied in other geographical areas (Pipp, 2002). Diatom species may not necessarily follow unimodal environmental linkages, instead represent marked floristic difference among regions (Bere and Tundisi, 2011). Additionally, even a least dominant species of diatom may be highly susceptible to small environmental changes. Thus, lack of unimodal/symmetrical environmental distribution, variability in functional controls and species sensitivity to stressors reduce the applicability of diatom indices as a water quality monitoring tool across geographical boundaries. Factors such as climate, upstream basin size and river flow further question the generality of data comparison across geographic scale. Thus, despite great significance, these issues constrain bridging these narrative criteria to geographical scale policy implementation.

For accurately understanding the magnitude of human-driven impacts, the status of eutrophy and associated feedbacks in rivers, more sensitive diagnostic criteria are needed. Nitrogen (N) and phosphorus (P) are known to be the critical nutrients influencing ecosystem processes such as formation of biomass and abundance and distribution of organisms. Absolute concentration as well as the ratio of these nutrients are often linked with the status of eutrophication (Elser *et al*., 2009; Pandey *et al*., 2014b). Recent studies suggest approximately 2.4 to 2.7 fold increase in N and P driven eutrophication of the waters, if the present trend of anthropogenic flushing continues (Kundu *et al*., 2015). Linking such a proportionately high increase in the systems subjected to high discharge/flow rate is relatively difficult.

Temporal shift in the river discharge changes the dilution effect, influencing autotrophic-heterotrophic niches with concordant river responses both in terms of biological functioning and ecosystem feedbacks. Additionally, urban rivers often witness continuous or intermittent flushing of untreated sewage (Islam *et al*., 2015) which makes predictions further difficult.

The primary objective of this study was to explore cost effective alternative alert systems to address changes in water quality and status of eutrophy in the Ganga River. Based on the basic observational science, the study identifies four diagnostic domains namely 1. Biodiversity linkages; 2. Transparent exopolymeric particles; 3. N:P:Si stoichiometry; and 4. Sediment metabolism. These alternative criteria can be translated into practical approaches in assessing the quantum of anthropogenic flushing of carbon and nutrients, status of eutrophy and ecosystem feedbacks in the Ganga River.

The water quality of the Ganga River is rapidly degrading and the Government of India has given particular attention towards its monitoring and management. Because physical and chemical measurements of water quality have their own limitations primarily due to the influence of river discharge, heterogeneous point sources and intermittent flushing from non-point sources, there is an emerging need to develop cost effective alternate measures for assessing water quality status, ecosystem feedbacks and associated efforts for rejuvenation. The merit of these alternative monitoring tools studied through our field and laboratory trials include: a) These are ecologically viable and cost effective; b) predict quantum of external carbon and nutrient inputs; c) identify patchiness and niche partitioning; d) assess dilution effect and need to regulate river flow; e) identify the limit of self-purification capacity/ecological assimilation capacity of the river; f) sensitive to environmental stressors; g) have strong relationships with human-driven impacts; and h) can be tested over full range of river ecosystem.

Materials and Methods

Study area

The data presented here are the outcome of our published and unpublished study results conducted on the Ganga River. Overall, these multi-year protocols constitute four tiers of studies including: (a) basin-scale investigations covering 2525 km river stretch between Dev Prayag and Ganga Sagar (Fig.1); (b) middle segment of the river covering 518 km between Kanpur upstream and Varanasi downstream; (c) Varanasi region representing 37 km long stretch between Sitalamata upstream and Varanasi downstream; and (d) a 1.5 km trajectory analysis downstream a point source along the Varanasi city . The point source selected for the trajectory analysis was Assi drain previously known as Assi River (Fig. 2). The rivulet adds ~66.45 MLD of waste water into the river. The study zones differ in geomorphology, ecology and the magnitude of anthropogenic pressure. Different study zones were divided further into different sub-sites for detail studies.

The Ganga River basin covers 1,086,000 km^2 area and is the 4th largest river basin in the world. In India, the drainage area covers ~26.2% of the total geographical area of the country. The major part of the basin in Indian Territory represents agricultural land accounting for~74.44% of the total area. About 3.47% of the basin is covered by water bodies. The River Ganga traversing a distance of 2525 km from its source to its mouth drains eleven states of India. In its long course the main river is joined by a number of tributaries such as Bhilangna, Alaknanda, Ramganga, Kali, Yamuna, Gomti, Ghagra, Gandak, Kosi, Sone and others. In the upper segment it flows on steep, narrow and rocky bed, carries cold water and subjected to much less anthropogenic pressure. Middle segment of the river (Kanpur to Varanasi) flows in plains, meandering mostly on bed of fine sand and influenced largely by human interventions in terms of water diversion and high degree of pollution load. Lower segment (from Varanasi to Ganga Sagar) represents strong human pressure and downstream influences.

The study region represents a wide array of climatic conditions ranging from sub-tropical to tropical humid zones. The year shows distinct seasonality: a cold and dry winter (November to February), a warm and humid summer (April to June) and a humid monsoon season (July to September). October and March represents transition months. Southwest monsoon brings over 80% of the rainfall. The river is fed by the Himalayan snow from April to June and by rain-driven surface runoff during monsoon months. The precipitation varies from 780 mm in the upper stretch through 1040 mm in the middle part; 1820 mm in the delta region to 2500 mm in the northeast. In summer, temperature in some areas exceeds 46°C. During winter, in some part, temperature may drop below 0°C.

Measurements

Analytical variables include parameters associated with water quality, diatom biodiversity, transparent exopolymeric particles and sediment metabolism. Water quality variables were measured in replicates and in the composite samples following standard methods (APHA, 1998). The changing patterns of diversity-dominance linkages of benthic diatoms were studied at the confluences of four tributaries of the Ganga River (Yamuna, Assi, Varuna, Gomti). Diatom volves were counted under Nikon trinocular inverted microscope (Model TF 100-F) and Metzer light microscope. The detailed description of methodology is available in Pandey *et al*. (2017). Transparent exopolymeric particles (TEP) concentration in water samples was measured spectrophotometrically (Passow and Alldredge 1995). The abundance of TEP stained in Alcian blue was also analyzed using microscopy.

A very interesting aspect that we studied for the first time in the Ganga River was a land-water interface associated trajectory analysis downstream of a point source (Assi drain). We selected 15 sites considering 1.5 km downstream of the Assi drain (point source that adds ~66.45 MLD of sewage water into the river at Varanasi). The land-water interface along the trajectory was studied with respect to CO_2 emission and microbial variables. The CO_2 was collected at all sites in steel chambers and measured following volumetric analysis and greenhouse gas analyzer (Trace 1110, Thermo Fisher Scientific India Pvt. Limited).

For quality control, samples were collected at the same time (early morning) during whole sampling period to avoid the effect of any major change in moisture and temperature.

Methods for variables associated with sediment samples (collected from the land-water interface and from the riverbed) such as basal respiration (BR), substrate induced respiration (SIR), microbial biomass and activity, microbial metabolic quotient (qCO_2) and enzyme activities have been described elsewhere (Jaiswal and Pandey, 2018; Jaiswal *et al*., 2018). Sediment oxygen demand (SOD) was measured in the riverbed sediment to understand the state of oxygen tension at sediment-water interface in the river. The SOD was measured at five study sites (37 km stretch) following Ling *et al*. (2009).

Results and Discussion

Diatom-dominance transference and production of TEP

Anthropogenic environmental changes are continuing to drive biodiversity loss and altering ecosystem processes. A recent global synthesis by Hooper *et al*. (2012) reveals that biodiversity loss could be ranked among the major drivers of ecosystem change. This global scale synthesis suggests the need for systematic database on the interactive effects of biodiversity loss and environmental changes and associated effects on ecosystem functioning. Diatoms, a diverse group of photosynthetic protists in aquatic ecosystems, are commonly used as indicator of environmental change and are important producer of transparent exopolymeric particles (TEP). This diverse group of benthic producers are regulated by the concentrations of nutrients, ionic strength, pH, depth of light penetration and temperature regimes (Potapova and Charles, 2003; Alakananda *et al*., 2011). In our earlier study (Pandey *et al*., 2017) conducted along 268 km stretch of Ganga River between Allahabad and Varanasi downstream, we observed significant variation in diatom abundance and diversity in concordance with changes in carbon and nutrient pollution. Species diversity declined with decreasing N:P stoichiometry. Diatom-abundance respond sharply to the changes in the concentration of nutrients. Sites highly rich in nutrients were found to be less favorable for most species (Table 1). Some species may adapt to high nutrient concentrations (Pan *et al*., 2006) and can accommodate heterogeneous habitats by dominance transference. This ability of diatoms tends to restore the ecosystem functioning including the production of functionally active acidic bio-polymers (Pandey *et al*., 2017).

Diatoms are important producers of acidic polysaccharides released in the water environment in the form of transparent exopolymeric particles (TEP). The TEP are transparent organic particles, ranging in size from >0.4μm to <200μm and can be stained with the Alcian blue. These acidic polysaccharides are excreted by microbes, especially when C acquisition is high. Some species of diatoms may follow C_4 photosynthetic pathway and capitalize on carbon resources rapidly (Riebesell *et al*., 2007). This carbon capture and storage remains unbalanced if nitrogen resources are not available proportionately. Accordingly, excess of carbon excreted as acidic polysaccharides which ultimately gets converted to TEP.

These transparent exopolymeric particles, because of their ability to form coagulates and aggregates, regulate DOC-POC pump. Thus, TEP plays important role in carbon sequestration. Adsorption of high-density particles such as heavy metals and calcium carbonate increases the density of TEP aggregates and consequently the sedimentation of nutrients, heavy metals and pathogens (Passow and Alldredge, 1995; Passow *et al*., 2001). Studies show that the number of microorganisms, bacterial production and community respiration are highly dependent on the size of diatom aggregates (Grossart *et al*., 2003).

A recent study conducted in our laboratory shows that diatom tends to cope-up with nutrient stressors and diatom-driven production of TEP and associated changes in sedimentation-removal of turbidity may be an important mechanism imparting to self-purification capacity of the Ganga River (Pandey *et al*., 2017). The study observes that a drop in the concentration of TEP was compensated partially by diatom-dominance transference. The low profile guild representing *Cocconeis placentula, Cymbella affinis, Cyclotella meneghiniana* and *Synedra ulna* was found dominant at phosphorus poor sites. On the contrary, high profile guild representing *Diatoma vulgaris, Gomphonema parvulum* and *Fragilaria intermedia* appeared abundant at P-rich sites (Table 1). Thus, the diatom ecological guilds, rather than the distribution of individual species, may be considered more holistic indicators of short term changes or disturbances. This seems not only an indicator of ecosystem resilience but also an important mechanism of natural cleaning of this major river system. Additionally, because TEP shows dependence on Chl **a** and N:P stoichiometry (Fig. 3), it can also be used as an indicator of trophic status and nutrient pollution.

Excessive nutrient loading shifts diatom-dominance pattern and species with ability to occupy different available niches accommodate wider range of distribution. Pandey *et al*. (2017) observed a marked skewness in diatom dominance-diversity linkages in the Ganga River. A synchrony in the skewness to changes in water quality indicate availability of resources and ability to cope with nutrient stressors and disturbances. Bojorge-Garcia *et al*. (2014) observed almost a similar synchrony in a tropical mountain stream of Mexico. Although benthic diatoms are well influenced by depth of light penetration, ionic strength, concentration of chloride etc., species differ in their ability to withstand variable concentrations of nutrients and organic pollution. This ability possibly regulate their heterogeneous distribution by capitalizing on available niches and resulted niche partitioning and, in turn, helps improving the water quality (Cardinale, 2011). For instance, among the TEP producers, *Cocconeis placentula, Cyclotella meneghiniana* and *Cymbella affinis* could flourish at nutrient poor sites. On the contrary, *Aulacoseira granulata, Diatoma vulgaris, Melosira varians* and *Fragilaria intermedia* extensively capitalize upon nutrient rich resources (Table 1). This shows that despite variable ecological conditions, principally driven by human activity, TEP production is maintained partly by changes in diatom dominance-diversity linkages. Thus, the concentration of TEP if coupled with diatom-dominance transference could be an important indicator of nutrient pollution and self-purification potential of the river.

N:P:Si stoichiometry

Biogeochemical cycles of major elements such as carbon (C), nitrogen (N), phosphorus (P) and silica (Si) are intricately linked with each other. Ecosystems with naturally low N and P levels are highly sensitive to their external supply. In the past decades, sources such as agricultural fertilizer use and combustion of fossil fuel have significantly contributed to N pollution in coastal areas (Galloway *et al*., 2004). In the Ganges basin, extensive landscape transformation accompanied by massive use of agricultural fertilizers together with urban-industrial releases add substantial amount of carbon and nutrients into the Ganga River. Massive but disproportionate supply of nutrients into the river are leading to a shift in their stoichiometric ratios (Pandey *et al*., 2014b, 2016a). Nitrogen and phosphorous are often considered as limiting nutrients because their demand to supply ratios generally remain unity or below. Silica (Si) is an equally important element for the growth of diatoms. The N and P in surface waters are mainly added from anthropogenic sources. Opposite to N and P, concentration of silica (Si) in surface water is largely controlled by natural processes such as weathering and erosion. The N, P and Si stoichiometric ratio of 16:1:16, known as Redfield ratio, is important for balanced growth of phytoplankton (Turner *et al*., 2003). A deviation in this ratio can influence community composition and the trophic cascade of aquatic ecosystems (Turner, 2002). Systematic studies on N:P:Si ratios and associated shift in phytoplankton growth may help linking anthropogenic drivers to changes in aquatic ecosystem functioning.

Studies show that the concentrations of N and P in many ecosystems are increasing while those of Si are either stable or declining. Although the use of silica in washing powders and in fertilizers constitutes an additional source, a decrease in Si results due to damming and regulation of rivers (Humborg etal., 2006). Hydrologic shifts in the watershed may reduce Si concentration by as much as 50% (Correll *et al*., 2000). The Si is an essential nutrient for growth of siliceous algae, especially diatoms, a group that dominates primary production in estuaries, rivers and coastal areas. A decrease in dissolved silicain coastal marine ecosystems has been shown to shift the composition of phytoplankton communities from siliceous to non-siliceous species (Humborg *et al*., 2000). Diatoms are the largest driver of biosilicification, regulate biological pump and contribute to over 20% of global primary production. In a recent study conducted in the Ganga River at Varanasi by Pandey and Yadav (2015), the N:P stoichiometric ratios were reported between 4.96 and 14.29. The values were particularly low at downstream urban sites receiving excessive P from anthropogenic sources and possibly experiencing the loss of N through denitrification at low oxygen tension in the river bottom. Further, the conditions that enhances denitrification, increases the sediment P release causing its enrichment. Lower Si:N and Si:P stoichiometry than the canonical Redfield ratios shows the impact of N and P enrichment relative to Si. Consistently high N and P at low Si concentrations may alter the diversity and dominance of green and blue-green algae (Teubner and Dokulil, 2002). In eutrophic systems, the sediment related feedbacks increase P supply, but decrease the Si availability, and thus favors the development of harmful algal blooms (Howarth *et al*., 2011). Low Si:N favors the dominance of non-silicious flagellates while low N:P to those of diazotrophic cyanobacteria.

Another study by Pandey *et al*. (2015), representing a relatively longer stretch of the Ganga River, has shown a declining trend on N:Si along the study gradient. These authors observed the N:P:Si ratio to be

14:1:13 at Chunar which declined sharply to 5:1:4 at Rajghat Site (downstream Varanasi city) indicating strong urban influence. Similar results were observed in a watershed scale study of the Ganga River (Pandey *et al*., 2016a). The N:P ratio was highest (14.55) at Dev Prayag Site and lowest (5.08) at Kolkata Site. An almost similar trend was observed for Si:P. The N:Si showed an opposite trend with values being highest (2.65) at Kolkata and lowest (0.46) at Dev Prayag. Increasing levels of P as observed down the cities (Pandey *et al*., 2015; 2016a) and thereby a decrease in N:P stoichiometry may cause a shift in diatom population in the Ganga River towards P favored species. Watershed scale and regional scale studies conducted in the Ganga River have shown N:P stoichiometry to have skewed toward N limitation (Pandey *et al*., 2014a; 2014b; 2016a). In an approach to minimize variances, we conducted a mesocosm study (unpublished results) in a canal flushed directly by the Ganga River upstream the Varanasi city. The main objective was to study the TEP-N:P stoichiometry linkages. We found that TEP and biogenic silica (BSi; an important proxy for diatoms) peaked at N:P ratio of 6:1. Chlorophyll **a** biomass and gross primary productivity peaked at N:P ratio of 24:1. These observations suggest that high N favors productivity and high P, which the Ganga River is experiencing at many parts, at least partly, favors the TEP producing diatom species. This has relevance in view of self-assimilation capacity of the river as well as from a river management perspective.

Nutrient enrichment of surface water enhances primary productivity and, if it persists for long time period, may change the trophic status. We observed a downstream rising trend in the productivity variables (gross primary productivity and chlorophy11a biomass) having strong synchrony with nutrients (Fig. 4) indicating that the nutrient enrichmentfavors the growth of phytoplankton. Further, sites with low BSi:Chlaratios show relatively increased proportion of non-siliceous diatoms contributing to overall primary productivity downstream the cities. Low N:P and Si:P ratios in relation to BSi:Chl**a** further shows high P input to be a major factor for diatom growth in the river down the cities. We found significant positive correlations between BSi:Ch1a ratios and stoichiometric N:P ratios (R^2 = 0.78; p<0.001) and Si:P (R^2 = 0.69; p<0.001) and negative correlations between BSi:Chl **a** and N:Si (R^2 = 0.65; p<0.001) (Fig. 4). Increased phytoplankton biomass production with increasing contribution of non-siliceous species downstream signifies Si limitation. It seems that the increasing levels of N, P and declining levels of Si downstream the cities in the river would lead less silicified or non-siliceous diatoms in near future. Overall, our observations clearly suggest that systematic studies on N:P:Si stoichiometry and associated shift in diatoms and TEP would help predicting human-driven shifts in the ecology of the Ganga River.

Sediment Metabolism

Recent scientific efforts have yielded a bountiful return to our basic knowledge on biomonitoring of human-induced ecosystem changes and have added a number of new horizons in the domain of limnological research. Despite being critical in predicting changes, biomonitoring tools used in riverine systems often suffer with a number of limitations. Scientists continue to delineate the limitations in using specific biomonitors of water quality and trophic status of river ecosystems (Lafont, 2001). Most of the biomonitoring approaches known for riverine systems are based either on time consuming extensive field studies or depend on cost-intensive analytical techniques. Additionally, factors such as hydrologic and climatic regimes, upstream influences and anthropogenic drivers further limit the use of specific bio-assessment tools in river ecosystem health analysis (Turley *et al*., 2016; Pearson *et al*., 2016). The data presented here are the result of multi-year and multi-scale studies targeted to explore, in addition to other variables, the use of extracellular enzyme activities as a biomonitor of the river health. To enhance validity of comparison, we performed two interlinked but well defined and variable scale site-specific studies. These include: (a) site-wise variations in riverbed sediment quality along a 518 km gradient of the Ganga River. The focus was to assess the role of active channel changes and up- and downstream urban influences. To ensure accuracy and to minimize variances, samples were collected during low flow; (b) site-wise variations at land-water interface along a trajectory showing 1.5 km gradient from a point source. The samples were collected from 15 selected sites with 100m distance from the preceding one. We hypothesize that the land-water interface minimizes variances and serve as proxy of point source downstream influences on riverine ecosystems.

Rivers receive large amount of carbon and nutrients from the drainage basin as well as from within-stream processing, erosion and transport. Exploring the state of the changing links and associated shifts in microbial processes in riverine ecosystems has become an important challenge for limnologist (Castillo *et al*., 2003; Gibbons *et al*., 2014). The microbial processes in the rivers are influenced by episodic events driven by storm water and intermittent urban-industrial flushing. Anthropogenic nutrient enrichment increases the autochthonous-C which, together with allochthonous-C, enhances the microbial activities. The β-1,4-glucosidase(β-Glc) is an extracellular enzyme produced by heterotrophic bacteria. It is used as a model ectoenzyme to analyze bacterial decomposition, cellulose degradation and C acquisition (Sinsabaugh *et al*., 2009). This enzyme catalyzes the hydrolysis of β-linked dissacharides of glucose, celluhexose and carboxymethylcellulose. Accordingly, it can be used as an indicator of carbon turnover in soil, animal manure and sewage sludge. Its activity is highly sensitive to environmental changes (Ndiaye *et al*., 2000; Madejón *et al*., 2001). In the present study, this extracellular enzyme showed marked spatial and temporal variations in the study river. The enzyme activity showed substrate dependence and high degree of correspondence with total organic carbon (TOC) except at Jjmu and Rjht Sites (Fig. 5). The deviation at these two sites could be the result of high concentration of heavy metals and associated toxicological implications (Jaiswal and Pandey, 2018).

Intensive agriculture, high population density and urban-industrial growth in the Ganges basin add large amount of nutrients into the Ganga River (Pandey *et al*., 2014a). A recent study conducted by Pandey *et al*. (2016b) has shown that each year the Ganges basin receives ~3.32 Tg reactive-N and ~173 Gg P through atmospheric deposition (AD). Along with direct deposition on water surface, AD input enhances nutrients in surface runoff reaching to the river. This additional supply together with sewage input and other point sources can significantly change the autotrophic-heterotrophic linkages in the Ganga River. Some limnological studies have monitored the carbon and nutrient fluxes and consequent eutrophication as a predictor of river health (Anderson *et al*., 2002). Total microbial activity together with hydrolytic enzymes are commonly used as an indicator of organic matter turnover in soil and water (Schnürer and Rosswall,1982; Costa *et al*.,2007). Recent studies suggest that sediment microbial enzyme activities can be used as a proxy of carbon and nutrient fluxes and the latter can directly be linked with the nature and magnitude of anthropogenic effects (Sinsabaugh *et al*., 2009; Hill *et al*., 2010; Gibbons *et al*., 2014). The enzyme proteases play an important role in mineralization of nitrogenand are used as a measure of N-mineralization (Rejsek *et al*., 2008). This enzyme cleaves proteins to polypeptides and oligopeptides to amino acids. The study conducted between Kanpur upstream and Varanasi downstream showed protease activity in the riverbed sediment ranging from 49.36 to 269.87 µg L-tyrosine g^{-1} h^{-1}. The trends in enzyme activity down the study gradient were synchronous to the concentration of NO_3^- and NH_4^+ in riverbed sediment. Rjht and Jjmu Sites showed exception to this trend (Fig. 5) due possibly to metal toxicity. The enzyme activity was highest at Sngm Site and lowest at Jjmu Site.

Point-source flushing of carbon and nutrients induces niche partitioning promoting diversity of heterotrophs and autotrophs to colonize available niches in the river. Thus, despite stress-induced shifts in dominance-diversity relationships, the groups with potential to exploit these niches may continue to remove greater proportion of available nutrients (Cardinale, 2011). Extracellular enzymes that regulate nutrient availability can be used as predictor of nutrient enrichment and associated shift in ecosystem functioning (Watanabe, 2001). Alkaline phosphatase (AP) is an important ectoenzymes in the riverbed sediments (Sinsabaugh *et al*.,2009) that regulates P cycling and, can be used as a proxy of P starvation (Duhamel *et al*., 2010). Aerobic bacteria contributes~78% of the AP activity while a group of anaerobic bacteria increases the level of orthophosphate and consequently the AP activity declines (Mhamdi *et al*.,2007). The negative influence of P enrichment on AP activity makes it an important indicator of P-status in rivers (Sayler *et al*.,1979). Further, oxygen status in the river bottom regulate feedbacks associated with internal P flushing. Thus, quantifying AP activity can help understanding the anthropogenic P-eutrophication and associated feedbacks in the river. The AP activity in this study showed a declining trend downstream with increasing concentration of PO_4^{3-} in the riverbed sediment. When studied between Kanpur and Varanasi, some deviations were observed. The values were found to be highest at Nwbj Site (392.67 µm p-Np g^{-1} h^{-1}) and lowest at Jjmu Site (71.12 µm p-Np g^{-1} h^{-1}). Contrary to the other extracellular enzymes studied here, the AP activity showed a declining trend on temporal scale. In a downstream point source (Assi drain) study of the riverbed sediment, Pandey and Yadav(2017) observed increasing trend in AP activity. The enzyme activity was close to zero at the mouth of the drain and increased subsequently with distance with a trend opposite to PO_4^{3-}. The AP activity declines with decreasing oxygen availability at sediment-water interface (Mhamdi *et al*., 2007). We found highest sediment oxygen demand (SOD) at Assi drain Site (Fig. 6) where AP activity has been reported to be the lowest. It seems that high SOD (low oxygen availability) at sediment-water interface favors feedback that drives the release of P from the riverbed sediment. Additionally, minimum SOD during high flow period (Fig. 6) indicates the dilution effect and need to maintain flow as a measure to rejuvenate the river.

