REPORT OF

PLANNING COMMISSION-WORKING GROUP

ON

MEGA SCIENCE AND GLOBAL ALLIANCES

Government of India
Department of Atomic Energy

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Chapter – 1

INTRODUCTION

During the first meeting of the Working Group, the broad outlines of what constitutes “mega science projects” was adopted. Essentially, these projects should appeal to scientific curiosity and challenges to provide answers to some important path breaking questions in the field of contemporary science. Such projects, by their complexity, large outlays and potential scientific and technological impact, would involve the expertise and talents of multi-intuitional teams and may also include international collaboration.

Some of these projects would entail creation of associated scientific and technological facilities in the country. The advantage of bringing together a large group of researchers and other experts at these mega projects will spur further scientific activities and will go a long way in enhancing the scientific awareness and temper in society at large. In this connection it should be ensured that there should be a broad academic framework associated with such projects which serve the twin purposes of training and induction of fresh new talents into the overall scientific system.

Such projects, though identified after discussions, consultations and consensus amongst several scientific institutions and groups, should be anchored in a mutually agreeable host institution in order to channelize the funding for the project.

The benefits of such projects should cover a wide range of academia, science, technology and possibly industry. Thus opportunities for our young scientists and engineers to participate in a holistic manner in cutting edge technologies which require the discipline to work together. The need to build newer and larger components and subsystems will expose industry to entirely new areas and also have the possibility to spur start – ups by young entrepreneurs in advanced science and engineering areas.

On the question of global alliances, it was felt that such collaborations should be on a reciprocal basis and mutually beneficial for both sides. The major thrust of the Indian contribution should be on in-kind contributions as far as possible. This will ensure that the benefits of such projects as outlined above can be realized. Another important issue is that during the negotiations for international collaborations, India's independent decision making autonomy should be preserved.

The Working Group had sought inputs about various possible projects and after discussion, the following projects/ ideas emerged.

A. Continuing projects

(i) High Energy Physics projects at CERN - **Participating Organizations:** BARC, TIFR, VECC, SINP, IOP, IIT-Bombay & Indore, Bose Institute and several Universities.

(ii) Facility for Anti-proton Ion Research (FAIR), Germany – **Participating Organizations:** Bose Institute, VECC, BARC, RRCAT, ECIL, TIFR, SINP, IOP, IIT- Bombay, Indore & Kharagpur and several universities.

(iii) India-Based Neutrino Observatory (INO) Pottipuram, Tamil Nadu - **Participating Organizations:** TIFR, BARC, VECC,RRCAT, SINP, IOP, IMSc, PRL, HRI, IIT- Bombay, Madras, Indore & Guwahati and several universities.

B. New Projects

(i) CSIR Supercomputing facility for Innovative Research

(ii) Development of a National Civil Aircraft*

(iii) Monsoon Mission

(iv) Weather and Demographic Data Collection

(v) Earthquake Studies and Prediction - Deep borehole investigation in Koyna-Warna Region

(vi) Water Cycle studies

(vii) Enabling R & D Technologies for Indian High Intensity Proton and Electron Accelerators with collaboration with CERN and US Labs

(viii) Laser Interferometric Gravitational Observatory (LIGO)

(ix) Square Kilometre Array (SKA)

(x) Thirty Metre Telescope

(xi) Solar Energy Development

(xii) Detection of Life in Other Planets

(xiii) Programme on Metabolic Diseases

(xiv) Observatory for Species Protection

(xv) Renewable Energy Development

(xvi) Advanced Transportation

(xvii) Indian Synchrotron for Materials and Energy Research (ISMER)

(xviii) Institution-Industry Consortia for International Mega Science Projects

* **This project would perhaps fall in the domain of the Civil Aviation Ministry.**

Brief details of these projects with funding requirements are given in the next chapter.

Chapter – 2

SUMMARIES OF PROJECTS

A. Continuing projects

1. High Energy Physics Research with the Large Hadron Collider

The Large Hadron Collider (LHC) is the most ambitious project undertaken by CERN. It is designed to produce proton-proton collisions with a centre of mass energy of 14 TeV and heavy ion collisions with centre-of-mass energy of 5.5 TeV per nucleon. LHC is also designed to be a high-luminosity machine which would ensure detection of relatively rare processes and new particles including the elusive Higgs particle. Through ultra-relativistic heavy ion collisions, it will enable study of the properties of the resultant hot dense phase of matter and a definitive search for the existence of Quark Gluon Plasma.

India has made in-kind contribution in terms of hardware, skilled manpower and software towards the construction of LHC machine and sub-systems of CMS and ALICE detectors and towards the development of the LHC Computing Grid. India's contributions were greatly acknowledged and India was accorded the 'Observer status' by CERN with only Israel, Japan, the Russian Federation, Turkey, USA, EC and UNESCO being the other Observers.

