XII Plan Report on " Enrichment of the Knowledge Base"

Preamble

The Government of India has launched many schemes, especially during the XI plan period to rapidly develop the base of science and technology in India. The schemes, programs and institutions established during the XI plan helped augment and strengthen the basic research infrastructure and capability of researchers in our country. However, a great deal more needs to be done. The working group (composition given below) was entrusted with the responsibility of identifying emerging areas and suggest mechanisms for strengthening research which will improve, substantially, the position of India on the landscape of global science.

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The working group met twice (May 10 and Aug 11, 2011) and held further discussions among themselves through email. The working group also sought suggestions from members of the scientific community outside the committee. The present report is an outcome of the extensive discussion emanating from this exercise.

Introduction

Considerable effort has been made during the XI Five Year Plan to expand the base of Science Education and Research. The major focus of the XII Plan should be to rapidly expand scientific research and teaching at all levels across the country. In the case of the education sector, India has already put in place a vast network of colleges, universities, national institutions and laboratories in which science is practiced. A significant matter of concern has been the relatively poor level of facilities and infrastructure available in a large number of institutions, thus denying aspiring students the opportunity to be exposed to the rapidly developing frontier areas of modern science. A further matter of concern is that the base of scientific research depends critically on the university system, which has been slowly eroded over the years; the focus of activity shifting largely to national institutions, some of which function in highly specialised areas. In considering strategic plans to enrich the knowledge base across the country, the committee suggests that special attention be paid to schemes that promote human resource programs, creation of interdisciplinary centres and establishment of Inter-university consortia that provide wide access to major research facilities.

The report is divided into six sections. Section 1 deals with the development of human resources (HR) programs. The working group is aware of a separate report on HR prepared for the Department of Science and Technology, and the recommendations given here are in addition to those presented in that report. Section 2 discusses the inter-university consortia. Section 3 discusses the mega projects. Section 4 contains the list of facilities/centres required to be established. Section 5 contains a discipline-wise listing of important emerging areas in each field. Finally, Section 6 provides a guide to the cost implications of the proposed schemes.

1. Human Resource Development Programs:

Human Resource Development is an important component for furthering scientific research in our country. Many schemes have been launched to attract, nurture and retain young researchers and women scientists in the field of scientific research. These include schemes like INSPIRE, Kothari Fellowships, Fast Track Young Scientist Schemes, Women Scientist Schemes and several fellowships. For example, the Ramanujam and Ramalingaswamy Fellowships have attracted many active, young researchers working abroad to come back to India and start independent scientific careers in India. The Kothari and Fast Track Young Scientists Scheme have helped a large number of young researchers to undertake independent research. Research Fellowships (JRF, SRF and RA) given by various agencies have also benefited a large number of researchers. Many of these schemes were launched during the XI Plan period, and these must be continued and expanded. In addition, the following new schemes are proposed:

1.1 Research Interns: Several institutions implement a large number of R&D projects sponsored by various funding agencies. These projects are implemented by young entrants to science with designations such as JRF, SRF, RA, Project Assistant etc. The recruitment of manpower, especially JRF, SRF with the condition that they are required to pass the NET examination is becoming difficult, since only a very small percentages of candidates qualify in the NET exam. Even those qualified often come with their own fellowship and, therefore, do not prefer to join sponsored projects. This has led to a considerable delay in the execution of projects. It is proposed that positions of “Research Interns” be created to alleviate the problem. The Research Internship can have different grades based on qualifications and experience, and the salary may be fixed accordingly. The main criterion of appointment is the candidates’ ability to work in the project as assessed by the appropriate body, without a need to qualify in national level exams. Further, these research interns may be considered to be floating and will be able to work in the project and institutions of their choice for a certain period, not exceeding two years. This will increase the pool of practically trained researchers who can be drawn from the very large number of B.Sc. and M.Sc. graduates being produced. Decoupling the requirement of Ph.D registration (a NET condition) will enhance the pool of active laboratory workers.

1.2 Doctoral Schemes: The number of researchers who qualify through national level entrance examinations such as CSIR-UGC NET, GATE etc for enrolment into doctoral degree programs with fellowships, is quite small when compared to the number of researchers enrolled in universities without qualifying in any national examination. Therefore, many of them work for doctoral degrees without any significant financial support. It is proposed that a scheme be developed to cover a substantial number of researchers enrolled for PhD programs with a fellowship. For example, 100 universities may identify 50 research scholars each every year for the university fellowship. This would enable an appreciable expansion of doctoral students in science and engineering.

1.3 Post- doctoral Schemes: Existing schemes have benefitted a relatively small number of researchers. There is a clear need to develop new schemes for post doctoral fellowships. The number of post doctoral candidates supported every year is very low and their numbers in specific disciplines such as medicine and engineering is dismal. The fellowship amount is also not attractive. It is proposed that a CNRS type model of funding post-docs offering contract fellowships with teaching and research responsibility, be launched. UGC has been offering the Research Scientist (RS) position but the selection was done by the UGC (without the involvement of host institution), and the researchers were posted at various institutions. This has created a certain level of discomfort between the institution and the researcher. Though the objective of the scheme was laudable, it was hampered by the disconnect between UGC and the implementing institutions. It is proposed that similar scheme be launched /revived with modification. It is suggested that UGC or AICTE or any other agency earmark certain number of RS positions in carefully chosen academic or research institutions. A large number of post-docs working in various countries abroad are willing to come to India for carrying out research work. It is important to work out schemes to attract them here. It is proposed that 1000 positions be created for attracting post-docs from within the country and abroad.