The enzymes which hydrolyze fluorescein diacetate (FDA) have been shown to favor decomposition of many types of tissues (Schnürer and Rosswall, 1982). Such hydrolytic enzymes are present in plentiful in the soil and sediments. The amount of fluorescein produced by the hydrolysis of FDA is directly proportional to the microbial population (Swisher and Carroll, 1980). For this reason, the FDA hydrolysis is used as an indicator of overall microbial activity (Schnürer and Rosswall, 1982; Costa *et al*., 2007). Further, over 90% of the energy flow in a soil system passes through microbial decomposers, therefore suitable microbial enzyme bioassays can provide a good estimate of total microbial activity. The FDAase activity in riverbed sediment measured between Kanpur and Varanasi downstream (Fig. 5) and at land-water interface downstream to the point source (Fig. 7) showed strong dependence on carbon and nutrient concentrations. Similar resource dependency of FDAase has been reported in our earlier study (Yadav and Pandey, 2017). Substrate regulation was clearly evidenced through TOC-FDAase linkages and associated change in CO_2 emission (Fig. 7). Similar to the other extracellular enzymes, FDAase activity was found to be negatively influenced at Jjmu and Rjht Sites due possibly to the toxic effect of high concentration of heavy metals. Thus, the activities of β-1,4-glucosidase, protease, FDAase and alkaline phosphatase measured in the riverbed sediment and at land-water interface can serve as a proxy of carbon and nutrient pollution provided the river is not overstressed with toxic pollutants such as heavy metals.

Conclusion

The study concludes, because diatom tends to cope-up with nutrient stressors, dominance transference in diatom communities and production of TEP and, associated changes in sedimentation-removal of turbidity constitutes an important mechanism imparting self-purification capacity of the Ganga River. We observed that a drop in concentration of TEP was compensated partially by diatom-dominance transference. The study further showed that TEP, if coupled with diatom-dominance transference and N:P:Si, could be an important indicator of human-driven shifts in the ecology of the Ganga River. If the present trend of anthropogenic influences continue, phytoplankton growth in the river, particularly downstream the cities will shift towards N- and Si-limitation. The activities of enzymes such as β-1,4-glucosidase, protease, FDAase and alkaline phosphatase in the riverbed sediment can be used as indicators of carbon and nutrient pollution in the river provided that the system is not overstressed by toxic contaminants such as heavy metals. Among the enzymes studied here, alkaline phosphatase showed superiority as a diagnostic tool for monitoring the changes in river health and associated feedbacks. Analyses of these activities can be used to resolve constraints in river rejuvenation and management.

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Fig 1. Map of Ganges basin showing the main study zones. 1: Dev Prayag; 2: Kanpur; 3: Allahabad; 4: Varanasi; 5: Kolkata

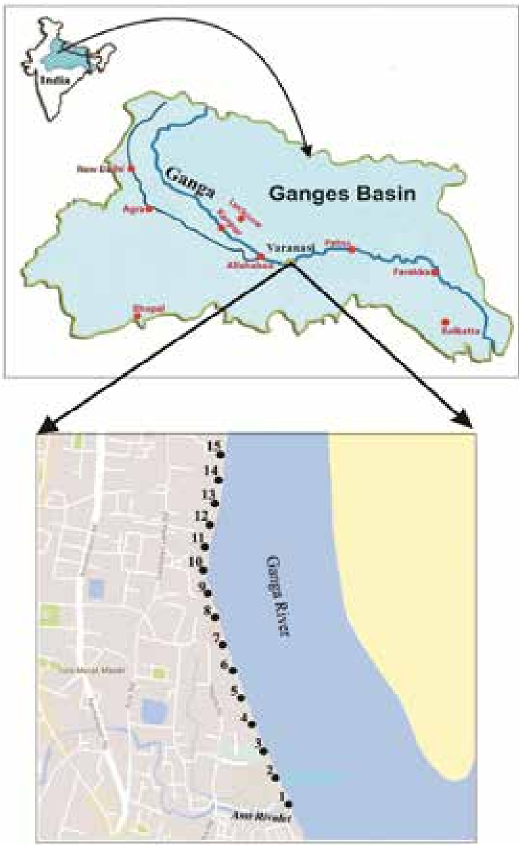

Fig 2. Part of the Varanasi city along the Ganga River showing point-source downstream sites (1 to 15) considered in land-water interface studies

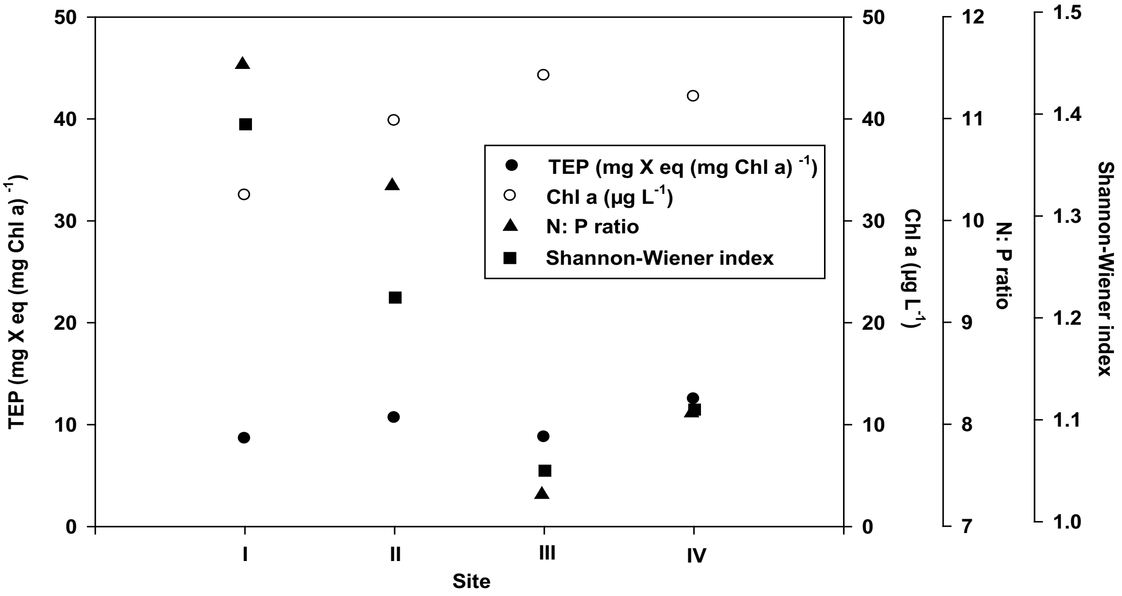

Fig. 3. TEP trends relating chlorophyll **a** biomass, N:P stoichiometry and diatom diversity. *Reprinted from Pandey et al. (2017) with permission from Current Science

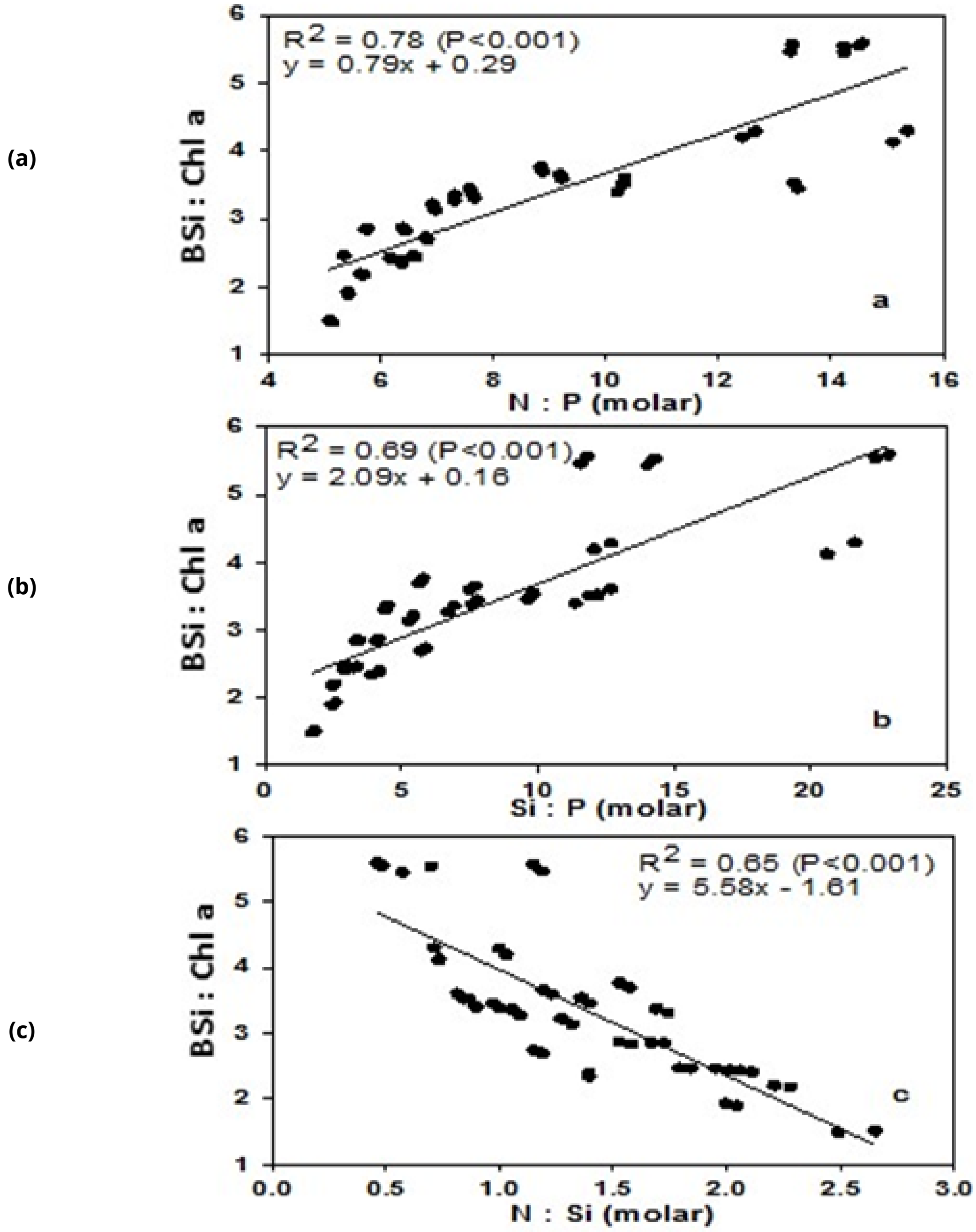

Fig 4. Correlation between a) N:P and BSi:Chla; b). Si:P and BSi:Chl a; and c) N:Si: and BSi:Chla

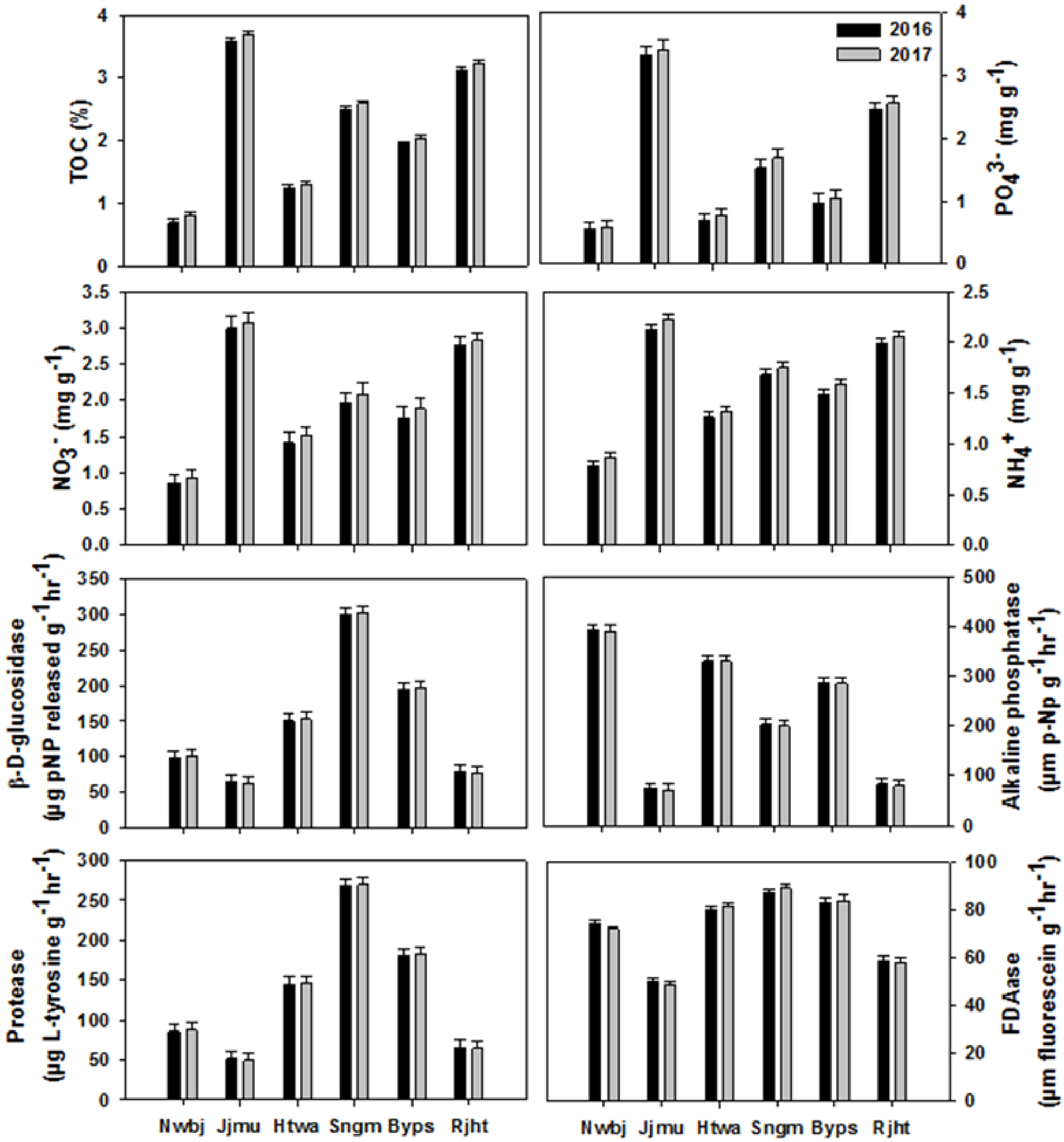

Fig 5. Total organic carbon (TOC), nutrients (NO_3^-, NH_4^+ and PO_4^{3-}) and extracellular enzyme activities in riverbed sediment at study sites in the Ganga River. Values are mean (n = 6)±1SE. Nwbj: Nawabganj; Jjmu: Jajmau; Htwa: Hatwa; Sngm: Sangam; Byps: Bypass; Rjht: Rajghat

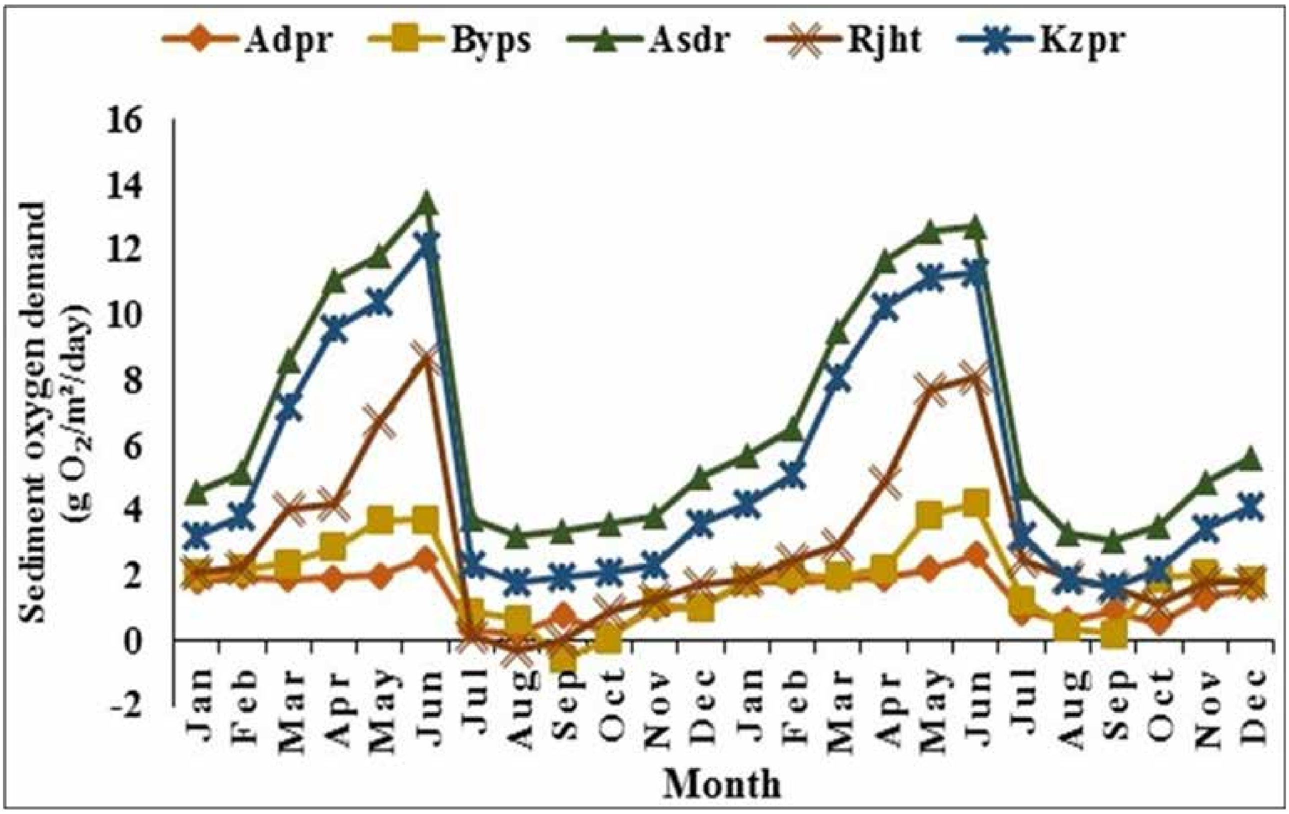

Fig 6. Monthly variation in sediment oxygen demand (SOD) in the Ganga River in Varanasi region. Adpr: Adalpura; Byps: Bypass; Rjht: Rajghat; Kzpr: Kazzakpura; Asdr: Assi drain. Values are month-wise means for the year 2016 and 2017

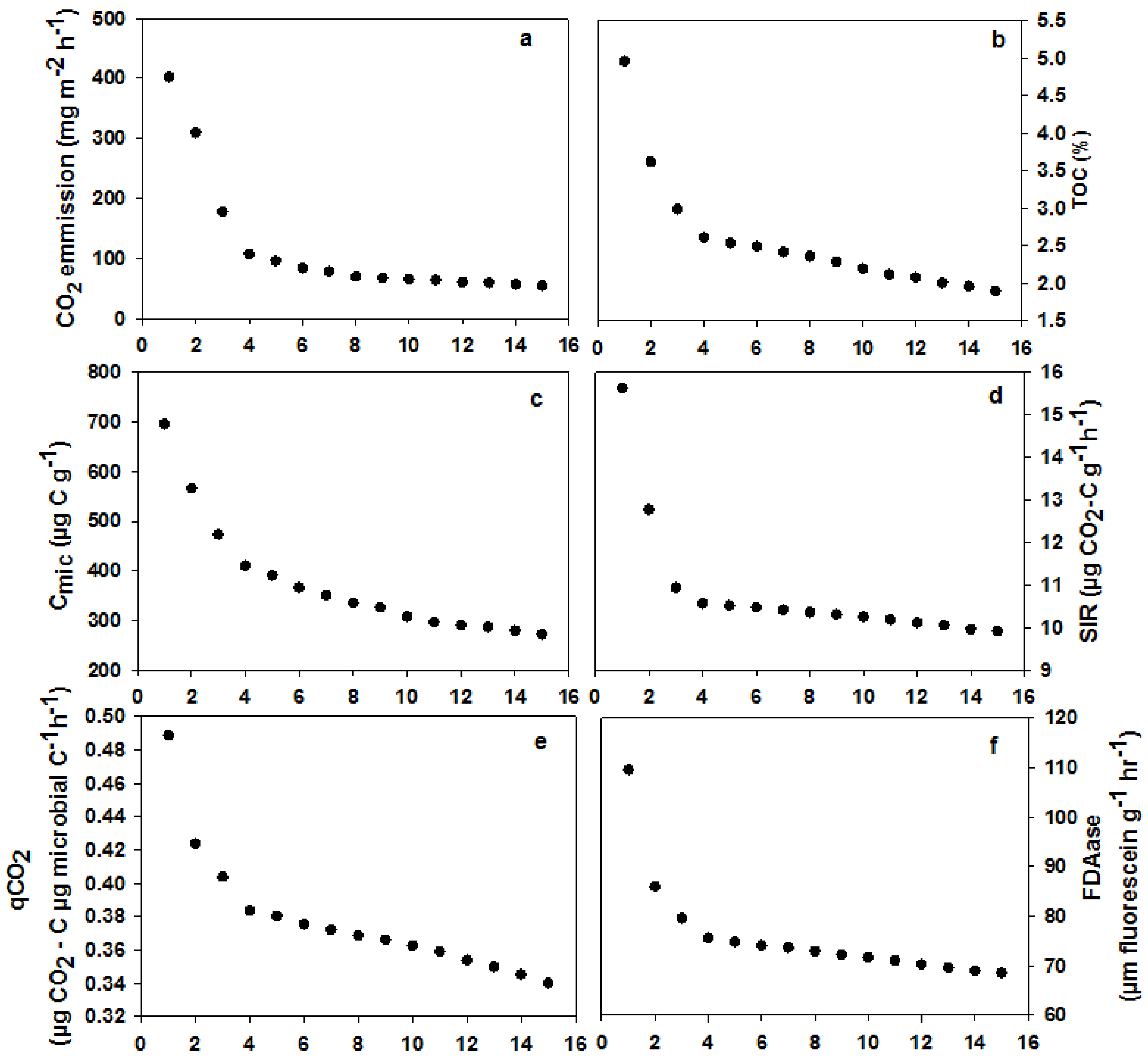

Fig 7. Point source to downstream trends in a) CO_2 emission, b) total organic carbon (TOC), c) microbial biomass-C (C_{mic}), d) substrate induced respiration (SIR), e) microbial metabolic quotient (qCO_2), f) FDAase activity at land water interface downstream of a point source of the Ganga River. The values are means for the year 2016 and 2017

Table 1. Relative abundance (%) of epilithic diatoms at four sampling sites of Ganga River

Species	Relative abundance				
	Code	**I**	**II**	**III**	**IV**
Achnanthes exigua Grun.	Aexi	2.20	3.60	2.08	5.20
Achnanthidium minutissimum (Kütz.) Czarn.	Amin	2.41	2.50	4.20	4.26
Asterionella formosa Hassall	Afor	2.10	2.00	1.06	4.88
Aulacoseira granulosa (Ehr.) Simonsen	Agra	2.50	8.50	7.30	2.00
Cocconeis pediculus Ehr.	Cped	6.10	2.60	2.00	2.86
Cocconeis placentula var. lineata (Ehr.) van Heurek	Cpla	16.60	3.56	5.50	2.20
Craticula halophila (Grun.) Cleve F. robusta (Hust.) Czarn.	Chal	3.26	2.20	1.20	4.25
Cyclotella meneghiniana Kütz.	Cmen	10.96	3.85	2.50	3.10
Cymbella affinis Kütz.	Caff	10.15	5.77	3.00	3.26
Diatoma vulgaris Bory	Dvul	4.56	15.50	12.32	2.65
Eunotia exigua (Bŕeb. ex Kütz.) Rab.	Eexi	9.00	2.68	3.10	2.10
Eunotia alpine (Naeg.) Hust.	Ealp	1.15	1.25	1.20	1.15
Fragilaria intermedia Grun.	Fint	3.10	10.50	13.00	1.20
Gomphonema parvulum (Kütz.) Kütz.	Gpar	2.26	9.00	10.00	2.50
Gyrosigma acuminatum (Kütz.) Rab.	Gacu	2.20	2.56	2.05	2.60
Melosira varians Agardh	Mvar	1.50	12.50	8.50	2.32
Navicula lanceolata (Ag.) Ehr.	Nlan	2.10	3.68	2.50	7.50
Navicula simplex Krass.	Nsim	2.00	8.25	4.50	10.07
Nitzschia amphibia Grun.	Namp	2.15	3.68	2.50	7.10
Nitzschia palea (Kütz.) W. Smith	Npal	2.20	3.50	1.00	10.40
Pinnularia viridis (Nitzsch) Ehr.	Pvir	1.00	2.50	1.50	10.10
Surirella elegans Ehr.	Sele	2.30	1.50	1.50	2.30
Synedra ulna (Nitzsch) Ehr.	Suln	8.25	4.50	4.90	6.00

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Elimination of Toxic and Endocrine Disruptive Contaminants from Domestic Waste Water using Tertiary Treatment

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Abstract

Endocrine disrupting chemicals (EDCs) are exogenous substances that change the function (s) of the endocrine system(s), affecting the way an organism or its progeny reproduces, grows or develops. Almost all EDCs have octanol-water coefficient of more than 3 which implies that these compounds are bioconcentrated and biomagnified when present in the environment.

This paper discusses the results of analysis of municipal sewage in terms of EDCs and pharmaceutical and personal care products (PPCPs) and their impact on health in terms of toxicity as well as endocrine disruption potentials. The outcome of the investigation suggests that conventional treatment of sewage in STP is not sufficient to remove these micro- pollutants and tertiary treatment shall be required to eliminate these chemicals from the environment.

Prologue

Endocrine disrupting chemicals (EDCs) are exogenous substances that change the function (s) of the endocrine system (s), affecting the way an organism or its progeny reproduces, grows, or develops. Almost all EDCs have octanol-water coefficient of more than 3 which implies that these compounds are bioconcentrated and biomagnified when present in the environment.

It is well recognized that surface water contamination is a crucial issue. The major contamination of surface and ground water occurs through the disposal of untreated or partially treated sewage waste into water streams. In this regards, increasing the waste-water treatment efficiency and capacity will reduce the discharge of untreated waste. Conventional methods used in the sewage treatment plants (STPs) cannot effectively remove emerging contaminants (xenobiotics, metals, drugs, hormones etc.) from the waste water. Therefore, efforts are needed to adopt advance technologies for waste water treatment that can efficiently remove emerging contaminants.