In December, 2008 the CERN Council set up a Working Group to examine steps necessary for geographical and scientific enlargement of CERN. Observer states and other major partners were invited to present their views on the matter at a special meeting held on 3rd September, 2009 at CERN. Indian suggestions for modified conditions for Associate

Membership were appreciated. The Working Group, after due deliberations, submitted its report to the CERN Council, which ratified new rules for Associate Membership in its meeting held in June, 2010. Essentially, the rules have been made very flexible, requiring a minimum of 10% of the full financial contribution of a member, which could be increased over the years as per mutual agreement. In practice for India this implies an annual cash contribution of around **Rs 57 Cr** at current exchange rates**.**

The Large Hadron Collider, started functioning in November 2009. Its energy was slowly ramped up and is now operating at half its energy (3.5 TeV). Even at this energy, it is the highest energy accelerator ever built. The luminosity is even better than the designed specifications and LHC has already faithfully reproduced particle physics results gathered over several decades.

India is participating in three activities at CERN: (i) the **CMS Experiment** aiming at particle physics studies including search for Higgs; (ii) the **ALICE Experiment** aiming at search for quark gluon plasma with some preliminary investigations at Ringing Imaging Cerenkov Detector, 'RICH' at Brookhaven National Laboratory, USA; (iii) development of the **LHC Computing Grid** which aims at developing a world-wide grid infrastructure for analyzing the large volume of data coming out of CERN Experiments. Indian groups from DAE labs and universities have already made significant and well-acknowledged contributions to all these three activities including publications in reputed journals. Participation in these three activities is jointly funded by DAE and DST with DAE as the lead agency.

Continuation of these activities in the 12th Plan Period is a high-priority item. The groups participating in these activities from India are BARC, TIFR, VECC, SINP, IOP, IIT-Bombay & Indore, Bose Institute and several Universities. The funding will be shared between DAE and DST as per the existing arrangements. The total funding for the XII Plan will be **Rs. 248 Cr.**

2. Facility for Antiproton and Ion Research (FAIR)

India has signed the Convention on 4 October 2010 to participate in the construction of the Facility for Antiproton and Ion Research (FAIR) project at GSI, Darmstadt, Germany. 3000 scientists from 20 countries will be participating in this international venture.

India is a founder member country in this global endeavour. With a contribution of 36 MEuro at 2005 prices, India is the 3rd largest contributor in terms of resources. This is also a joint DAE-DST project with DST as the lead agency. Bose Institute, Kolkata (a DST institution) has been designated as the Indian nodal institution and the Indian shareholder in the FAIR Company. VECC, Kolkata is the lead DAE institution in the collaboration.

FAIR will be the next front-ranking accelerator facility for particle physics and nuclear physics after the Large Hadron Collider at CERN, Geneva. It is expected to be built by 2018 and will give valuable data till the 2030's. The advantages of participating in FAIR will be two-fold:

(i) As the major portion of Indian contribution will be "in-kind", it will give access to Indian scientific community and also industry to high technology by way of building accelerator and detector components.

(ii) This will allow Indian scientists to carry out scientific studies on cutting-edge topics, like QCD studies with cooled beams of antiprotons, nucleus- nucleus collisions at highest baryon density, nuclear structure and nuclear astrophysics investigations with nuclei far off stability, high density plasma physics, atomic and material science studies, radio-biological and other application-oriented studies.

A total of 22 institutions including 15 universities and the Electronics Corporation of India will be participating in this collaboration from the Indian side. This list may as well grow in future. XII Plan requirement for this project will be **Rs. 230 Cr.**

3. India-Based Neutrino Observatory (INO)

The India-based Neutrino Observatory (INO) Project is one of the larger national mega science projects, based in India, to be undertaken in the near future. This is a high-energy physics project aiming at carrying out sophisticated measurements with neutrinos. Neutrinos are elementary or fundamental particles which are electrically charge-neutral. Recent experiments indicate that neutrinos are massive, with very small, but currently unknown masses. A major complication in determining neutrino masses comes from the fact that neutrinos may not propagate as the same ‘flavour’ in which they were produced. This is because the different massive neutrino ‘flavours’ mix, thus leading to a quantum-mechanical phenomenon known as neutrino oscillations. Neutrino oscillations are not only a new paradigm in physics but also the first known evidence for physics beyond the Standard Model of Particle Physics.

The project includes construction of an underground laboratory under a hill top near Madurai in Tamil Nadu. A 48 kiloton iron neutrino detector called ICAL is proposed to be built there in a modular fashion. The ICAL detector will study the neutrinos (and anti-neutrinos) produced by interactions of cosmic rays in the Earth's atmosphere. ICAL, apart from identifying whether the particle is a neutrino or an anti-neutrino, will also measure the energy and direction of the particle. Separate identification of is a unique feature of ICAL that is not present in any other large neutrino detector of comparable size. These phenomena will, in turn, throw light on details of the parameters of neutrino oscillations. The ICAL detector will consist of layers of iron plates 6 cm thick interspersed with active detector elements called Resistive Plate Chambers (RPCs).

Apart from important particle physics experiments, the underground facility at INO will also be useful for carrying out some other important basic physics projects which require low cosmic wave background. The project will expose the young researchers to cutting edge science and technology.

The INO-Collaboration consists of nearly 90 scientists from about 16 Institutes and Universities in India and one from abroad.

The 12th Plan budgetary requirement will be **Rs. 1323.77 crore** shared between DAE and DST.

B. New Projects

1. CSIR Supercomputing Facility for Innovative Research

This project envisages setting up of a pyramidal structure for high performance computing in CSIR with the objective to establish a world class High Performance Computing (HPC) environment which should promote advanced scientific computational research embracing simulation (third paradigm) and data centric (fourth paradigm) activities that will be the hallmark of future science. The project envisages establishing an Apex HPC system at CSIR C-MMACS, capacity computing systems at cluster/regional level and basic HPC infrastructure at lab level.

