Basic science and 'Make in India'

There is much talk about 'Make in India', nowadays. This was highlighted by statements made by four Nobel laureates and a Fields medalist Manjul Bhargava, at the Indian Science Congress held in Mysuru in 2016. David Gross recommended that we replace 'Make in India' by 'Discover, Invent and Make in India'. The Nobel laureates and Bhargava also recommended (i) increased investment in basic science (Gross), (ii) need for a long-term plan, since the incubation period for basic science to deliver goods is 10–20 years (Haroche), (iii) need for a cultural shift where people are oriented to pursuing science, which will also lead to discovering in India rather than just making in India (Bhargava), (iv) expand education ten times (Gross), (v) start science teaching early in schools (Schectman), which we already do and (vi) need to introduce financial schemes (Gurdon). The laureates have largely talked about basic science. Making in India has actually more to do with the complementary part of science and technology, namely manufacturing and less to do with basic science per se. They have emphasized that making without the backing of basic science is incomplete.

It is nice to know that the greats of science are in complete consonance with what our own scientists have been emphasizing year after year. Each one of the points mentioned above, has been explicitly expressed by our scientific community at different times during the last 50 years and continues to be done now. Homi Bhabha's address to the International Council of Scientific Unions (ICSU) in 1966 was a landmark speech on the subject. He emphasized the need to be able to do good mathematics and basic science, in order to develop good technology; he wrote, '...if much of the applied research done in India today is disappointing or of inferior quality, it is entirely due to the absence of sufficient number of outstanding pure research workers...'. He successfully built the programme of the Department of Atomic Energy on this premise. From Bhabha then to C. N. R. Rao now, many senior scientists of standing have emphasized this time and again. Though some steps have been taken by the various governments on the above-mentioned points, they are far from adequate.

Every Prime Minister in his inaugural speech to the Indian Science Congress repeats the need to increase investments in science like a litany, but does pretty little to accomplish the same. The net result is that the budget for science has remained flat at nearly 0.8% of GDP for more than a decade. We scientists have not succeeded in persuading the governments to raise the allocation. Real improvement will not happen without this. We have three Academies of Science based in Allahabad, Bengaluru and New Delhi, and they have work cut out for them; this should be their highest priority.

Is there any other way than the Central and State governments directly increasing this allocation? Governments have consistently shown that they will not do this in a hurry. Other models for funding are available from other countries. Every country which has made scientific progress in recent decades, from Korea in the east to the United States in the west, has substantially larger percentage input for R&D from non-governmental sources.

Industries are the prime beneficiaries of R&D in science and technology. It is fair, therefore, to expect them to contribute to this national effort. To my knowledge, this is less than 15% in India. It is important for the government to make sure, through an actionable policy that input for R&D from industries comes compulsorily up to about a figure matching that of the government in the next decade. If the government contribution is raised to say, 1.0%, the total can come up to about 2.0%, which will still be below that of USA today (South Korea spends 4.5%). Details of the scheme can be worked out in a straightforward fashion, as several models from different countries are already available.

Finally, let me briefly adduce to the requirements of real technological growth. An idea is born in a scientist's mind. The idea has to be validated by an experiment. Then one makes a prototype which is upgraded to an engineering model. This has to stand the test of the market in regard to quality and marketability (need, cost, affordability, etc.). Feedback from the user (market) results in improving the product or rejecting the same as non-viable. Each stage in the chain is likely to be more expensive than the previous one. Often it is possible that one does not start from an idea, but at an intermediate stage, as envisaged in 'Make in India'. Here one must make effort to understand the design, either from basic considerations or through reverse engineering. This is necessarily required for making any progress through innovation over the existing design. This last component is a must to 'Make in India' lead to real technological progress.

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Fungal endophytes: nature's tool for bioremediation of toxic pollutants

Industrial processes, agricultural practices and the use of chemicals in many areas of our daily life result in the deliberate and accidental release of potentially toxic chemicals into the environment[1]. Oil pollution as an environmental challenge has been widespread during the production, storage and transport activities. Similarly, accumulation of plastic waste is another major man-made problem today. It has been reported that more than 140 million tonnes of plastics was manufactured worldwide in 2001 alone[2]. Plastics have accumulated in almost all places of our environment such as roadsides, forests, rivers, lakes, including oceans. Gyre is the rotating ocean current, the propelling force to accumulate plastic waste and create the plastic soup along with the contribution of tidal force and UV radiation. Bioremediation is an environment-friendly method which uses the capability of microorganisms and/or plants (i.e. phytoremediation) to degrade, remove and stabilize various types of pollutants.