1.4 Diamond Jubilee Scheme for Women Science and Technology Professionals: In any knowledge based society it is important to ensure that trained professionals are provided employment opportunities taking into consideration the social and cultural milieu. While an increasing number of women are entering the S & T domain as graduate, post-graduate and Ph.D. students, it is a challenge to keep them engaged in S & T activities. Family responsibilities and the lack of options that provide adequate mobility are some of the reasons for the "leaky pipeline". The DST women scientist scheme has been a forerunner in providing a re-entry point for women who have taken a break from their career for a variety of reasons. However, we also need to address the problems of women scientists who are unable to continue in their jobs because of the challenge of mobility caused by personal or other reasons. This is essentially due to the difficulty in securing jobs in another city. This scheme is proposed to address this problem. It is also important to provide re-entry fellowships for women at various stages of the career. Thus, a person who has spent a few years in the industry and wants to come back to academic/research should have an appropriate re-entry scheme.

1.5 Summer Fellowship programs: The summer fellowship program being operated by science academies provide opportunities to a large number of young students and faculty members to interact with established scientists and get exposed to scientific research and access to facilities. It is necessary to expand this exposure to larger numbers of students. In addition to the services provided by various science academies, it is necessary to involve some academic institutions and national laboratories with the financial support coming from government.

1.6 Training Scheme for Science Teachers: The government has taken many steps to augment higher education during the last 5 years. It is increasingly felt that the "quality of science teaching" is poor, and some urgent steps are required to improve the standard of science teaching both at the school as well as college level. The Homi Bhabha Centre at Mumbai and the Indian Institute of Science, Bangalore are helping science teachers in imparting training to them. It is necessary to expand these activities and replicate such centres in many parts of the country, with active involvement of state governments and central agencies. An appropriate structure with dedicated faculty members, laboratory facilities, guest house etc should be established in different regions. The training program should be made compulsory for career growth of the science teachers.

2. Inter- University Consortium Type Centres:

The XII Plan should make a special provision for the creation of a set of Inter-University Centres in chosen areas of Science and Engineering, which will function as a means of providing access to state-of-the art facilities for researchers in universities and academic institutions. At present, the experience with the existing Inter-University Centres (IUCAA, Pune; IUC-Indore; and NSC, Delhi) has been very encouraging. All these centres focus largely in the area of Physics and Astronomy. The facilities established by UGC in collaboration with Department of Atomic Energy in the area of Physics such as Inter-University Consortium at Indore and Delhi may be a suitable model to replicate at different places in other areas as well. These centres will not only provide access to sophisticated instruments but will also function as a "hub of activity" for university researchers with the facility for training in instrumentation and also facilitate collaboration between faculty members at the Centre and researchers from elsewhere. The IUCs will be mandated to conduct regular workshops and training sessions to enhance technical skills of students from Universities across the country. It will be desirable to facilitate the creation of Inter-University Centres, which promote cross disciplinary research in important areas of science and technology at specific locations in the country. The following large centres, functioning autonomously within an existing university/institution, are proposed.

2.1. Inter-University Consortium for Advanced Materials

Development of advanced materials for specific applications remains a challenge. Molecular materials, including nanomaterials, are expected to play an important role in the near future. Efforts will be directed to make all kinds of materials in a simple, cost effective and environment friendly manner. Special emphasis should be given to developing energy storage materials, sensors, materials for solar energy applications, biomimetic materials, polymeric materials and nano-catalysts for industrially important reactions.

While lab-scale synthesis/fabrication of nanomaterials/devices is now an area attaining maturity, integration of nanomaterials and components in actual applications poses challenges including large scale, rapid, low-cost manufacturing practices and integration of nano with larger scales and system structures. This requires a strong interdisciplinary approach involving engineering, physics, chemistry, materials science and in some cases, biology/health sciences. Some important applications include composites, large area functional coatings, food and pharmaceuticals, energy storage and conversion systems, environmental remediation, lab-on-a-chip devices and even fast moving consumer goods where the potential impact of basic nanotech is enormous. Special emphasis should be given to developing at least two very comprehensive national centers of nanofabrication, characterization and applications.

Recent years have seen an upsurge in scientific activities in the area of nanotechnology all over the world and India has made a good beginning by starting the Nano-Mission under

DST. This has fostered research and development in nanomaterials, nanodevices and nanosensors. The effort is still sub-critical in our country as the facilities required to fabricate and characterize state-of the art devices are sophisticated and expensive. It will be essential to set up Centres in the country which can allow our scientists and students access to fabrication facilities and a wide range of tools to characterize them.