The effort is aimed at putting India on the global HPC map by 2015 to be within the first 10 of the TOP500 super computers list. This list is one of the major indicators of advancement in science for any country. The US has the largest compute power share with about 43%, Japan second with about 19% followed by China with 12%. France and Germany have a share of approximately 5.5 percent each while India's share is about 0.32%.

The HPC environment proposed would provide for massive computing power, storage and data management, visualization and ease of remote computing with minimal front end systems. The availability of vast software tools and the human resources will enable CSIR to take on a leadership role for future innovations in Simulation and data centric research. Some of areas of technological importance useful to society at large include materials research, drug discovery, climate and monsoon modeling, chemical sciences and engineering systems.

The pyramidal structure will involve setting up 5 – 10 TeraFLOP systems in each lab. Each cluster/regional level will have a system with hundreds of TeraFLOPS for capacity computing. CSIR C-MMACS will host a world class HPC environment with an apex facility of tens of petaFLOPS computing power. All the systems will be connected through the National Knowledge Network (NKN). CSIR C-MMACS will nurture a team to help algorithm development for multi-core architecture, application scalability etc.

The project will be implemented in terms of five work packages and would entail an investment of **Rs. 1458 Cr**.

2. Development of a National Civil Aircraft (NCA) *

There is a general consensus that India must launch its own civil aircraft development programme. In pursuance of this objective, a High Power Committee was constituted by CSIR for overseeing the feasibility study of a national Civil Aircraft Development Programme. Based on an extensive study and market assessment in India and abroad by CSIR-NAL (National Aerospace Laboratories), a roadmap for the development of a 90 seater National Civil Aircraft (NCA-90) and a strategy of its production has also been evolved.

As per the Committee's mandate, a design bureau has been set up to undertake indigenous design and development of a civil aircraft. Capabilities of Indian industries are addressed and a proposal for a joint venture is made to maximize the participation of industries and establishing a production venture, with participation of private entrepreneurs /consortiums, which is capable of handling the production, marketing and after sales services, effectively meeting the international competition from established aircraft manufacturers in the regional transport aircraft segment. It is proposed that the design and development phase to be substantially funded by the Government with participation of technical partners whereas the production phases are to be managed through a joint venture with majority partnership from the private sector.

A total of 7 prototypes are proposed to be developed by CSIR-NAL to prove the design and demonstrate compliance with respect to airworthiness requirements and certification. In line with the practice followed by all OEMs, the design and development will consist of four phases: Preliminary Design Phase; Detailed Design Phase; Full Scale

Engineering Development (FSED); and Flight test, Evaluation and Certification.

While advantage will be taken of the facilities that already exist by way of test-rigs and test-plants, provision has been made towards suitable augmentation and build-up of new facilities. Assembly, integration and testing of various subsystems are planned to be done, ensuring their proper function in an integrated manner. Financial projections have been made based on detailed cost estimates. Further, the design is planned to have the following unique features: (a) enhanced fuel efficiency, the use of biofuel with low carbon footprint; (b) short to long range haul; (c) shorter air strip requirement; and (d) ultra modern avionics.

Through the project, CSIR-NAL will lead an Indian initiative with global participation to envisage design and development of a regional transport aircraft (90/70 seater) with state-of-the-art technologies – the aircraft will be tailored to suit the market requirements and will have attractive operating economics; a design and development capability for civil aircraft in India which can be used for follow on programs; facilitation of the growth of the Indian civil aircraft industry and associated cluster which can be used for global programs; development of skilled manpower that will have a economic multiplier effect; and spin-offs into their other strategic sectors like defence.

The design and development of the aircraft would cost **Rs.4355 crore**. The estimated series production cost would be Rs. **3200 crore**. The total project cost thus would be **Rs.7255 crore.**

***This project would perhaps fall in the domain of the Civil Aviation Ministry.**

3. Monsoon Mission

The Monsoon Mission is important for improving the predictability of Indian Monsoon. Better monsoon prediction will help the nation in taking advance action in preparing for the agricultural and other impacts of the monsoon. The mission consists of two sub-themes viz. a) Seasonal and Intra-seasonal Monsoon Forecast b) Medium Range Forecast. The mission will support focused research by national and international research groups with definitive objectives and deliverables to improve models in the medium range as well as in the extended and seasonal range scales through setting up of a framework for generating dynamical forecasts and improving skill of forecasts. It will also support observational programs that will result in better understanding of the processes. In a bid to improve the skill of the forecasts in various temporal and spatial ranges, proposals will be invited from National as well as international Institutes on very specific projects and deliverables. Provisions for funding the National partners as well as the international partners will be earmarked. These partners will be allowed to use the HPC facility at IITM and NCMRWF which will be suitably enhanced for the purpose.

A National Steering group is being put in place to steer the program and review the progress of the mission. The international participants would be from reputed organization from the US and UK. It was felt that the large student population in schools and colleges can be utilized for local meteorological data collection using simple devices which could be provided to them. The estimated cost of this project would be **Rs. 400 crores**.