In addition, surface water gets contaminated due to several other anthropogenic activities and interventions. Therefore, regulatory framework is needed to restrict these activities. Restrictions should be imposed on the disposal of dumps, garlands, idols, flowers and other article of offering to God, cremation activities, washings, anthropogenic activities etc. These restrictions can be prioritized by keeping the sensitive locations into considerations.

Analytes (metals, hormones, pharmaceuticals etc.) studied in the present investigation comes under the category of emerging contaminants. Emerging contaminants are not routinely analyzed in the water quality programs. Regulatory limits for these contaminants in water sources are not well defined due to unavailability of significant documentary and scientific evidence on the occurrence and fate of these compounds in different water sources. The current data sets on the occurrence of emerging contaminants in water sources are weak and have regional biases. USEPA/USGS have given high importance to evaluate the occurrence of emerging contaminants in environmental sources. The EU has introduced specific legislative obligations aimed at phasing out endocrine disruptors in water, industrial chemicals, plant protection products and biocides. In REACH (Registration, Evaluation, Authorization and Restriction of Chemicals), endocrine disrupting chemicals are considered of similar regulatory concern as substances of very high concern.

Objectives

The objectives of the present studies encompass:

- Chemical characterizationof water contaminants using analytical methods.
- Determination of toxic effects of water contaminants using *in vitro and in vivo* model.
- Determination of endocrine disruptive potential of water contaminants using *in vitro and in vivo* model.
- Assessment of the health of human population residing near STP.
- The present study helps in strengthening the data sets on the occurrence of emerging contaminants in waste water.

Observations

Different water samples [inlet and outlet of a municipal waste treatment plant, hand pump (HP) and municipal corporation (MC)] were collected for the analysis. Different conventional physicochemical parameters (pH, DO, TDS, TOC etc.) were analyzed for the water samples. All the parameters were within the range prescribed by CPCB and BIS. The samples were then processed for liquid-liquid extraction (LLE) and solid phase extraction (SPE). GC-MS analysis revealed the occurrence of xenobiotic compounds (benzene, phthalate, etc.) in inlet/outlet waste water LLE extracts. ICP-MS analysis determined the presence of heavy metals (Pb, Cd, Ni, Be, Mn, etc.) in different water samples, which were within the permissible limit prescribed by CPCB and BIS.

Exposure to the pre-concentrated inlet or outlet STP-LLE extracts at different concentrations (0.001% to 1%) induced dose-dependent toxicity in MCF-7 cells, whereas drinking water extracts did not induce cytotoxicity in exposed cells. Cells exposed to inlet/outlet extracts showed elevated levels of reactive oxygen species (ROS: inlet: 186.58%, $p < 0.05$, outlet, 147.8%, $p < 0.01$) and loss of mitochondrial membrane potential ($\Delta\psi m$: inlet, 74.91%, $p < 0.01$; outlet, 86.70%, $p < 0.05$) compared to the control. These concentrations induced DNA damage as determined by the Comet assay (Tail length: inlet: 34.4%, $p < 0.05$, outlet, 26.7%, $p < 0.05$) in treated cells compared to the control (Tail length: 7.5%). Cell cycle analysis displayed drastic reduction in the G1 phase in treated cells (inlet, G1:45.0%; outlet, G1:58.3%) compared to the control (G1:67.3%). Treated cells showed 45.18% and 28.0% apoptosis compared to the control (1.2%). Drinking water extracts did not show any significant alterations with respect to ROS, $\Delta\psi m$, DNA damage, cell cycle and apoptosis compared to the control. Genes involved in cell cycle and apoptosis were found to be differentially expressed in cells exposed to inlet/outlet extracts. *In vivo* study was performed using zebra fish model. Exposure to sub-lethal concentration of inlet water resulted in DNA fragmentation in the liver cells of the zebra fish. SPE extracts of the water samples were analyzed by LC-MS-MS to detect the occurrence of endocrine disrupting chemicals (EDCs) in different water sources. Four representative compounds viz., two pharmaceuticals (primidone and diclofenac sodium salt) and two hormones (testosterone and progesterone) were selected for the analysis. Testosterone was detected in inlet and outlet samples while progesterone was detected only in the inlet sample. Pharmaceuticals (diclofenac and primidone) were not detected in any of the waste water (inlet/outlet) sample. All the tested compounds were not identified in HP and MC water samples.

Effect of water contaminants on endocrine signalling pathway was analyzed using human RT profiler PCR array. Results revealed differential expressions of genes involved in estrogen receptors (ER) and ER-mediated pathways in MCF-7 cells treated with sub-lethal concentration of inlet and outlet waste water extract. The **D**atabase for **A**nnotation, **V**isualization and **I**ntegrated **D**iscovery (DAVID) analysis showed the involvement of different genes along with their biological functions.

Male Zebra fish exposed with SPE extract showed the expression of vitellogenin (VTG; bio-marker of endocrine disruption) compared to the control. VTG expression was confirmed by analyzing the expression of VTG gene and its signalling receptor - ER-β.

To assess the impact of environmental contaminant on endocrine system, urinary excretion of 17-ketosteroid (17-KS) was assessed in male prepubertal subjects (8–11 years; n=90). Children living near sewage treatment plant and solid waste disposal plant (Group P) showed significantly higher levels of urinary 17-KS (Group P: 3.27 ± 1.63 μg/mL/CRE; $p < 0.01$) than children living in cleaner area (0.50 ± 0.53 μg/mL/CRE; Group C). Occurrence of urinary dibutyl phthalate in representative subjects of Group

P [odds ratio: 9; $p < 0.05$; 95% of Confidence interval (CI) 1.93–72.99] was higher compared to Group C. Urinary concentrations of Cd (0.85 μg/g CRE ± 0.11), Mn (24.25 μg/g CRE ± 6.11) and Pb (12.39 μg/g CRE ± 2.86) in Group P were significantly ($p < 0.01$) higher than those found in Group C (Cd (0.28 μg/g CRE ± 0.03), Mn (13.33 μg/g CRE ± 3.20) and Pb (5.67 μg/g CRE ± 0.53). It can be concluded that elevated levels of urinary 17-KS in Group P could be attributed to higher exposure of these subjects to endocrine disrupting chemicals (EDCs) compared to Group C.

Summary

Present study provides data on the occurrence of xenobiotic compounds (benzene, phthalate etc.), metals (Cd, Co, Ni, Pb), hormones (progesterone and testosterone) and pharmaceuticals (diclofenac and primidone) in the tested water samples. In addition, the present study also details the toxicity, endocrine disruptive potency of tested water samples and bio-monitoring study in pre-pubertal subjects residing nearby polluted area.

Waste water matrices are highly complex and contain variety of organic and inorganic compounds. The present study demonstrated that cell-based assays can be efficiently used to evaluate the toxicity of complex waste water matrices. Flow cytometric assays facilitated the quantitative estimations of end point indicators (ROS, $\Delta\psi m$, DNA damage, cell cycle and apoptosis) of toxicity in MCF-7 cells exposed to water or waste water extracts. Future research can be focused on the cell based toxicity characterization of waste water during different stages of recycling process. Further, an integration of cell-based assays with physicochemical and biochemical assays can strengthen the toxicity assessment procedures during waste water recycling processes.

Surface water contamination is a crucial issue. The major contamination of surface and ground water occurs through the disposal of untreated or partially treated sewage into water streams. In this regards, increasing the waste water treatment efficiency and capacity will reduce the discharge of unwanted pollutants. Conventional methods used in the sewage treatment plants (STPs) cannot effectively remove emerging contaminants (xenobiotics, metals, drugs, hormones etc.) from the waste water. Therefore, efforts are needed to adopt advance technologies such as activated carbon filters, membrane technologies and/or advanced oxidation processes for waste water treatment that can efficiently remove emerging contaminants.

In addition, surface water gets contaminated due to several anthropogenic activities and interventions. Therefore, regulatory framework is needed to restrict these activities. Restrictions should be imposed on dumping garlands, idols, flowers and other article of offering to God, cremation activities, open defication, washings and similar anthropogenic activities. These restrictions can be prioritized by keeping the sensitive locations into considerations.

Analytes (metals, hormones, pharmaceuticals etc.) studied in the present investigation comes under the category of emerging contaminants. Emerging contaminants are not routinely analyzed in the water quality programs. Regulatory limits for these contaminants in water sources are not stipulated due to unavailability of significant documentary and scientific evidence on the occurrence and fate of these compounds in different water sources. The current data sets on the occurrence of emerging contaminants in water sources are weak and have regional biases. USEPA/USGS have given high importance to evaluate the occurrence of emerging contaminants in environmental sources. The present study will help in strengthening the data sets on the occurrence of emerging contaminants in waste-water.

Levels of endocrine hormones in our body may vary with puberty, gender, psychological factors (pleasure and stress), etc. Thus, it is difficult to distinguish between the effects caused due to inbuilt physiological mechanism with those caused due to environmental pollution. In the present study, the influence of confounding factors such as age, gender, exposure period, medication and location of residence was taken into consideration. Significantly elevated levels of urinary 17-KS, urinary metals (Cd, Mn and Pb) and higher prevalence of urinary DBP in pre-pubertal male subjects residing near STP and solid waste disposal plant indicated their higher exposure to EDCs compared to the subjects residing in cleaner area. Preliminary findings obtained in this study need to be further validated by conducting a long-term cohort study on more number of pre-pubertal subjects (boys and girls). In the current study, subset of EDCs was analyzed in ambient air and in urine samples of tested subjects. EDCs comprise of a wide class of compounds such as metals, pesticides, steroids, hormones, drugs and personal care products. Therefore, further studies on long-term monitoring of different classes of EDCs in body fluid of subjects, ambient air, water and food will help to understand the temporal associations between environmental pollutants emitted from the localized sources and risk of endocrine disorders.

Curiosity and Serendipity in Research

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Introduction

Serendipity means making happy and unexpected discoveries by accident. “Accident” is the key word. The noun was first coined by the writer and politician Horace Walpole in 1754 and is supposed to have occurred to him from the fairy tale “Three Princes of Serendip”. “Serendip” by the way is often thought of as ancient Sri Lanka, although there are other interpretations. In that fairy tale, the three princes are observant and intelligent protagonists, although they did make certain deductions by accident. Rather than their sagacity, their accidental discoveries appealed more to the readers and the word “serendipity” has been linked thereafter to accidental and unintentional conclusions and discoveries, and as an antithesis to methodical search. Science and technology has benefitted enormously from serendipity, and it is the intent of this article to eulogize serendipity in research (scientific and technological), as well as to look into different forms of serendipity.

Curiosity is a mandatory and essential quality for good to outstanding research. Whether it is methodical research or accidental discoveries, curiosity is the principle human trait which drives inventions and innovations. While hair-splitting arguments are made about applied and basic research, it is the intent of this article to show that they are nothing but two faces of the same coin, with curiosity being the prime driver.

Degrees of Serendipity

We make serendipitous discoveries in our daily lives, which are so trivial as to go unrecorded. Our grandmothers would have found that certain spices come together to enhance the flavor of certain dishes, we find that a certain food taken at a certain time of day gives indigestion, but not at other times. All serendipitous events and observations have underlying scientific explanation without fail, but the observer may not be aware of the same at the point and time of observation. Routine serendipities may be sheer accidents or they may have some bearing on our quest, for instance, a grandma looking for a new recipe, or they may be totally against the grain of thought or pursuit. This is equally true for scientific serendipities. Thus I would like to classify serendipities as follows:

Sheer Serendipity: These are sheer and absolute accidents. Such discoveries happened by chance and were in no way connected to the pursuits of the discoverers. It was simply something he never even dreamt of. Discovery of Fire is a very good example of sheer serendipity. No-one knows who or where it was discovered first. It most likely happened by opportunistic use, like when a lightning struck a tree and it burnt. The heat and light would have appealed to the humans of about a million years ago and they may have decided to preserve it. This of course required certain cognitive abilities to recognize the usefulness of fire. The discovery of artificial creation of fire would have happened by chance, maybe while rubbing rocks or dry wood against each other. That was sheer serendipity. Humans of the time devoid of any scientific understanding of friction and of using friction to create heat and fire, would have been rubbing stones either just for the fun of it or to make sharp weapons. A later discovery, which was sheer serendipity, was magnetism. According to legend magnetism was first discovered around 2000 BC by a shepherd named Megnes, who lived in Magnesia, Greece. Megnes, while herding sheep found that the ferrule of his stick and nails in his sandals had got stuck to a rock. He dug up the ground and found lodestone. The attractive mineral came to be know as magnetite either after the name of the shepherd or of the island.

Thus "Sheer Serendipity" was and is characterized by

- A chance event
- The discoverer had no idea or explanation of the event
- Quite often the discoverer did not understand the significance of his/her find
- The discovery became well known only with later use

The use and application of sheer serendipities often took time especially the early serendipities in the history of civilized man. And the scientific explanations often came hundreds or thousands of years later. A good case in point is static electricity. This discovery is largely credited, although not undisputedly, to Thales of Greece at around 600 BC. The Greeks observed that rubbing fossilized tree resin, or amber, with animal fur made the resin attract dried grass. It was after 2200 years that Gilbert referring to the attractive property of amber, coined the term "electricus" to describe it. However, detailed experiments with and on static electricity were conducted by Benjamin Franklin in 1752, and he was able to identify the lightning as one huge static electricity burst. Others like Otto von Guiricke and Coulumb advanced the understanding of static electricity significantly. And when Van de Graff designed his generator in 1931, humans could truly harness and control very large amounts of electricity. Thus from the discovery of static electricity to its full-fledged application took nearly 2500 years. But the timeline between discovery and useful application does vary. It depends on the realization of the usefulness of the discovery. It is not documented how soon after creation of fire artificially (by friction of stoner or sticks) was it put into use. Possibly immediately. In fact, humans most likely preserved natural fires (from lightning and meteor strikes) in their crude hearths, much before they could create fire on their own. According to archaeologist

JAJ Gowlett [1] the development of fire use possibly followed these timelines: a. opportunistic use of fire from natural occurrences; b. limited preservation of fires lit by natural occurrences, using slow-burning substances to maintain fires in wet or cold seasons; c. kindled fire. The serendipitous discovery of magnetism in 600 BC was followed soon by applications worldwide. There is some belief that around 500 BC, Susruta, the famous Indian Surgeon, used magnetic surgical instruments. And magnetic compass was used by the Chinese as early as 1000 AD.

Directed Serendipity: Directed serendipities refer to discoveries which were unexpected and accidental to the pursuit of the discoverer, and yet was broadly in his/her area of pursuit. Directed serendipities happen to people who are actively looking for a product or process, but what they get is not exactly what they had in mind, and yet something whose appreciation is immediate. The most celebrated example of directed serendipity is the discovery of penicillin by Dr. Fleming. Directed serendipities happen in the presence of a person with domain knowledge. Therefore, its appreciation is fast and application of the knowledge for common use also quite fast.

In 1907, Leo Baekeland was looking for a product to replace shellac when he discovered bakelite; and Baekeland being an expert chemist, and being sufficiently intelligent, immediately understood the significance of the developed product; by 1909 Bakelite was selling like hot cakes. Dutch physicist, Kammerlingh Onnes was researching on the change in resistivity with temperature. At liquid helium temperatures, he discovered what was along expected lines, that is, the resistivity of a conducting material (mercury in this case) decreased with a decrease in temperature, but he never expected zero resistivity at above absolute zero. Although the appreciation of the finding was immediate, its application was not due to practical considerations, namely, there are very few large scale applications which would economically justify a liquid helium environment.

The discovery of the now ubiquitous "post-it" note was serendipitous but the discovery was in the broad domain of the discoverer. The idea for the Post-it note was conceived in 1974 by Arthur Fry. He was aware of an adhesive accidentally developed in 1968 by fellow 3M employee Spencer Silver, who, while trying to develop a strong adhesive, ended up with a week glue. Its initial use was for holding bookmarks in Fry's hymnal while singing in the church choir. The 3M company after initial hesitation, introduced the product in 1980, and today, Post-it notes are sold in more than 100 countries [2]. Another instance of directed serendipity was the discovery of microwave oven. The inventor, Percy Spencer worked for a company named Raytheon, and was experimenting with microwave radar transmissions during World War II. One day in 1945, he noticed that a candy bar he had in his pocket had melted. Intrigued by this, he experimented with eggs and corn, and figured out that microwaves could be used to heat food.

Inverted Serendipity: Serendipitous discoveries of the "Inverted" class are those where the finding or observation was something that the discoverer neither expected nor was it in the general direction of his pursuit. A classic example of inverted serendipity was the discovery of Saccharin. Russian chemist, Constantin Fahlburg forgot to wash his hands before sitting down for a meal. In 1879, after a day spent reacting coal tar with phosphorous, ammonia, and other chemicals, he realized at home that his hands tasted sweet. He patented the chemical and started mass producing saccharin in 1884. The most lucrative inverted serendipity ever was possibly the invention of "Viagra". Pfizer developed a pill named UK92480 to help constrict coronary arteries to relieve chest pains. The pill failed its primary purpose, but the secondary side effect was startling. Pfizer sold $288 million worth of the little blue pill in the first quarter of 2013. Coca-cola was also a result of inverted serendipity. John Pemberton, a pharmacist, just wanted to cure headaches. Two main ingredients in his hopeful headache cure were coca leaves and cola nuts. When his lab assistant accidentally mixed the two with carbonated water, the world's first Coke was the result. Chinese alchemists, of the ninth century were looking for an elixir of life. And a test mixture of salt peter, sulfur and charcoal resulted in gunpowder, a harbinger of death. Kodak Engineer, Harry Coover, was trying to develop clear plastics for gunsights, he ended up creating superglue. Dupont chemist, Roy Plunkett, was looking for a new chlorofluorocarbon refrigerant, he ended up inventing a new polymer, polytetrafluoroethylene, which is popularly known and used as Teflon.

Irrespective of the class of serendipity, attributing them to sheer chance, is a denigration of the inventor. It was the curiosity of the inventor, which led him to investigate into such serendipities and his domain knowledge and intelligence which allowed him/her to interpret it profitably. When any non-curious researcher would have brushed off such results which seemed accidental, the curious and methodical inventor forged ahead with the new knowledge provided by dumb luck. And science, technology and humanity benefitted (with the exception of gunpowder and such).

The Role of Curiosity in Research

The Great Divide: Research, especially post 19th Century, became categorized into two verticals, applied research and basic research. The definitive difference of the two lies in that Basic Research is interested in the "Why" of an observation, while Applied Research is interested in the "What (to make out of it)" and "How (to exploit it)" of an observation. Pure Basis Researchers may still exist today, but they are becoming rare. The pure applied researcher was the alchemist of past, who was goal and material or immaterial gain oriented, with little interest in the explanation of the observation. Pure Applied Researchers are extinct in that the goals and gains they want out of a scientific discovery and invention have to be explained phenomenologically for its full exploitation.

One of the prevailing misconception is that basic research always precedes applied research. The following discounts that concept.

We can start by considering examples where applied research follows basic research. One good example of the last two centuries is the discovery of quantization and quantum mechanics. Plank in 1901 and

Einstein in 1905 laid the cornerstone of Quantum Theory. Born, Schroedinger and Heisenberg added significant contributions in the 1920s. In the 1940s and 50s, Dirac, Hilbert and numerous others refined it. For nearly a half a century thereafter the theory and its ramifications drew the most renowned physicists and chemists towards high-end basic research. It was only in late 20th century and 21st Century that the quantum effect was put into practical use. Quantum dots, LEDs, and various Q-devices are very recent manifestations, the so called applied research on Q theory. This is a good example of applied research exploiting and following basic research and trailing by nearly half a century.

Let's examine an extreme opposite. Magnetic attraction was discovered in Greece in 600 BC. Within 100 years, around 500 BC, Susruta is reported to have made use of magnetic surgical instruments. By 1000 AD, the magnetic compass was invented by the Chinese. No one on earth knew about magnetism, domain theory and electron spin, in fact it would take another millennium before man knew about electrons. So, well established applications of a serendipitous discovery were in vogue around the world, much before the basic understanding of the phenomenon was even attempted. It was only in 1600, that Gilbert proposed that earth was a great magnet. Please note that this was not an explanation of magnetic attraction, only a related development. In fact, till the famous Maxwell's equations were derived (in 1861), man did not have a proper grasp of the phenomena. It should also be noted that these equations were possibly of greater use to applied researchers as they gave a control on electrical and magnetic fields. Only when Weiss, in 1906, propounded the domain theory, did we come to have a "basic" understanding of magnetism. Thus, basic research, in this case trailed applied research by about 2000 years!

The great divide has become amorphous and irrelevant today. A so-called basic researcher cannot rest on his hypothesis, he has to validate it. For that he requires tools and gadgets made possible by applied research. An applied researcher, likewise, cannot ignore the phenomenological explanation, which is provided by basic research. As we see less and less hit and trial mode of investigations and more and more of educated guesses in research, basic understanding of the event is essential for the applied researcher to reduce time, effort and cost in new developments. Today, basic and applied research feed on each other, they are symbiotic and therefore requires synthesis and collaboration, irrespective of which follows which. Even the time lag between the two is becoming infinitesimal. The reason for this is the fast dissemination of knowledge, the proliferation of researchers in any discipline or area, the emphasis on intellectual property creation, and the huge cost of time.

Research Flow: It is worthwhile looking at the sequence in research to understand the action points and catalysis for each. If we look at basic research the logical steps followed are as follows. The first event in both applied and basic research is an observation or thought, the latter more evident in basic research. In basic research, that is followed by an explanation - the answer to the "Why" The answer becomes a hypothesis and stays a hypothesis till it is validated. The confirmation of the hypothesis establishes a "Law" or "Equation" or "Reasoning". This is summarized in Fig.1. It should be realized that validation and confirmation of a basic research hypothesis most often requires tools and gadgets which were a product of applied research. As an example, if we take the origin of universe as the prime query, we see that thoughts can be catalyzed by observations and introspections. The rudimentary explanation is a cataclysmic event which created something from nothing. Hence "the big bang". The big bang preceded human cognizance by about 14 billion years, so there is no direct observational proof of that event. The development of that hypothesis was the result of collective observation of paradoxes and tell-tale signs [3]. The fact that the night sky is mostly dark (Olber's paradox) instead of glittering with starlight in all directions pointed to a non-infinite universe both in time and size. The existence of Quasars pointed to a very different past of the universe compared to today. The expanding universe evident from redshift, the nature of residual radiations surrounding us, and the relative fractions of hydrogen and helium in the universe, were clinching evidences for the "Big Bang". The thought was validated and confirmed, thanks to products of applied research, like radiotelescopes, microwave telescopes and supercomputers.

In Applied Research, the observation of an uncommon event or occurrence stimulated the applied researcher to find ways to exploit it for her material gains or for the benefit of humanity. The discovery cannot be commercialized as such and needs fine tuning. The stumbling blocks to successful utilization of the product or knowledge may be as simple as cost in its present form, or more complex like integration into state of the art product and knowledge hierarchy. This is the adaptation stage in applied research. Before the final product is marketed it goes through a series of mock-ups and dummy runs and modifications. This is the exploitation stage. And then the finished product or knowledge is marketed. The sequence is provided in Fig. 2. If we take the case of superconductivity, the initial discovery was never commercialized because the operational temperatures required were very low and not viable for practical applications. However, once superconductivity had been discovered, it ignited a search for materials which were superconductive at more congenial temperatures. The focus thereafter shifted to oxides, a class of which were found to be superconductors at temperature higher than metals. This required adaptation of research focus. And eventually materials which were superconductor above liquid nitrogen temperatures were found and thus much more practical superconductors could be made.

Curiosity in Research

What drives research? If we overlook the obvious needs for fame and money, the only other driver is human curiosity. The basic researchers will vouch for it, and, in spite of appearances, so would the applied researchers, although their end objectives may be different. The first observation of an uncommon event, sets the researcher thinking, triggers his imagination. What others may pass off as an aberration, the curious researcher does not let go. The hypothesis that follows in basic research, or, the adaptation in applied research is driven only by curiosity. The applied researcher sees the possibility of benefits, but is not sure of it. The basic researcher, in his efforts to develop a hypothesis, becomes curioser and curioser about the different facets of the research. The profit motif, or benefit considerations makes the applied researcher more and more curious about the discovery. Of course, the full exposition of the discovery, requires domain knowledge, experimental knowledge and funding.

Why are some people more curious than others? The exact reason is not known, it may lie in the genetic make-up or in her upbringing. But what has been reported [4] is that when people are curious to learn the answer to a question they are better at learning that information. Secondly, when curiosity is stimulated, the research found that there is increased activity in the hippocampus, the region of the brain associated with memory. And lastly, there is increased activity in the regions of the brain associated with reward when curiosity is stimulated. Research therefore is possible because some selective humans become curious about an event or observation. In scientific research curiosity does not kill the cat, it nurtures and sustains it.

