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

Report by NASI Study group
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THE NATIONAL ACADEMY OF SCIENCES, INDIA

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राष्ट्रीय विज्ञान अकादमी, भारत
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Foreword

Capability to build new technologies that significantly impact nations and societies is clearly one of the most important factors that determine relative competitiveness of nations. Our country has had a very distinguished heritage in knowledge and technology domain. In the post-independence era, determined efforts have been made to strengthen and grow knowledge and technology institutions and inculcate scientific temper among masses. It is clear that intense scientific pursuit is the key to broadening and deepening frontiers of our knowledge as well as creating new technologies ahead of others. In addition, one needs a conducive environment to encourage innovation and facilitate translation of new knowledge acquisitions to new technologies. Clearly, the resources we mobilise, ambiance to nurture talent and creativity that we sustain, healthy value system and enlightened peer governance that we nurture etc. are some of the key factors that would determine our success.

Efforts so far have led to significant progress in our science and technology indicators. As a matter of fact, the rate of improvement in terms of scientific publications has been among the best in some areas. We also know that young Indian S&T professionals have made spectacular impact abroad. Some of our mission mode S&T programmes have taken India to global leadership position. It should thus be possible to envision an India that is fully self-reliant on her technology needs and is a major provider of technologies to the world at large. This is a major challenge that we must realise.

The National Academy of Sciences, India, the oldest and the largest Science Academy of our country, has been pursuing the agenda of Science & Society right since the beginning. In this context, it was felt desirable to study "Indian Science, its Competitive Strength and its Relevance to National Needs". I am glad that the study group consisting of Prof. Ashok Misra, Prof. Jayesh Bellare, Prof. Rohini Godbole, Dr. Chandrima Saha, Prof. K.V.R. Chary, Dr. S. L. Hoti and Dr. Sampat Kumar Tandon has completed this work in a diligent manner. I would like to express my gratitude to them as well as to all other contributors to this effort.

I do hope that the report would trigger comprehensive national level discussion and appropriate actions by all stakeholders in this important area.

Anil Kakodkar

Indian Science, its Competitive Strength and its Relevance to National Needs – Report by NASI Group Study

A. Preamble

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

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

Scientific Academies can be a beacon of this and the National Academy of Sciences, India (NASI) has taken a lead. The Council of NASI deliberated on this issue in its meeting held in February, 2017. This subject is close to the basic tenets of NASI, India's first and hence oldest Science Academy, which has taken on a mandate of Science and Society. This subject is also a matter of personal conscience of the Fellows and Members of NASI. Therefore, it was decided that the Academy should look at:

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

ii. Leveraging basic research for demand driven technology programmes.

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

iv. How basic research can address and solve national problems?

A group was set up to look into and give their views to the Council in due course. The group consists of the following:

Prof. Ashok Misra

Prof. Jayesh Bellare

Prof. Rohini Godbole

Dr. Chandrima Saha

Prof. K.V. R. Chary

Dr. S. L. Hoti

Dr. Sampat Kumar Tandon

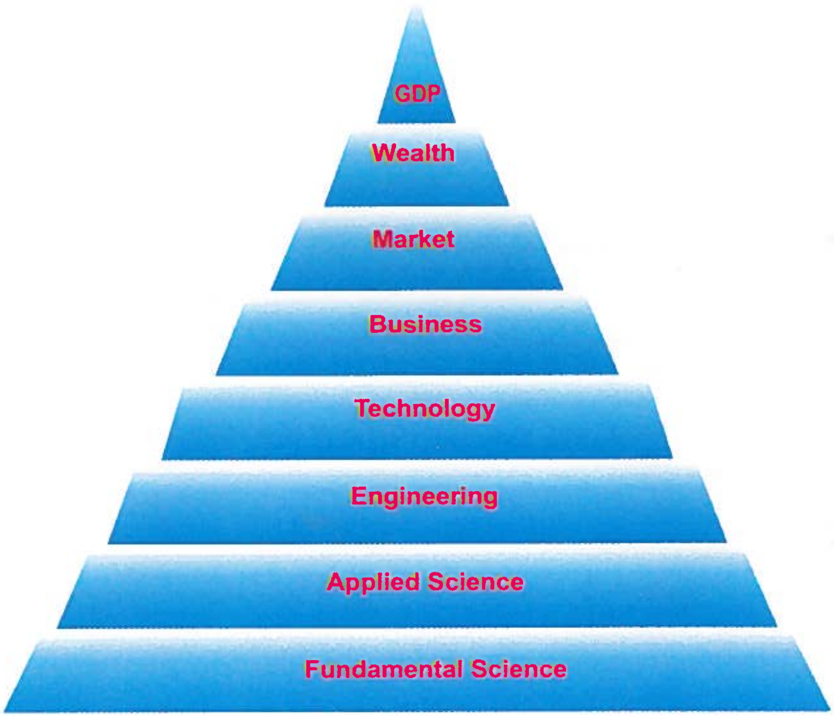
The terms of reference set by the committee for itself were the following:

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

2. *Analyse the feasibility potential for translation of these into applied work and in turn their applicability to technology transfer.*
3. *Determine the technology and innovation needs in national context and the extent to which inventions and innovations nurtured in India can be leveraged.*
4. *Critically review the status of the intellectual properly canvas and its growth.*
5. *Examine if the systems for invention, innovation and Intellectual Property development are adequately addressed.*
6. *Analyse the impact of basic research leading to technology development and in turn leading to technology transfer for addressing the national needs.*
7. *Assess areas of science of high technology importance and bridge gap areas, if any.*

B. Background

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



Many of our older universities with a rich scientific heritage (e.g. Allahabad University, located in the city where NASI is headquartered) have ceased to be centers of excellence mainly due to dearth of quality faculty, lack of good facilities for experimentation as well as state-of-the-art scientific research and administrative lethargy. Even some of the largest and historic universities like Mumbai University and Banaras Hindu University have not been spared this downturn.

Of the established institutions, a few have acquired a powerful brand name worldwide and are performing reasonably well on the science and technology front. Among them are the Indian Institutes of Technology (IITs), Indian Institute of Science, Bangalore(IISc), Indian Institutes of Science Education and Research (IISERs), Tata Institute of Fundamental Research (TIFR) and its sister institutions like National Centre for Biological Sciences (NCBS), All India Institute of Medical Sciences (AIIMS), Tata Memorial Centre-Advanced Centre for Treatment, Research and Education in Cancer (TMC-ACTREC), Inter-University Centre for Astronomy and Astrophysics (IUCAA), Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Indian Association for the Cultivation of Science (IACS), National Institutes of Technology (NITs), Indian Statistical Institutes (ISIs) and several Institutions under the GOI agencies and departments like Department of Atomic Energy (DAE), Department of Science & Technology (DST) and Department of Bio-Technology (DBT). However, the emphasis on basic science is given its due place only in a few of these institutions. The above is a representative list and not an exhaustive one. The mandate of the science departments in a handful of these institutions is not enough to meet the aspirations of the nation. Enthusiastic students wanting to pursue science are not able to find a place that can satisfy their zeal. Coupled with this is the lack of enthusiasm amongst the youth to pursue higher level studies in the fields of science.

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

Research in basic sciences has always been the foundation of transformational technology. Basic sciences sits at the base of the national progress pyramid (shown above), followed by applied sciences, engineering, technology, business, market and wealth of the nation at its apex as depicted in the pyramid. Clearly fundamental science is the key to technology development and in turn wealth creation and increase in GDP.

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

Nevertheless, education and research in basic sciences has to remain our nation's highest priority and it should go hand-in-glove with education and research in applied research and technology development. What do we mean by science in this context? It is pertinent to locate the type of scientific endeavour in a diagram that includes Pasteur's quadrant, along with Bohr's and Edison's :

Applied and Basic research			
		Considerations of use?	
		No	Yes
Quest for fundamental understanding?	Yes	Bohr	Pasteur
	No		Edison

1. Science is search for knowledge for knowledge's sake alone, without regard for any application (a.k.a. blue sky research, thirst for knowledge, individual craving, creativity, seeking truth).

2. Technology is the application of knowledge for an economic or social good.

3. Directed science comes in-between. It is fundamental knowledge that in itself does not translate to applications but is essential to translate a basic science into innovation and then into an application. The synergy between science and technology is influenced by directed basic research. This is best described as 'locating research in Pasteur's quadrant.