4. Weather and Demographic Data Collection

Ever since the Industrial Revolution began about 150 years ago, man-made activities have added significant quantities of Green House Gases (GHGs) to atmosphere. An increase in the level of GHGs could lead to greater warming, which, in turn, could have an impact on the world's climate, leading to the phenomenon known as climate change. Indeed, scientists have observed that over the 20^{th} century, the mean global surface temperature has risen. Climate change leads to increase the occurrence of extreme events *viz*. drought, flood, tropical cyclones, heavy rainfall activities, heat wave, cold wave etc. It is therefore necessary to develop general awareness on environment and weather which may begin from the schools. In addition, information regarding education, health and crop patterns constitute complete and holistic data which can be useful for various stakeholders in the country like Governments, funding agencies etc. It is therefore proposed to establish Data Collection Centres in the school premises at district level throughout the country. The data collected in these observatories may also be utilized for carrying out climate research studies towards sustainable development and also collect other demographic data like health and education and crop patterns. The main objectives of the project are (i) Collection of meteorological data and other demographic data like health and education and crop patterns at school level. (ii) Innovative use of data and information in sustainable development and (iii) Hands on experience by the students on recording of meteorological parameters.

For understanding the impact of weather on human life, plants and collecting other demographic data., the school children may be provided with basic ideas about how the meteorological parameters *viz.* temperature, rainfall, humidity, wind speed and direction and atmospheric pressure are important for development of weather phenomena and also their possible impact on human lives and crops. Therefore, it is proposed to establish Data Collection Centres (DCCs) at schools at district level, installing instruments having the facilities to record observations on above mentioned parameters.

The schools where the Data Collection Centres to be installed and the workshops to be conducted for general awareness of the students may be identified by the existing Agromet Field Units (AMFUs) located at different State Agricultural Universities (SAUs), ICAR institutes, IITs etc. The AMFUs may also coordinate the other aspects on establishment of observatories and recording of all the data. The technical assistance in establishment of meteorological observatories and also the annual maintenance of the instruments may be provided by the respective Regional Meteorological Centres (RMCs) / Meteorological Centres (MCs),IMD for different States. The schools may be provided with the Desktop computers with internet facilities through which data collected at the station may be sent to IMD HQ and elsewhere as applicable, for their operational utilization as well as archival purposes for future use. Observations may be recorded by one trained staff members of the school against honorarium. Training on recording observation may be provided to the designated persons at respective RMCs / MCs in view of recording accurate observations. Each training course will be conducted for two neighbouring districts i.e. 20 observers at a time, one from each school. Annual Workshops may be arranged at the identified schools to involve the students to aware regarding possible impacts of change in climate on human lives, plants and also the possible measures to be taken in day-to-day activities for sustainability of the climate to avoid the adverse impacts.

Observations of weather parameters *viz*. max. and min. temperature, rainfall, humidity, wind speed and direction and atmospheric pressure may be recorded at the proposed Meteorological observatories everyday at 3 UTC (0830 IST) and 12 UTC (1730 IST) and data may be sent to IMD for the purpose of operational utilization as well as archival for future use. Conducting workshops will also benefit in developing general awareness among the students.

The Budget **(**based on 630 districts,10 schools/district; Phase wise installation and training) during the XII Plan is **Rs 362.76 Cr.**

5. Earthquake Studies & Prediction -- Deep Borehole investigations in Koyna-Warna Region

Koyna Dam in Maharashtra is a leading example of Reservoir Triggered Seismicity (RTS), where triggered earthquakes have been occurring in a restricted area of 20x30 sq km since the impoundment of Shivajisagar Lake in 1962. The RTS was further enhanced by impoundment of the nearby located Warna reservoir in 1993. The seismicity is restricted in depth generally in the top ~10 km, but more commonly in the top ~7 km of the Earth's crust. This makes it an ideal observatory for earthquake studies. Accordingly, a project has been planned for a suite of observations in deep borehole(s) in the area of persistent and focused seismicity, before, during and after earthquake. Continuous observations directly within the fault zone at seismogenic depths will help in testing and extending current theories about phenomena that might precede an impending earthquake. Also, the roles of fluid pressure, intrinsic rock friction, chemical reactions and the physical state of active fault zones in controlling fault strength will be evaluated. The deep borehole investigations will also provide insight into Deccan volcanism and Mass Extinction; Thermal structure and state of stress in the lithosphere; Geothermal potential of the West Coast Belt as well as Geothermal Record of Climate Change in the region. The major participating centres from India are NGRI, DAE, GSI, IMD, NCAOR and the probably foreign participants could be from experts from Germany, US etc. The estimated cost of the project would be **Rs. 400 Cr**.