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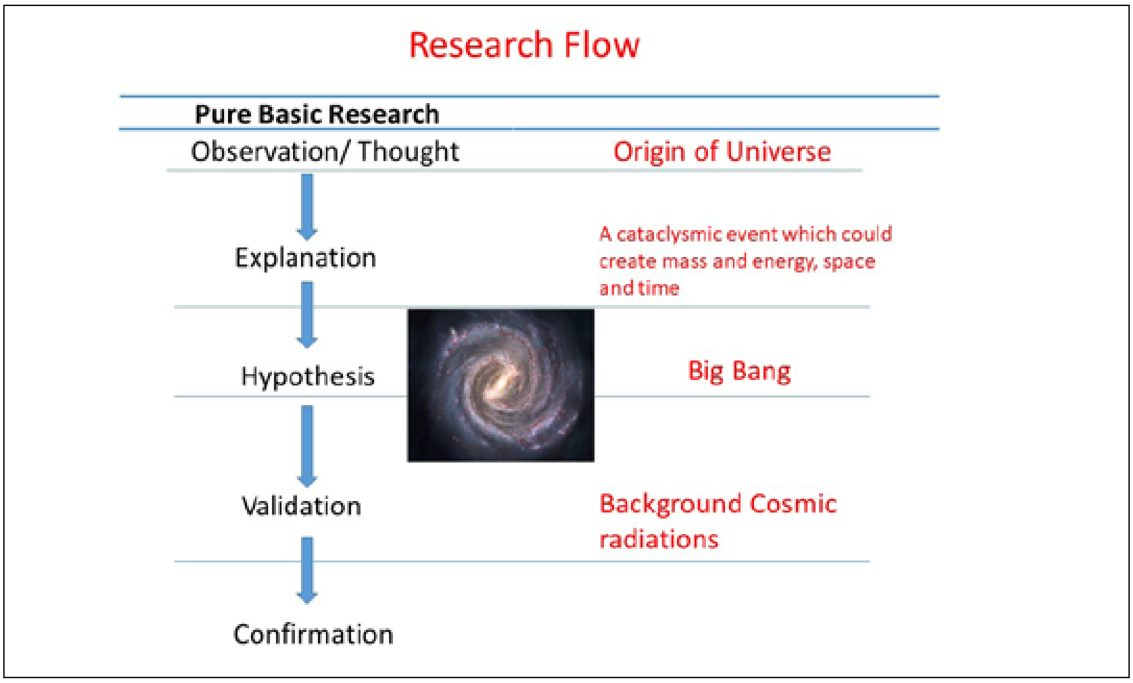

Fig. 1: Research Flow in Basic Research

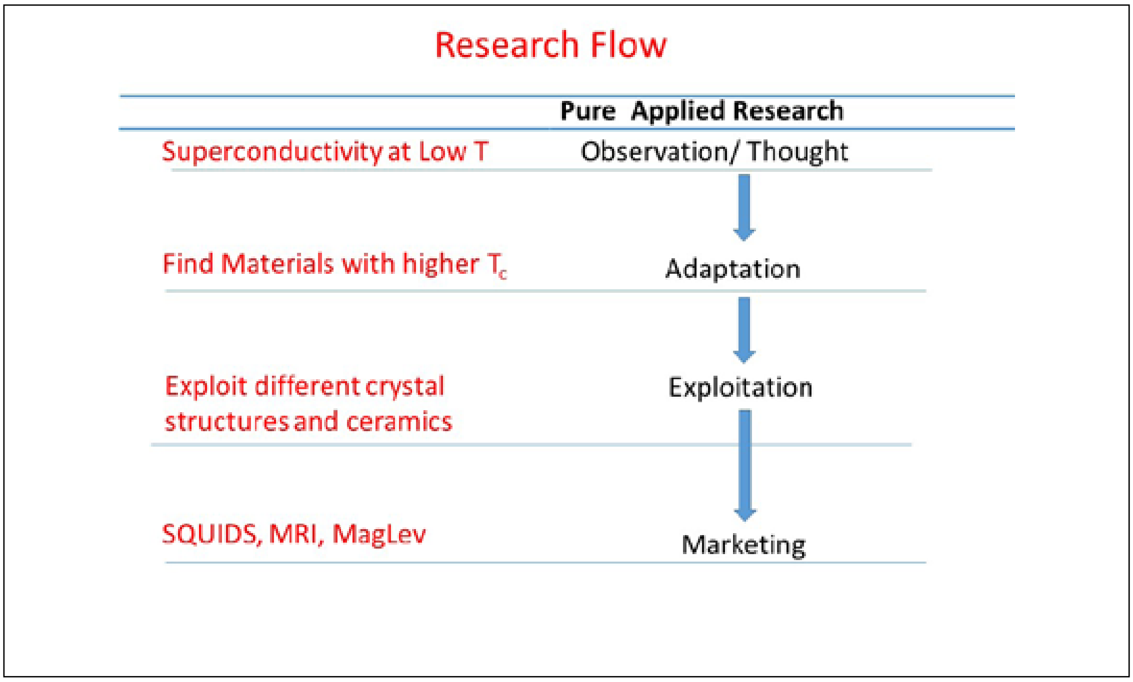

Fig. 2: Research Flow in Applied Research

Sustainable and Traditional Wisdom of Nutritious Foods from Adaptable Agriculture for Health and Wellness Reachout

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With the global population reaching almost 10 billion (predicted by 2050) the need for Food from all different sources and feed from much larger sources is unavoidable and is the need of the hour. Hence the conservation and sustainability of Food as also to prevent Food losses and wastes becomes an important and mandatory agenda. The varieties required for Sustainable Nutrition agenda are not the same agenda perhaps used for higher yield? This puts a very high agenda pressure on the agri system and economy especially with an economic shift in the consumption pattern which is rapidly moving towards the mass market and convenience Foods. This movement towards a healthy, functional, organic, traditional and ethnic Food appears to be one of the main concerns that need to addressed for the future? It is in this context that the regulators, the research institutions, the academia and the industries especially which are focused on Nutrition to Masses in the manufacturing sectors must get into a people centric sustainable approach of consumer need for innovative and affordable new products.

It is said that there is nothing more precious than agriculture and food that supports the life of the humans, animals, birds, the aquatic and the microbial life apart from air and water. There is no medicine that is comparable to food in its vast composition of variety of biomolecules in one single food let alone combination of foods! A typical Indian traditional Food wisdom or a Chinese traditional Food Wisdom is more than 5000 years old both based firmly on the epidemiological data and the biodiversity of many traditional and ethnic Foods. How to feed that huge population with the problems of hunger and malnutrition as years roll down inspite of this vast knowledge and abundance in nature ?? It is in this context that the government, the research institutions, academia and the industries especially which are focused on Nutritious and Healthy Food manufacturing sector as well as the market must get to people centric approach. It is true that Asia's and Mediterranean traditional knowledge and practices is today webbing into modern science with the emergence of a new model for reaching out of Nutrition knowledge to society in the closed loop and ambit of agriculture. The value of food was known to our ancestors and there lies the origin of traditional wisdom and ethnic value of foods which had a great journey through several generations and sustainably and as evidenced also of safety protocols by combinatorial Foods is well established. This has reached us today in same distilled form being more Nutritious than we can imagine. In the current scenario of the modern tools of science we have a great opportunity to understand traditional foods and its value for health and wellness through evidence based nutrition approach and make it useful to the society by spreading this knowledge of Foods handed down from generation to generation. It is quoted by many that nearly 100,000 plus medical manuscripts have the legacy in the Indian medical heritage which perhaps is one of the largest in the world and many of them can be directly related to food consumption pattern and Sustainable Agriculture in that region.

However, the complexity of combination of Foods and positive effect on health is always a debatable agenda depending upon the evidence available both epidemiologically and how much, the modern science can understand it following mining the data to connect that thousands of years of knowledge for a meaningful output. The potential of having a plateful of Nutrients and Nutraceuticals is much higher in Traditional, Ethnic and diverse foods than a monotonous food which is sold in today's fast Food market including Functional Foods and Nutrition.

The Functional Foods and Beverages have alarmingly captured a large segment of Food market which is expected to reach almost US $ 200 billion by 2019 with a booming category of Health claims in Foods for luring the consumer. The paradoxical question is also which Food is not Functional! Perhaps every Food is Functional but the Science has not been able to completely understand each Food and its bioactives for its functional benefits to humans or animals both in long and short term. The perceptions through Traditional Food, Fast Food and perhaps even the Slow Foods (!) have all a role to play in Food based approach for Sustainable Nutrition.

Healthy beverages are tapping into emerging market trends with almost every Food company having an eye on it as Functional drinks with added Herbals and Botanicals into it apart from snacky functional Foods. The formulation of a healthy beverage has become a major scientific challenge which almost every Food industry wants to be in the health beverage segment. However, the key Bioactive ingredients of a Food is not that easy to isolate (many success stories are there through Nutraceuticals) but the trend is to take it as caplets or capsules and / or tablets. However the holistic food based approach cannot be kept aside in the modern era of single molecule benefits overriding the totality of Foods. Many a times beverages have a much rapid absorption into the body and are highly acceptable especially in tropical countries where climatic factors also matters. An excellent example is *'Lassi'* an Indian dairy fermented cultured milk and is the new class of beverages that has begun to dominate the global market. One can see several companies getting into 'Lassi Race' with spices and condiments added to it. What was supposed to be a well-known traditional beverage of India both economically viable and sensorily excellent for rich or poor families is being commercialized.

An example of the above point is the Traditional way of using the knowledge and let us look at Rice depth. Today we know that rice by itself can be a subject with hundreds of traditional approaches of cooking of rice based foods for a variety of culinary marvels and at the same time even the broken rice goes to many of the dishes with all the Nutraceuticals by-products such as crude rice bran after deoiling from the rice bran as well as the dewaxed oil are used as major food ingredients. The defatted rice bran has become common ingredient today from where the protein is extracted or for the rice bran oil processing, by-products such as lecithin is isolated, oryzanol is refined, fatty acids are concentrated, vitamins and minerals are enriched just to give a few examples. All these have a role to play when we look at the rice in the paddy which is the traditional brown rice (hand pounded) which actually is a capsule containing all these vitamins, minerals, antioxidants and even anticancer agents along with carbohydrates, proteins and fat. We are losing it in a perfect organized manner today with segmented approach!

Another aspect that draws our attention today is the role of Proteins and Peptides from many traditional sources using evidence based Science, Technology and Engineering Developments which have improved so significantly that the cost effectiveness of the peptide and protein rich products have become much lower. The synthetic peptides are able to cascade into the biochemical, immunological and cellular reactions and sometimes even mimic protein domains and even simulate protein functions, thus opening a large window for its application. Peptides of different sizes, structures and functions can be today, designed and customized using the Reverse Pharmacological principles. These synthesized and customized peptides are used both in high end medicines and treatments as well as in translational medicines. It is also important that when we look at lifestyle changes, the trends of healthier breakfast, healthier snacking and the obesity issues as related to NCDs; the challenging role of Functional Foods and Beverages has become very vital as this forms the key structure of the fluid intake habits while eating habits across the globe is dynamically changing.

The plant based foods, naturally occurring functional foods and the power of proteins (catering to weight wellness and dairy nutrition), the approach of Super Foods emerging out of Functional Foods all touted as breaking news from time to time are different. Today one has Functional Foods in the labeled category of digestive health, the inner health as well as the fortification issues that go into the arena of pre and probiotics and even the gene silencing effect of Nutraceuticals through Functional Foods have become very pivotal in the larger umbrella of *Food be thy Medicine* ! There are several databases in the world on traditional foods and one such database which I have personally visited and spent a lot of time is situated about 70 kms from Mysuru in India called as Melukote where a data bank on *Ahaaradhikaranam* is documented. The Chemistry of writing on palm leaves using finger millet ink then lacquering them with the base of essential oils from spices such as sesame oil emulsion to preserve these palm scripts forever is indeed a super marvel of understanding the chemistry combination translated to data management on palm scripts. It is this trend of going back into scriptures and finding out what was used to bring in a correct way of mixing of foods for the benefit of joy and enjoyment of taste and health on the one side and the nutrition and wellness benefit on the other side is perhaps more important. The large amount of nutrientloss is never realized in the current 1.3 billion tonnes of food lost globally not counting the wasted food after cooking which can add to food many billion tonnes especially if we count the carbon footprint and energy chain. There are several reforms that may be needed as the healthcare in India changes rapidly with one that of *Digitized health* all the way to *Homecare health* demanding some of the preventive health aspects including immunomolecules on a food based approach. It is this healthcare of prevention or delaying of diseases (like NCD's) through proactive health care through food based approach which needs *knowledge* to mediate this transformation.

In the capacity building area it is worthwhile giving the example of shortage of Food Engineers. Nearly a quarter of a century back Chemical Engineers supplemented and complemented as Food Engineers! However, the Physics and Chemistry and behavior of food products (powders, viscous liquids, granulated mixing *etc*.) being entirely different and many other demands and complications actually triggered the need for Food Engineering as a specialization. Therefore a lot of training and orientation given by many of the Academia and R&D Institutes for Engineers to evolve as Food Engineers has made today's Food Industry more comfortable in the production lines than a quarter century back. Also food is more nutritious perhaps and safe and much more quantity is available than even money in the pockets for average middle class and thus causing more obesity in urban population. However the sad situation is almost one child dies before it reaches 5 years of age every 20 – 30 seconds in India due to various causes of ill health, malnutrition and undernutrition. But this is totally preventable indeed. All the scientists and society have responsibility towards this one goal whether he or she is an Astro Physicist or a Physical Chemist or a Nutritionist or a Doctor or an Engineer or a Pilot or a Policy maker. We have to STOP this daily death of children for no reason at all, by any means in the most urgent manner. It is this passion that Prof. Menon had in him that many Scientists contributed beyond their profession and I humbly include myself in that motivated long list of scientists.

(Disclaimer: The contents of this write up of my talk delivered on December 8, 2017 at NASI Annual meeting at Pune has much of the material coming from my own analysis of data and the write up and the slides I have done as well as link up of some of my own write ups in several popular articles and magazines and scientific editorials so that the chain of thoughts for the article is built up addressing *Nutrition and Agriculture* in a more generic way. I would like to place on record that in any Statistical data that is mentioned is only close to approximation and many a times they are well documented by word of mouth and gives only magnitude of the figure rather than the exact number. The claims, the links for evidence especially of traditional wisdom, what is regulated over several hundred of years is all resourced from several reviews, books, papers, presentations by perhaps many others in the field and what has been captured here as my talk that was delivered and is put in a printed form. *This article will not be claimed in my CV as a publication).*

Commercialization of University Research via Startups

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Introduction

The "knowledge economy" is a reality today. In advanced economies such as US, UK, Germany and France, the gross value added to the economy has a significant fraction — as much as 40% — attributed to knowledge intensive services and high tech manufacturing (Ref. 1). Furthermore, the fraction is increasing with time. Such knowledge intensity is becoming increasingly important for traditionally labour intensive economies to remain competitive internationally. This is creating a pressure for research and innovation in all nations, including India.

Several factors have built up over the years to facilitate research and innovation in India. Although research funding as a fraction of the GDP has remained flat at about 0.9%, the rapid growth of the economy has meant that research expenditure has increased in absolute terms and stands at USD 18 bn (more than Rs 1 lakh crore, Ref. 2), which is substantial. The fraction of R&D funding by the private sector is about 30% and is increasing with time. Thus, substantial resources are being invested in R&D, particularly in public institutions. This has led to the improvements in facilities and capabilities in these Institutions. The focus on research and post graduate education in public educational institutions has resulted in increasing numbers of PhD graduates. The relatively robust patent regime and the availability of well-qualified manpower with advanced degrees has attracted a large number of multinational corporations to set up R&D laboratories in India. More than 1100 such laboratories are functional and are addressing issues for the global markets of the companies. Indian companies are also ramping up their R&D efforts. A number of technology based startup companies have been set and the numbers of such companies are growing. Government programmes are also providing support for innovation; examples of such programmes include Make in India, Digital India and Startup India. All the above factors are contributing to a new era of R&D led innovation in India.

The above trends appear to contradict the broadly held view that India and Indians are not innovative. The well-researched recent work of Kumar and Puranam (Ref. 3) gives authoritative evidence to debunk these beliefs. India thus has the potential to be a significant contributor to the global innovation ecosystem and its economy could benefit substantially if the innovation is harnessed. Commercialization of research is a key factor for the growth of the knowledge economy.

R&D done within industry is put into commercial practice through internal mechanisms, and the path of such commercialization is relatively smooth. University research may be commercialized either through technology transfer to industry, which is usually difficult, or by means of startups. In this paper we focus on commercialization of research through startups, using the ecosystem of IIT Bombay as an example. We note that similar efforts are underway in several other Institutions. In what follows, we give an overview of the different components of the ecosystem, followed by examples of some successful startups. Conclusions are given in the final section.

The IIT Bombay Ecosystem

Several factors contribute to the vibrant entrepreneurial ecosystem at IIT Bombay. At the core are the strong educational programmes. The undergraduate programmes are rigorous and yet provide students considerable choice in the form of electives or the option to do a minor in a discipline other than their major. Students are also given opportunities to engage in hands-on projects, which include participation in international competitions such as the Student Formula 1 and the Solar Decathlon. Post graduate programmes are at an advanced level and have a substantial research component. The educational programmes of the Institute are broad in scope and include engineering, science, humanities and social sciences, design, management and a number of interdisciplinary programmes.

Research is a strong focus of activity across all academic units and the following statistics serve to highlight the scale and contours of research in the Institute. The Institute has 640 high caliber faculty, 200 recruited in the last 5 years, and 3000 PhD students, all engaged in research. The Institute receives around Rs 400 crore in extramural research funding each year. About 100 patents applications are filed and 1300 journal papers published each year. There is a keen interest within the Institute to commercialize research results where possible, and more than 100 technologies have been licensed in the last decade. The Institute has close interactions with more than 500 companies and 100 peer universities at any given time. A research park has been set up on campus to enhance collaboration with industry.

A number of multidisciplinary research centres have been set up to carry out focused research in a specific area to achieve well-defined deliverables. The centres are well funded by external agencies, which has enabled them to build up state of the art experimental facilities. Faculty and students from several different departments participate in the research centres, providing for a wholistic approach to the problems taken up. Examples of the centres include:

- Centre for Excellence in Nanoelectronics (Rs. 184 cr, DEITY, AMAT)
- National Centre for Photovoltaic Research and Education (Rs. 42 cr, MNRE)
- National Centre for Aerospace Innovation and Research (Rs. 34 cr, DST, Boeing)
- Wadhwani Research Centre for Bioengineering (Rs. 24 cr, Wadhwani Foundation)

- National Steel Research Centre (Rs. 32 cr, Steel Ministry)
- Tata Centre for Technology and Design (Rs. 94 cr, Tata Trusts)
- National Centre of Excellence for Technology for Internal Security (Rs. 92 cr, DEITY)
- Centre for Propulsion Technology (Rs. 130 cr, DRDO, jointly with IIT Madras)

The funding amount and funding agency are indicated in parenthesis.

The research intensity of the Institute has grown significantly in the last decade and an indication is the increase in the number PhD students on the rolls as well extra-mural research funding received, shown in figure 1. The strong educational programmes as well as the high level of research activity are providing a foundation for innovation and entrepreneurship at the Institute.

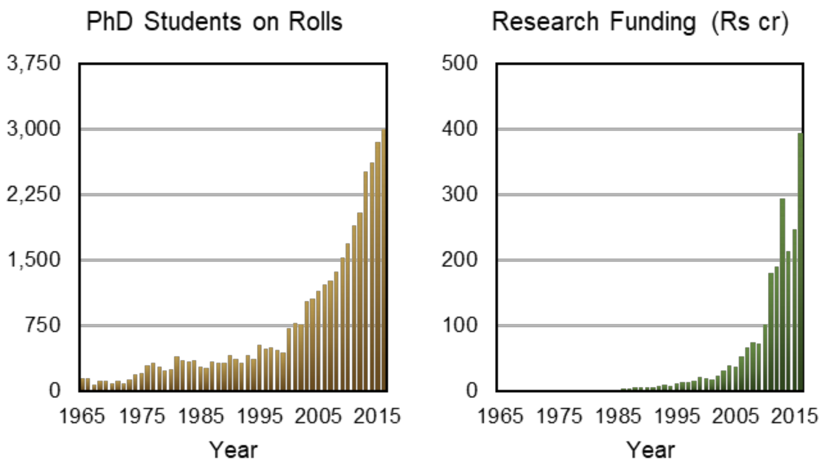

Figure 1. Increase in PhD student numbers and research funding over 4 decades at IIT Bombay

Entrepreneurship

Students of IIT Bombay have shown an increasing interest in entrepreneurship and the Institute has provided support for various related activities. Student clubs, the Tinkerer's Lab and student teams participating in different international competitions give students an opportunity for hands-on work and development of their business ideas. The eCell, a student entrepreneurship club, conducts workshops and events that promote entrepreneurship. The club claims to have initiated more than 300 startups through its programmes over the years. The Institute has set up the Desai-Sethi Entrepreneurship Centre to conduct academic programmes and research related to entrepreneurship. The centre offers a minor in entrepreneurship for undergraduates and various courses that give students a practical introduction to conceiving, starting and building a business. More than 30 startups have emerged through the support of the centre in the last 3 years. The pipeline of startups created by the above activities are supported by the IIT Bombay incubator, SINE. The incubator, set up more than a decade ago, provides space, at a subsidized rent, initial seed funding and soft support for setting up a business. The incubator has a strong network of mentors, venture capitalists and consultants for accounting, HR, sales and marketing, which is of great benefit to the startups. In addition to supporting incubated startups, SINE actively engages with the IIT Bombay community to create a pipeline of strong startups. An important continuing initiative is to provide an entrepreneurship orientation to PhD students. SINE has so far incubated 112 startups and a significant fraction (about 50%) have succeeded in raising funds from external sources. In the past 5 years, the cumulative revenue of SINE startups was about Rs 1000 crore, the funds raised by the startups were about the same amount and the total number of employees was about 3000. SINE startups have served as significant vehicles for commercialization of IIT Bombay research and 28 technologies have been transferred via SINE startups so far. We highlight three examples of such technology based startups, below; two are based on research carried out in the Institute, one is engineering design based. Sensibol Audio Technologies is a company based on the PhD research related to analysis of audio signals. The founders of the company are the PhD student and the faculty member, who was the supervisor. Starting with a product based on a patented technology, the company has diversified its offerings considerably and has clients in India and abroad. Sedemac is a second example in which research from a group in the Mechanical Engineering Department resulted in the development of an engine control system for small engines, that gives significant fuel savings. The founders are the faculty member and PhD and MTech students from the faculty member's group. The company has expanded its portfolio of applications and has grown substantially, with an annual revenue of Rs 120 crores and around 300 employees. A third example is Atomberg Technologies, founded by undergraduate students. The company initially developed a data acquisition system for laboratory use. Though the product was successful, the market for the product was small and the company did not get sufficient business. The company then developed an energy efficient fan with modern features. The product became a success in the market and the company has sold more than 100,000 fans, with annual revenues of Rs 14 crore.

The locality around IIT Bombay is becoming a hub for entrepreneurship and there are a large number of startups located in the vicinity of the Institute. Some of the companies are set up by alumni of IIT Bombay (Ola Cabs is one example) but many are set up entrepreneurs from elsewhere, who are attracted by the facilities available. The locality is attractive because of the availability of technical manpower and technical support of IIT Bombay, as well as the availability of suitable commercial space. The presence of many startups and their support systems is creating an ecosystem that is attracting startups from around the country.

Conclusion

The economies of nations are become increasingly centred around knowledge, in both, the service and manufacturing sectors. India is well-positioned to participate in the new knowledge economy, given the trained manpower available, the increasing investment in R&D and support for innovation through various government programmes. An important component of the innovation ecosystem are the public research universities and research laboratories of the nation. Commercialization of the research done in these entities can have a significant impact on the economy. Taking the example of IIT Bombay, we show the scale and diverse range of activities that are contributing to the innovation ecosystem. Experience of the Institute indicates that product development and refinement is iterative and needs to be done in engagement with the market. Inventors and technical experts must, consequently, be a part of the technology transfer. We find that this is most easily achieved when the vehicle of technology transfer is a startup. The innovation, which is the basis of the startup, may come from high end research or from good engineering design. The existence of an ecosystem with appropriate support structures is important. Such an ecosystem for startups is developing in the vicinity of IIT Bombay.

Acknowledgements

Prof. M. G. K. Menon was closely associated with IIT Bombay as the Chairman of the Board of Governors of IIT Bombay from 1997 to 2003 and made many lasting contributions to the Institute. It is a privilege for me to have this contribution, which highlights some of the current activities of IIT Bombay, be included in the collection being brought out to honour his memory.

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Continuous flow-based methods for large scale synthesis of nanoscale materials

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Abstract

Flow based wet chemical syntheses are turning out to be effective approaches for scaled-up preparation of nanomaterials with maintaining quality in terms of their size and shape. This brief review gives the background of such methods bringing out the genesis of why such methods are becoming more attractive. Finally, this article also presents a brief discussion on the rapid microwave-assisted flow synthesis of Pd/Ni nanoparticles with increased production rate developed by us. We show that microwave based flow synthesis approach could be realized for mass production of inorganic, organic-inorganic hybrid nanomaterial to satisfy industrial demand.