A few examples include the discovery of X-rays, n- and p-type semiconductors, the phenomena of nuclear magnetic resonance, penicillin and the cross-linking of rubber. There are two aspects to this: one excelling in domain knowledge of applied importance and the second providing solution to an important problem leveraging the latest in scientific enquiry. The demand driven research with the involvement of users can perhaps deliver better results in the latter case. There is a need to give relative priority to the above three when under resource constraints as well as to decide what to work on: industry, agriculture, health, others. This follows to develop a system to prioritise the areas to work on. Finally there is a need to do a sensitivity analysis to relate investment spends to scientific outcomes. A national science policy and vision should be developed for this.

How to account for long lead times of impact? Basic research often takes many years/decades/ or even longer to have a meaningful impact. It is almost impossible to predict how discoveries would shape the future. Some examples of interest are:

1. It took 40 years after the discovery of DNA before it became known as the basis of genetic engineering. Remarkable uses of recombinant DNA technology in forensic sciences, medicine, agriculture, industry and environment have revolutionized our existence in the world.

2. The discovery in the 1950s on the basis of sickle cell disease due to substitution of a single amino acid resulted in better tests for detection of the disease and ways to treat in the 1970s. The life span of these patients and the quality of life vastly improved due to this fundamental discovery two decades earlier.

3. Determination of structure of transthyretin 30 years ago in UK has provided better diagnosis and development of possible treatments for Alzheimer's disease.

4. When GSK3 protein was discovered in the 1970s, it was not possible to predict that it would revolutionize dentistry by transforming the ways by which cavities are treated.

5. Shambhu Nath De's clinical observations in the late 1950s on Cholera suggesting that an exo-toxin was the cause of pathology of cholera stimulated by water loss induced by the toxin, resulted in the formulation of oral rehydration therapy in the 1990s. This saved

millions of lives. It took 40 years for a fundamental discovery to be translated into a life saving effort.

6. P. C. Ray, a chemist of repute, interested in mercury because of its importance in ayurvedic medicine, described the preparation of mercurous nitrite in 1912. This compound, years later was used in dyeing and printing, photography and many other applications that were not apparent at the time of its discovery.

7. Today, 25% of GDP of developed countries is attributed to applications of quantum theory that was not envisaged at the time of development of the theory many years ago.

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

Some specific industry and corporate examples where excellent research facilities have been set up include Mahindra (incorporating engineering polymers); Bharat Forge (including metallic materials), Sabic (making polymers); GE India (MRI machines for low cost); Praj (ethanol); Biocon (enzymes and biologicals); DRL (drugs) and several others. If Industry involvement is there at the conceptualization stage of projects then it can bring fruitful result and Industry can provide funding. However, it was pointed out that in most cases, Industry is asked to fund when half of the work is done and at that the relevant Industry may find it not to be useful. There is a great amount of scope to enhance collaboration between the Industry and the research / academic institutions. Clearly much more is still needed to be done, particularly at early stages of problem identification.

Competitiveness cannot come at the price of safety or compromise in research integrity and ethics. The issues of safety and ethics are central to the practice and excellence of science. Although some of academic and research institutions have put in place safety measures and ethical practices pertaining to human, animal and research, the situation is grave in institutions belonging to lower strata including universities and colleges. For example, in most of the colleges students of chemistry stream continue to do pipetting of hazardous chemicals through mouth and use burners without fire safety tools in their laboratories. There is a need to provide appropriate equipment and safety devices (such as safety glasses, gloves and mechanical pipetting devices, for example) at all levels of education and research institutions of different disciplines.

Unethical research practices, especially scientific misconduct is a major challenge for sustaining of institutional excellence. Duplication of research, data cooking and engineering, plagiarism, honorary authorship and publishing in predatory journals are some of the factors, which contribute to the decay of excellence. In some of the institutions, although ethical codes are instituted, scientists tend to flout these norms. Hence, the institution heads need to ensure compliance. Fang et al have reported in 2012 that 21.3% of retractions were attributable to error. In contrast, 67.4% of retractions were attributable to misconduct, including fraud or suspected fraud (43.3%), duplicate publication (14.2%) and plagiarism (9.8%). A close watch on violators and penalizing them is very essential. This calls for framing and institution of appropriate guidelines to curb such unethical practices.

The highest level of ethics is to be used in animal and human experimentation. Animals are increasingly used for education, research and pharmaceutical production purposes, for which billions of small and large animals are used every year. The principles of animal experimentation emphasizes that it is morally acceptable to use nonhuman animals for human purposes as long as they are treated humanely and do not impose unnecessary suffering on them. Although, there is growing awareness about adopting ethics in animal experimentation, in view of the guidelines framed by CPCSEA (Committee for the Purpose of Control and Supervision of Experiments on Animals) and establishment of institutional ethics committees wherever animal experimentation is performed; strict vigilance needs to be in place for ensuring total compliance. Wherever possible, alternate systems such as use of models in educational institutions and cell lines and other biological systems in research and manufacturing units should be used. Further, when animal use is absolutely necessary the animals being used are to be treated in the most humane manner.

Unethical practices in the use of human subjects both in research and clinical trials by institutes and pharmaceutical industries are major issues. There have been a few thousand deaths recently due to clinical trials of pharmaceutical products in India alone, as also deceitful activities by researchers, often inflicting sever sufferings to the study subjects. Such activities need to be curbed and strict vigilance regarding the compliance of the ethical guidelines need to be ensured.

C. <u>Deliberations.</u>

The highlights of the deliberations of the NASI committee are given below. Overall, it was recognised that the competitiveness of Indian science with respect to basic research, as well as its speedy translation to technology, needs attention in the context of growing importance of basic knowledge in economic and other activities of national importance.

Some of the dimensions of this multifaceted issue that we need to address are:

1. **Nurture excellence in research**: Basic research should lead to the invention that feeds innovation. Enabling systems should be put in place for this to happen as mentioned in subsequent points.

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

    a. **Provide high quality Education** in order to develop quality manpower.
    b. **Conduct Basic Research and Development** and develop new knowledge.
    c. **Carry out Applied Research and Development** and develop advanced technologies.
    d. **Create Inventions, Innovation and Intellectual Property.**

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

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

5. **Enhance industry-academia interaction**: This would include interactions with the micro, small and medium enterprise (MSME) industry, particularly receptiveness of industry to new and/or indigenous technology, through awareness, education and joint research that gives rise to meaningful collaboration and ability to absorb inventions. Industry investment in science can be a good measure of excellence in

translational research along with parameters like: i) number of start-ups bigger than a threshold level of investment, ii) investment attracted by domestic technology developed and IP generated through research, iii) first of kind technologies with user impact developed, and iv) significant strategic advantage for the country.

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

7. **Translation of basic research to technology development**: We may have missed the silicon foundry, but we should build the mechanism to absorb the micro/nano-electronics inventions and innovations. This is a very important and critical aspect for the translation of basic research to technology development. This needs the involvement of the concerned industry as partners in the research projects from an early stage. Such an interaction would provide researchers directions to their research to address industrial needs. On the side of the industry, they need to develop an appreciation of basic research to address their problems. Initially it would make more sense to tap the industry demand to start directed research projects.

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

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

10. **Set up translation institutions**: Like the Faridabad health cluster of DBT for validation and improvement of technology readiness levels (TRL) of basic science being translated to technology. Agencies like CSIR and ICMR should be proactive in this direction.

Their labs should be re-dedicated to the task of technology innovation and translation rather than solely on teaching or pursuit of blue sky research.

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

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

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

14. **Encourage and inculcate the scientific temper and method in the public at large through programmes/curricular at school and for lay public**: There is a need to train the trainer at all school and college levels. Public advocacy should be there through Information, Education and Communication in local communities and through massive online courses. There should be advocacy to 18-year olds. To encourage students from school upwards, the scientific method of inquiry and questioning should be encouraged at home and at school. As a part of learning science, there should be emphasis in STEM for developing and rewarding experimental skills and innovativeness such that student's experience, apart from excitement of doing science, offers multiple exciting career opportunities that makes taking to science more popular.