2.2. Inter-University consortium for Advanced Manufacturing and Fabrication

Large volume/area, rapid manufacturing technologies that are economically viable pose special challenges in the realm of engineering that are very different from fabrication of small quantities for research purposes in a laboratory. Yet, competitiveness of a nation is critically dependent on the development of scale-up technologies that have been paid very scant attention in academic R&D. Examples are roll-to-roll manufacturing and coatings of paper, plastics, films, packaging materials, metal sheets, etc. which require new paradigms of engineering fabrication. While lab-scale synthesis/fabrication of many new materials and devices is now an area attaining maturity, integration of materials and components in actual applications poses challenges including large scale, rapid, low-cost manufacturing practices and integration many scales from nano to macro. This requires a strong interdisciplinary approach involving engineering on one side and participation of basic sciences such as physics, chemistry, materials science and in some cases, biology/health sciences. Some important applications include composites, large area functional coatings, food and pharmaceuticals, and even fast moving consumer goods where the potential impact of basic research combined with engineering scale-up is enormous.

2.3. Inter-University Consortium on Analytical Geochemistry

Universities in India are poorly equipped to generate high quality data on diverse earth materials including those containing energy elements. This situation needs to be addressed, especially as many of our university departments train students in geology and in view of the increasing emphasis at the national level on revitalising earth science education and research. There have been dramatic advances in recent years in the area of chemical;/materials analysis which require well maintained, professionally run facilities, which can not be easily established at individual institutions. Many student scholars come out of their institutions with little experience of data generation and processing. Many professors also go out of the country for data generation. Elements in trace and ultra-trace concentration levels, and isotopic ratios of radioactive, radiogenic, cosmogenic and stable elements in a large variety of earth materials are essential to understand subsurface and surface earth processes, mineral concentrations and pollutants transport and fixation processes. Setting up and running a few inter-universities with centralized, analytical facilities is essential to improve the quality and credibility of scientific data in earth sciences.

3. Major Facilities/Centres:

In order to provide a concerted thrust to enhancing the quality and impact of scientific research in academic institutions and national laboratories, it is proposed to create several advanced facilities during the XII plan period. This may be established within institutions with a proven track record of maintaining centers which collaborate easily with researchers across the country.

3.1. Centre for High-throughput Plant Phenomics

Global climate change, environmental pollution and the conservation of biodiversity are the major ecological problems that the world is facing today. Solutions to these problems are hidden underground, in the responses of the roots and the processes in the rhizosphere. As these processes are notoriously difficult to study, our understanding of crucial below ground interactions is as yet very limited.

The Phytotron is a controlled environment facility specifically designed to make progress in these fields. The facility can host whole plant and ecosystem studies at the mesocosm scale, while simultaneously fully equipped to study the underlying mechanisms in the soil. Situated under a transparent rain shelter, experiments are carried out under near-field conditions and soil properties, water quantity and water quality can be fully and automatically controlled. A variety of soil sensors is available for researchers to provide all relevant measurements on the appropriate spatial and temporal scale. Sensors are monitored and data are processed automatically using commercial greenhouse technology.

Plant phenotyping and high throughput screening under greenhouse conditions have become essential for generating reproducible and scientifically sound results. Depending on the objective, evaluations need to be conducted in a comprehensive manner taking all environmental variables into consideration. The development of specific growth patterns under stress conditions could help identify particular gene functions in plant phenotyping, which in turn could be a key element in plant breeding.

3.2. Centre for Animal Models for Biological Research

Animal models are essential for understanding various biological phenomena so that the knowledge gained from these studies can be extrapolated to human beings. Animal models are widely used to study the biology of human diseases, especially when human experimentation is not feasible or considered unethical. There is tremendous confusion in the country at present in carrying out experiments involving animal models and even premier research institutions lack the infrastructure for carrying out animal experimentation. Thus, establishing centres for the creation of transgenic and knock out animals, non-human primate research facilities as well as animal models for infectious, neurological and metabolic disorders will tremendously enhance our ability to carry out cutting-edge research in several key areas of biomedical research. Such centres would be able to comply fully with all legal and ethical requirements for the use of animals in biomedical research.

3.3. Centre for High-Throughput Platform Technologies

Over the last two decades there has been a rapid growth in biology research, which is directly correlated with the quantum of money that the government has invested in research institutes. This was necessary because advances in biology require large investments of money and infrastructure. At the same time this has also led to problems because the infrastructure created through these investments are not within the reach of everybody, especially those in universities. The universities are woefully lacking in infrastructure needed for research in biology. Setting up high level infrastructure in every university is not feasible. Although small individual centres have been set up as National facilities within research institutes, these are not readily accessible to one and all, especially to those from universities. Modern biological research is highly dependent on the availability of such facilities. Therefore, it is proposed to establish centres that will house the high throughput facilities and will be managed by scientists whose primary responsibility will be to provide service to the scientific community, especially those from universities and research institutes.

It is proposed that world class facilities to enable research at the cutting edge areas of biology be established. This would consist of facilities for high throughput analysis of genomes (including next generation sequencing), transcriptome and proteome analysis as also facilities for high throughput histology. Such centres would also provide a platform for entry into the rapidly developing area of synthetic biology. The long-term vision of this proposal is to set up 5 such centres, with an appropriate distribution of locations. This could be achieved in a phase-wise manner, starting with one or two such centres.