Introduction

Nano has recently become a buzz word both in the science and technology fronts. The great attraction towards nanoscale materials is ascribed to their unique properties that are different than their bulk and atomic/molecular counterparts. Due to these unique properties nanomaterials also find many applications in the field of energy, healthcare, electronics, catalysis, construction, and transport. As is well known the optical, electronic, magnetic, structural, and surface properties of nanomaterials are highly sensitive to their size, shape and composition. Based on many experimental observations it has become evident that the size and shape of nanomaterials are highly sensitive to the method of synthesis and reaction conditions such as temperature, pressure, concentration, type of precursor, addition rate etc. Therefore, finding reliable nanomaterial synthetic methods is declared to be of paramount importance to realize their true application potential[1]. The synthesis of nanomaterials can be accomplished via two routes -1) Top-down and 2) Bottom up approaches. In the top-down approach, a bulk material is broken into the smaller pieces using external physical forces to produce nanomaterials. Top-down approach involves ball milling, laser ablation and lithography methods for production of nanomaterials. Amongst these, ball milling is widely used top-down approach for nanoparticles synthesis. Unfortunately, it is difficult to obtain good quality material through this method as one ends up with non-uniform or poly-disperse nanoparticles. On the other hand, bottom-up approaches involve assembling of atoms and molecules to form nanoparticles. Various bottom-up methods have been used to produce different nanomaterial such as chemical vapor deposition, laser vapor deposition and wet chemical synthesis. Among the bottom-up methods, wet chemical synthesis is the simplest, modular and scalable method to obtain the desired nanomaterials. It also does not need any expensive instrumentation or extremely high temperature, and pressure condition. Enormous progress has been made in our ability to synthesize nanomaterials via wet chemical methods with the desired size and shape by adjusting reaction parameters such temperature, concentration, addition rate and sequence of reagents and pH.[2, 3]

Wet Chemical Synthesis of Nanomaterials

The wet chemical methods include various methods such as reduction, precipitation, sol-gel, reverse micelle, thermal decomposition, hydrothermal or solvothermal, and microwave-assisted synthesis.[4] Typically, the wet chemical synthesis of nanomaterial is conducted in a batch reactor (reaction flask, see Figure 1) and it involves carrying out an appropriate chemical reaction (reduction/hydrolysis/ complexation and/or precipitation) using metal precursorsin the presence of an organic molecule (that acts as a passivating/capping agent), in a solvent with constant stirring. Though, these bottom-up approaches offer great control over size and shape of nanomaterial one of the major problems with these procedures is scale up as these in general result in the production of sub- gram quantities of

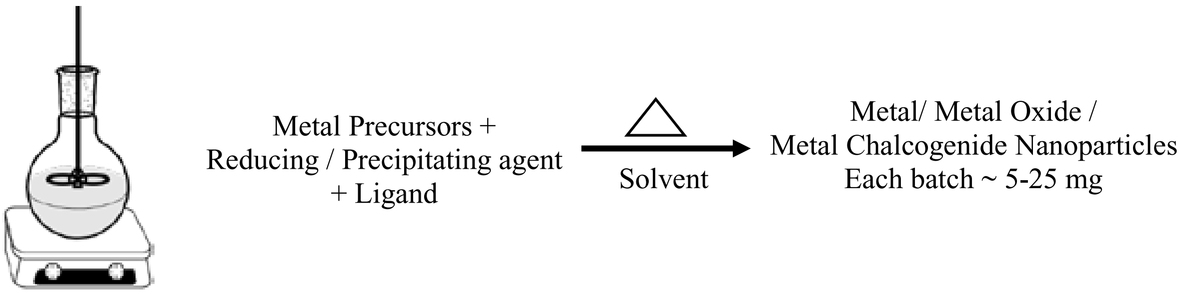

Figure 1: Schematics of typical wet chemical synthesis of nanoparticles in a batch reactor.

material.[5, 6]

Batch and Flow Synthesis of Nanoparticles

According to global market surveys, by 2025, the requirement of many classes of nanomaterials would be in the order of millions of tons[1]. Hence, satisfying this requirement using batch synthetic methods is quite challenging. In this context, various options are being tried in the pursuit of scalable synthesis of nanoparticles. These are i) conducting the synthesis in multiple batches, ii) increased batch/reaction volume and iii) conducting the synthesis using continuous flow method. Generally, for the sake of simplicity more quantities of nanomaterials can be synthesized by repeating it in multiple batches or increase the batch/reaction volume. But only few of these methodswere successful in terms of maintaining the quality of nanomaterial even after scale up. [7, 8]

Scale-up of nanomaterials synthesis using multiple batches is always hindered due to batch-to-batch variation in the product, and low yield. Scale-up of batch reactions is associated with some inherent limitations such as non-homogeneous mixing, slow mass and heat transfer lead to non-uniformed size and shape of nanoparticles. Typically, in lab scale operation, mixing is achieved using magnetic bar in the small size of the batch reactor. When such reaction scaled up to 100 times, achieving uniform mixing at large volume becomes a difficult task. Similarly, increase in batch volume also inhibits homogeneous heat and mass distribution throughout the reactor. The consequences of such a scenario are chemical wastage, loss of efforts, and time. Hence, achieving scale up by just increasing the batch volume cannot be always a reliable practice to obtain consistent product at large scale.

It is in this context that flow synthesis is becoming popular and has potential to produce nanomaterials in large quantity to fulfil the industrial requirement. Continuous flow processes are a more reliable approach than the batch processes as it gives reproducible results due to controlled addition and mixing of reagents. Flow synthesis has an added advantage of high production rate and can be automated.[9]

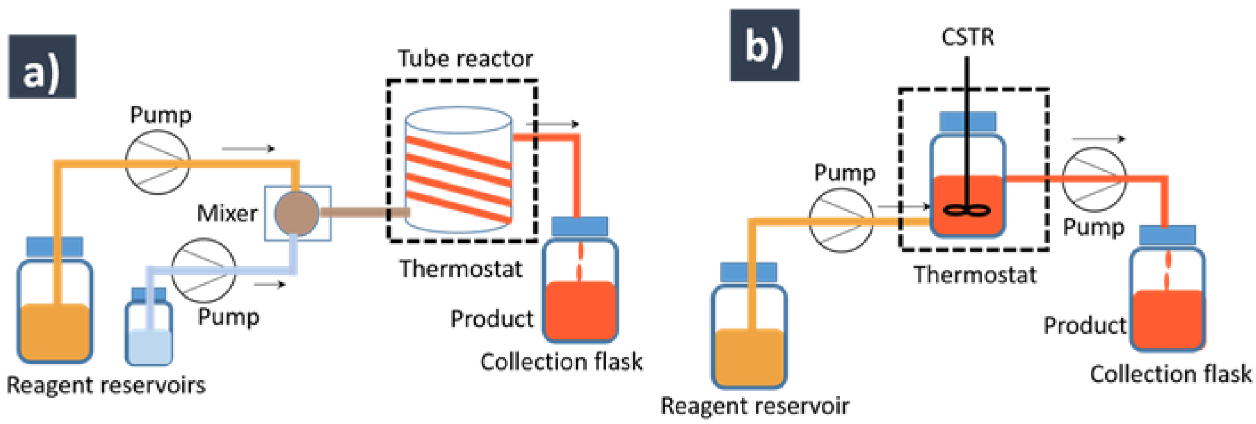

Figure 2: Schematics of continuous flow setup for a) tubular reactor and b) continuous stirred tank reactor (CSTR).

In a typical flow process, reaction is carried out in a narrow channel (tube, capillary or microfluidic devices) or continuous stirred tank reactor (CSTR). Experimental setup for tube reactor and CSTR is shown in figure 2. Experimental set-up of flow synthesis involves various components such as reagent reservoirs, tubings, pumps, mixer or impeller, thermostat, the reactor (tube reactor, see Figure 2a, and CSTR, see Figure 2b) and collection flask. Typically, in flow synthesis, reagents from the reservoir are injected through a tubing either into a reactor or sometimes for thorough mixing they are introduced into mixers. Subsequently, this reaction solution enters into a reactor placed in thermostat, where product starts forming. This resulting product can be collected at the outlet. For maximizing the product yield, it is important that the reaction solution spends necessary residence time in a reactor, reaches the temperature required to start the reaction very fast and the reaction is carried out in such a way that the nucleation and growth steps occur separately. Over last decade, flow synthesis has been practiced in miniature reactors such as small size tubing (I.D., 0.5 -3.0 mm) and capillaries (O.D., 0.1-0.5 mm). Mixing of reagents in capillary and tube size mixer is faster compared to batch reactor due to high surface to volume ratio.[10] This small size reactor is operated in a laminar flow regime where Reynolds number ($R_e = \rho VDh/\mu$) is less than 2000. Reynolds number is dimensionless number predicting flow patterns (laminar, stratified and turbulence flow). At the same time, rapid heat transfer and homogeneous temperature distribution is achieved due to the high surface area to volume ratio of the reactors.[11] Mostly, synthesis of nanomaterial is carried out by heating reaction solution in range 25˚C to 300˚C. In such cases, uniform heating could be achieved using micro or mill-fluidic reactor having a high surface area to volume ratio.[9]

In the first few years the continuous flow methods were restricted to simple nanoscale systems. For instance, in 2002, deMello and co-workers showed usage of micro-reactor for continuous synthesis of CdS nanoparticles from $Cd(NO_3)_2$ and Na_2S as cadmium and sulfur precursors respectively.[12] Similarly many other nanomaterials such as Au,[13], Pd,[14], CdS,[12] and $BaSO_4$[15] were prepared using continuous flow processes.

Microwave-assisted Continuous Flow Synthesis of Nanomaterials

For last few decades, microwave-assisted synthesis is becoming popular for rapid synthesis of nanomaterials due to fast and homogeneous heating.[16] Coupling of microwave and the continuous process would drastically increase the production rate. Many laboratories and industries started using this coupled technology for synthesis of organic compounds.[17] Recently, this coupled technology has been realized for the synthesis of inorganic nanoparticles and has potential to meet production rate with expected industrial requirements.

Herman *et al*. showed the use of segmented flow microwave for the synthesis of size-controlled PdSe nanoparticles.[18] In a recent report, Kunal *et al.* disclosed the scalable synthesis of bimetallic RhAg alloy nanoparticle using microwave-assisted continuous flow synthesis method.[19] Zhang *et al.* reported one step, facile and ultrafast synthesis of phase and size-controlled Pt-Bi intermetallic nanocrystal through continuous flow microfluidic device.[20] The controlled phase of Pt_1Bi_1 and Pt_1Bi_2 were synthesized at 260 ˚C and 360 ˚C respectively, using polyethylene glycol as a solvent. Wu *et al.* reported microfluidic reactions in a capillary tube reactor for rapid synthesis of ultrafine, surfactant-free PtSn alloy nanocrystals which are directly deposited on to various carbon supports with high-density of nanocrystal and uniform loading.[21] Synthesis of PtSn alloy on carbon support is also reported in pressurized condition. Nu *et al.* synthesized NiPt-octahedra in continuous flow reactor for scalable synthesis by droplet flow.[22] In this report, $W(CO)_6$ was used to generate gas which caused segmented flow and also acted as the reducing gas. However, WO_3 was formed as an impurity during the synthesis.

We recently introduced, a simple procedure for the synthesis of palladium supported on nickel nanoparticles (Pd/Ni) in a batch and a continuous flow manner, where the solvent can be recycled and reused[23]. Here, we have employed benzyl alcohol as a solvent and reducing agent for sequential reduction of Ni^{2+} and Pd^{2+} to synthesize Pd/Ni heterostructure using continuous flow synthesis technique. Benzyl alcohol is good microwave absorbing solvent with a 0.627 tan value. Upon continuous microwave radiation benzyl alcohol attains 200 °C temperature within 4 min. Due to the rapid microwave heating, formation rate of Ni nanoparticles was enhanced and reaction accomplished in 4 min. On other hand, same reaction performed using conventional heating requires 6h of reaction time. Thus, the production rate for microwave reaction is high in comparison to reaction performed using conventional heating. Interestingly, from our results it is evident that coupling microwave and continuous flow synthesis technique further increased the production rate of Pd/Ni nanoparticles due to less dead time required to perform reaction at large scale. We are now in the process of preparing the NiPt alloy nanoparticles using microwave-assisted flow synthesis. Our investigation proves that flow synthesis can be used for production of bimetallic nanoparticles in large quantity.

Conclusion

Batch synthesis of nanoparticles is limited to lab-scale production and study. Flow synthesis offers highly reproducible, controllable and automatable synthesis of nanoparticles due to superior mixing and heat transfer characteristics. We envisage that flow synthesis would become the most sought aftermethod for the preparation of large-scale production of hybrid inorganic-organic, inorganic-inorganic and organic-organic nanomaterials in near future.

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R&D to Product Realisation, Case studies from LCA Tejas Programme

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Introduction

Aviation is a knowledge intense activity. Its direct contribution to economic prosperity is a measure of its success in pioneering the "Knowledge Society". The people directly employed in the aviation enterprises are highly skilled "knowledge" workers, well practiced in the use and exploitation of advanced technologies including the new digital information technologies. Others working in the laboratories push forward the technological frontiers developing the knowledge that is crucial for economic growth.

In aviation the largest investments are made on military aircraft development since they are linked to national security. Military aircraft also have the most demanding and the most diverse performance requirements. It is therefore not surprising that the best science and technologies are required, and often evolve from the development of military aircrafts. These technologies then find their way into civil aviation sector and often to one's delight, also to non-aviation sector.

Taking into consideration, the military and financial aspects, the Indian Light Combat Aircraft program was initiated in the mid-eighties. This fighter aircraft is world's smallest, lightweight supersonic fighter of its class. This necessitated development of new infrastructure, new enabling technologies and new core technologies requiring frontline basic research. Collaborative effort between academic institutions, R&D laboratories and industry was undertaken on a very large scale. Hundreds of new products, processes, facilities and technologies were developed as a part of this program. This talk outlines the strategy adopted to develop and manage the science and technology base and industrial eco system.

Indian Light Combat Aircraft (LCA)

LCA is the world's smallest, lightweight, multi-role supersonic aircraft designed to meet the stringent requirements of Indian Air Force (IAF) as its frontline, multi-mission single seater tactical aircraft for the 21st century (Fig. 1).

Fig. 1 : Light Combat Aircraft

The key requirements for LCA are:

- Higher agility and maneuverability
- Multi-mission capability
- All weather, day and night missions
- Cockpit compatible with night vision systems
- Capability to carry
  - Precision guided weapons
  - Conventional bombs and rockets
  - Close Combat and beyond visual range missiles
  - Sensor and Electronic counter measure pods
- High survivability in ECM/ECCM environment
- Adequate range for close support and interdiction

The need was that point performance must be superior to fighters such as F-16 of American origin, Mirage-2000 of French origin and Mig-29 of Russian origin. Another requirement was that the technology deployed should enable the aircraft to remain current for the duration of its service without requiring major upgrades. It was evident that these goals of performance and life could be achieved only if the best of technologies available in the field of aviation were harnessed in the making of LCA (Fig. 2).

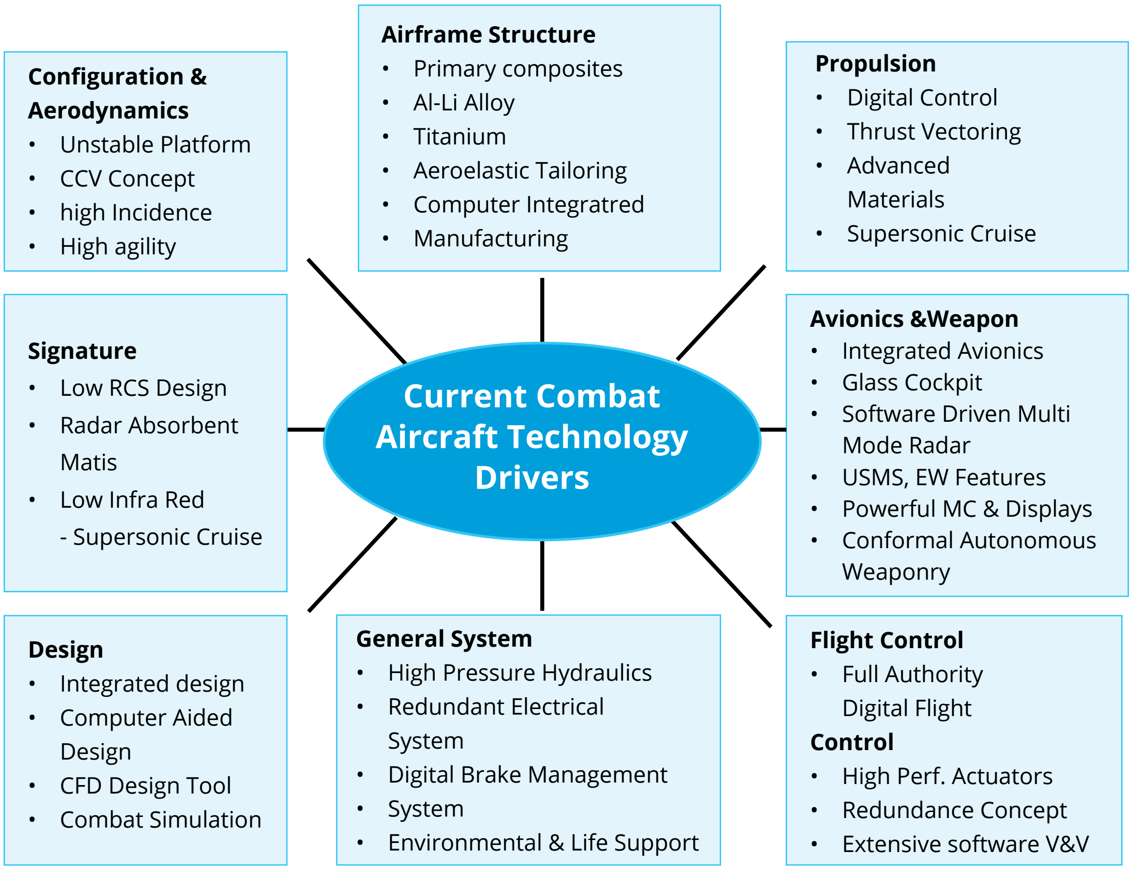

Fig. 2. Current Combat Aircraft Technology Drivers

Core Technologies and Design Concepts of LCA

LCA integrates modern design concepts and state-of-art technologies such as compound delta plan form with relaxed static stability, fly by wire flight control system, advanced digital cockpit, multimode radar, integrated avionics system, advanced composites for airframe and a state-of-art, high performance engine. (Fig. 3)

LCA is a total weapon system capable of precision weapon launch. There are eight weapon stations with capability to carry and deliver a wide range of missiles (close combat, beyond usual range, air-to-air, air to surface and air to sea), bombs, rockets, etc.

In addition to the multimode radar, which is the prime sensor of LCA, it is designed to carry additional sensors such as FLIR (Forward Looking Infrared sensors), IRST (Infrared Search and Track System), LDP (Laser Designation Pod) and Reconnaissance Pods.

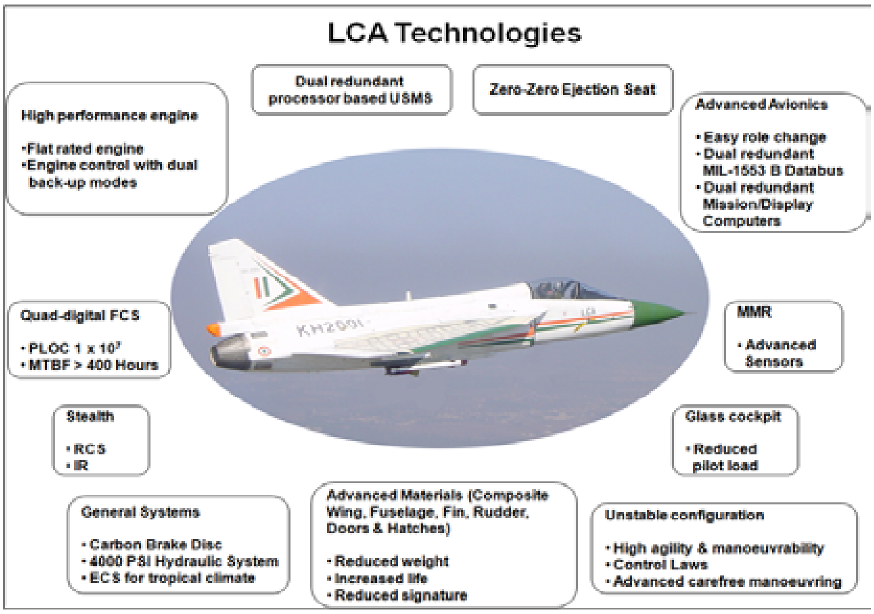

Fig. 3. LCA Technologies

Enabling Technologies for LCA Design Development and Production

LCA is packed with latest technologies relevant to contemporary fighters. The performance, weight and cost targets specified by the customer demanded not only the best of core technologies but also best of design processes, manufacturing technologies, testing infrastructure / testing facilities / testing technologies, software development, testing and validation methodologies and a host of other enabling technologies and management tools. Some of the enabling technologies needed for development of LCA were:

- Computer Aided Design (CAD)
- Computer Aided Manufacturing (CAM)
- Computer Aided Engineering (CAE)
- Digital Prototype Assembly (DP)
- Virtual Prototyping (VP)
- Rapid Prototyping (Rapid Tooling [RP/RA])
- Reverse Engineering (RE)
- Product Data Management (PDM)
- Enterprise Resource Planning (ERP)

A few of the CAD tools such as CATIA were available in the commercial market. However, most of the CAD/CAE/CAM/DP/VP/RP/RA tools needed to be developed by the LCA teams as they were not available in the commercial market. The aircraft industries develop these tools in-house and would not like to part with them as they are their knowledge base and provide them competitive advantage. The Indian Industry had not developed any of these tools and technologies earlier as they did not have a development program which demanded such tools and facilities.

Challenges of Technology Development and Management

For a proper understanding of the significance of LCA for Indian Aeronautics, one needs to know a little bit about the historical background of fighter aircraft design and development in India. The last fighter prototype, the HF24, Marut flew in 1961. This aircraft development was undertaken in India under the leadership of a German design team using mostly imported materials, equipment and processes. This aircraft was a contemporary first generation fighter. However, no follow-on program was undertaken for the next two and half decades. As a result not only did the technology base, not grow but even the existing knowledge base got dissipated. In a field such as aviation, one has to continue to develop new technologies and products to retain their position, whereas in India, no significant initiative was taken to develop new technologies. As seen in fig.4 technology of HF24 was of Gen1 whereas the LCA's technologies are of Gen4. The challenge was to bridge this huge gap of technologies through the LCA programme.

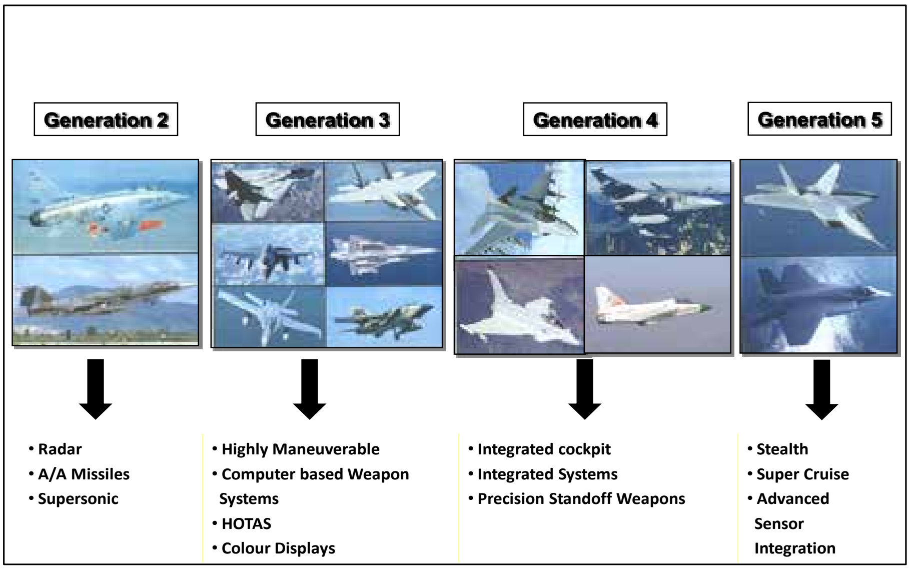

Fig.4: Evolution of Fighters

Unlike the previous generation aircraft, LCA systems are totally software dependent. The flight control system is an all-digital system incorporating safety critical onboard software. The Glass Cockpit does not incorporate any discrete instruments. The multifunction displays are driven by software and instruments on demand are created. The onboard avionics computer is driven by onboard mission critical software which not only manages vehicle management functions but also carries out multiple functions such as control of displays, weapons management, sensor management, systems health management, electronic counter measures and a host of other related tasks. The software is so critical that new development and testing technologies were required to be established and mastered through indigenous research efforts.

The new generation fighters such as LCA are highly integrated systems, each element is dependent on many other elements and together they serve the multiple objectives of vehicle management, weapon management, mission management, life management, vulnerability/survivability management. Development of such an integrated system, needed concurrent engineering approach and related tools; ground rigs for testing at component, subsystems and system level; simulators mimicking the major systems, the vehicle itself and also the complex environment in which the vehicle has to operate. Development of a complex system such as LCA needed a structured process of validation and verification leading to certification for safe flying leading to service induction. The testing involves not only on ground but also flight testing. It is a complex process needing lot of know-how and know-why (research) along with excellent professional management skills. This is a complex technology and resource management which was developed from scratch.

A complex system such as LCA needed thousands of scientists/engineers/technicians with expertise in multiple disciplines. No single organization within India had the abilities to develop these complex technologies. Hence along with technology innovation there was a need to bring in organizational innovation to achieve the objectives. Fig. 5 outlines major innovations that were achieved in the process of developing the LCA.