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

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

17. **Improve trained scientists in terms of number and quality**: This is a critical issue as we have to have scientists for the future. How can the students in these institutions be excited for pursuing basic sciences and be innovative. Although there is a lot of interest and enthusiasm for science, but insufficient exposure to role models or clear prospects in science, added with struggle for access to appropriate infrastructure/facilities,

discourages many potential science graduates to veer away from pursuing scientific careers. There is a need to attract good graduate students into project-mode R&D. For example, success of large science projects like GMRT/LIGO/Astrosat/LHC, can be leveraged to draw-in students and sustain their careers. For this, more job opportunities through long-term schemes need to be created.

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

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

20. **Establish linkages between CSIR and academic institutions** (like IITs, AcSIR, IISc, IISERs, TIFR, NCBS, AIIMS, TMC-ACTREC, IUCAA, JNCASR and NITs). This would synergise their expertise. There should be greater engagement between basic science institutions and technology institutions.

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

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

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

24. **Government should have more of the DBT - BIRAC type small business funding models, for start-up proof-of-concept, industry-institution collaboration and more**: BIRAC has been a good model that can be pursued in other areas. Uchhatar Avishkar Yojna type schemes have been good, but they should begin with industry-led problem definition; Government should ask industry first for a wish-list, then fund institutes. Some industries have funded master's and other students and academic programs, e.g., NTPC at IIT Delhi; Bharat Forge and BPCL at IIT Bombay and Steel Industry at IITB.

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

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

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

28. **To gauge the value of national investments, we can compare various countries**: Countries like South Korea and China have increased their expenditure in science steadily over the last decade whereas in India it has remained almost constant; India and China have similar population but the number of scientifically trained people in China is about 6 to 7 times that in India. USA has 18 out of every 10000 involved in Science, in China it is 20 out of 10000 and in India 4 out of 10000 are involved in science. China, which was poorer than India 30 years ago, but now the situation is flipped and experts like Prof. David Gross credit doubled spending on scientific research for the country's growth.

    Countries which have a strong base in science and technology are the ones that developed faster. Examples: Russia, Japan, Brazil, China, India and more. USA which invests a large amount for research and development is in the highest stratum of development whereas countries like Nepal who invest less remain in the lowest ladder of development.

    A graphic from the Times of India Oct 29, 2017 illustrates the situation well (Annexure 3)

E. Executive summary of recommendations:

1. Identify and setup systems to transform basic research into inventions that feed innovations. Government to fund basic research and keep the industry in the loop. This can be facilitated by organisations like CII.
2. Constitute a Science Policy Task Force to identify what exactly is needed scientifically, how to prioritize it, and how to achieve it. Yet allow for blue-sky research, here again with the active participation of the industry.
3. Partner with policy institutions to flesh out this report by putting numbers to quantify parameters identified in this report and to develop new and better measures of the impact of science because GDP is not a good measure. To convince policy makers to provide economic value of some scientific/technological discoveries or innovations made by Indians in India.
4. Have sufficient technology incubators and translation institutions that can take the basic research to a new level of forming enterprises. For this involve the Venture Capitalists and the relevant industry to provide timely "Invention Capital" and avoid the proverbial Death Valley syndrome.
5. Have a scheme to link industries to scientific institutes through projects for specific long term deliverables identified by industry and funded by Government.
6. Promote tool building (including advanced tools like those used in GMRT, LIGO, etc.) at various levels, like through hardware hackathons.
7. Have better publicity of the impact of basic research through traditional media (print, TV) and modern media (Facebook, Twitter, etc.).
8. Nurture IP awareness amongst students at all levels, including Ph.D., Masters, and Bachelors as well as in high schools.
9. There should be persuasion of research. As an example, it should be ensured that the research output does not die when a Ph.D. is completed or the Professor retires.
10. Develop means to excite students into science through mentorships, internships (expand National Academies' internship programmes). Emphasize science teaching with modern labs in metro schools as well as remote area schools, since scientific talent can come from anywhere.
11. Use health improvement measures like: infant and child mortality, DALYs (disability-adjusted life year), child nutrition status, social and mental health, quality of life indicators or even socio-economic indicator to publicise program benefits like polio mission, Asha, etc.
12. Establish network amongst basic research groups to prevent duplication of efforts. Further, the institutions should avoid duplicating research done in Advanced Countries, and if done it should go beyond the level achieved so that India creates IPR in the competitive areas.

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

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

References

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2. https://www.indiabudget.gov.in/budget2017-2018/ub2017-18/eb/stat24.pdf
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Annexure 1: Autonomous/Grantee Bodies Supported by Government of India

The Government of India supports several autonomous institutes/organizations under various Ministries and Departments. The budgetary support for select bodies in the domain of Science and technology are given in table below.

Source:

Ref. 2: https://www.indiabudget.gov.in/budget2017-2018/ub2017-18/eb/stat24.pdf

Ref. 3: https://www.indiabudget.gov.in/ub2018-19/eb/stat24.pdf

(inRs. Crores)

Ministry/Department		2016-17 Actual	2017-18 Budget Estimate	2017-18 Revised Estimate	2018-19 Budget Estimate
	Grand Total	**55976.30**	**62799.64**	**69422.54**	**66962.60**
Ministry of Agriculture and Farmers' Welfare		**6317.33**	**6909.26**	**7046.23**	**7206.57**
Department of Agriculture, Cooperation and Farmers' Welfare					
1	National Institute of Agricultural Extension Management	38.95	57.49	6.00	8.30
2	National Institute of Plant Health Management	17.92	33.18	33.18	41.58
3	Protection of Plant Varieties and Farmer's Rights	20.50	19.50	16.50	20.00
Department of Agricultural Research and Education					
1	Central Agricultural University, Imphal	120.00	120.00	120.00	134.00
2	Dr.Rajendra Prasad Central Agricultural University, Pusa	35.50	76.00	82.00	89.00
3	Indian Council of Agricultural Research	6023.33	6549.02	6740.55	6855.18
4	National Academy of Agricultural Sciences/Indian Agriculture Universities Association	1.50	2.00	1.50	1.56
5	Rani Lakshmi Bai Central Agriculture University, Jhansi	44.50	39.00	33.50	47.00
Department of Animal Husbandry, Dairying and Fisheries					
1	Coastal Aquaculture Authority	3.80	4.00	3.50	4.00
2	National Fisheries Development Board	10.33	8.07	8.50	4.95
3	Veterinary Council of India	1.00	1.00	1.00	1.00
Department of Atomic Energy		**2124.98**	**2179.38**	**1997.81**	**2000.00**
Atomic Energy					
1	Tata Institute of Fundamental Research	643.39	644.00		
2	Tata Memorial Center, Mumbai	452.00	472.12		
3	Institute of Plasma Research, Gandhinagar	519.70	521.55		
4	Other Autonomous Bodies	509.89	541.71	1997.81	2000.00

Ministry/Department		2016-17 Actual	2017-18 Budget Estimate	2017-18 Revised Estimate	2018-19 Budget Estimate
Ministry of Ayurveda, Yoga and Naturopathy, Unani, Siddha and Homoeopathy (AYUSH)		**665.03**	**722.61**	**849.97**	**906.70**
Ministry of Ayurveda, Yoga and Naturopathy, Unani, Siddha and Homoeopathy (AYUSH)					
1	All India Institute of Ayurveda (AIIA), New Delhi	26.00	24.00	19.59	32.00
2	Central Council for Research in Ayurvedic Sciences	159.00	175.00	216.07	252.91
3	Central Council for Research in Homoeopathy (CCRH), New Delhi	81.50	95.50	112.25	109.50
4	Central Council for Research in Siddha (CCRS), Chennai	24.17	25.00	26.94	28.50
5	Central Council for Research in Unani Medicines (CCRUM), New Delhi	118.00	123.00	133.93	130.00
6	Central Council for Research in Yoga and Naturopathy (CCRYN), New Delhi	27.00	32.00	32.00	29.00
7	Indian Institute of AYUSH Pharmeceutical Sciences	...	0.10	0.10	...
8	Institute of Post Graduate Teaching and Research, Jamnagar	29.60	31.00	30.99	34.00
9	Moraji Desai National Institute of Yoga, New Delhi	8.00	9.00	12.02	16.00
10	National Institute of Ayurveda, Jaipur	55.07	56.00	95.41	90.00
11	National Institute of Homoeopathy, Kolkata	35.17	37.50	51.90	46.00
12	National Institute of Naturopathy, Pune	25.90	26.00	5.50	24.00
13	National Institute of Siddha, Chennai, Tamilnadu	25.00	30.00	29.42	35.50
14	National Institute of Sowa Rigpa	4.00	1.00	0.50	1.00
15	National Institute of Unani Medicine, Banglore	21.50	25.00	50.50	36.50
16	North Eastern Institute of Ayurveda and Homoeopathy, Shillong	7.55	10.00	11.45	18.00
17	North Eastern Institute of Folk Medicine, Passighat	7.45	10.00	8.55	10.00
18	Pharmacopoeia Commission of Indian Medicine (PCIM)	3.62	3.51	3.85	5.29
19	Rashtriya Ayurveda Vidyapeeth	6.50	9.00	9.00	8.50
Ministry of Chemicals and Fertilisers		**192.46**	**219.69**	**224.73**	**226.13**
Department of Chemicals and Petrochemicals					
1	Central Institute of Plastic Engineering and Technology(CIPET)	57.67	68.08	68.08	83.64
2	Institute of Pesticides Formulation Techonology	7.30	9.16	7.50	7.50
Department of Pharmaceuticals					
1	NIPER, Mohali	27.48	40.46	28.32	29.26
2	NIPER, Ahmedabad	19.48	22.96	22.96	22.96
3	NIPER, Hyderabad	35.00	25.00	30.00	22.00