3.4. Centre for Low-Temperature Physics and Superconductivity Research

The demonstration of superconductivity in quaternary cuprates at temperatures above the boiling point of liquid air in 1987 had raised hopes of large scale applications of such materials in electrical systems, in magnetic levitation based transportation systems and freely moving, frictionless devices. However, the progress on all these fronts has been slow due to severe difficulties encountered in realizing the full potential of material attributes of cuprate based superconductors in bulk form. Superconductivity holds the promise of increasing the efficiency and capacity of the power grid system, without any additional cost for grid infrastructure. The superconducting transmission lines would carry large DC-current instead of an AC current, thereby, completely eliminating ac-losses. Superconductivity is also envisaged to provide solution to the problem of storage of energy expected to be generated from non-conventional energy resources, like, the solar energy and the wind power. Superconducting Magnet Energy Systems (SMES) are like assembly of superconducting magnets held in persistent mode. The research in all aspects of superconductivity ranging from fundamental discoveries to materials science to metallurgical aspects to electro-mechanical engineering, including cryogenics, to power engineering could be identified as an integrated thrust area in India, with a view to participate in and to monitor the developments at all stages of this emerging field from the strategic point of view.

3.5. Centre for Astroparticle Physics

Astroparticle Physics is a vast field that deals with the early universe, its large-scale structure, the extragalactic and galactic sources of high energy radiation etc. The European community and the United States have identified several thrust areas to be pursued in the coming decades. However, the most ambitious scientific program is by the Chinese, who plan to focus on studies of the universe through different aspects of Astroparticle Physics with emphasis on cosmic rays. In view of this international scenario, it is vital for us to identify specific niche areas where India can effectively and successfully set up state-of-the-art experiments. At present the GRAPES-3 experiment located at Ooty is a collaboration of several Indian groups, is the largest Astroparticle Physics facility in India probing a number of fundamental questions. Understanding the presence of high energy particles in nature from 100 mega eV to 100 mega-mega-mega eV is one of the greatest challenges of science. It is almost impossible to conceive mechanisms that could accelerate particle to such energies without modifying knows laws of physics. With enhanced resources it would be possible to study phenomena at several energy scales including acceleration of particles during thunderstorms in Earth's atmosphere, in interplanetary medium following solar flares, in our galaxy and in the nearby universe up to 100 mega light years. The energy range to be covered would be from 100 mega eV to 100 mega-mega-mega eV. A number of world-class technologies including, high quality plastic scintillators (a strategic item developed at Ooty is used in over a dozen laboratories worldwide), high speed (25~ps) signal processing electronics designed and fabricated in-house with performance comparable to the best anywhere already exists. It is suggested that a centre be established at Ooty for which sufficient land and initial infrastructure already exists. A supporting centre at Darjeeling is also proposed which would complement the project in a meaningful way and fill up the geographical void in studying solar phenomena through cosmic rays. This facility would also cater to a comprehensive study of the interrelation between aerosols, cosmic rays and the microphysics of cloud formation, one of the most challenging emerging areas in the context of global change and climate (especially monsoon) stability. The recent results from CLOUD experiment at CERN have established that cosmic rays play a role in cloud formation that is an order of magnitude bigger than previously thought. Thus the cosmic ray-cloud formation connection is expected to play an increasingly pivotal role in this area of science. The existing expertise in astroparticle physics would provide India a unique advantage that needs to be fully exploited in this multidisciplinary area of science.

3.6. Centres for Extreme Matter / Cosmic Matter

With the advent of the international Facility for Antiproton and Ion Research (FAIR) coming up in Germany, with India as a major stakeholder, the emphasis on studying extreme states of strongly interacting matter, found in astrophysical scenarios, in a controlled and systematic way is undergoing a paradigm shift. The international consensus is that this will constitute the primary focus of high energy nuclear, particle, atomic and plasma physics research for the next several decades. Many countries have already taken substantial initiatives to prepare themselves for the challenges and the opportunities. The Helmholtz Foundation of Germany has established several new institutes/centres under the theme “ExtreMe Matter Institutes (EMMI)” all over Germany. Russia has established a Russia-FAIR centre with a very active programme. All these centres are expected to form a global chain of research centres of intense collaboration. India must also not lag behind in this venture. Since most of the activities related to FAIR in India are coordinated at two locations (Bose Institute & VECC at Kolkata and TIFR & BARC in Mumbai), two India-FAIR research centres should be created, one in Kolkata and one in Mumbai.

3.7. Centre of Heat transfer and Combustion

Although there exists considerable expertise in the country dealing with heat transfer, the experimental facilities for carrying out research at a reasonable scale, which can be used to extrapolate and understand real life situations is lacking. Although few of the facilities are available in the Department of Atomic Energy establishments, facilities which are designed to meet diverse research needs are not available in academic institutions. It is proposed to establish a centre which can develop facilities for users which are otherwise not possible at an individual level. These include various thermal loops and combustion chambers containing imaging and other diagnostic tools operational at different temperature domains. Such a facility will stimulate the entire field of energy research, including solar energy.