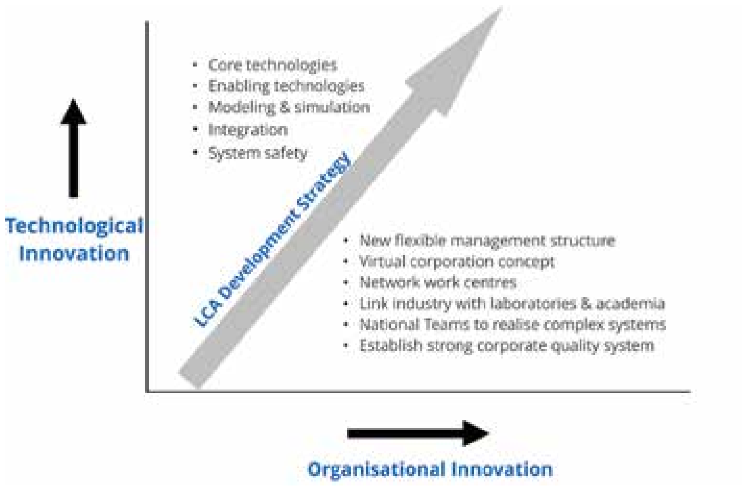

Fig. 5: LCA Development Strategy

Approach to Technology Development

Realization of LCA involved development of materials, processes, components, equipment, subsystems and onboard software. All the materials and equipment developed would need test facilities for performance validation and certification. Test rigs including simulators were also needed for integration of subsystems and systems and integration checks on the aircraft. All the equipment and test facilities had to be created de novo as none were existing before start of LCA program.

LCA is a highly software intensive aircraft with millions of lines of code for mission critical and safety critical applications. None of the aircraft either made under license or designed earlier had any safety critical software. This was a major challenge for the LCA team.

The development of LCA required new management style and procedures as the work demanded substantial coordinated efforts involving industry, R&D Labs and Academia. The management of LCA involved four major elements

- Strong project team to assess, review, ensure quality/safety and timely completion.
- Formation of national team to take up development of difficult and complex systems/tasks.
- Consortia for technology development.
- Consortia for testing, system integration and validation.

These four mechanisms brought in both horizontal and vertical knowledge/technology evolution. One of the essential features of the LCA program is this multilevel and multifunctional coordination.

In these effort more than 300 industries, 40 R&D laboratories and 20 academic institutions participated leading to a fourth generation fighter with world class technologies. This was an effort where whole nation participated as could be seen in fig. 6.

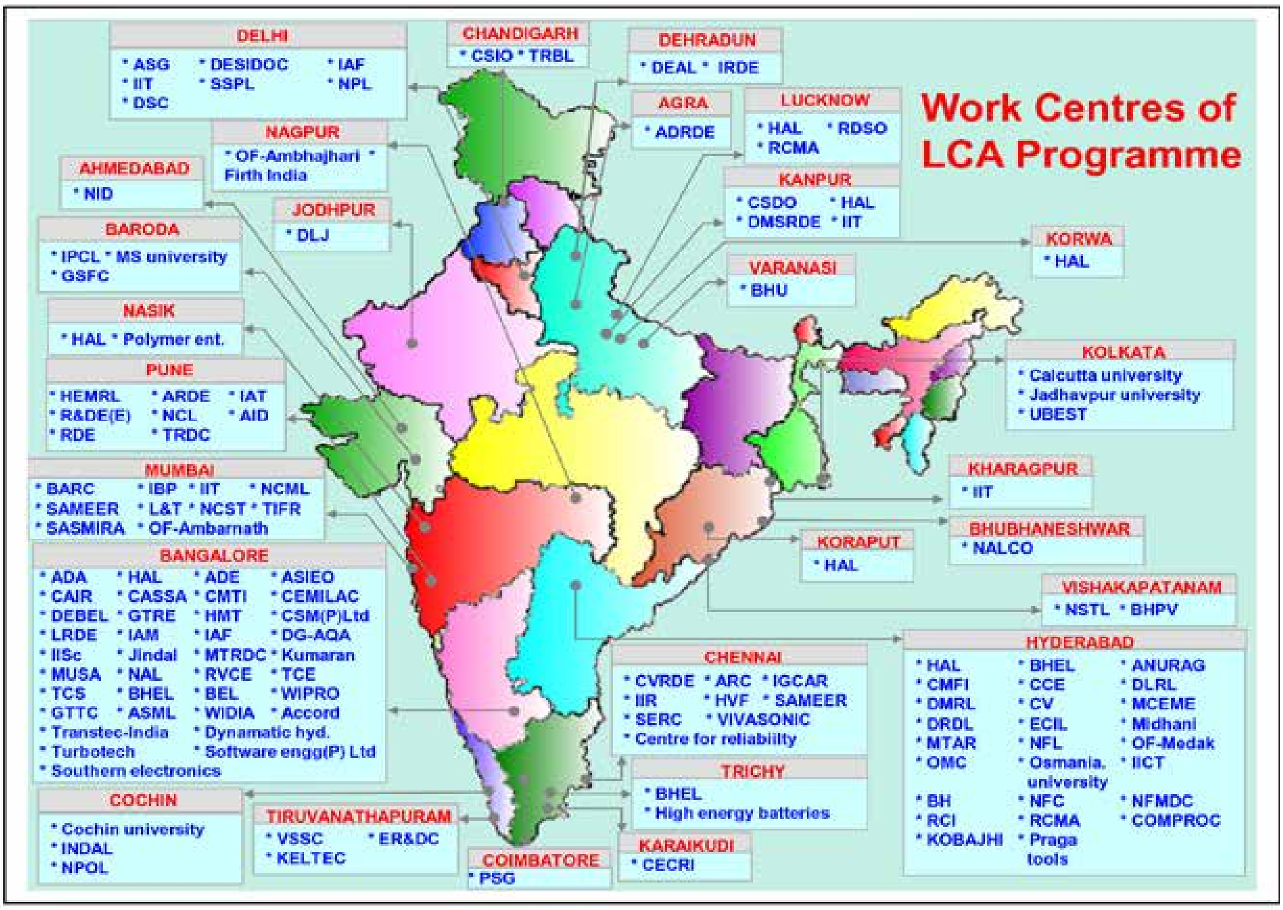

Fig. 6: Work Centres of LCA Programme

Creation of Ecosystem for Aviation in India

LCA project enabled creation of an ecosystem in the country with capability to develop state of art aircraft. The four pillars of the ecosystem are:

- Knowledge/technology development
- Technology/system integration
- Knowledge/technology/system validation
- Transfer of knowledge for production

All the four segments required for establishing a firm ecosystem was created through the LCA program. It is this ecosystem established in the country, which could be gainfully deployed for development of next generation military and civil aircraft.

Bridging Academic R&D with Product Innovation: An Indian Perspective

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Abstract

This paper discusses the need for translating the research and development studies conducted in academic institutions into viable, useful as well as cost-effective products to meet the pressing societal needs in low income economies. It has been observed that though the Indian labs produce a high number of peer-reviewed scientific publications, the effort to protect the intellectual property is minimal. Even where the IP is protected, the quality of patents is rather abysmal. Consequently, viable and useful products do not come out of research work going on in Indian lab settings. In order to correct this, we discuss some of our efforts made at IIT Bombay and IIT Delhi, which led to a slew of high technology prototypes meeting the pressing needs of the society. This in a way set the culture of innovation leading to deep technology product development activities in these institutions. This paper tries to outline a blueprint for developing such a deep technology product development eco-system in Indian academic institutions. Though high quality Research & Development (R&D) is happening in some of the leading Indian academic institutions, the delivery part is the one that needs strengthening at this stage.

Scientific Research in India

India is progressing steadily if scientific output as measured from research publications is taken as a metric. Currently India is ranked sixth in terms of research output and is growing at a humongous rate of 14% in comparison to the world average of 4%. It is projected that by the year 2030, India will occupy third position in the world in terms of research output. The best part of Indian scientific research is that, all of this is being achieved with minimal investments in science and technology, when measured in dollar terms. Though there are many areas that need to accelerate to make India a global scientific leader, in certain domains like Nanotechnology, the country is already ranked third globally in terms of number of peer-reviewed publications, lagging only behind China and USA [1]. Though these are excellent achievements, the situation is entirely different when one looks at the innovation or the product development potential in the country. For example, India ranks very poorly on the Global Innovation Index (GII), and the research undertaken by Indian academic institutions, whether public or private, has hardly resulted in any major commercial breakthrough on the world scale.

Given this scenario, in order to make the Indian research competitive and sustainable in terms of innovation and product development, a multitude of initiatives have recently been contemplated and launched by the Govt. of India at the national level. In this paper, we will discuss the changing scenario for product innovation in Indian academic and R&D institutions, and also see how one can accelerate the culture of product innovation in the country. We shall discuss this by using Nanotechnology as a test case, since considerable investments have already been made in the country in this area.

Government of India (GoI) has taken several initiatives to promote the research activities in the field of Nanotechnology by establishing five Centres of Nanotechnology in 2007, seven Units of Nanoscience in 2009 and six Thematic Units of Excellence in 2011. Over the years, publication of research articles in peer-reviewed journals has drastically increased from a few hundred in 2001 to approximately 6000 papers per annum in 2013. Similar trend has been reported for the number of patents filed from India, rising from less than ten in 2001 to close to 500 filed in 2013. However high the rise seems to be in the case of number of patent filings from India, the country still lags behind many countries (ranking 16^{th}) having a share of 0.2% patents in the world, whereas USA has close to 60% of the patent share worldwide. As per a Lux research report "Ranking the Nations: Nanotech's Shifting Global Leaders", India falls into the minor league of nations having very low technology development strength. There is an immediate need to address this in order to make our R&D investments sustainable. In this regard, GoI has set up a networked programme, known as N-NETRA (National Nanoelectronics Network for Research & Applications), consisting of six IITs and IISc Bengaluru to address such concerns. A funding of roughly Rs. 300 crores has been earmarked for this initiative for the period 2018-2021. According to one estimate India has invested over Rs. 2000 crore during the last decade in building the necessary infrastructure for Nanotechnology research. India has also allocated Rs. 1000 crores to fund the research labs to come up with socially useful products under the IMPRINT (an acronym for Impacting Research Innovation and Technology) programme, in 10 different domains out of which Nanotechnology is one of the key sectors. It is also supporting scientists under various funding schemes to boost scientific research activities in academic as well as commercial settings. Third phase of the Nano-mission initiative is also currently underway with over Rs. 300 crores of funding. A Nano-mechanical prototype fabrication facility has also been established at IIT Bombay for start-up companies who wish to fabricate their proof-of-concept devices at nominal costs, without having to invest huge amounts into establishing fabrication facilities for their products.

Introduction to Nanotechnology

Nanotechnology is defined as *the design, characterization, production and application of structures, devices and systems by controlled manipulation of size and shape at the nanometer scale (atomic, molecular and macromolecular scale) that produces structures, devices and systems with at least one novel/superior characteristic or property* [2]. At the nanometer scale, where physical properties become size-dependent, the increase in surface area to volume (A/V) ratio increases with decrease in the size $(\propto \frac{1}{R})$. A more practically relevant example delineating the power of scaling down to nanometer scale is that a 5 cm^3 solid material when divided 24 times (into 24^3 pieces) would effectively yield a surface area equaling the size of a football field. Such a property is particularly useful in developing sensors by giving an exposure area as high as a football field with a mere 5 cm^3 volume, thus leading to a much higher sensitivity.

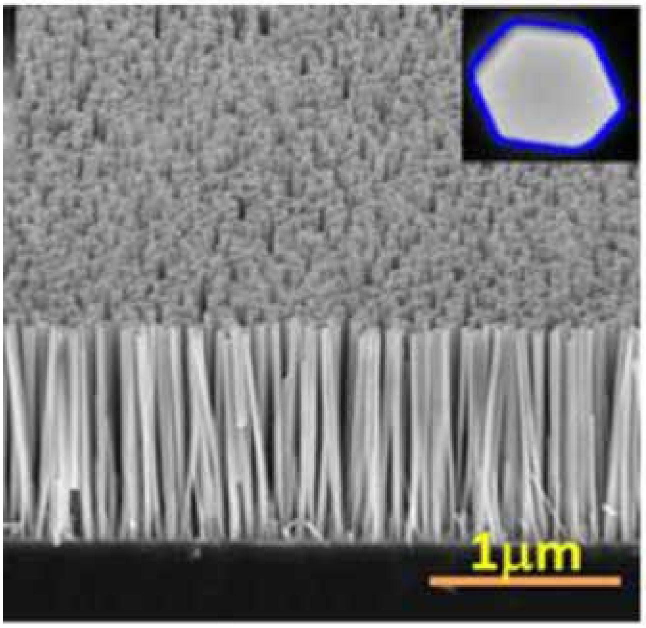

Fig. 1 ZnO nanowires, meeting the essential requirement of high surface area to volume ratio, grown by hydrothermal method on a solid substrate for sensing/pre-concentrating applications. These nanowires were grown in our lab at IIT Bombay.

One such generation of high surface area to volume ratio is shown in Fig. 1, depicting the ZnO nanowires grown on a solid substrate, which has potential applications in pre-concentrating the gaseous phase trace analytes like volatile organic compounds and explosive molecules (e.g. TNT, RDX etc.) in the environment, to name a few.

Nanotechnology will have significant impact on the sensor technologies and these sensors are expected to soon pervade our lives in all possible ways. Nowadays, everyone is used to and sometimes extremely dependent upon their mobile phones for all sorts of mundane activities. Any typical high end phone today comes with over two dozen sensors like an accelerometer to heartrate monitor. Even household refrigerators have become smart enough to inform about the status of ingredients stored inside and order for stocks using pre-programmed data. All routine and repetitive tasks will soon be done automatically with mobile phone serving as the platform around which the technologies will converge. This makes life much easier and helps us reduce clutter in our lives. This area is fast developing and is categorized broadly as "Internet of Things (IoT)" or "Internet of Everything" technology. *The Internet of Things (IoT) is the network of physical objects or "things" embedded with electronics, software, sensors, power source, network connectivity which enables these objects to collect and exchange data* [3]. As per an Electronic Engineering (EE) Times report published in 2013, sensors would become a multi-trillion dollar industry by the year 2040 [4].

Such sensitive sensing platforms on handheld devices like mobile phones are usually based on MEMS (Micro-Electro-Mechanical-Systems) devices like accelerometers etc. The ultimate aim of the sensing platforms is to replace the organic sensing of environment by means of five senses, viz. sight, hearing, touch, smell and taste. Out of these, today's mobile phone technology assists us in replacing the three senses of sight, hearing and touch. With the advances in Artificial Intelligence/Machine Intelligence technologies, the information gathered through the existing sensors in a mobile phone can be put to an intelligent use, which is bound to happen soon. The remaining two senses, smell and taste, are yet to be incorporated into a commercially available mobile phone. It has been our group's focus to develop MEMS/NEMS-based sensing platforms to substitute for the senses of taste and smell. In addition, we are also working towards developing MEMS-based point-of-care diagnostic kits for monitoring heart diseases and monitoring the soil nutrient/moisture levels using similar platforms. The same is discussed briefly in the upcoming sections of the paper.

Research Works at IIT Bombay being Translated into Products

As discussed earlier, our group's focus in the development of MEMS/NEMS-based sensing platforms can be broadly divided into three subsections. All three are discussed briefly, further in the paper:

- A low-cost cardiac diagnostic system
- A vapour-phase explosive detection system (electronic nose): A potential substitute for sniffer dogs
- Soil moisture and nutrient sensors for agricultural applications
- For the above mentioned sensing platforms, microcantilever arrays are being employed to achieve the desired goals. The schematic of such an array is shown in Fig. 2.

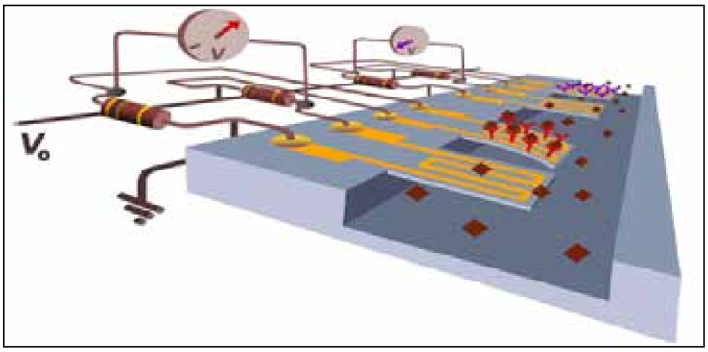

Fig. 2 The analytes bind to their specific receptors on the cantilever surface. As a result, surface stress is generated on the cantilever which is further analyzed by either piezoresistive (change in electrical resistance due to surface stress) or piezoelectric (generation of electric potential due to surface stress) mechanisms. The schematic is adapted from [5].

The low-cost cardiac diagnostic system consists of the microcantilever-based sensing platform. On the microcantilever surface, receptor molecules (typically an antibody) that specifically recognize the marker of interest (e.g. troponin, CKMB, myoglobin, for myocardial infarction) are immobilized. Upon exposure of this setup to the blood sample, the marker binds covalently to the specific receptor molecule thus generating a surface stress. This surface stress causes some mechanical duress on the microcantilever structure. A piezoresistive layer is sandwiched within the in-house fabricated microcantilever. Thus, the mechanical stress causes the resistance of the cantilever to change which is subsequently monitored using a balanced Wheatstone bridge method. The technology has been licensed to NanoSniff Technologies Pvt. Ltd., a company incubated at IIT Bombay. The packaged product is shown in Fig. 3.

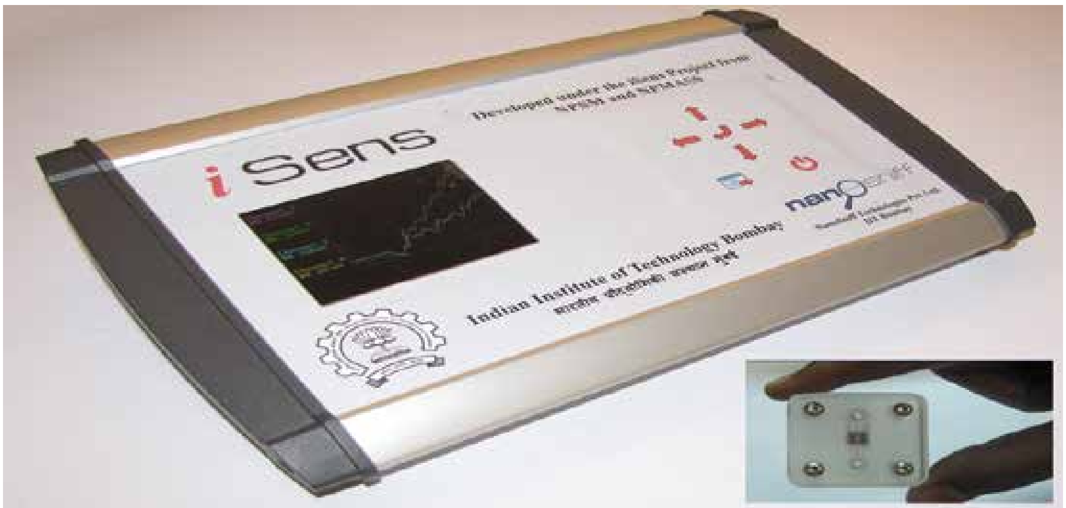

Fig. 3 The packaged cardiac diagnostic kit, iSens, developed at IIT Bombay in collaboration with NanoSniff Technologies Pvt. Ltd

In today's terror stricken world, security in public places has trumped all other priorities. Security forces have to be ever vigilant and have to function with 100% efficiency in an attempt to deter any untoward incidents. They employ specially trained sniffer-dogs, as the name suggests, helping to sniff out "hidden from the plain sight" explosive materials. This requires huge manpower to train and tame the dogs. But there are no viable alternatives to the sniffer dogs in such cases, yet. But there is a considerable risk of missing out on explosives if the animal is fatigued due to high alertness, working overtime. To overcome this, we have developed an indigenous technology using microcantilevers to detect trace amount of explosive vapours at IIT Bombay. Vapour-phase explosive detection (i.e. electronic nose) kit involves microcantilevers with their surfaces chemically modified with molecules that specifically bind to explosives (e.g. calix-arenes, 4-mercapto benzoic acid, 6-mercapto nicotinic acid, Fluoro-alcohol polysiloxane polymer, porphyrin molecules etc.). After the explosive molecules bind to surface of microcantilevers, surface stress is generated which is further detected using either piezoresistive or piezoelectric mechanisms with the help of sandwiched layer inside the microcantilevers. It has the ability to be trained for specific levels and concoctions of explosives and is believed to be able to detect very low concentrations of explosives in harsh environments. The technology has been packaged into a handheld product, as could be seen in Fig. 4.

Fig. 4 The handheld vapour-phase explosive detection prototype, X-niff, developed by our group at IIT Bombay with support from the Principal Scientific Advisor's office, GoI.

While working in places where the explosive detection devices cannot remain connected to the electrical supply most of the time, there arises an imminent need to power these devices offline. One such mechanism that we have harnessed for this purpose is based on the power generation by vibrations of public transport vehicles like buses, trains etc. (where these devices would be eventually deployed) using piezoelectric materials (like ZnO, PZT etc.).

Agriculture has always been the backbone of Indian economy. In recent times, however, the situation has started to appear grim with the GDP share of agriculture dropping from 40.6% in 1972 to a mere 17.8% in 2010. For people who are still employed in the field of agriculture, this may be mainly due to lack of knowledge required for proper decision making in events of sporadic or no rains, deterioration of essential soil nutrients required for plant growth. Currently available commercial sensors for this purpose are very costly for Indian settings, with almost zero customer support service. It has become imperative that every society needs to solve its own problems with whatever available resources. After having much scientific prowess as well as better economic conditions than ever before on our side, we cannot always look outwards for solutions to problems pertinent to Indian context. We chose to address this problem by developing low-cost soil moisture as well as nutrient detection platforms and translate them into a packaged product. This product aims to empower the agriculturists with the knowledge about the levels of moisture as well as nutrients in the soil so that they may make appropriate decisions with regards to the sites and amounts of irrigation and sprinkling of fertilizers. The paucity as well as overdose of water as well as nutrients might harm the crops irreversibly, so a proper information system is required to be in place. The soil moisture sensing prototype developed in our lab with its on-site working is shown in Fig. 5.

Fig. 5 Soil moisture sensing prototype developed and field-tested at IIT Bombay is shown. The moisture levels are communicated to an off-field base location by means of wireless transmission. The technology is being commercialized by Proximal SoilSens Technologies Pvt. Ltd. incubated at IIT Bombay.

For the soil nutrient sensing, we have devised a novel low-cost sensing platform by using polyethylene terephthylate (PET) cantilevers. PET is a commercially available transparency sheet. Using the PET as a structural material for cantilever fabrication helps us in cutting the cost of conventional lithography techniques. The surface of PET cantilevers is chemically modified by ionophores specific to soil macronutrients like nitrate, phosphate and potassium ions. After the macronutrient ions bind to the receptor ionophores, surface stress develops in PET cantilever which is further measured by piezoresistive mechanism.

Specific steps to be taken for connecting academic R&D to product innovation in our institutions:

1. Creation of high end research facilities in our leading institutions is an important need facing the country right now. It is not only important to create high end facilities but also make them accessible to researchers using a transparent online system. Very often, lot of good work remains undone for want of facilities. Even after development of research prototypes, scale up is one major issue for field trials. Prototype manufacturing facilities are required with innovative models for their usage that take into account IP protection.

2. Institutions need to put in place simpler processes for IP protection. Patent filing times must be brought down to about a month and the patent drafting process must be outsourced to professionals. "Patent-Publish-Prosper" needs to become an institutional philosophy.

3. Multi-disciplinary culture is very essential for developing solutions to the problems being faced by the society. Institutional processes to seed and encourage such multi-disciplinary efforts are essential for institutions right now. A grand challenges kind of an approach with top down planning is an important requirement in this direction.

4. R&D in academic institutions is primarily driven by North American and European models. There is a need to innovate in areas where there is domestic demand.

5. Local R&D for product development is absolutely essential for reducing the costs and for taking care of the needs of the people in India – be it for agriculture or security or healthcare applications.

6. Ph.D. research problems today are generated mainly through a literature review. It is important that more institutional mechanisms are created where we expose our faculty and students to the societal problems. It could be through various immersion programmes or industry interactions. Ph.D. problems also need to be identified to some extent through societal interactions.

7. It is also important that we find solutions to major issues facing the country through collaborative projects involving multiple institutions. A system oriented approach for project execution is the key. Top down planning is highly essential for this purpose. A Grand Challenge approach at the national level, run through a system oriented multi-institutional approach is helpful. Industry participation in such projects with clearly defined IP policies and technology transfer agreements is essential. The agreements must also have clauses where the industry gets the technology transfer and doesn't pursue it, the IP must revert back to the academic institution based on certain pre-conditions. .

8. Our review processes for projects need to be strengthened and there is an immediate need to remove the bureaucracy and give the financial freedom to the project investigators within the approved project outlay of the project. Close monitoring of the project progress and timelines is an important requirement. There is also a need to accept that not all projects will succeed, despite the best efforts of the investigators. One must not crucify the researchers, if a project fails for reasons beyond their control. One also learns from failures.

9. Creation of Technology Parks on the academic campuses is highly desirable. Industry interactions often bring the much required focus to the project objectives.

10. Basic research must always be encouraged through special schemes. Today's basic research is tomorrow's technology and cutting down funding for basic research will break the pipeline of innovation, which can be detrimental in the long run.

11. Faculty entrepreneurship must be encouraged in our educational institutions. Clear policies for conflict of interest and measures to encourage faculty led startups will go a long way in building the ecosystem of product innovation in our educational institutions.

12. Aesthetics is becoming an important aspect of product design right now. Departments of Design focusing on product design and facilities for rapid prototyping must be created in academic institutions. Schools to facilitate interdisciplinary research (on the lines of School of Interdisciplinary Research at IIT Delhi) need to be created on our academic campuses for Ph.D. students to work on well defined interdisciplinary projects.

13. It is important to train our students for group efforts. Schemes need to be designed in our academic institutions where we formally prepare our students to become good at working in a group.