4	NIPER, Kolkata	8.00	6.00	11.50	10.00
Ministry/Department		**2016-17 Actual**	**2017-18 Budget Estimate**	**2017-18 Revised Estimate**	**2018-19 Budget Estimate**
5	NIPER, Rae Bareli	6.25	8.50	9.50	9.25
6	NIPER, Hajipur	5.00	6.00	6.00	6.00
7	NIPER, Guwahati	26.27	31.50	38.85	33.50
8	NIPER, Chhatishgarh	...	0.02	0.01	0.01
9	NIPER, Rajasthan	...	1.00	1.00	1.00
10	NIPER, Madurai	...	1.00	1.00	1.00
11	NIPER, Maharashtra	0.01	0.01	0.01	0.01
Ministry of Civil Aviation		**42.30**	**45.00**	**45.00**	**49.90**
Ministry of Civil Aviation					
1	National Aviation University	42.30	45.00	45.00	49.90
Ministry of Communications		**415.00**	**390.00**	**287.00**	**260.00**
Department of Telecommunications					
1	Centre of Development of Telematics (C-DOT)	415.00	390.00	287.00	260.00
Ministry of Drinking Water and Sanitation		**9.50**	**34.00**	**36.00**	**52.00**
Ministry of Drinking Water and Sanitation					
1	International Centre for Drinking Water Quality (ICDWQ)	9.50	34.00	2.00	...
2	National Rural Drinking Water Programme			34.00	52.00
Ministry of Earth Sciences		**159.87**	**165.93**	**145.07**	**162.00**
Ministry of Earth Sciences					
1	Indian Institute of Tropical Meteorology (IITM) Pune	63.96	65.90	60.36	65.00
2	Indian National Centre for Ocean Information Services (INCOIS) Hyderabad	27.01	30.05	23.17	25.00
3	National Centre for Antarctic and Ocean Research (NCAOR) Goa	18.90	19.74	14.35	20.00
4	National Centre for Earth Science Studies (NCESS), Thiruvananthapuram	21.00	20.84	19.09	20.00
5	National Institute of Ocean Technology (NIOT) Chennai	29.00	29.40	28.10	32.00
Ministry of Electronics and Information Technology		**767.27**	**1692.96**	**2360.65**	**2678.47**
Ministry of Electronics and Information Technology					
1	Centre for Development of Advanced Computing (C-DAC)	370.50	448.00	448.00	515.00
2	Centre for Material for Electronics Technology (C-MET)	31.60	41.00	41.00	50.60

3	ERNET India			90.00	90.00
4	Media Lab Asia	5.00	5.76	5.76	5.00
Ministry/Department		**2016-17 Actual**	**2017-18 Budget Estimate**	**2017-18 Revised Estimate**	**2018-19 Budget Estimate**
5	National Institute of Electronics and Information Technology			307.99	328.04
6	Society for Applied Microwave Electronics Engineering and Research (SAMEER)	86.50	97.20	96.00	128.00
7	Software Technology Parks of India	273.67	201.00	171.90	186.83
8	Unique Identification Authority of India (UIDAI)	...	900.00	1200.00	1375.00
Ministry of Environment, Forests and Climate Change		**232.60**	**244.80**	**279.00**	**301.50**
Ministry of Environment, Forests and Climate Change					
1	GB Pant Himalayan Institute of Environment and Development	18.00	19.00	20.00	26.50
2	Indian Council of Forestry Research and Education	163.20	171.00	195.00	210.00
3	Indian Institute of Forest Management	17.10	20.60	22.00	25.00
4	Indian Plywood Industries Research and Training Institute	7.80	7.75	9.00	10.00
5	Wildlife Institute of India	26.50	26.45	33.00	30.00
Ministry of Food Processing Industries		**60.98**	**72.74**	**78.43**	**84.90**
Ministry of Food Processing Industries					
1	Indian Institute of Food Processing Technology(IIFPT)	9.33	21.16	25.11	29.10
2	National Institute of Food Technology Entrepreneurship and Management(NIFTEM)	51.65	51.58	53.32	55.80
Ministry of Health and Family Welfare		**7096.73**	**7606.98**	**8689.62**	**8534.21**
Department of Health and Family Welfare					
1	All India Institute of Medical Sciences, New Delhi	2293.00	2400.00	2967.00	3018.00
2	All India Institute of Speech and Hearing, Mysore	75.82	128.02	97.62	133.47
3	Chittaranjan National Cancer Institute, Kolkata	70.00	121.26	121.26	128.54
4	Dental Council of India	0.20	0.25	0.25	0.30
5	Food Safety and Standards Authority of India	72.00	133.58	185.58	141.60
6	Indian Nursing Council	0.21	0.21	0.21	0.21
7	Indian Pharmacopoeia Commission	24.50	33.44	4.00	...
8	Indian Red Cross Society	0.40	0.40	0.40	0.40
9	International Institute of Population Sciences, Mumbai	28.78	32.00	41.75	33.92
10	Jawaharlal Institute of Post Graduate Medical Education and Research, Puducherry	874.00	1034.63	1034.63	1096.70
11	Kasturba Health Society, Wardha	55.00	63.85	41.35	...
12	LGB Regional Institute of Mental Health, Tejpur	80.00	80.00	55.00	60.00

13	LRS Institute of T.B. and Allied Diseases, New Delhi	272.60	71.00	80.20	75.26
14	Medical Council of India	1.00	1.00	1.00	1.00
Ministry/Department		**2016-17 Actual**	**2017-18 Budget Estimate**	**2017-18 Revised Estimate**	**2018-19 Budget Estimate**
15	National Academy of Medical Sciences, New Delhi	1.55	1.80	1.70	1.80
16	National Institute of Biologicals, Noida	37.47	50.02	51.92	41.79
17	National Institute of Health and Family Welfare	52.10	58.30	60.30	65.00
18	National Institute of Mental and Neuro Sciences, Bangluru	302.30	350.94	379.40	382.60
19	New Delhi TB Centre	3.50	4.06	4.91	4.30
20	North-Eastern Indira Gandhi Regional Institute of Health and Medical Sciences, Shillong.	260.20	200.00	335.00	212.00
21	Pasteur Institute of India, Coonor	54.50	70.00	73.50	74.20
22	Pharmacy Council of India	0.20	0.20	0.20	0.20
23	Post-Graduate Institute of Medical Education and Research, Chandigarh	938.58	1139.60	1205.00	1207.98
24	Regional Institute of Medical Sciences, Imphal	269.00	190.00	309.83	201.40
25	Regional Institute of Paramedical and Nursing Sciences, Aizwal	42.05	42.00	37.20	32.00
26	St. John's Ambulance	0.04	0.04	0.04	0.04
27	Vallabh Bhai Patel Chest Institute, Delhi University, New Delhi	53.73	62.38	62.38	65.50
Department of Health Research					
1	Bhopal Memorial Hospital and Research Centre, Bhopal	140.00	188.00	124.39	140.00
2	Indian Council of Medical Research, New Delhi	1094.00	1150.00	1413.60	1416.00
Ministry of Heavy Industries and Public Enterprises		**458.50**	**503.39**	**331.18**	**216.38**
Department of Heavy Industry					
1	Central Manufacturing Technology Institute (CMTI))			...	10.00
2	Development Council for Automobile and Allied Industries	70.50	17.50	24.18	27.50
3	National Automative Testing and R and D Infrastructure Project	388.00	485.89	307.00	178.88
Ministry of Human Resource Development		**29888.01**	**33783.70**	**36784.59**	**32886.14**
Department of School Education and Literacy					
1	Central Tibetan Schools Administration	54.84	54.00	58.62	56.00
2	KendriyaVidyalayaSangathan	3987.25	4300.00	4600.53	4425.00
3	National Bal Bhawan	17.19	18.00	18.91	20.00
4	National Council of Educational Research and Training	228.64	230.00	248.94	253.94
5	NavodayaVidyalayaSamiti	2614.78	2700.00	3025.00	2793.00