3.8. Centre for Dynamic Studies of Materials Behaviour at Atomic Scale

The understanding underlying atomic processes allow us to not only understand but also to fine tune metallurgical and chemical processes. These are, in particular important, for processes occurring at interfaces. With the advent of various sophisticated techniques it is now possible to probe the processes at an atomic scale. Although currently most of these are obtained in an indirect manner, it is possible to visualize the atomic process directly through imaging by utilizing new generation atomic resolution microscopes including SPM and TEM, together with associated analytical techniques coupled with high temporal resolution cameras. These facilities are difficult to maintain and need to be accessed through a national facility structure. Though several such centres are now under development around the world, no such facility is available in this country

3.9. Centre of Water Research

Water resource management is clearly one of the most critical areas in the immediate future. There is a strongly felt need to create a multidisciplinary centre focusing research on the physics, chemistry, microbiology and ecology of water on the landscape. Specifically the center should be designed to initiate research on

(a) Weathering Engine – a very fundamental first-order earth surface process involving everything (rocks-water-air-life) on the landscape, generating and regenerating life-critical resources. Rock weathering and photosynthesis are symbiotic processes providing potable water, flowing rivers, breathable air, farmland with water and nutrient rich soils/sediments, comfortable climate and habitats for all life with its diversity. The physics, chemistry and biology of the process, their relative controls and rates of critical-resources regenerating capacity are to be clearly understood as this knowledge base would determine the limits to economic growth.

(b) River Basins of India – To manage rivers we need to a) characterize the interactive earth-life system processes and the resultant ecology in the catchment, floodplains and deltas-estuaries-mangroves, 2) study the consequences of climate change on the dynamics of glacier-melting in the Himalayan rivers, flow regimes and water-sediment-nutrients mass balance of all rivers, 3) study the consequences of large scale interventions through damming-draining-diverting of major rivers on the hydrologic, erosional, nutrient cycles and biogeochemical cycles and 4) to study the complex land-water-microbes/plants geochemical/biochemical mechanism in different segments of major rivers.

3.10 Centre for Chemical Biology and Bioengineering

Creation of a centre in this area will provide interdisciplinary research at the interface of biology, physics, chemistry and engineering. Engineering design of systems which perform at the interface of biology and study of biological systems from an engineering perspective require specialized techniques. These include ultra low load testing systems, including the use of laser tweezers, measurements of load and displacements on a very small scale, ultrafine sensors and experimental systems to study biochemical processes as unit processes and measurement of heat and mass transfer on a very small scale. These require a specialized centre which will develop such facilities and will make them available to researchers all over the country for carrying out diverse experiments. A vibrant, interdisciplinary centre which provides a platform for engineers, biologists, physicists and chemists to work together will further research in the key areas of developing new chemical entities, molecular diagnostics and chip based technologies and novel biomaterials for medical applications.

Further, the objectives of this centre will also be to develop as a centre of excellence in understanding the molecular structure and function of biological macromolecules, using a variety of advanced techniques, and consequently bring about a better understanding of the molecular-level origins of various disorders and diseases. In addition to hosting researchers in the relevant areas of biology and chemistry, the centre will maintain state-of-the-art facilities for elucidation of molecular structure of biomacromolecules and for the study of their interaction with potential drug candidates. Specifically, it will provide access to instruments, such as mass spectrometers, high throughput DNA sequencing, proteomics platforms and imaging technology, including electron and optical microscopy that are needed for life sciences research. It would actively seek to engage with chemists and biologists from various regions of the country, through regular workshops and site-visits.

3.11 Centre for Imaging and Spectroscopy

Imaging using various types of radiations and different methods to cover a range of length scales is used in almost all branches of basic sciences such as physics, chemistry, biology and engineering. There has been an unprecedented progress in the development of new probes and tools. These include aberration corrected transmission electron microscopy for atomic resolution, scanning probe microscopies, multi-photon confocal microscopy, near-field scanning microscopy, tip-enhanced Raman microscopy, infrared imaging, magnetic resonance imaging, positron emission tomography etc. The Centre should also have a wide range of spectroscopy tools covering different windows of the electromagnetic spectrum, scanning probe spectroscopies, electron energy loss spectroscopies etc. A very important area to be covered is time-resolved spectroscopies using femtosecond lasers – an area in which tremendous progress is being made in the world covering both basic and applied aspects. It will be prudent for our country to invest in this field of femtosecond spectroscopies which is being used to uncover basic issues in photosynthesis and related subjects.

Imaging in life science and biomedical research has transformed the way biological and biomedical research is carried out. At one level, advanced imaging techniques such as multi-photon imaging, PALm etc have provided us an insight into the organization of cells at the molecular level. At the same time, imaging techniques, such as optical imaging, MRI, PET etc have provided a window at the organ level. For example, functional MRI has provided a unique opportunity to observe the human brain while the individual is performing a task. In India, we need to enhance the expertise in imaging techniques in general and image analysis in particular. This is a rapidly evolving field and it is essential to that our scientists are at the cutting edge of these technologies.