Summary

There is so much of untapped potential in our higher educational institutions given the high concentration of talented individuals on our campuses. Structural reforms at the institutional level with supportive schemes at the national level, can go a long way in bringing out this hidden potential to the surface. The specific steps for this transformation are documented in this paper, based on the experience of one of the authors (Rao), who has led these efforts in two of the leading institutions in the country. It is high time we realize that, creativity in our higher educational institutions is as important as literacy at the grassroots level. The transformation that we wish to see for the country needs to begin at the doorsteps of our higher educational institutions.

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Commercialization of Advanced Products using In-house Research

Dr. Baba N. Kalyani, Chairman & Managing Director
Bharat Forge Limited

Organization Philosophy

Bharat Forge (BFL) a part of the Kalyani Group, strives to be a world class organization and a leader in every aspect of its business. The Spirit of Innovation fuels the Group to aggressively grow its businesses by accessing global markets, to deliver products and services of uncompromising quality and integrity, consistent with the Kalyani brand and image.

The Business Philosophy of the organization is "To use our specialized skills and innovative technology to contribute to the welfare of the society. It is our intention to grow along with our employees and to aid and encourage them to participate in our goals in order that they realize their full potential. Our prosperity is linked to the prosperity of our customers". This guides the group towards a culture of continuous learning and skill up-gradation wherein the organization has invested significantly in building strong knowledge resources.

BFL has leveraged its tie ups with leading academic institutions including ITI's, regional engineering colleges, BITS, Pilani, University of Warwick, UK and IIT, Bombay and created a strong talent pipeline.

- Enhance skills of employees
- Developing capabilities in new technology areas
- Deliver innovative solutions to customers

It has also been able to devise application oriented focused programs with these institutes to jointly develop capabilities in new material, advanced manufacturing, performance validation, investigation and failure analysis, product research and prototype development. The research objectives of these programs are aligned with the organization's medium to long term growth strategy, critical for commercialization.

The Group has been able to successfully form 5 Centers of Excellence (CoE), bringing together a combination of expert scientists & young engineers working on advanced R&D programs across the globe in the fields of Material Technology, Manufacturing Process Technology, Tactical Systems, Jet Propulsion & Electric Propulsion Technologies facilitated with State-of-the-Art equipment.

Process Innovation | Components for Oil & Gas Industry

1. Process Optimization and validation using Virtual Manufacturing

With objectives of improving the grain flow (and hence strength), optimizing the input material required for the process & the optimizing the complete component cycle time (as forged or forged & Machined) in components, products at BFL go through periodic Process-Optimization activities. This is supported with validation through the use of Virtual Manufacturing tools, which have been customized to provide up to 97% correlation in all cases.

2. An Innovative Process for making Forged and Machined Components

This invention relates to the geometry (shape and size) optimization of a component, Fluid-End for Oil & Gas Industry and innovate a new process resulting in enhanced productivity and higher strength by a combination of forging (closed and open) and machining techniques.

The conventional fluid end manufacturing methods involve machining of all surfaces. This demands more input stock for manufacturing process and a lot of material wastage during machining process. In the conventional processes involving open die forging followed by machining result into only about 34 % utilization of material. Another important limitation of the existing design and existing manufacturing method of Fluid End is that the machining route cuts through the continuous grain flow lines hence grain flow lines are not continuous along the contours of Fluid End.

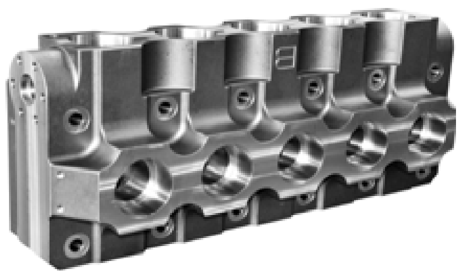

Fig. 1: Fluid-End for FRAC Pumps

In the method of the innovation, only the assembly surfaces are required to be machined whereas. The method also results in significant reduction in machining time and chip removal.

With the process of the present invention, 55 to 60% of the shape and size of the final component is achieved through forging and remaining 40 to 45% through machining. Incorporating the closed die forging stage in between open die forging and machining stages of the results in about 27% material reduction and over 60% reduction in machining time.

3. Development of a Controlled Sequence Quench Process [CSQP]

In this innovative process a way to obtain hardened steel component through controlled sequence quenching using two types of quenchants, is established. The process of the invention minimizes distortion, avoids quench cracks and improves mechanical properties during hardening of carbon and alloy steels. This process is mainly useful in thick components like fluid ends where achieving mechanical properties at the core is difficult by conventional quench methods.

During first stage of quenching, surface layers of steel component undergoes phase transformation due to higher cooling rates at surface, while core is still at austenitic temperature region. Subsequent holding of the component in the slow cooling medium results in reduction in thermal gradient, thereby reducing stress level in component during quenching. This progressive cycling between two quenchants relieves the stress built up and hence the distortion is minimized and quench crack is avoided. The progressive tempering also leads to beneficial microstructure.

Product Development | ATAGS Development

The group's Defence Team in a very short time (less than 4 years) has been able to design, develop and manufacture: Four Artillery Platforms equipped with best-in-class technology.

The flagship Advanced Towed Artillery Gun System (ATAGS) program, developed in collaboration with DRDO, created a new world record of achieving more than 48 KM range at Pokhran on 08 Sep 2017. This surpassed all previous records for any 155mm artillery gun in the world.

The vertically integrated group was able to deliver the system first-time-right with four key areas requiring intensive development efforts and several innovations resulted in success of the product in record time of 18 months:

- **Design of Ordnance** – to achieve a triad of high Strength, Fatigue and Fracture Toughness requirements in a high strain and wear working conditions to cater for zone 7 (critical technology) posed a challenge in defining the metallurgy to the Ordnance. With the Group's metallurgical extensive know how and experiments this was overcome.
- **Design of Super Structure** – Use of simulation to identify Stresses in static and dynamic scenarios and designing a strengthened super-structure.
- **Design of RecoilSystem** - Multi-Body dynamic analysis to establish the sustenance of the designed recoil system in all operating scenarios.
- **Integration** – Training the workforce to establish a simplified procedure of integrating and disassembling the artillery system.

With these, the first proof firing of the armament was conducted in 2015 with maximum record chamber pressure of over 560MPa as P2 pressure.

Figure 2 Kalyani Group - ATAGS

Product Development | Small Gas Turbine Engine Development

The Jet Propulsion Technology Center has successfully demonstrated capability to design and manufacture small gas turbine engines in a short period of time. The team comprising of a mix of specialists and engineers designed, developed and manufactured KCTI-120, a small single spool jet engine from ab-Initio Design in less than 18 months. Initial Trials – Nov/Dec 2017. This was fired establishing success of the first of many upcoming design checks in the engine development cycle.

The design was initiated with 1D calculations and optimized and validated using advanced software for Aero-Thermodynamic cycle analysis, 1D design of compressor & turbine, computational fluid dynamics, combustion chamber analysis, finite element analysis and rotor dynamics. With the base design, manufacturing and analysis of the prototype were initiated in parallel to allow the group more insights and develop the design for manufacturability from the first prototype itself.

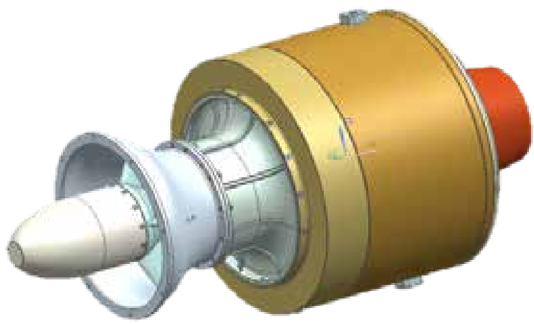

Fig. 3: KCTI 120 – Small Gas Turbine Engine

The prototyping of the engine involved use of advanced manufacturing techniques like 3D printing, 5 Axis machining, to develop the components quickly and allow flexibility for design changes (if any). In parallel the Group was able to establish another highlight in establishing manufacturing of critical components through 3D printing.

Nurturing a Conducive Environment for Bioentrepreneurship in India

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Biotech Consortium India Limited
Ms. Shreya Malik, Deputy Manager
Biotech Consortium India Limited

The Indian biotechnology industry is one of the fastest growing knowledge-based sectors. India currently ranks amongst the top 12 biotechnology destinations in the world and is a global leader in the production of drugs and vaccines. For an economy like India, biotechnology is a powerful enabling technology that can revolutionize agriculture, healthcare, industrial processing and environmental sustainability. According to a forecast by the Association of Biotechnology Led Enterprises (ABLE), the Indian biotechnology industry sector has the potential to be $ US 100 billion (Rs. 6 lakh crore) industry in the next decade.

The Indian biotechnology industry can be broadly classified into five categories namely biopharmaceuticals, bioagriculture, bioservices, bioindustry and bioinformatics. There are approximately 800 – 850 large, medium, small and startup companies in the biotechnology and allied sectors. Within the different sectors in biotechnology, there are multiple disciplines which are huge specialties on their own.

- Biopharma – Drugs, vaccines, diagnostics
- Bioindustrial – Biofuels, nutraceuticals, enzymes
- Bioagri – Hybrid crops, biopesticides, biofertilizers
- Bioservices – Custom synthesis & manufacturing and contract research
- Bioinformatics – Data analytics and software and database services.

Entrepreneurship is the fundamentally most important driver of innovation, business growth and economic change. Entrepreneurs create jobs. Entrepreneurs drive and shape innovation, thereby speeding up structural changes in the economy. Entrepreneurship is thus a catalyst for national economic growth and global competitiveness.

There are very few quality jobs being added to the economy every year to meet the aspiration of its growing workforce, leaving many people under-employed, poorly paid or outside the labour force. Automation technology is eliminating jobs in nearly every industry at an ever-increasing pace. Hence, entrepreneurship has become increasingly prominent in a rapidly globalizing economy.

Most policymakers and academics agree that entrepreneurship is critical to the development and wellbeing of society. Entrepreneurs create jobs. They drive and shape innovation, thereby speeding up structural changes in the economy. To realize the triple dreams of 'Innovate in India', 'Startup India' and 'Make in India' of the Government of India, there is a need to establish thriving innovation ecosystem by prioritizing product innovation and commercialization. Sustainable economic development and growth in India is expected to originate from indigenous innovations, technologies, products and services.

Biotechnology offers immense scope for strengthening economic growth through innovative technologies for mass multiplication/enhancing productivity of elite plant varieties, production of value added products, etc. However, utilization of biotechnology applications in commercial operations needs to be strengthened. There is an urgent need to encourage biotech entrepreneurship.

Science and Technology based entrepreneurship particularly amongst the youth of our country is the key to higher level employment generation and wealth creation in the new age India.

Biotechnology has the power to provide solutions to myriad challenges that humanity deals with from climate change, disease burden, food & nutritional security, clean fuel to environmental degradation. The engine of bioeconomy is powered by the fuel of entrepreneurial energy- this can be seen in all major hubs of biotechnology across the world. India has commenced on a mission to achieve the target of becoming $US 100 billion bioeconomy by 2025.

The potential of India to be a global innovation hub especially in biotechnology exists India is already recognised as a global destination for vaccines, bioservices and contract manufacturing especially biosimilars. Many firms are exploring exciting areas of stem cell biology, synthetic biology, agri-biotechnology, systems biology and exploring evidence based traditional medicine.

The Indian biotechnology industry has also shown that when proper support systems exist it can deliver scaled-up innovative products that are affordable and are of high quality. However, to scale up and increase the frequency of such innovations from India and make it a top destination for biotechnology, implementable strategies need to be formulated to promote innovation, translation, commercialization and entrepreneurship taking into account the views of industry, scientists and other stakeholders. The Indian bio-innovations need to address challenges in healthcare, food and fuel security based on four important paradigms- high quality, sustainability, affordability and accessibility.

The Government of India has initiated several policies and programmes, funds and incubators to foster innovationled entrepreneurship. To help new technologies come to market, many universities and institutions have established incubators for entrepreneurs hoping to turn leading edge research into marketable products. Such initiatives have been discussed below.

Policy Initiatives to Foster Entrepreneurship

Promotion of the Indian biotechnology sector is high on the policy agenda of the Government of India. Biotechnology has been recognized as one of the key priority sectors under the 'Make in India', 'Skill India' and 'Startup India' initiatives of the Government of India, being one of the few sectors on strong growth trajectory to drive sustainable economic growth and generate large scale employment opportunities.

The Government of India has initiated several policies, programmes, funds and incubators to foster entrepreneurship which has led to an encouraging atmosphere in the country for innovations. The DBT National Biotechnology Development Strategy 2015 – 2020 provides a strategic roadmap for India's emergence as a global biotechnology innovation and manufacturing hub and to contribute towards enterprise creation, innovation and economic growth.

The Government of India has introduced several initiatives such as setting up Ministry of Skill Development and Entrepreneurship, NITI Aayog and Atal Innovation Mission and initiatives such as 'Startup India', 'Make in India', 'Skill India', 'Digital India' and 'Ease of Doing Business in India' to foster and nurture entrepreneurship and manufacturing in India.

India's first integrated National Policy for Skill Development and Entrepreneurship was launched in 2015. The Policy acknowledges the need for an effective roadmap for promotion of entrepreneurship as the key to a successful skills strategy.

Niti Aayog through "Atal Innovation Mission" is actively promoting a culture of innovation and entrepreneurship in the country. With the Atal Innovation Mission (AIM), NITI Aayog provides an environment of creativity and innovation for the children of the country with the establishment of 500 Atal Tinkering Labs (ATL) across schools in India.

Awareness campaigns, talks, entrepreneurship development programmes, etc. are being organized across the country to motivate the youth towards entrepreneurship. The National Academy of Sciences, India (NASI) has been organizing such entrepreneurship development programmes to inculcate a spirit of entrepreneurship amongst students and researchers. In addition, NASI has released a publication titled 'Trailblazers – Mapping the Journey of Young Bioentrepreneurs' which chronicles the entrepreneurial journey of 65 young biotech entrepreneurs in hope that they shall be role models for the next generation entrepreneurs.

Some of the key policy initiatives to promote entrepreneurship are given below:

- Compliance Regime based on Self-Certification of Startups under Labour Laws
- Single point of contact via Startup India Hub
- Simplifying Processes with Mobile App and Portal (for registration, filing compliances & obtaining information)

- Legal Support and Fast-tracking Patent Examination at Lower Costs
- Relaxed Norms of Public Procurement for Startups
- Faster Exit for Startups
- Providing Funding Support through Fund of Funds (FFS) with a Corpus of Rs. 10,000 crore
- Tax Exemption on Capital Gains
- Tax Exemption to Startups for 3 Years
- Tax Exemption on Investments above Fair Market Value
- Removal of Angel Tax
- Credit Guarantee Funding
- Annual Startup Fests (National & International)
- Launch of World-class Innovation Hubs under Atal Innovation Mission (AIM)
- Set up of country-wide Incubator Network
- Innovation Centres to augment Incubation and R&D
- Research Parks to propel innovation
- Promote Entrepreneurship in Biotechnology
- Innovation Focused Programs for Students.

Infrastructure to Foster Entrepreneurship

There has been an increased activity towards applied research and technology development by both the academia and the industry leading to increase in innovation. There is also an increasing trend to set up start-up companies by technocrats based on technology leads. Moreover a number of first generation entrepreneurs and established companies operating in other areas are showing interest in investment in biotechnologies developed indigenously or sourced from other countries. This has led to increase in corporate research activities.

To promote innovations and investments in biotechnology, biotech parks, technology incubators and special economic zones have been set up in India to promote technology incubation and scale up as well as manufacturing activities by providing infrastructure support, facilities and incentives so as to minimize the above constraints for technology development, commercialization and large-scale manufacturing.

Technology Incubation Centers consist of laboratory modules, specialized facilities and a well-equipped instrumentation facility. The laboratory space could be leased out to the tenant for specified periods. TIC would enable the tenants to translate their research ideas into commercializable technologies as well as upgradation of existing technologies without making huge investments on buildings, equipment etc., initially. This facility would be useful for technically competent small and medium scale enterprises (SME) and entrepreneurial scientists with limited financial resources particularly because of non-availability of financial assistance for R&D projects under conventional funding schemes. This facility could also be used for small scale manufacturing of the biotech products by SMEs.

Incubators are entities that aim to help new companies start up, survive and grow. They tend to provide at least four of the following five things: office space, business services (e.g. legal/ accountancy), coaching and mentoring, funding and access to networks. Given business incubators have been around for over 60 years now, it's not surprising that designs and methods have proliferated. Traditionally, business incubation was real-estate based: shared office space alongside advice and assistance. Now, however, the term is used much more broadly, to cover models ranging from short-term, highly-structured, intensive *'accelerator' programmes*, to longer-term, flexible support, as well as competitions, courses and co-working spaces. Recent approaches emphasize not only helping a firm to 'survive its formative years', but also ensuring it has a 'positive impact on the economy and society'.

Funding Opportunities to Foster Entrepreneurship

Biotechnology is a high-growth and high-risk industry. A biotechnology entrepreneur in India is faced with several opportunities and challenges while he sets out to create, develop and commercialize technologies. Apart from identifying the right idea, right markets and being able to recruit the right human resource, the most crucial challenge a bio-entrepreneur faces is raising funds for the new venture. The upfront investment on R&D and clinical trials can be enormous even before initiation of human efficacy trials for regulatory approval. Potential blockbuster market returns are possible, but they usually come with a high front-end investment and a proportionate high risk of R&D.

There are widely known sources of funding such as venture capitalists, angels, banks, and friends and family. The Government through an array of programs and initiatives, offers funding for technology development from early-stage development to full-scale commercialization, which the bio-entrepreneurs could take advantage of.

In order to prioritize innovative R&D and promote indigenous technologies through accelerated commercialization, there are government funding sources that have been set-up to specifically support and fund innovative technologies right from idea validation stage to the full-scale commercialization stage. A number of national agencies i.e. Department of Biotechnology (DBT), Department of Science and Technology (DST), Department of Scientific & Industrial Research (DSIR), Council of Scientific & Industrial Research (CSIR), Ministry of Micro Small Medium Enterprises (MSME), National Research Development Corporation (NRDC), Defence Research & Development Organization (DRDO), Technology Information, Forecasting and Assessment Council (TIFAC), etc. have been supporting biotech companies as well as academia in various areas of biotechnology with a view to strengthen innovative R&D and technology development. Several international India-specific Grand Challenges i.e. Wellcome Trust, Bill & Melinda Gates Foundation, Lockheed Martin Corporation, Grand Challenges Canada and bilateral/multi-lateral programmes with other countries also support innovative technology development in India.

An indicative list of funding opportunities is given below.

1. Department of Biotechnology (DBT) - Biotechnology Industry Research Assistance Council (BIRAC)

a) BIG (Biotechnology Ignition Grant) Scheme

b) SBIRI (Small Business Innovation Research Initiative) Scheme

c) BIPP (Biotechnology Industry Partnership Programme) Scheme

d) SPARSH (Social Innovation Program for Products Affordable & Relevant to Social Health) Scheme

e) BIRAC DeitY Industry Innovation Programme on Medical Electronics (IIPME) Scheme

2. Department of Scientific and Industrial Research (DSIR)

a) PRISM (Promoting Innovations in Individuals, Start-ups and MSMEs) Scheme

b) PACE (Patent Acquisition and Collaborative Research and Technology Development) Scheme

c) NRDC (National Research Development Corporation) Techno-commercial Support for Promising Inventions Scheme

3. Department of Scientific and Technology (DST)

a) TDB (Technology Development Board) Assistance Loan/Equity Fund

b) TDB (Technology Development Board) - Seed Support System Scheme

c) NSTEDB (National Science & Technology Entrepreneurship Development Board) - Seed Support System Scheme

d) NSTEDB NIDHI (National Initiative for Developing and Harnessing Innovation)

4. Small Industries Development Bank of India (SIDBI)

a) TIFAC- SIDBI Revolving Fund for Technology Innovation-(SRIJAN Scheme)

b) Credit Guarantee Fund Trust for Micro and Small Enterprises (CGTMSE)

c) Make in India Soft Loan Fund for Micro Small & Medium Enterprises (SMILE)

5. IPR and Market Assistance Funds

a) Startup Intellectual Property Protection (SIPP) Scheme, DIPP

b) Technology Acquisition & Development Fund (TADF), DIPP

c) National Patent Protection Scheme, National Research Development Corporation, DSIR

d) Marketing Assistance Scheme, National Small Industries Corporation

e) Financial Assistance on Grant of Patent and Registration under Geographical Indications, National Manufacturing Competitiveness Council

6. International Programmes

a) BMGF (Bill & Melinda Gates Foundation) – BIRAC Grand Challenges India

b) DST Global Innovation and Technology Alliance (GITA) Fund (CII-TDB)

c) United States–India Science & Technology Endowment Fund (USISTEF)

d) Wellcome Trust – BIRAC Scheme

e) USAID-FICCI-TDB Millennium Alliance

Funding schemes for supporting innovative ideation and early stage R&D

There are multitude of early stage seed grants offered by the Government of India for fostering innovative ideas by individuals, start-ups and small enterprises. These are aimed at promoting entrepreneurship in the young innovators who have an exciting idea but need funding support to validate their idea till proof-of concept stage. One of such scheme which is successfully being implemented by BIRAC, a Government of India enterprise is Biotech Ignition Grant (BIG). BIG offers itself as a unique grant-in-aid opportunity being provided by the government wherein an individual scientist or entrepreneur with no formal engagement with a company can also avail this funding and validate ones innovation. More than 100 projects have been supported through BIG scheme.

Funding opportunities for technology advancement, validation scale-up and commercialisation

Several funding schemes are focussed on funding advanced stage technologies. These schemes are aimed at fostering innovations which have proof-of-concept but need further development, validation and regulatory approvals before these are ready for entering the market. SBIRI and BIPP are such schemes which extend funding support to high risk innovative research by industry and is provided to grantees in a public-private partnership (PPP) mode. Support is extended in the form of grant-in-aid, equity or soft loans, which varies with the type of funding scheme. Funding support by such schemes accelerates technology development and its validation. Contract Research Scheme (CRS) of BIRAC is also a PPP scheme for facilitating technology validation and translation by academia through an industry partner. TDB provides assistance in the form of soft loan and/or equity fund under its Seed Support System Scheme. International organisations such as BMGF, Wellcome Trust, Indo-US S&T forum, CEFIPRA etc. also provide funding support to healthcare innovations. Most international schemes have priority areas for providing funding support and are aimed towards commercialisation of technologies for societal impact. Funding opportunities are also provided through collaboration and fund allocation by Indian and foreign governments for promotion of joint activities that lead to innovation and technoentrepreneurship through application of science and technology eg. Indo-US Science and Technology endowment fund financially supports promising joint US-India entrepreneurial initiatives through grant programme.

Recommendations

Though offering extraordinary promise and value, the record of success in biotechnology has been mixed. An institutional and structural framework has to be built to help India achieve its potential as a breakout nation for biotechnology innovation. Strategies to become a vibrant and innovative bioeconomy should involve encouraging innovative R&D, build infrastructural and human resource capacity for translation and commercialization, facilitate technology access as well as market access for innovative products to achieve scale through public procurement, provide access to risk capital for all stages of biotechnology product's lifecycle, creating a robust regulatory system, conducive tax and fiscal environment and enabling a collaborative environment for fostering academia – industry networks. These recommendations, if implemented within a similar timeframe, could propel the startup economy in India forward.

Sustainable economic growth and development in India is expected to originate from indigenous innovations, technologies, products and services. In such a scenario, there is an immense opportunity for the Indian biotechnology sector to play a positive an important role in the Indian economy as well as contribute to the global economy.

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5. Biotechnology Industry Research Assistance Council http://www.birac.nic.in/
6. National Institution for Transforming India, Government of India http://niti.gov.in/#
7. National Science and Technology Entrepreneurship Development http://www.nstedb.com/
8. Council of Scientific & Industrial Research http://csirhrdg.res.in/
9. Indian Council of Agricultural Research (Ministry of Agriculture and Farmers Welfare) http://www.icar.org.in/
10. Indian Council of Medical Research http://www.icmr.nic.in/
11. Ministry of Micro, Small & Medium Enterprises http://msme.gov.in/
12. Department of Industrial Policy & Promotion http://dipp.nic.in/#

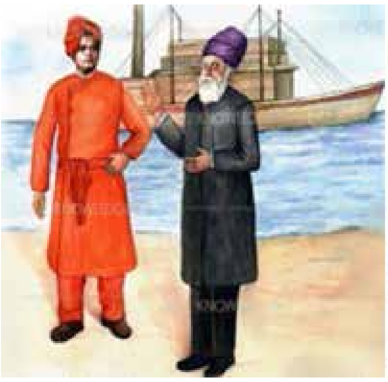
Basic Research is the Foundation of Innovate & Make in India Mission – An Industry Perspective

Dr. Jitendra N. Verma, Founder & Managing Director
Lifecare Innovations Pvt. Ltd.

Knowledge based socio-economic development of today is fuelled by innovation and technology led enterprises. India is undisputedly member of leading innovation nations where every loop of mind to market chain has attained maturity and consequent ease of progression from concept to commerce has encouraged broad-band of 25-55 age group to engage in technopreneurial pursuits. Both public and private sector industry of every sector has leveraged on collective technological prowess and formidable innovative capacity of the country.

Indigenous Basic Science Research is the foundation of cascade from concepts to science to technology to applications. While nascent independent India was seriously wanting in institutions for higher learning and research, visionaries like Vivekananda, Jamshedji Tata, Madan Mohan Malviya, Rabindra Nath Tagore, Mahatma Gandhi, Sir Syed Ahmad Khan made awakening calls and initiated Institution building for a glorious India.

Vivekananda's inspirational discourse with JN Tata during their ship journey together culminated in creation of Tata Institute known today as Indian Institute of Science. IISc as perceived is a world class institution that has catalysed both basic and applied research. Such institutions have fostered global networking between and development of both industry and academia.