Ministry/Department		2016-17 Actual	2017-18 Budget Estimate	2017-18 Revised Estimate	2018-19 Budget Estimate
Department of Higher Education					
1	All India Council for Technical Education	481.00	485.00	485.00	485.00
2	Andhra Pradesh and Telangana Tribal Universities			...	20.00
3	Assistance to Other Institutions	353.82	373.38	438.45	396.65
4	Board of Apprenticeship Training, Bombay, Calcutta, Madras and Kanpur	17.14	19.00	23.50	20.00
5	Central University Andhra Pradesh	1.00	10.00	...	10.00
6	Deemed Universities Promoted by Central Government			60.00	60.00
7	Grants to Central Universities (CUs)	6355.93	6485.93	7261.42	6445.23
8	Grants to Councils/Institutes for Excellence in Humanities and Social Sciences	271.31	285.00	293.50	285.00
9	Grants to Institutes for Promotion of Indian Languages	335.15	350.90	390.31	351.00
10	IIM Andhra Pradesh			41.00	42.00
11	Indian Institute of Science, Education and Research (IISERs)				
	11.01 Support to Indian Institute of Science, Education and Research (IISERs)	740.00	600.00	665.00	640.00
	11.02 IISER Andhra Pradesh	40.00	50.00	50.00	49.00
12	Indian Institutes of Information Technology				
	12.01 Support to Indian Institutes of Information Technology (Allahabad, Gwalior, Jabalpur and Kancheepuram)	148.50	240.00	240.00	214.47
	12.02 Setting up of Indian Institutes of Information Technology in PPP mode	60.00	109.45	109.45	119.45
	12.03 IIIT Andhra Pradesh	20.00	30.00	20.00	30.00
13	Indian Institutes of Technology				
	13.01 Support to Indian Institutes of Management	667.78	800.00	917.00	828.00
	13.02 Setting up new IIMs	160.00	190.00	110.00	166.00
	13.03 Support to Indian Institutes of Technology	4953.51	7171.00	7503.50	5613.00
	13.04 IIT, Andhra Pradesh	40.00	50.00	51.30	50.00
	13.05 IIT, Andhra Pradesh			25.00	10.00
	13.06 IIT Hyderabad (EAP)	20.00	75.00	75.00	75.00
	13.07 Indian School of Mines, Dhanbad	185.20	210.00	240.00	240.00
14	Indira Gandhi National Open University (IGNOU)	101.00	100.00	100.00	100.00
15	National Institute of Industrial Engineering Mumbai	35.10	35.10	38.25	37.25
16	National Institutes of Technical Teachers Training and Research (NITTTRs)	119.75	130.00	132.00	130.00
17	National Institutes of Technology				
	17.01 Upgradation of Indian Institute of Engineering, Science and Technology (IIEST)	99.00	110.00	130.00	130.00

	(BESU and CUSAT)				
	17.02 Support to National Institutes of Technology	2755.92	3280.00	3484.40	3019.40
	17.03 NIT Andhra Pradesh	20.00	50.00	53.77	54.00
Ministry/Department		**2016-17 Actual**	**2017-18 Budget Estimate**	**2017-18 Revised Estimate**	**2018-19 Budget Estimate**
18	New Schools of Planning and Architecture	89.74	100.00	102.00	202.00
19	Setting up New IITs			350.00	338.00
20	Support to Indian Institute of Science (IISc)	422.52	450.00	520.00	455.00
21	University Grants Commission	4491.94	4691.94	4922.74	4722.75
Ministry of Micro, Small and Medium Enterprises		**318.74**	**338.15**	**1360.79**	**1474.63**
Ministry of Micro, Small and Medium Enterprises					
1	Coir Board	36.85	46.15	68.20	90.00
2	Khadi And Village Industries Commission	271.74	282.00	1282.59	1374.63
3	Mahatma Gandhi Institute For Rural Industrialisation	10.15	10.00	10.00	10.00
Ministry of Mines		**25.05**	**29.54**	**27.67**	**19.24**
Ministry of Mines					
1	Jawahar Lal Nehru Aluminium Research and Design Development Centre (JNARDDC)	10.05	13.29	13.29	9.29
2	National Institute of Miner's Health (NIMH)	3.06	3.26	3.02	1.96
3	National Institute of Rock Mechanics (NIRM)	11.94	12.99	11.36	7.99
Ministry of Minority Affairs		**114.00**	**113.00**	**113.01**	**125.01**
Ministry of Minority Affairs					
1	Maulana Azad Education Foundation	114.00	113.00	113.01	125.01
Ministry of New and Renewable Energy		**35.00**	**53.00**	**45.00**	**41.00**
Ministry of New and Renewable Energy					
1	National Institute of Bio Energy	3.00	8.00	2.00	3.00
2	National Institute of Solar Energy	7.00	20.00	20.00	18.00
3	National Institute of Wind Energy	25.00	25.00	23.00	20.00
Ministry of Petroleum and Natural Gas		**116.95**	**156.78**	**203.76**	**102.29**
Ministry of Petroleum and Natural Gas					
1	Centre of Excellence for Energy, Assam			1.00	1.00
2	Centre of Excellence for Energy, Bangalore			1.00	1.00
3	Indian Institute of Petroleum Technology			1.00	32.00
4	Petroleum and Natural Gas Regulatory Board (PNGRB)	15.23	18.34	35.99	26.07
5	Rajiv Gandhi Institute of Petroleum Technology	100.00	135.10	159.75	37.00

6	Society for Petroleum Laboratory (SFPL)	1.72	3.34	5.02	5.22
Ministry/Department		**2016-17 Actual**	**2017-18 Budget Estimate**	**2017-18 Revised Estimate**	**2018-19 Budget Estimate**
Ministry of Power		**178.04**	**263.39**	**141.75**	**359.21**
Ministry of Power					
1	Bureau of Energy Efficiency (BEE)	60.04	49.00	27.00	100.16
2	Central Power Research Institute9 CPRI)	65.79	150.00	50.36	150.00
Ministry/Department		**2016-17 Actual**	**2017-18 Budget Estimate**	**2017-18 Revised Estimate**	**2018-19 Budget Estimate**
3	Joint Electricity Regulatory Commission (JERC) Goa and UT	6.81	7.19	7.19	8.50
4	National Power Training Institute (NPTI)	45.40	57.20	57.20	100.55
Ministry of Rural Development		**113.20**	**112.92**	**112.93**	**161.00**
Department of Rural Development					
1	Council for Advancement of People's Action and Rural Technology (CAPART)	10.00	20.00	20.00	24.00
2	National Rural Road Development Agency (NRRDA)	23.00	34.00	34.00	37.00
3	National Institute of Rural Development (NIRD)	60.20	50.00	50.00	75.00
4	National Rural Liveihood Promotional Society (NRLPS)	20.00	8.92	8.93	25.00
Ministry of Science and Technology		**5771.46**	**6264.39**	**6370.13**	**6586.22**
Department of Science and Technology					
1	Agharkar Research Institute, Pune	22.32	23.90	23.68	25.45
2	Aryabhatta Research Institute of Observational-Sciences, Nanital	32.58	33.71	17.23	18.80
3	BirbalSahni Institute of Palaeobotany, Lucknow	72.61	86.12	36.49	39.27
4	Bose Institute, Kolkata	135.12	81.99	82.79	91.51
5	Centre for Nano and Soft Matter Sciences, Bangalore	14.61	19.14	12.44	13.22
6	Indian Academy Of Sciences, Bangalore	13.50	14.31	11.50	12.17
7	Indian Association for the Cultivation of Science, Kolkata	91.12	113.14	109.50	115.05
8	Indian Institute of Astrophysics, Bangalore	64.08	68.17	59.48	66.61
9	Indian Institute of Geomagnetism, Mumbai	39.45	42.05	39.77	42.84
10	Indian National Academy Of Engineering, New Delhi	6.99	7.41	5.51	5.91
11	Indian National Science Academy, New Delhi	23.50	23.24	19.00	20.70
12	Indian Science Congress Association, Kolkata	8.50	7.22	9.50	10.46
13	Institute of Nano Science and Technology,	58.00	91.68	63.34	54.49