6. Water Cycle Studies

Over the last few years there have been perceptible changes in the hydrological cycle. It is therefore pertinent to undertake research to address this. In this context, the projects on following specific aspects would be launched: (i) Response of forests and agro-ecosystems to extreme rainfall events in the Western Ghats,(ii) South Asian Precipitation, (iii) Hydro- meteorological feedback and changes in water storage and fluxes in northern Indian basins, (iv) Mitigating climate change impacts on India agriculture through improved irrigation water Management, (v) The structure and dynamics of groundwater systems in northwestern India under past, present and future climates, and (vi) Understanding the role of different regional drivers on erosion and flood risk hazard in the Ganges – Brahmaputra Basin. The likely participating agencies from India are IISc Bangalore, IITs, IITM Pune, NCWRF Noida; NIITs, TIFR Mumbai, IITs etc., and the international participants will be pioneer institutes of UK. The estimated cost for the project would be **Rs. 120 Cr.**

7. Enabling R & D Technologies for Indian High Intensity Proton and Electron Accelerators with collaboration with CERN and US Labs

Particle accelerators have become an integral part of our lives spanning from basic and applied research, energy application, health care, industry to national security. During last several decades Indian scientists have participated in many projects and contributed in basic and applied research using low and high energy accelerators in countries like USA, Switzerland (CERN), Germany, France, UK, Italy, Russia, Japan and many other countries. With the advancement of Indian economy and technology base it is now prudent to build state of the art accelerators in India for domestic programmes including energy production.

Department of Atomic Energy (DAE) laboratories have studied the feasibility of an accelerator system that is one of the first essential building block as part of the third phase of the Indian Nuclear Energy programme. The same accelerator technology can also be used for an Indian Spallation Neutron Source (ISNS) for material science and industrial applications.

It is proposed that spent nuclear fuel processing followed by accelerator based transmutation could significantly reduce the lifetime and amount of nuclear waste. At the same time this process could also be used to produce clean electricity (nuclear energy). There are several programs being developed in the world to demonstrate the utilization of ADS technology for the transmutation of spent nuclear fuel and power generation. Accelerators can also be used to produce fissile materials from elements such as thorium. Using the thorium fuel cycle instead of uranium to fuel the nuclear reactors reduces the production of actinides and increases significantly the clean nuclear energy contribution.

Accelerator driven reactors by design run in the subcritical mode, hence would be safe to operate. The main components of ADS are: a high power proton accelerator (~1 GeV, 10’s of mA current), Spallation target (heavy element like Pb, W, U…) and a sub-critical reactor.High power proton accelerators have various other applications like Spallation Neutron Sources (SNS), next generation of Radioactive Ion Beam (RIB) facilities, neutrino factories etc. Therefore it is necessary to develop accelerator both for high energy and high beam currents.

DAE has discussed these issues in great detail and has come out with a roadmap to build a 1 GeV, 30 mA proton linac. It is proposed to build it in three phases, namely, 20 MeV, 100-200 MeV and 1GeV. In the first stage, a 20 MeV Low Energy High Intensity Proton Accelerator (LEHIPA) is under construction at BARC as the front end injector to the Linac. The power requirement and the cooling issues are considerably reduced if Superconducting Radio Frequency (SRF) structures are used in the accelerators. In SRF structures much higher accelerating gradients are achievable leading to reduction in the construction and operational cost of the system. Accelerators are now being designed using about 30-35 MV/m accelerating gradients and accelerating gradients in the range of 40-45 MV/m are routinely achieved in single niobium cavities. However, superconducting technology is very complex and difficult and at present India does not have the technology to build a high intensity proton accelerator using superconducting radio frequency technology. In view of this Indian laboratories (BARC, RRCAT, VECC and IUAC) have initiated a R&D programme to build components of SRF technology for its proposed programme to build an SCRF cavities based 1 GeV H-ion linac and 1 GeV Accumulator Ring for Indian Spallation Neutron Source (ISNS) at RRCAT and a 200 MeV proton accelerator for ADS Programme at BARC. The BARC proton linac will be the low energy part of the 1 GeV, 30 mA linac to be operating in CW mode. The project involves collaboration with various universities and laboratories in India and other countries like Jefferson Lab, Fermi Lab (US) and CERN. An interesting physics programme which involves several DAE labs and some universities, IITs as well as universities in US, has also been discussed and finalized.

The project will taken up in two phases, viz. 1) R&D phase and 2) Construction phase. The R&D phase of about 5 years duration would involve: i) Development of physics design of various sub-systems of proton accelerator and accumulator ring, ii) Development of enabling technologies and associated infrastructure, iii) Engineering design and simulation of various sub-systems and vi) prototype developments. The total cost which will be across the XII and XIII Plan is estimated to be Rs 5000 Crore. The XII Plan requirement would be **Rs. 3000 Cr**.

8. Indian Particitation in Laser Interferometer Gravitational - Wave Observatory (LIGO)

Gravitational-wave (GW) science holds the potential to address some of the key questions in fundamental physics, astrophysics and cosmology. These include the correctness of the Theory of General Relativity and constraining its validity under strong gravity conditions, properties of GWs and the nature of black holes, equation of state of neutron stars, abundance of stellar-mass black holes and the existence of intermediate-mass black holes, merger history of galaxies and supermassive black holes, the central engine of gamma ray bursts, internal processes of supernovae, nature of dark energy, and phase transitions in the early Universe. Gravitational waves distort space-time and thus change the physical distances between free test masses. The key to gravitational-wave detection is the very precise measurement of small changes (~10-18 metre) in distance, which can be achieved using laser interferometers. Interferometric GW detectors have been built in the USA (LIGO), Europe (GEO600, Virgo) and Japan (TAMA300).