Indian Institute of Science, is a humble homage to two great personalities- Swami Vivekananda and Jamshedji Tata, who wanted India to be self reliant in research.
(Biography of Jamshedji Tata and http://www.simplydecoded.com/2014/06/25/idea-finest-reality-indian-institute-science/accessed on 9/7/2018)

To which Swami Vivekananda replied, "Well, Sir, Even IF these sacks contain Iron-rich soil, do you honesty believe that the Germans will tell you the TRUTH??? You must understand that No/NONE of the European Nations wish to see a Strong/Steel-Rich/Economically Independent India. The soil is probably rich in Iron-ore but the sad truth is all you will get from your enquiries across Europe is Disbelief and Pessimistic reactions."

Needless to say, having interacted with several Europeans J.N. Tata knew this to be true. Swami Vivekananda continued, "Why don't you start an excellent/up-to-date Research Facility and College here in India??? Why don't you train some good Indian Youngsters to identify soil and conduct these tests and find ways of profitably extracting metals??? It may seem like a wasteful; burdensome expenditure right now, but in the long run-It will save you many trips to Europe and you can have the assurance of knowing the Truth quickly-rather than taking muliple opinions due to Doubt".

(http://www.simplydecoded.com/2014/06/25/idea-finest-reality-indian-institute-science/ accessed on 9/7/2018)

(http://www.simplydecoded.com/2014/06/25/idea-finest-reality-indian-institute-science/ accessed on 9/7/2018)

Vivekananda's belief in Indian Science is evident from his instructions to a follower Sara Chapman Bull to file Jagdish Chunder Bose's US Patent 755840 for "A Detector for Electrical Disturbances, believably the first Patent from India to highlight relevance of Indian Science and Technology. (PKBondyopadhyay and S Banerjee, Indian Journal of History of Science, 43.1 (2008) 57-72)

Father of the Nation may not be seen either as a scientist or educationist, but he and leaders of his time had visionary approach and placed trust in S&T leadership in shaping the destiny of India. We today realistically aspire for innovate and make in India because of innate self-reliance of India in basic research.

It is obvious that Gandhi laid enormous emphasis on Study, Thinking & Research and analysing the Fundamentals

Important scientists such as J. C. Bose, C. V. Raman and P. C. Ray were put as Members of the Khadi Development Board.

With independence of India in 1947, despite massive challenges India continued engagement with research and innovation-based development for self-reliant sustenance and progress. Scientific Organizations viz. CSIR, DSIR, DST, DBT, ICAR, ICMR, DRDO etc. each created and nurtured a chain of laboratories for research and development in super-specialized domain.


FEATURE ARTICLE

By the time he died on 1 January 1955, he had created a chain of twelve laboratories dealing with different disciplines ranging from physics and chemistry to leather and pharmaceuticals.

Sir Shanti Swarup Bhatnagar with Pt. Nehru, the then Prime Minister of India, and Ms Indira Gandhi

SHANTI SWARUP BHATNAGAR

A Science Czar

S.P.K. GUPTA

Shanti Swarup Bhatnagar will always be remembered as a great institution builder, a scientist and a visionary.

NISCAIR Online periodicals Repository, NISCAIR Publications, Gupta SPK, SR Vol.48(08)[Aug 2011] (http://nopr.niscair.res.in/handle/123456789/12533)accessed on 9/7/2018)

DSIR - Linkage of R&D with Socio-economic Development

Linlithegow made sure Bhatnagar was allowed his desire to have a research laboratory of his own and to bring with his the six Steel Research Scholars at the University Chemical laboratories, and that his official position was designated Director of Scientific and Industrial Research.

NISCAIR Online periodicals Repository, NISCAIR Publications, Gupta SPK, SR Vol.48(08) [Aug 2011] (http://nopr.niscair.res.in/handle/123456789/12533) accessed on 9/7/2018)

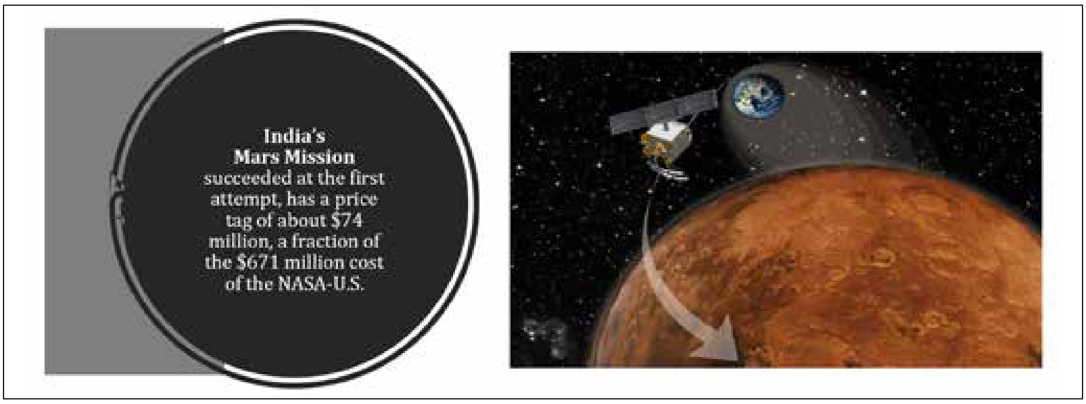
Last two decades have witnessed replication of top institutions in Science, Engineering &Technology, and Medicine. Large number of IISERs, IITs, IIITs, NITs, NIPERS, AIIMSs, and IIMs have been established to ensure access to technical education and enlarge talent pool for research, development, and innovation. *In situ* basic research, development, innovation combined with incubation centres, technology parks, management expertise for commercialization, industry-academia- government partnerships have created sustainable ecosystem for socio-economic development. Basic research has been pivotal for achieving aspirations of people of this large country. Strong basic research infrastructure and human resource has strengthened intellectual capacity for fulfilment of “Innovate and Make in India”.

Indian Institutes of Science Educations and Research

The Indian Institutes of Science Education and Research (IISERs), are a group of premier science education and research institutes in India. These institutions have been declared by an Act of Parliament as institutions of national importance and are intended to be the leading institutes in the country in the field of basic sciences.

(https://en.wikipedia.org/wiki/Indian_Institutes_of_Science_Education_and_Research) accessed on 9th July 2018

Investments in basic research has given dividends in all areas of engagements. Green revolution for food, white revolution for dairy, and success of space missions have made India's scientific achievements legendry on global scale. ISRO's success and economy of Mars Mission – "Mangal Yan in maiden attempt, and success of Polar Satellite Launch Vehicle (PSLV-C37) in launching record 104 satellites has left indomitable imprint of India's S&T prowess.



(Hindustan Times Wednesday, Jul 11, 2018)

India's conjuring might in Information Technology and potentials in Bio-Technology are epitomized as "India Today & Bharat Tommorrow".

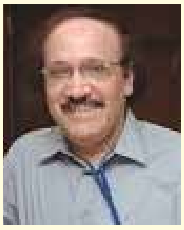
Department of Biotechnogy reffered to generally as DBT in scientific community initially engaged in institution building and human resource development for research in Biotechnolgy has been headed by formidable scientists who all believed in India's aspiration of self-reliance by addressing unmet needs of India and beyond.

The Department of Biotechnology has been headed by several formidable scientists since its birth in 1986

Dr. S. Ramachandran
First DBT Secretary
(1986-1992)

Dr. C. R. Bhatia
Secretary
(1993-1995)

Dr. Manju Sharma
Secretary (1995-2004)



Dr. M. K. Bhan
Secretary
(2005-2012)

Dr. K. Vijay Raghavan
Secretary
(Former)

- In 1982, after detailed deliberations with the scientific community, and on the basis of recommendations by the then Scientific Advisory Committee to the Cabinet, a National Biotechnology Board (NBTB) was constituted by the Government to identify priority areas and evolve long term perspective for Biotechnology in India. It was also responsible for fostering programmes and strengthening indigenous capabilities in this newly emerging discipline.
- The NBTB was chaired by the formidable scientist Professor MGK Menon, the then Member (Science) of India's Planning Commission. All the Secretaries to the various departments of the government dealing with science were appointed as Members of this Board.
- A separate Department of Biotechnology (DBT) was finally set up in February, 1986 and the NBTB selected Dr S Ramachandran as the first Secretary of the department.

http://www.nii.res.in/ accessed on 9th July 2018

National Institute of Immunology (NII):
Formally dedicated to the Nation by Prime Minister Rajiv Gandhi on 6th October, 1986

- The NII is committed to advanced research
- A view to understand body's defense mechanisms for developing modalities of immune system manipulation that can intervene with disease processes.
- The institute's research thrust areas under immunology and related disciplines cluster in four main themes, namely:
  - infection and immunity,
  - molecular design,
  - gene regulation and
  - reproduction and development

Shanta Biotech-1993

Founder:
K. I. Varaprasad Reddy

- Shantha Biotechnics is an Indian biotechnology company based in Hyderabad.
- It is the first Indian company to develop, manufacture and market recombinant human healthcare products in India.
- The company is a wholly owned subsidiary of Sanofi group.

Leprosy Vaccine Developed by NII

THE HINDU

CHENNAI, AUGUST 21, 2016

The vaccine, called *Mycobacterium indicus pranii* (MIP), will be administered as a preventive measure to people living in close contact with those infected. It was developed by the National Institute of Immunology, New Delhi, and has been by approved by the Drug Controller General of India and the FDA in the U.S.,

India has developed its first vaccine - Rotavac -- under public-private partnership

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Now, a desi rotavirus vaccine

Durgesh Nandan Jha| TNN | May 15, 2013, 02.34 AM IST

(from left) Dr. Nita Bhandari, Director, Centre for Health Research and Development, Dr. M. K. Bhan, former secretary, Department of Biotechnology, Dr. K. Vijay Raghavan, Secretary, DBT, Govt. of India and Dr. Krishna M. Ella, Chairman & Managing Director, Bharat Biotech, at the relase of Rotavac phase-III trial data in New Delhi on Tuesday.

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Now, a desi rotavirus vaccine

Durgesh Nandan Jha| TNN | May 15, 2013, 02.34 AM IST

To steer the development of Liposomal Amphotericin B from "Bench to Bedside", I joined DBT's journey of "Innovate and Make in India" in 2000 much before it became a popular slogan. DBT had by then created two Liposome Research Centres (LRCs)- one at Delhi University and another at SGS Medical College Mumbai to steer Liposomal Amphotericin B development in India. Liposomal Amphotericin B is a Gold Standard Drug for treatment of life-threatening fungal and leishmanial infections. Until the Indian drug – FUNGISOME was made available; Liposomal Amphotericin B was imported at a prohibitive cost long-term daily dose of $1200. FUNGISOME with a daily dose cost down to 10% of the imported drug became accessible to much larger section of patients. "FUNGISOME is the first Liposomal and Nano-Drug developed and made in India".

It was concerted effort of Team India that included, DBT, DSIR, TDB, Delhi University, SGSMC, Mumbai and myself as founder of Lifecare Innovation that led to the launch of India's first Liposomal and Nano Drug on Technology Day May 11, 2003.

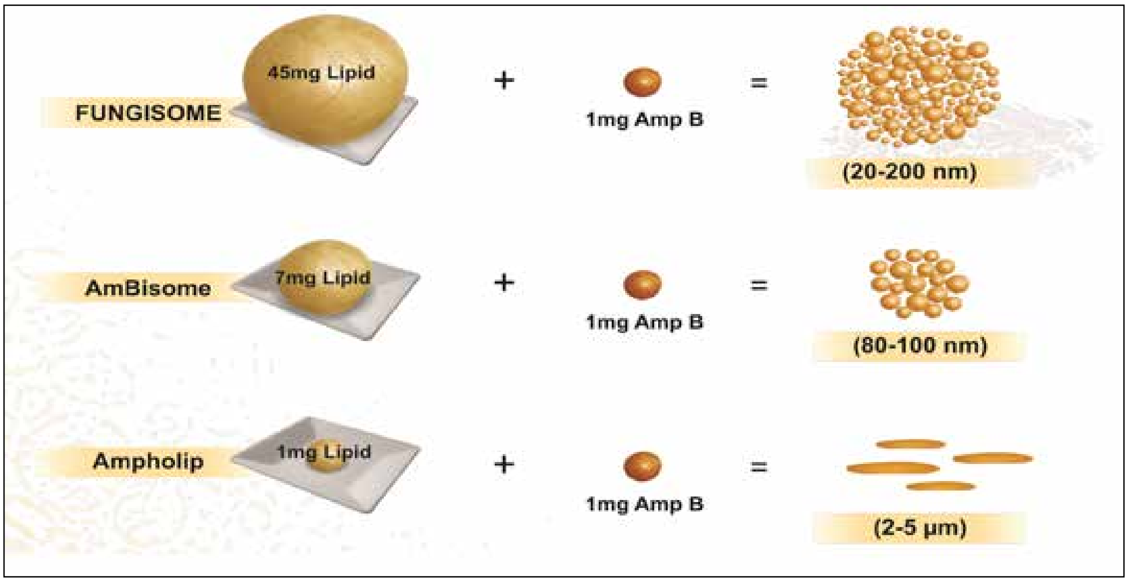
Not only FUNGISOME drasti-cally lowered treatment cost, with its matchless nephrosafety and high efficacy, it was markedly superior alternative to imported AmBisome. The clinical merits of FUNGISOME are intrinsic to its strategically designed multi-molecular assembly of Nanosome.

FUNGISOME is credited with distinction of being the most nephrosafe and most effective all Amphotericin B formulations and other antifungal drugs and finds place among "Top 10 Innovations in Last Decade" in India.

Shape and size of different Lipid Preparations of Amphotericin B

Product	Type	shape	size	Lipid:Drug	Dose	Success
FUNGISOME™	Liposomal	Round	.02-.2µm	45:1	1-3mg/kg	91%
AmBisome	Liposomal	Round	.08-.1µm	7:1	3-5mg/kg	77%
Abelcet	Lipid Complex	Ribbon	2-5µm	1:1	5mg/kg	33%
Amphotec	Colloidal Dispersion	Disc	12-15 µm	1:1	4-6mg/kg	46%

More the lipid matrix: drug, more are the numbers of liposomes with optimal drug load/ mg of drug, thus better reach.



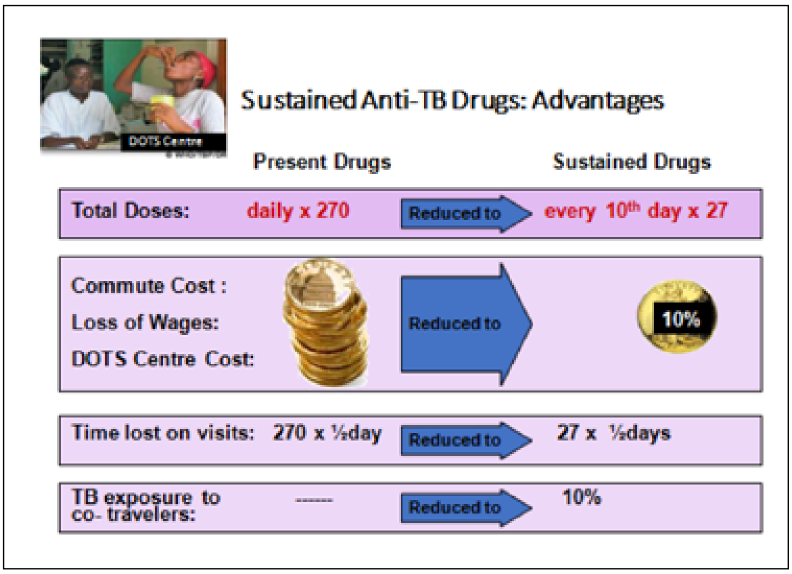
Every liposomal formulation is an individual drug having its own properties

The increase in efficacy and minimization of dose limiting toxicity is achieved by strategic designing of FUNGISOME/ AmBullet by employing optimal lipid to drug ratio, Lipid composition of Liposomal Matrix, stabilizing the formulation in Saline to render nephrosafety, Nanosomization for better bio-distribution and consequent high therapeutic efficacy at lower dose that translates into very economical daily dose and treatment cost.

Lifecare Innovations - A Medical Biotechnology Company established in 2000
I. P. Protected Technologies

Lifecare Innovations pioneered establishment of Liposomal and Nano-Drugs in India that encouraged both Academic Institutions and Pharmaceutical Industry to engage in "New Drug Development based on NDDS (Novel Drug Delivery Systems).

An oral sustained release nano-drug is under development that is aspired to convert daily dose to once in 10days, reduce treatment time, help reverse rising trends of MDR, minimise transmission and offer better logistics to control programs.



It was our strength of basic research, in-depth understanding of Liposome Technology and Lipids, and mechanisms involved in targeted and controlled drug delivery that FUNGISOME now exported as AmBullet - a unique Liposomal Amphotericin B that is the most effective and most safe of all anti-fungal drugs including other Lipid and Liposomal Amphotericin B. Lifecare Innovations and its collaborating institutions are applying this to develop nano drugs to address other medical needs viz. Treatment for, Cancer, Malaria, Kala-Azar etc. in addition to other institutions expanding on our initiative.

Fundamentals of Basic Science are Pivotal in Strategic designing of Novel Drug Delivery Systems:

Carrier based Controlled Release Formulations involve strategic designing that requires understanding the relationship between disease / target, drug/ action mechanism, and carrier matrix constituents and sometimes even the suspension medium. The design also takes into account the route of administration. Basic Science plays important role in understanding interplay between drug, carrier, and target. Following examples are briefly narrated to highlight Basic Science aspects in innovative designing some products Lifecare portfolio.

1. FUNGISOME – a unique Liposomal Amphotericin B for targeted delivery of Amphotericin B to fungal pathogen in Systemic and Topical fungal infection to increase efficacy and avoidance of interaction with host organs to minimize dose limiting inherent toxicity of Amphotericin B, the Liposome constituents were selected based on affinity differential of such constituent with target molecule in the fungal pathogen cell membrane.

   Making FUNGISOME sugar-free was achieved by replacing conventionally used dextrose with saline to make Amphotericin B i.v. suitable for diabetics and improve nephrosafety.

2. Psorisome Gel (Liposomal Dithranol) is designed to prevent cascade of oxidation reaction of encapsulated pro-drug Dithranol and allow only 1st oxidation step to convert the pro-drug to active drug. Oxidation products beyond first step cause etching, burning, and redness of the skin and bring down compliance. To minimize the undesirable effects of oxidation products of Dithranol, the encapsulation was done in oxygen free soft Liposomes suitable for trans-membrane delivery of carrier Liposomes and release of drug. This required understanding, of role of Dithranol oxidation cascade, designing soft liposome for effective trans-membrane delivery and ensuring first oxidation step in-vivo.

3. In designing "Oral Sustained Release Nano-Drug for Tuberculosis", the objective was to reduce dose frequency from daily to weekly. To achieve this goal, nano-material were selected to allow depot-formation and sustained release by slow erosion of the drug-carrier nano-particles. This required understanding of pathway from oral dose to depot sites and material suitable for drug release by slow erosion. The concept is now being used number of NDDS formulations.

Understanding and application of Basic Science knowledge permits placing reliance on systematic product designing and innovation and creates an ecosystem for sustained Research, Development, and Innovation.

III. RECOMMENDATIONS

Recommendations

1. Knowledge generation based on Basic Research is the fundamental basis of all S&T and R&D activities. Recognizing it as a “Public Good” needs public support while providing for S&T budget.
2. To make efforts to reclaim our rightful place as a science leader among the comity of nations in the coming years. A bridge to be constructed between our ancient past and the modern present.
3. It is essential that capacity building of teachers and organizing regular workshops for them is given high priority. To ensure close rapport between our science institutions, schools, colleges and general public.
4. Every science organization and the universities to have a cell exclusively for science communication and interpretation. They should also organize a science festival every year. Organizations like Marathi Vigyan Parishad to be strengthened.
5. An eminent peer group for guidance and mentoring of institutions and their autonomous functioning needs to be created. An academy can do it best.
6. A right institutional value system, appropriate mind-set of individual researcher and a conducive innovative eco-system is important to develop technology for economic competitiveness.
7. For programs like science communication, science and society especially for technological empowerment of women, S&T interventions for Tribal population, availability of safe drinking water, health promotion and disease prevention. Local Chapters of NASI to be strengthened.
8. There is need to focus on philosophical, cultural and intellectual aspects of basic research. Appropriate environment, climate and financial support for the same needs to be ensured.
9. A self-reliant base for science and technology is essential for attaining self-reliance in important sectors of human welfare. But it requires a sustained basic research strategy. For application of S&T for national development, adequate investments have to be made.
10. Basic research needs to be supported in educational institutions; it has to comply with international standards. Centres of Excellence should be set up. Linkages between educational institutions, national laboratories and industrial organizations need to be encouraged. We have to be selective in choosing the thrust areas for research.

11. Need to treat agriculture as an industry, keeping in mind profitability of the farmers. Use of innovative technologies in agriculture holds the key for doubling the farmer's income at the earliest.

12. The under explored microbial world needs to be examined more critically for deriving agronomic benefits. Solar energy harvesting and robotics will have a key role in future Indian agriculture.

13. More public funding for basic and strategic research for sustainable and profitable agriculture is a must.

14. Advanced research on molecular aspects of plant reproductive biology, including those involving transcription factor etc. could provide novel alternatives to starch industry and can have direct impact on food research for space explorations.

15. R&D efforts are required for developmental projects such as the rejuvenation and management of river systems, control of communicable diseases like malaria, dengue, tuberculosis etc. The scope of the cutting edge tools like genetically modified insects, use of Wolbachia bacteria and CRISPR-Cas9, is tremendous along with the need for evaluation and development of new tools for vector control.

16. Biomedical research must be focused on social inclusion of Gandhian practice. There must be a fine balance in innovation and cost effectiveness.

17. Fundamentals of ecosystem protection and pollution abatement studies need sustained research support.

18. Evolutionary biology research and education in India needs revamping and strengthening. Universities need to have post-graduate departments of evolutionary biology. There is a pressing need for setting up a National level research cum training Institute on Evolutionary Biology. (This should be given utmost priority.)

19. Strong Basic Research infrastructure and human resources to be strengthened for fulfillment of "Innovate and Make in India" program.

20. Opportunities to be created for flow based wet chemical synthesis; especially microwave based flow synthesis approach could be realized for mass production of inorganic, organic – inorganic hybrid nanomaterial for industrial demand. Eventually flow synthesis according to the NCL, Pune scientists would become the most sought after method for the preparation of large scale production of hybrid nanomaterials in future.

21. Optimization of the resources and talents at the national level through the involvement of R&D and academic institutions is essential for developing cutting edge technologies. It has been recognized that creating internationally competitive space systems with stringent performance is in the interest of the country.

22. Need for emphasis on creation of game changing innovations; fundamental research provides a base for the same.

23. Recognizing the importance and need for implementing JAM (Jan Dhan Yojna, Adhar Identification, Mobile Telecommunication) is essential both for rural and urban India. This policy innovation will allow large scale technology enabled and real time delivery of welfare services.

24. For the game changing STI, there is need for change in our thinking; moving from current best practices to creating next practice.

25. Full efforts to be made for becoming a vibrant innovative bioeconomy by strengthening and encouraging R&D, infrastructure and human resource capabilities for translational research and establishing a robust regulatory system.

26. Importance of basic research and serendipity, and sustained funding has been a major focus in this symposium.

27. Research to meet the challenges of prevalent malnutrition in the country taking into account traditional food of value for health and wellness must be encouraged on a sustainable basis. Plant based foods, and other functional foods require sustainable attention. There is shortage of Food Engineers; capacity building to wipe out this deficit is very important.

28. There is need for promoting culture of continuous learning and skill up gradation. Need to tie up between the industry and the academic institutions is very important. Application oriented, focused programs are important to be developed with such collaborations. Industry has to be persuaded to join the academia.

29. Structural reforms at the institutional levels with supportive schemes at the national level have a great potential. Creation of high end research facilities in the leading institutions, IP protection systems, multi-disciplinary collaboration and need to innovate in the areas of domestic demand (Local R&D) are essential for national development.

30. A grand challenge approach at the national level, top down planning, strong review and monitoring system, creation of technology parks in the academic institutions are essential ingredients. Basic Research through scheme wise support, encouraging faculty, entrepreneurship and focus on the aesthetics of product design need special attention. Students must be encouraged to work in teams and groups.

31. It is recommended that for successful application of S&T for developmental objectives there must be a proper balance in endogenous capabilities at all levels.

32. Academies to under take the responsibility to inform the public and policy makers of the importance of basic research and the strategy for the application of S&T for development.

33. The example of IIT, Mumbai shows diverse range of activities contributing to the innovation ecosystem. This can be replicated. An ecosystem for promoting the startups is developing in the country specially which near IITs needs to be promoted.

34. The need for creation of ecosystem for aviation in India has been fully recognized. LCA project enabled the creation of the ecosystem to develop the state of art aircraft. There are four pillars of this ecosystem which can be gainfully deployed for the development of next generation military and civil aircraft.

    The recommendations have been given in the paper on Indian Science............to National needs, therefore they have not been repeated here.

IV. ACKNOWLEDGEMENT

ACKNOWLEDGEMENT

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V. BIODATA OF THE EDITORS

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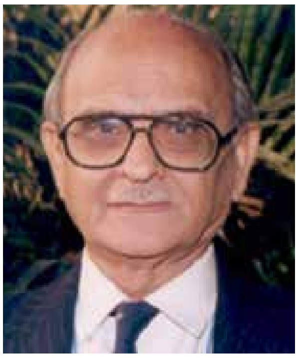

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