	Ministry/Department	2016-17 Actual	2017-18 Budget Estimate	2017-18 Revised Estimate	2018-19 Budget Estimate
	Mohali				
14	International Advanced Research Centre for Powder Metallurgy and New Materials, Hyderabad	59.89	59.90	62.38	64.05
Ministry/Department		**2016-17 Actual**	**2017-18 Budget Estimate**	**2017-18 Revised Estimate**	**2018-19 Budget Estimate**
15	Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore	79.73	81.39	78.91	84.62
16	National Academy Of Sciences, Allahabad	12.50	11.49	15.31	16.17
17	National Innovation Foundation	15.84	16.80	18.80	20.38
18	Raman Research Institute, Bangalore	43.79	43.48	48.35	52.17
19	S.N. Bose National Centre for Basic Sciences, Kolkata	36.11	38.50	42.20	45.23
20	SreeChitraTirumal Institute for Medical Sciences and Technology, Trivandrum	169.13	202.84	202.11	189.62
21	Technology Information, Forecasting and Assessment Council (TIFAC)	10.50	11.13	16.00	17.71
22	The Institute of Advanced Study in Science and Technology, Guwahati	39.40	30.28	32.37	33.38
23	VigyanPrasar, New Delhi	17.83	18.91	17.80	19.67
24	Wadia Institute of Himalayan Geology, Dehradun	32.64	35.70	38.02	41.04
Department of Biotechnology					
1	Assistance to Autonomous Institutions			...	748.99
2	Centre for DNA Finger Printing and Diagnostics,Hyderabad	60.00	38.20	40.20	...
3	Centre of Innovative and Applied Bioprocessing, Mohali	16.00	16.50	14.46	...
4	Institute for Stem Cell Research and Regenerative Medicine, Bengaluru	71.00	79.00	87.36	...
5	Institute of Life Sciences, Bhubaneswar	37.00	64.80	59.40	...
6	Institute of Bioresources and Sustainable Development, Imphal	38.16	27.00	27.00	...
7	International Centre for Genetic Engineering and Biotechnology, New Delhi	29.00	39.59	34.50	...
8	National Agri-Food Biotechnology Institute, Mohali	68.50	33.84	31.00	...
9	National Brain Research Centre, Gurgaon	31.00	42.00	43.01	...
10	National Centre for Cell Science, Pune	48.50	53.80	54.85	...
11	National Institute for Plant Genome Research, New Delhi	28.50	30.65	38.00	...
12	National Institute of Animal Biotechnology, Hyderabad	36.50	64.80	75.50	...
13	National Institute of Biomedical Genomics, Kalyani	27.00	29.40	26.94	...
14	National Institute of Immunology, New Delhi	60.00	68.50	67.00	...
15	Rajiv Gandhi Centre for Biotechnology, Thiruvananthapuram	52.00	64.40	65.66	...
16	Regional Centre for Biotechnology, Faridabad	21.50	23.50	25.65	...

17	Translational Health Science and Technology Institute, Faridabad	33.50	36.00	34.00	...
Department of Scientific and Industrial Research					
1	Consultancy Development Centre	0.50	2.00	1.00	2.00
2	Council of Scientific and Industrial Research	4013.06	4387.91	4582.12	4734.71
Ministry/Department		**2016-17 Actual**	**2017-18 Budget Estimate**	**2017-18 Revised Estimate**	**2018-19 Budget Estimate**
Ministry of Skill Development and Entrepreneurship		**14.66**	**20.00**	**2.00**	**0.00**
Ministry of Skill Development and Entrepreneurship					
1	National Skill Development Agency (NSDA)	14.66	20.00	2.00	...
Department of Space		**551.01**	**541.63**	**664.20**	**615.00**
Department of Space					
1	Indian Institute of Space Science and Technology (IIST)	96.50	100.00	100.00	110.00
2	National Atmospheric Research Laboratory (NARL)	23.17	30.00	24.20	40.00
3	North Eastern Space applications Centre (NE-SAC)	20.47	21.63	30.00	35.00
4	Physical Research Laboratory (PRL)	151.00	180.00	190.00	180.00
5	Semiconductor Laboratory (SCL)	259.87	210.00	320.00	250.00
Ministry of Statistics and Programme Implementation		**268.81**	**282.15**	**271.65**	**279.42**
Ministry of Statistics and Programme Implementation					
1	Indian Statistical Institute	268.81	282.15	271.65	279.42
Ministry of Textiles		**16.32**	**27.00**	**3.00**	**2.00**
Ministry of Textiles					
1	Central Wool Development , Jodhpur	16.32	27.00	3.00	2.00
Ministry of Water Resources, River Development and Ganga Rejuvenation		**22.50**	**27.25**	**951.37**	**1596.68**
Ministry of Water Resources, River Development and Ganga Rejuvenation					
1	Brahmaputra Board			102.17	112.88
2	HRD/Capacity Building Program	3.50	3.50	4.40	13.69
3	National Institute of Hydrology	19.00	23.75	37.75	58.14
4	National Mission for Clean Ganga			723.44	1320.00
5	National Water Development Agency			83.61	91.97

Annexure 2: Central Sector Schemes Government of India

The Government of India has several central sector schemes under various Ministries and Departments. The budgetary support for select schemes in the domain of Science, Engineering and Technology are given in table below.

Source:

Ref. 3: https://www.indiabudget.gov.in/ub2018-19/eb/vol1.pdf

(inRs. Crores)

Ministry/Department		2016-17 Actual	2017-18 Budget Estimate	2017-18 Revised Estimate	2018-19 Budget Estimate
	Grand Total	**36946.32**	**41642.61**	**38685.26**	**52067.40**
Department of Agricultural Research and Education		**4643.56**	**1902.66**	**1902.66**	**2640.42**
1	Agricultural Engineering	190.86	42.68	42.68	100.00
2	Natural Resource Management Institutes including Agro Forestry Research	610.24	167.68	167.68	174.39
3	Climate Resilient Agriculture Initiative	70.00	50.00	50.00	52.00
4	Crop Science	1347.93	387.41	399.66	800.00
5	Horticultural Science	522.29	154.90	154.90	200.00
6	National Agricultural Science Fund	35.00	48.80	36.55	50.75
7	Animal Science	811.05	271.97	271.97	400.00
8	Fisheries Science	395.40	115.85	115.85	170.69
9	Agricultural Universities and Institutions	660.79	663.37	658.37	684.70
10	National Agricultural Higher Education Project			5.00	7.89
Atomic Energy		**2994.52**	**3507.34**	**2776.75**	**3482.21**
1	R and D Basic Science and Engineering	977.80	982.32	833.11	880.00
2	R and D for Fast Reactor Science and Technology	291.17	294.07	227.00	210.00
3	Advanced Technologies for Laser, Synchrotron	175.70	152.53	152.53	130.16
4	and Accelerator				
5	R and D in Exploration and Mining	105.33	122.50	87.06	108.42
6	Grants to other Institutions	144.80	163.84	118.56	124.49
7	Backend Fuel Cycle Projects	451.49	500.00	350.00	580.00
8	Heavy Water Board	15.01	46.20	35.50	56.89
9	Radiation and Isotopes Project	13.52	124.50	55.15	107.91
10	Nuclear Power Projects	83.86	75.90	56.90	87.09
11	Nuclear Fuel Projects	120.33	156.95	156.95	164.50
12	Advanced Technology for Acclerator	65.29	73.50	71.30	64.17