IndIGO, the Indian Initiative in Gravitational-wave Observations, is an initiative to set up advanced experimental facilities, with appropriate theoretical and computational support, for a multi-institutional national project in gravitational-wave astronomy. The IndIGO collaboration is in the process of constructing a road-map and a phased strategy towards building a gravitational-wave observatory in the Asia-Pacific region. Initially, India has decided to participate in the construction and operation of LIGO-Australia, an advanced gravitational wave observatory in an international collaboration involving the LIGO-USA and the Australian Consortium for Gravitational Astronomy (ALIGO)-Australia. A MOU has been signed between IndIGO and ACIGA- Australia, which aims to initiate collaboration between scientists in India and Australia in the field of GW detection. A proposal has recently been submitted by IndIGO. The project has now been formally offered to India and by March 2012, India is expected to give its firm commitment for this project.

About 16 Indian institutions are expected to participate in this project. The total Projected cost 2011-27: Rs. 1260 Crores and the XII Plan requirement for this project will be **Rs. 650 Cr**.

9. Square Kilometre Array (SKA)

SKA will be the world's largest and most sensitive radio telescope. An array of thousands of receptors will extend out to distances of about 3,000 km from a central core region. The SKA will address fundamental unanswered questions about our Universe including how the first stars and galaxies formed after the Big Bang, how galaxies have evolved since then, the role of magnetism in the cosmos, the nature of gravity, and the search for life beyond Earth.

67 organizations in 20 countries, together with industry partners, are participating in the scientific and technical design of the SKA telescope which will be located in either Australia – New Zealand or Southern Africa extending to the Indian Ocean Islands. Currently the SKA Founding Board is in the process of finalizing the location and working

out the detailed plan. The target construction cost is approximately €1,500 million, which will be done in phases. Phase-I is scheduled to start in 2016 and expected to cost about € 500 million. Indian scientists primarily from TIFR and IUCAA are planning to participate in SKA construction with about 5% contribution.

XII Plan requirement for this project will be **Rs. 70 Cr**.

10. Thirty Metre Telescope (TMT)

Large aperture (in the range 25-40 metre) optical telescopes will mark the next giant leap in the field of Astronomy. Three major international bodies have taken up the challenge of setting up such facilities in the world. India was invited to participate in these endeavors. After careful assessment by its astronomy community, India, in June 2010, decided to join the Thirty Metre Telescope (TMT) project at Mauna Kea in Hawaii as an "Observer". The Observer status of India is the first step in becoming a full partner in TMT and participating in engineering development and scientific use of the world's most advanced and capable astronomical observatory. As an Observer, we can begin exploring the specific areas where India can contribute to the project and look forward to their becoming a full partner with a formal agreement and commitment for funding. This project is being piloted by the California Institute of Technology (Caltech), USA and has several international partners including Canada, Japan and China. TMT is expected to be operational in roughly eight years at which time it will be the first of the next generation of ground-based optical observatories. This revolutionary telescope will integrate the latest innovations in precision control, segmented mirror design, and adaptive optics to correct for the blurring effect of Earth's atmosphere. The core technology of TMT will be a 30-metre segmented primary mirror which will give TMT nine times the collecting area of today's largest optical telescopes and three times sharper images. TMT has begun full-scale polishing of the 1.4-metre mirror blanks that will make up the primary mirror. TMT also has developed many of the essential prototype components for the telescope, including key adaptive optics technologies and the support and control elements for the 492 mirror segments. The TMT project has completed its design development phase and the project has now entered the early construction phase. The TMT project is expected to be completed by 2019.

About 20 Indian institutions (IIA, ARIES, IUCAA, TIFR, universities, etc.) and half a dozen industries are expected to participate in the construction of this project.

XII Plan requirement for this project will be **Rs. 700 Cr.**

11. Solar Energy Development

Solar energy is one of the important sources available to India. There are several applications which need only solar heat like water heating, solar cookers etc. The world over, the technologies developed are based on high pure or amorphous silicon. However there is a need to have a fresh look at this technology and it was felt that a new paradigm has to be initiated in this respect. It was recognized that this research should be encouraged at the various universities of the country.

12. Detection of Life Forms in Other Planets

In the quest of scientists for detection of life forms existing in other planets than earth, a global program for exploring and proving through scientific experiments and expedition that other life forms exist in other planets is an interesting and challenging project. The research will use robotic operations initially to derive information on soil, water, air etc. A near human robotic system will be developed with capability for analysis and assessment of air, water and soil and detection of possible life forms.

The International Space Station is operated as a joint programme by the National Aeronautics and Space Administration of USA, Russian Federal Space Agency (RKA), Canadian Space Agency (CSA), Japan Aerospace Exploration Agency (JAXA) and the European Space Agency (ESA).

It would be worthwhile to explore partnerships with one of the five Space Agencies for development of suitable software and hardware for the robotic operations in outer space. The Indian Space Research Organization (ISRO) has already expressed its interest in joining the International Space Station programme at the International Astronautical Congress held in 2009.

The operational costs for development of robonaut may require considerable investments. The contribution from India for the robotic operations will depend on the tasks assigned and agreed to upon by all the partner nations. The costs of development and participation for design, modelling of software and hardware for robotic operations for detection of life forms in outer space and for initial studies, simulation, laboratory trials of critical components etc is expected to be around **Rs. 500 Cr.** during the XII Plan.