The center will also serve to train a large number of students and researchers in the latest methods in spectroscopy and imaging; in addition to serving as a facility that students from across the country could utilize for furthering their research goals.

3.12 National Centre for Applications of Mathematics

Taking in to account the enormous task involved in creating a viable culture, structure and programmes in applications of mathematics and taking this to industry and national strategic departments, it is proposed that a National Centre for Applications of Mathematics be created. It can be partly modelled on the lines of INRIA in France. The staff would include both mathematicians and engineers.

In addition to pursuing basic research in applied mathematics, the Centre would inform how application of mathematics can help industry/strategic departments to solve some of their problems and advise them when it comes up with specific problems. The centre will be a nodal point for applied mathematics training at all levels. It would organize study groups, modelling weeks, industry-academic workshops. World over, such activities have been clearly demonstrated to provide a strong linkage between mathematicians and industries/strategic departments. The centre should have provision for Associateships/Internships/ post-doctoral fellowships from academics and people from industry/government agencies.

4. Mega projects

Large scale scientific projects which involve commitment of considerable resources over a long period of time can also greatly expand the base of research across broad areas of research. The following mega projects may serve a very large section of the scientific community in India.

4.1 National Synchrotron Facility

The brilliance of synchrotron radiation is several orders of magnitude larger than other sources of electromagnetic radiation. Thus, the extremely high brilliance, besides possessing the desirable properties such as its polarised, coherent, and pulsed nature prove to be extremely useful deciphering properties of matter at fundamental levels in such diverse fields as physics, chemistry, biology, geology, medicine, and technology. Synchrotron facilities in most advanced countries have played crucial roles in expanding the knowledge base and in making technology flourish, besides being increasingly used in the field of medicine as well.

The need for an internationally competitive synchrotron source that will cater to the entire cross-section of the Indian scientific and technology community requires no debate. In fact, this was discussed extensively at the highest levels and recommended without reservation, leading to the inclusion of this possibility in the Planning Commission documents for the 11th five-year plan period; additionally, a specific budget allocation was made to study and come up with feasibility reports, probable site identification, preliminary designs, strategies to achieve the eventual goal, management of human resources including training and other aspects to establish such a facility within India as a part of techno-scientific mega-projects.

With this background in mind and keeping in sight the projected need of the Indian scientific community in about 7-10 years from now, it is proposed to setup a state-of-the-art synchrotron source that would cater to the Indian scientific research community cutting across all disciplines and thereby encompassing all forms of basic sciences (physics, chemistry, biology), technology, engineering and medicine.

4.2 Indian participation in FAIR

During the construction phase of the international research organisation FAIR, a minimum commitment of about Rs. 300 crores has been made by India. In order to derive full benefit of this investment, substantial efforts have to be made within the country to develop the necessary skills and build up the (primarily young) community of researchers.

4.3 Indian Initiative in Gravitational wave observations (IndIGO)

IndIGO (Indian Initiative in Gravitational-wave Observations) is a consortium of researchers with a common goal to set up advanced experimental facilities, with appropriate theoretical and computational support, for a multi-institutional national project in gravitational-wave (GW) astronomy. The IndIGO collaboration aims to bring about a significant enhancement of the Indian contribution in building as a part of the global network, a gravitational-wave observatory in the Asia-Pacific region. Based on very significant communication from the LIGO-Laboratory, USA, in June 2011. IndIGO is currently proposing LIGO-India as an exciting mega-science project at the frontiers of physics and astronomy in the upcoming 5 year plan of India. LIGO-India would be an advanced Laser interferometer GW detector assembled and operated by an Indian team within the global network. The entire detector components will be provided free of cost by LIGO, USA with NSF approval. The Indian team will manage and oversee the construction, at an appropriate site, of the entire infrastructure and the very large scale vacuum structure required to house the Laser interferometric detector system and assume responsibility for running the facility as part of the global network of detectors for a decade. This mega-science project promises a development of highly skilled technical and scientific manpower on an unprecedented scale. The discovery potential, the extreme technical challenges, the promise of initiating a new window to our universe and finally the high end technological spin-offs should make this an iconic science endeavour that would attract and retain the cream of a large body undergraduate and postgraduate science and engineering students.

5.Emerging Areas:

The committee also examined the areas of science that merit special attention in the present context. The following emerging areas are recommended for special support in schemes to be developed during the XII plan.

5.1 LIFE SCIENCES:

5.1.1 Bio-prospecting & Molecular taxonomy

The intrinsic potential of biodiversity as a key resource for evolving new kinds of food, cosmetics, drugs, pharmaceuticals and other chemicals of agro-industrial importance needs to be exploited. Bio-prospecting is emerging as a promising area. Molecular taxonomy would also help in preventing biopiracy and is essential to protect and preserve our natural resources.

5.1.2 Biology of mammalian development

The ability to culture embryonic and adult stem cells *in vitro* and induce their differentiation into desired cell types has revolutionized biomedical research in the last couple of decades. Despite these amazing advances, several basic aspects of mammalian development still remains unexplored and poorly understood.