Ministry/Department		2016-17 Actual	2017-18 Budget Estimate	2017-18 Revised Estimate	2018-19 Budget Estimate
13	Research and Development Projects	83.78	321.14	157.69	257.69
14	Industries and Material Projects	1.00	73.89	55.00	100.89
15	Fuel Cycle Projects (Fast Reactor Fuel Cycle Fascility)	465.44	420.00	420.00	610.00
Ministry of Ayurveda, Yoga and Naturopathy, Unani, Siddha and Homoeopathy (AYUSH)		**5.95**	**9.00**	**20.00**	**11.00**
1	Assistance to accredited AYUSH Centres of Excellence in Non Governmental/ Private Sector	1.75	4.00	11.00	5.00
2	Extra Mural Research Projects through Research Institutes etc.	4.20	5.00	9.00	6.00
Ministry of Coal		**8.50**	**10.00**	**10.00**	**10.00**
1	Research and Development	8.50	10.00	10.00	10.00
Department of Industrial Policy and Promotion		**0.00**	**10.00**	**10.00**	**10.00**
1	Startup India		10.00	10.00	10.00
Ministry of Defence		**7018.09**	**7596.95**	**7566.87**	**9876.29**
1	Research and Development	6771.50	7552.32	7552.32	9734.45
2	Projects of the Army - Techonology Development -Assistance for prototype development under make procedure	217.49	30.08		127.29
3	Projects of the Air Force - Techonology Development - Assistance for prototype development under make procedure	29.10	14.55	14.55	14.55
Ministry of Earth Sciences		**902.19**	**1079.70**	**1010.82**	**1183.23**
1	Ocean Services, Technology, Observations, Resources Modelling and Science (O-STORMS)	305.54	336.00	326.00	399.00
2	Atmosphere and Climate Research - Modelling Observing Systems and Services (ACROSS)	394.60	496.00	423.00	375.00
3	Polar Science and Cryosphere (PACER)	114.74	127.00	127.00	225.00
4	Seismological and Geoscience (SAGE)	51.04	76.70	88.82	110.00
5	Research, Education and Training Outreach (REACHOUT)	36.27	44.00	46.00	74.23
Ministry of Electronics and Information Technology		**802.67**	**1402.76**	**1037.63**	**1602.22**
1	Manpower Development	364.81	306.76	256.76	300.00
2	National Knowledge Network	250.00	150.00	135.00	150.00
3	Promotion of Electronics and IT HW Manufacturing (MSIPS, EDF and Manufacturing Clusters)	49.87	745.00	484.87	864.22

Ministry/Department		2016-17 Actual	2017-18 Budget Estimate	2017-18 Revised Estimate	2018-19 Budget Estimate
4	Cyber Security Projects (NCCC & Others)	21.99	100.00	60.00	110.00
5	R and D in IT/Electronics/CCBT	116.00	101.00	101.00	178.00
Ministry of Environment, Forests and Climate Change		**609.60**	**786.69**	**453.94**	**485.70**
1	National Coastal Zone Management Programme (EAP)	341.68	441.98	152.50	
2	National Coastal Mission (NCM)		5.00		165.00
3	Climate Change Action Plan (Funded from NCEF)	42.67	40.00	33.00	40.00
4	National Adaptation Fund (Funded from NCEF)	96.94	110.00	108.25	110.00
5	National Mission on Himalayan Studies (Funded from NCEF)	16.50	50.00	41.00	50.00
6	Environmental Education, Awareness and Training	43.80	60.00	58.29	67.00
7	Environment Information Systems (ENVIS)	13.45	23.00	23.00	24.00
8	Centres of Excellence	21.81	18.00	12.00	20.00
9	R and D for Conservation and Development	12.26	17.50	7.00	9.70
10	Environmental Impact Assessment	3.78	5.40	4.50	
11	International Co-operation	16.71	15.81	14.40	
Department of Financial Services		**600.00**	**520.00**	**500.00**	**500.00**
1	Start-Up India - India Aspiration Fund	100.00			
2	Stand-Up India (through NCGTC)	500.00	520.00	500.00	500.00
Ministry of Food Processing Industries		**700.79**	**725.00**	**633.84**	**0.00**
1	National Mission on Food Processing (SAMPDA)	700.79	725.00	633.84	
Department of Health and Family Welfare		**0.00**	**0.50**	**2.18**	**30.00**
1	Impacting Research Innovation and Technology (IMPRINT) Scheme	0.00	0.50	2.18	30.00
Department of Health Research		**107.79**	**150.00**	**190.00**	**210.00**
1	Setting up of nation wide network of laboratories for managing epidemics and national calamities	44.25	56.00	66.00	70.00
2	Development of Infrastructure for Promotion of Health Research	30.25	45.00	56.00	63.00
3	Development of tools/support to prevent outbreaks of epidemics	1.63	3.00	5.00	5.00
4	Human Resource and Capacity Development	31.66	46.00	63.00	72.00

Ministry/Department		2016-17 Actual	2017-18 Budget Estimate	2017-18 Revised Estimate	2018-19 Budget Estimate
Department of Heavy Industry		**576.87**	**802.89**	**656.26**	**768.88**
1	National Automotive Testing and Research and Development Infrastructure Project (NATRIP)	388.00	485.89	307.01	378.88
2	Scheme for Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicle in India - (FAME -India).	144.00	175.00	235.00	260.00
3	Development Council for Automobile and Allied Industries	42.87	20.00	24.25	30.00
4	Fluid Control Research Institute (FCRI)	2.00	2.00		
5	Research and Development project for development of Advanced Ultra Super Critical (AUSC) Technology for Thermal Power Plants		120.00	90.00	100.00
Department of Higher Education		**1078.31**	**1871.75**	**1582.52**	**4588.12**
1	National Research Professors	0.89	1.30	1.30	1.30
2	Establishment of multi disciplinary research universities including Central University of Himalayan Studies (CUHS), creation of Centres of Excellence and National Centre for Excellence in humanities		10.00		10.00
3	Higher Education Financing Agency (HEFA)		250.00	250.00	2750.00
4	World Class Institutions		50.00		250.00
5	PM Research Fellowship		75.00		75.00
6	M Tech Programme Teaching Assistantship		35.00		35.00
7	National Mission in Education Through ICT	145.24	150.00	160.00	150.00
8	Setting up of virtual classrooms and massive open online courses (MOOCs)	61.00	75.00	90.00	90.00
9	e-shodh Sindhu	235.00	240.00	240.00	180.00
10	Higher Education Statistics and Public Information System (HESPIS)	10.40	12.00	12.00	16.00
11	National Digital Library		10.00	10.00	10.00
12	National Academic Depository		10.00	6.00	10.00
13	Training and Research in Frontier Areas	15.00	15.00	15.00	15.00
14	Setting up of Inter-Institutional Centres, Creation of Excellence Clusters and Networks, Establishing Alliances across Institutions	2.00		2.00	
15	National Inititative for Design Innovation	20.09	32.00	32.00	32.00
16	Startup India Initiative in Higher Educational Institutions	50.00	86.45	86.45	84.23
17	Unnat Bharat Abhiyan	5.16	20.00	12.40	20.00
18	UchhatarAvishkarAbhiyan	75.00	75.00	88.48	95.00