13. Metabolic Diseases

The human body has a remarkable mechanism for conversion of food into energy which is called Metabolism. The ingestion of food in the form of carbohydrates, fats and sugar are assimilated by the body through metabolic pathways. The energy generated by this process, can be used immediately and is also stored as fat for further use when required in the liver, muscles and adipose tissue.

Any changes in the metabolic pathways which disrupts the conversion process, results in disorders. This would mean that the organ in the body does not function normally and requires immediate attention e.g. diabetes. The abnormal accumulation of fat also generates inflammatory pathways, which add to the insulin resistance that is associated with diabetes. Remarkably, the generation of inflammatory pathways may be linked to the properties of the microbial flora in the gut, indicating the interaction that occurs between the human phenotype, genome, and microbiome. Overall, this means that research needs to be conducted into diabetes through more novel pathways, than the traditional paradigm that is related to an excess of energy in the body due either to overeating or due to lowered physical activity.

World statistics show that the country with the largest number of people with diabetes is India. India ranks first in Diabetes and is well likely to be the diabetic capital of the world!

A number of agencies are focusing on support to programme on Diabetes Research. The ICMR has designed, developed and implemented a number of schemes, projects and programmes both national and international in the areas of diabetes research. It is important is to develop a programme with a mandate for scientists and medical practitioners or clinicians to collaborate actively.

A call for proposals for global alliance in diabetes research may be launched. This may be called India Programme XII on Diabetes Research. The areas of research will be identified by a Working Group. The programme will be identified on a project mode with selection/evaluation of proposals as per existing streamlined procedures and norms. The projected outlay is **Rs 25 crores** with partial funding coming from the participating countries.

14. Observatory for Species Protection

In India though we have a number of agencies and institutions working for protection of species especially those which are near extinction, there is no evaluation of risks to species because of technology. An Observatory for Species Protection can evaluate, assess and highlight the risks in the implementation of a particular technology on species and develop regulations for minimization of the risk.

It is not only individual species which face extinction but entire eco systems face destruction. Conservation ecology demands that species and eco systems are protected from extinction in view of the disastrous effect of technology to life forms and from other invasive species.

The marvel of nature is yet to be unravelled, replicated and completely understood by man in view of the robust, smart and perfect methods, mechanisms and systems adopted by nature. It is therefore important to ensure that the current generation leaves for the future generation an ecosystem which is cleaner and greener. The Observatory for Eco Conservation will have chemical & physical testing laboratories, advanced instrumentation facilities, species repository facilities etc

The investments for the Observatory will be through multiagency, multinational and private sector funding. The estimated initial investment for establishment of facilities without land and building with the assumption that the local State Government would provide these infrastructures is expected to be around **Rs 500 Cr**.

15. Renewable Energy Development

In the field of renewable energy; India should establish the largest hybrid solar thermal- fossil plant including flexibility of bio-waste or bio-fuel with smart intelligent transmission and distribution system. The plant should also integrate desalination and production of next generation bio-fuels; algae etc. The specification should be at the cutting edge (shall involve risk in achieving these specification and implementation) and time period should be ambitious.

A large research centre (with plan from inception to growth) coupled with this high technology project has to be created to enable success of the proposal. A Steering Committee with experts and linkages with the best in the country and the world should be set up to formulate Research, Development, Demonstration and Deployment. Implementation should be mission mode and the peer review should be a part of implementation mechanism. The Steering Committee should also focus on maximizing the social benefits.

16. Advanced Transportation

It is clear that urbanization shall increase rapidly in India. Sustainable cities, among many things, shall require advanced transportation, specific to India. There is a need to establish an R & D centre, preferably, in a university model, to involve a large no. of students and industry cluster including entrepreneurs to work on Research, Development, Demonstration and Deployment of advanced transportation systems in a targeted time schedule. The R & D centre should develop robust science based technologies with synergy of existing companies and corporations, etc. or newly created Corporations and Companies, (if needed) should implement the projects with specifically tailored private- public partnerships.

17. Indian Synchrotron for Materials and Energy Research (ISMER)

Synchrotron x-ray radiation is used to carry out measurements over such different fields as atomic and cluster physics, condensed matter physics, chemistry, materials science, structural biology, crystallography, geology etc.

Access to a synchrotron source that can provide high brilliance, nano-sized x-ray beam with tunable energy from a fraction to several tens of keV and with tunable polarization will enable the Indian material research community to determine structure-property relationships of novel materials synthesized in India. Availability of such synchrotron facility will also facilitate significantly Indian research in the fields of biomaterials ranging from protein crystallography to disease biology. Structural genomics and proteomics involve multi disciplinary research drawing expertise from areas as diverse as structural biology (crystallography and spectroscopy and other diffraction techniques including synchrotron light source), computational structure predictions and model building, gene cloning, expression of proteins and cell biology. New functional materials are required to convert, transport and store energy. Breakthroughs in nanomaterials and technology open up the possibility of moving beyond our current alternatives for energy supply. Particularly in development of the future generation (Gen IV) fission reactors such as sodium cooled fast reactors (SFR) or gas-cooled fast reactors (GFR) that requires materials, which withstand high irradiation loads at high temperatures. Nano-scale materials, in fact, play an important role in all the fundamental steps of energy conversion, i.e., charged species diffusion, electron transfer, molecular rearrangements, and chemical reactivity, take place at the nanoscale. Therefore, the invention of novel materials, and new methods to synthesise, characterise, manipulate, and assemble them, create an entirely new and exciting paradigm for developing new and revolutionary energy technologies. Apart from technological development, research in advanced materials including biomaterials have opened up various new basic science issues that could not be studied experimentally earlier and this in turn is giving us new insights in physics, biology, chemistry, environmental science and medical science.