5.1.3 Life style and degenerative diseases

It is imperative that we focus on identifying risk factors as well as protective factors through understanding of the pathogenesis of the disease and initiate research into development of disease modifying therapies for these disorders.

5.1.4 Biomaterials and bio-engineering

Biodesign involving development of novel bio-materials including nano-materials and bioengineering is another important area that needs to be pursued during the 12^{th} plan period. This area has long range implication in the biomedical field.

5.2 CHEMICAL SCIENCES:

Chemical sciences is moving away from traditional classifications like organic, inorganic and physical chemistry to a new paradigm where the borders between the so called traditional branches are fast disappearing.

5.2.1. Energy and Environment

Recent efforts in the area of flexible solar cells promise cheaper means with higher efficiency; this may help achieve energy payback and break-even levels more quickly. Novel materials to produce batteries and fuel cells will also emerge as important research areas.

5.2.2. Chemical Biology and Drug Science

Some of the key areas would be: activity-based protein profiling, small molecule probes for protein-protein interactions and micro-assay technologies. Further, areas like chemical ecology, glycobiology, lipid chemistry and membrane biology, chemical and structural biology, natural products chemistry, medicinal chemistry, new drugs and novel approaches for their delivery and novel imaging methods to combat disease will play a crucial role in the overall development of this area.

5.2.3. Materials Chemistry and Nanoscience

Materials chemistry, which has already emerged as one of the leading research fields, will continue to grow with special focus on areas, like bio-material chemistry, molecular nano-chemistry, smart and responsive materials, nanocrystal and cluster science, cost-effective nano-filtration techniques, graphene-based devices, electro-spun functional nanofibers, organic materials for photo-voltaics and other functional coatings. Theoretical and computational methods for improved understanding and prediction of molecular and material behavior will play a key role in the overall development of this area.

5.2.4. Catalysis

Catalysis is a field of research which will continue to evolve with changing times. In particular, studies related to development of catalysts for efficient energy conversion processes, for generation of liquid fuels from bio-mass, for biomass conversion to specialty chemicals, for photo-assisted transformation of molecules using solar energy. Important concepts would be the idea of atom-economy, environmentally benign catalysts, biological catalysis, solvent-free processes, green solvents etc.

5.3 PHYSICAL SCIENCES:

5.3.1. Photonics

The science of photonics encompasses diverse topics related to light, such as light emission, transmission, amplification, detection and manipulation. Photonics also includes within its ambit the study of photonic devices such as lasers, photodetectors and sensors, optical fibres, photonic crystals, planar waveguides and other passive optical elements. A distinguishing feature of the science of photonics lies in the natural and apparently seamless linkages that the subject provides between fundamental scientific studies and technological applications in diverse areas of contemporary and futuristic importance.

5.3.2. Quantum many body systems and Quantum Technologies

This includes the whole spectrum of novel low-dimensional condensed matter systems the unconventional properties of which are shaped by correlations and interactions, e.g., quantum dots, wires, nanotubes, artificially engineered structures, quantum spin systems, grapheme, quantum spin Hall systems etc.

5.3.3. Nanoscale Science and Technology

Nanomaterials continue to be the fountain head of novel scientific challenges with many applications. Special emphasis should be given to use nano-enabled technologies in energy storage materials, water remediation, energy production, catalysis for many applications including water splitting and artificial photo synthesis, sensors, devices, specially in the area of health etc.

5.3.4. Particle and Astroparticle Physics

One of the most important problems in particle physics is to understand the physics beyond the standard model. These models include grand unified theory, supersymmetry and supergravity, superstring inspired models, models with extra dimension, models with low scale strong gravity, and phenomenological extensions of the standard model. Theoretical studies of these models are important.

5.3.5 Physics of Global Change

The issue of Global Change has emerged as the greatest challenge facing the world. For countries like India, this is indeed of substantial significance, given the dependence of Indian agriculture and major portions of the Indian economy on climatic conditions, especially the stability of monsoons. The recent results from the CLOUD experiment at CERN have established that cosmic rays play a role in cloud formation that is an order of magnitude greater than previously estimated. Thus a comprehensive study of the cosmic ray flux, the variability with the sun, the study of atmospheric water vapour and liquid water through radiometric measurements, study of aerosols and the atmospheric charge state, together with thorough measurement of atmospheric (meteorological) conditions need to be carried out on a long term basis.