Ministry/Department		2016-17 Actual	2017-18 Budget Estimate	2017-18 Revised Estimate	2018-19 Budget Estimate
19	Implementation of the IMPRINT Research Initiative (Impacting Research Innovation and Technology)	50.00	85.00	85.00	102.00
20	Pandit Madan Mohan Malviya National Mission on Teachers and Teaching	70.04	120.00	100.00	120.00
21	National Institutional Ranking Framework	3.00	5.41	3.41	3.00
22	Global Initiative for Academic Network (GIAN)	20.00	25.00	25.00	30.00
23	Technical Education Quality Improvement Programme of Government of India (EAP)	109.78	260.00	158.75	275.00
24	Support to Skill based Higher Education including Community Colleges	50.00	50.00	25.00	40.00
25	Programme for Apprenticeship Training	97.72	110.00	110.00	125.00
26	Planning Administration and Global Engagement	59.99	67.59	71.73	67.59
Ministry of Minority Affairs		**0.00**	**0.00**	**0.00**	**2453.00**
1	Education Empowerment				2453.00
Ministry of New and Renewable Energy		**3464.58**	**4796.50**	**3694.00**	**4753.92**
1	Wind Power - Grid Interactive Renewable Power	488.95	400.00	750.00	750.00
2	Small Hydro Power - Grid Interactive Renewable Power	112.00	121.50	114.00	207.00
3	Bio Power - Grid Interactive Renewable Power	16.30	33.00	21.50	25.00
4	Solar Power - Grid Interactive Renewable Power	1992.32	2661.00	1117.10	2045.24
5	Green Energy Corridors - Grid Interactive Renewable Power	200.00	500.00	500.00	600.00
6	Externally Aided Project (EAP) - Component - Grid Interactive Renewable Power		39.00	0.50	7.25
7	Wind Power - Off-Grid/Distributed and Decentralized Renewable Power	2.38	8.00	4.90	7.43
8	Small Hydro Power - Off-Grid/Distributed and Decentralized Renewable Power	10.00	13.00	6.00	11.50
9	Bio Power - Off-Grid/Distributed and Decentralized Renewable Power	15.16	43.00	20.00	23.00
10	Solar Power - Off-Grid/Distributed and Decentralized Renewable Power	548.83	700.00	985.00	848.50
11	Biogas Programme - Off-Grid/Distributed and Decentralized Renewable Power	78.64	134.00	94.00	135.00
12	Research and Development - Research, Development and International Cooperation		144.00	81.00	94.00
Ministry of Petroleum and Natural Gas		**0.00**	**0.00**	**9.73**	**1300.00**
1	National Seismic Programme			9.73	1300.00

Ministry/Department		2016-17 Actual	2017-18 Budget Estimate	2017-18 Revised Estimate	2018-19 Budget Estimate
Ministry of Railways		**12.20**	**56.27**	**34.85**	**50.00**
1	Railway Research	12.20	56.27	34.85	50.00
Ministry of Road Transport and Highways		**127.23**	**250.00**	**171.00**	**315.00**
1	Research, Training and Studies	127.23	250.00	171.00	
2	Research, Training, Studies and Other Road Safety Schemes				315.00
Department of Rural Development		**73.83**	**70.00**	**70.00**	**99.00**
1	Grants to Council for Advancement of People's Action and Rural Technology (CAPART)	15.00	20.00	20.00	24.00
2	Grants to National Institute of Rural Development	58.83	50.00	50.00	75.00
Department of Science and Technology		**2747.59**	**3139.90**	**3153.00**	**3438.43**
1	Science and Technology Institutional and Human Capacity Building	932.38	1072.50	1007.86	1109.43
2	Research and Development	467.62	595.50	505.14	609.00
3	Innovation, Technology Development and Deployment	550.29	651.90	670.00	720.00
4	Science and Engineering Research Board	767.00	800.00	800.00	900.00
5	Technology Development Board	30.30	20.00	170.00	100.00
Department of Biotechnology		**1200.54**	**1453.58**	**1475.24**	**1599.24**
1	Biotechnology Research and Development	1012.64	1250.58	1252.42	1350.00
2	Industrial and Entrepreneurship Development	187.90	203.00	222.82	249.24
Department of Scientific and Industrial Research		**26.09**	**39.75**	**30.00**	**41.50**
1	Industrial Research and Development	15.44	24.00	16.50	26.50
2	Assistance to PSEs for Other Scientific Research Schemes	10.65	15.75	13.50	15.00
Ministry of Shipping		**4.37**	**22.00**	**16.00**	**14.00**
1	Oil Pollution and Research & Development.	4.37	22.00	16.00	14.00
Department of Space		**7365.23**	**8324.37**	**8280.55**	**8963.97**
1	Space Technology	4600.06	5850.69	5984.42	6576.02
2	Space Applications	1103.16	1767.01	1586.46	1746.25
3	Space Sciences	122.46	188.11	179.67	230.10
4	IN SAT Satellite Systems	1539.55	518.56	530.00	411.60

Ministry/Department		2016-17 Actual	2017-18 Budget Estimate	2017-18 Revised Estimate	2018-19 Budget Estimate
Ministry of Steel		**5.25**	**15.00**	**14.00**	**15.00**
1	Scheme for Promotion of Research and Development in Iron and Steel sector	5.25	15.00	14.00	15.00
Ministry of Water Resources, River Development and Ganga Rejuvenation		**1870.57**	**3100.00**	**3383.42**	**3626.27**
1	National River Conservation Programme		250.00	723.42	770.00
2	National Ganga Plan and Ghat Works	1675.00	2300.00	2300.00	2300.00
3	Flood Forecasting	39.36	65.00	45.00	
4	Development of Water Resources Information System	70.08	145.00	70.00	211.27
5	National Hydrology Project	51.77	300.00	185.00	250.00
6	Research and Development and Implementation of National Water Mission	34.36	40.00	60.00	95.00

Annexure 3

INCREDIBLE FACT

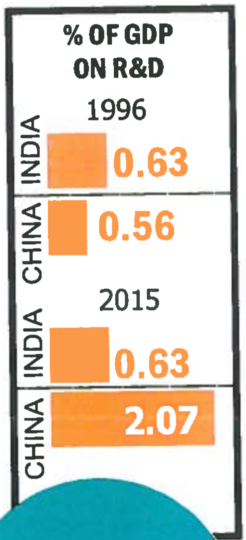
The response time a country attacked with a hypersonic missile - five times faster than sound - has if it detects the missile at a distance of about 1,000 km

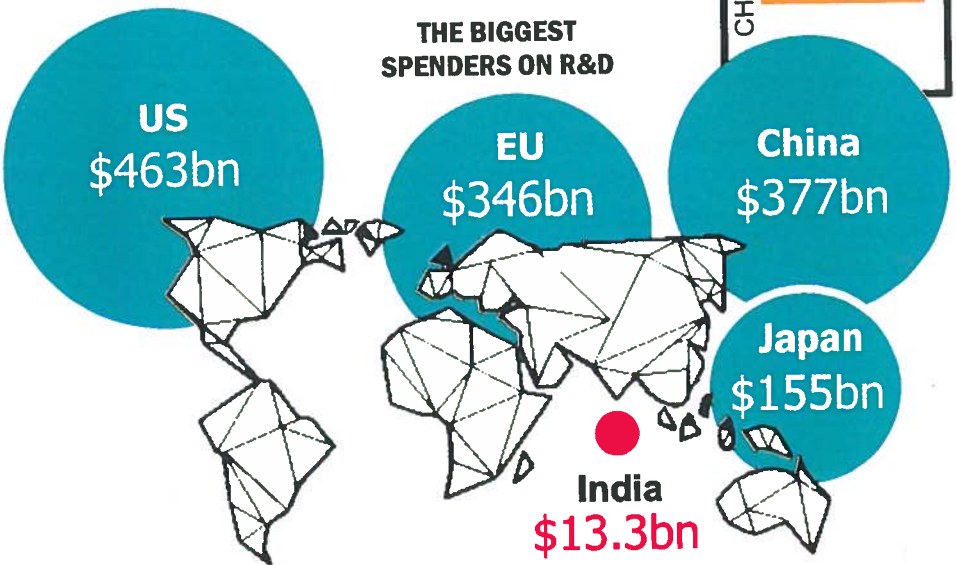
Source : Rand Corporation

How China sprinted far ahead of India in the fields of research and development

In 1996, India spent 0.63% of its GDP on research and development. Twenty years later, in 2015 its R&D expenditure as a percentage of GDP was still the same. China, in comparison, spent only 0.56% of its GDP on R&D in 1996, but increased it to 2.07% in 2015. It spent $377 billion (Rs 25 lakh crore), second only to the US, while India spent a relatively measly Rs 87,000 crore.

Three companies - Alphabet (Google), Volkswagen, and Amazon - spent more than India on R&D, and three others - Intel, Samsung and Microsoft - were close behind.





Corporates

Amazon $17.4bn | Volkswagen $15.1bn | Alphabet $14.5bn

Sources: visual Capitalist, World Bank

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

NASI 2018