There are about 400 Indian researchers who have used synchrotron sources primarily elsewhere and availability of state-of-the-art synchrotron facility within India will make this number much more respectable. In recent years the Indian scientific community has had access to advanced synchrotron sources in the world like ESRF-France, APS-USA, SPring8-Japan and PETRA-III-Germany and it is expected that the number of Indian scientists eager to use synchrotron sources will increase substantially within a few years.

It should be noted that across the globe only four high-energy synchrotrons, namely ESRF-France, APS-USA, SPring8-Japan and PETRA-III-Germany are catering the very demanding requirements of the world-wide large and growing user-community in the research fields of advanced materials that requires nano-sized (at least~50nm) x-ray beam of tuneable energy up to a high value like 100keV. Only one synchrotron facility, namely PETRA-III, can provide x-ray beam of 50nm or less size as the inherent emittance of the other three synchrotron sources makes it difficult to have x-ray beam less than 200nm size. It is commonly accepted that the need for analytical tools to interrogate in-situ and non-destructively, the functional nanostructures on a molecular level and under environmentally and technologically relevant conditions will rise exponentially in the next two decades and the proposed high-energy high-brilliance fifth source of the world “Indian Synchrotron for

Materials and Energy Research (ISMER)" will become a facility for international users.

ISMER will be a high energy high brilliance third generation electron synchrotron with beam energy of ~6 GeV, a beam current of ~200 mA, and a beam emittance of ~ 1 nm.rad leading to a brilliance of better than 10^{20} photons/s/mm^2/mrad^2/eV. The beam circumference would be about 1490 metres. It is proposed that in the first FIVE years of this planned project, the ISMER synchrotron light source will be developed with few (about 10) beamlines and in the next FIVE years 25 beamlines will be developed keeping rest of the beamlines (around 15) for future developments and some of them can be funded by other countries, if required.

The total estimated cost is **Rs. 5550 Cr** with **Rs. 700 Cr** in the XII Plan and the balance in the XIII Plan.

17a 3 Gev Synchrotron at IISC New Campus

A new 3 GeV synchrotron has been proposed by IISc in their new campus at Chitradurga. This synchrotron is a state of the art synchrotron to undertake fundamental research in physical, chemical and biological sciences.

18. Institution-Industry Consortia for International Mega Science Projects

Participation in building Mega Facilities has hitherto been led by scientists and consortia of scientific institutions in the country. They, in turn, have been outsourcing manufacturing of some of the in-kind items to industries after initial prototyping. As a result of this, industry in India has been limited to supplying some scientific and technical items.

Most of these projects are giant engineering ventures where almost technologies are pushed to extreme levels of sophistication. Contracts for such engineering jobs are usually restricted to the host country or the biggest financial partners.

It may be worthwhile to think of a mechanism whereby participation of Indian industry could also be ensured in the construction of such activities. This may require India pledging greater percentage of the cost, but large portion of the budget may come from the industry. Further, even if some investments need to be made by the Government in industry, it may be worthwhile as the technical know-how to be gained will be at the very frontiers of engineering. This will also generate employment for high-tech engineers.

While it may be argued that industry can always manage on its own and Government need not intervene. Planning of such projects, however, takes considerable time (roughly a decade) and contracts for large scale engineering jobs get restricted to the major financial contributors. Hence, unless industry is also involved in the collaboration consciously and from the beginning, it will be difficult to commit large funding which will bring such contracts to India.

With growing Indian economy, enhanced capabilities of Indian industry and credibility of the Indian scientific community, it is suggested that participation in such collaborations involve both industry and institutions and by leveraging public-private funding.

ANNEX

FINANCIAL SUMMARY OF PROJECTS

Serial No.	PROJECT TITLE	BUDGET Rs. Crore
1	High Energy Physics projects at CERN	248.00
2	Facility for Anti-proton Ion Research (FAIR), Germany	230.00
3	India-based Neutrino Observatory (INO)	1323.77
4	CSIR Supercomputing facility for Innovative Research	458.00
5	Monsoon Mission	400.00
6	Weather and Demographic Data Collection	362.76
7	Earthquake Studies and Prediction - Deep borehole investigation in Koyna-Warna Region	400.00
8	Water Cycle studies	120.00
9	Enabling R & D Technologies for Indian High Intensity Proton and Electron Accelerators with collaboration with CERN and US Labs	3000.00
10	Laser Interferometric Gravitational Observatory (LIGO)	650.00
11	Square Kiliometre Array (SKA)	70.00
12	Thirty Metre Telescope	700.00
13	Solar Energy Development	
14	Detection of Life in Other Planets	500.00
15	Programme on Metabolic Diseases	25.00
16	Observatory for Species Protection	500.00
17	Renewable Energy Development	
18	Advanced Transportation	
19	Indian Synchrotron for Materials and Energy Research (ISMER)	700.00
20	Institution-Industry Consortia for International Mega Science Projects	
	TOTAL	**10687.53**