5.4 ENGINEERING SCIENCES:

5.4.1. Energy

1a. Energy Harvesting:

i) Ultra supercritical technologies for higher efficiency
ii) Hybrid technology with solar and wind energy
iii) Carbon dioxide utilization and mitigation

1b. Energy storage technologies

i) From direct sunlight
ii) High temperature and high current density battery technologies
iii) Energy harvesting through grasses and algaes
iv) Water less technologies of thermal energy conversion
v) Super-capacitors
vi) Miniaturized energy sources for defense, space and on-chip power

5.4.2 Advanced Propulsion Technologies

i) Solar sail concepts
ii) Magnetism in propulsion
iii) Energy storage and release
iv) Hydrogen Fuel
v) Laser based propulsion

5.4.3. Smart structures

i) Self healing structures
ii) Smart structures with embedded sensors & actuators
iii) New concepts in space structure

5.4.4. Cyber Physical Systems

i) Array sensors and swarm technology
ii) Health related cyber physical system
iii) Cyber physical system related to security

5.4.5. Water

i) Water network as an engineering system
ii) Technologies of clean water
iii) Ocean mining and harvesting
iv) Conservation: evaporative loss, harvesting, recycling

5.4.6. Engineering – Biology/Health interface

i) Biomedical engineering: low-cost diagnostic devices, biomaterials, drug-delivery system
ii) Bio-inspired/mimic technologies
iii) Nano-bio interfaces
iv) Lab-on-a-chip
v) Medical imaging

5.4.7. Functional engineering materials including polymeric and carbon based materials including graphene

i) Graphene: large scale production and devices
ii) Metal-organic frameworks
iii) Electrospun functional nanofibers including production scale-up

5.5 MATHEMATICAL SCIENCES:

In case of Mathematical Sciences which covers Mathematics, Statistics and Theoretical Computer Science, research is required in highly specialized areas such as data mining, pattern recognition, stochastic process modelling, game theory, combinatorial optimization, mathematical finance, real-time computational algorithms and analysis of large data sets. The application of mathematics to areas like neuroscience needs to be explored.

5.6 EARTH SCIENCES:

5.6.1 Water Science: Water science is a basic natural science as it involves a holistic study of earth and life together (earth system), their complex interactions and their combined evolution. Because all environmental issues such as dying rivers, falling ground-water table, food security, soil erosion, biodiversity reduction land desertification, coastal erosion/submergence and climate change are related to human water use and abuse. The different roles of water in shaping our Nature need an integrated study of water science.

5.6.2 Cloud Microphysics –Parameters of cloud physical that lead to condensation and precipitation need to be studied. The role of different kinds of aerosols in this process and the consequence of global warming on cloud parameters and aerosol impact are to be understood.

5.6.3 Ocean Acidification – Impact on ocean primary productivity by atmospheric increase in CO_2 and its consequence on marine ecology directly and indirectly need to be investigated.

5.6.4 Medical geology There is a growing global concern on the impact of interactions among land (rock+soil+sediment)-water-air on human health. Other health problems related to land-water-air are many leading to a realization that the connection between geology and human health on various spatial scales is strong (As, F, Se, for example). Research on this aspect with quality data is essential.

5.7 ATMOSPHERIC SCIENCES:

5.7.1 Black Carbon Aerosols: It has been suggested that atmospheric black carbon (BC) might be second only to carbon dioxide and thereby complements global warming. It is very important to note that since BC (warming agent) and organic carbon (OC) are derived from same source. Mitigation strategies targeting BC will lead to reduction of OC as well. Thus, extensive studies on climate impacts of BC are essential for formulating policy on BC mitigation.

5.7.2 Climate Change and Indian Monsoon: Indian agriculture depends heavily on the regular occurrence of the seasonal monsoon rainfall. Deviations are usually less than 10% from the long-term average. Stronger variations could result in severe droughts or flooding with distressing impact on Indian agriculture. Role of atmospheric chemistry on warming patterns and hence Indian monsoon is an important topic least understood and to be investigated further.

5.7.3 Geoengineering: The concept of geoengineering is to deliberately manipulate the Earth's climate to counteract the effects of global warming from greenhouse gas emissions and is used to describe proposals to counter the effects of human-induced climate changeHowever, costs, benefits and environmental consequences associated with geoengineering should be assessed accurately and adequately before it is considered for implementation to mitigate climate change.

5.7.4 Dedicated Satellite Sensors: There have been several sophisticated satellite sensors dedicated for aerosol studies in the last decade. Despite the increased proficiency and use of realistic models in the aerosol retrieval algorithms, it appears that retrieval of anthropogenic aerosol over land is still a challenge due to irregular terrain characteristics and high surface reflectance. A dedicated satellite sensor would enable discriminating natural and anthropogenic aerosols, which is needed for the scientific community at large.

6. Budget

The programs and facilities mentioned above require investment of large quantum of funds. The following tentative estimate is proposed for these programs:

S.No	Name	Cost in Rs. Crore
	1. Human Resources Component: a. Research Interns: 5000 interns per year @ average rate of Rs.20000/ pm for 5 years, Rs.200 Cr. b. Pre-doctoral : 10000 per year @25000/- pm for 5 years = Rs.450 Cr c. Post-doctoral : 8000 per year @35000/- pm for 5 years = Rs.500 Cr d. Women Scientist : 5000 per year @30000 pm for 5 years = Rs.300 Cr e. Training Program for Teachers: 1 lakh teacher per year, centres in each state @ Rs.100 Cr for 50 centres = 5000 cr f. Summer Fellowship Program : 50,000 student @ Rs.10000 for 5 year = Rs. 50 Cr.	**6500**
	2. Inter-University Consortia **3. Centres/Facilities** **4. Mega Projects** **5. Emerging Areas**	**600** **3700** **3000** **2000**
	Grand Total	**15800**