All fungi are heterotrophic and obtain the organic substance necessary for their growth through saprophytism, parasitism (pathosistic symbiosis) and mutualistic symbiosis. Saprotrophic fungi play a key role in the decomposition of organic matter and therefore, in the circulation of both natural and man-made elements[3]. The ability of fungi to translocate nutrients through the mycelia network is another important feature for exploring heterogenous environments[4].

Fungi can degrade or solubilize pollutants, minerals and metal compounds either by direct biotic action (enzymes) or facilitating abiotic degradation, for instance, of pH and excretion of metabolites and several mechanisms, including acidolysis, complexolysis, redoxolysis and metal accumulation in biomass[5]. Around 60% of the currently used industrial enzymes are of fungal origin[6]. The transformation of PAHs (polycyclic aromatic hydrocarbons) by ligninolytic wood decaying fungi involves different enzymes like lignin peroxidase, manganese peroxidase, laccase, cytochrome P450 and epoxide hydrolase[7]. The fungi are believed to contribute to the weathering of silicate-bearing rocks, including mica and orthoclase and iron and manganese-bearing minerals[8]. Fungi like *Penicillium oxalicum* could solubilize different insoluble phosphates by producing malic acid[9]. Fungi also degrade hydrocarbon-based lubricants and promote metal solubilization by producing organic acids and chelating activities[10,11].

Endophytic fungi are the microbes which colonize the interior healthy plant tissues without causing disease[12]. The endophyte–plant association has existed for millions of years resulting in the evolution of multihost endophytes. The endophytes have been isolated from almost every host plant studied so far and plant–endophyte relationship involves both mutualism and antagonism. The endophytes use many mechanisms, including bio-transformation ability of complex compounds with the production of enzymes and bioactive substances[12]. The endophytes have the ability to utilize various organic compounds such as carbon sources, which enables them to play an important role in the degradation of structural components such as leaf litter, wood, lignin components and also environmental pollutants[12,13]. Recently, a number of investigations were carried out on the bioremediation potential of endophytic fungi. Fungi, especially *Acremonium* sp. from the roots and shoots of *Aphelandra tetragona* were found to be an active metabolizer of polyamine alkaloid apheladrine[13]. The biotransformation potential of phytoanticipins 2-benzoxazolinone (BOA) and 2-hydroxy-1,4-benzoxazin-3-one (HBOA) by endophytes living inside the roots and shoots of *A. tetragona* has been documented[14]. The phytoremediation of organic pollutants by endophytic fungi has been reported in *Cyperus laxus*[15], wheat, mungbean and egg plant[16], and phytoremediation by endophytic fungi from cadmium and nickel-contaminated soil in mustard[17], and heavy metals by endophytic *Mucor* sp. in rapeseed roots[18].

Other endophytic fungi from various plants also demonstrated the potential to improve phytoremediation. These include *Mucor* sp., *Trichoderma* sp., *Aspergillus* sp., AMF (anamorphic fungi) and species of *Phoma*, *Alternaria* and *Peyronellaea*[19].

A filamentous fungus identified as *Fusarium* sp. isolated from the leaves of *Pterocarpus macrocarpus* Kurz. was able to degrade benzo(a) pyrene, a five-ring polycyclic aromatic hydrocarbon[20] and phenantherene by *Phomopsis* sp. with rice plant[21]. Phytoremediation of petroleum-contaminated soil with two grass species (*Festuca arundinacea* Schrb. and *Festuca prantensis* Huds.) by endophytic fungi (*Neotyphodium coenophialum* and *Neotyphodium uncinatum*) has been reported[22]. Similarly, Dai *et al.*[23] demonstrated that endophytic fungus *Ceratobasidium stevensii* isolated from *Bischofia polycarpa* could degrade phenanthrene, a PAH. Fungal endophytes have been found to ameliorate metal toxicity by improving the supply of essential elements[24].

In a recent study, researchers identified species of *Pestalotiopsis* isolated from Amazon forest, which use polyster polyurethane, an important plastic, as a sole carbon source under aerobic and anaerobic conditions by producing an enzyme polyurethenase[25]. The endophytes such as *Phomopsis* and *Pestalotiopsis* were isolated from a large number of tropical and temperate forest host plants[26]. *Phomosis* produces a variety of enzymes, including cellulases, lipases, pectinases, pectate lyases and proteases. Similarly, *Pestalotiopsis* produces various secondary metabolites, including terpenoids, isocoumarin derivatives, coumarine quinines, semiquinones, peptides, xanthones, xanthone derivatives, phenols, phenol derivatives and lactones[27].

Endophytic fungi such as *Fusarium* sp. and *Cercospora* sp. isolated from *Baccharis dracunculifolia* D.C (Asteraceae) showed degradation of phenolic compounds by producing phenoloxidases *in vitro*[28]. Recently, it has been shown that endophytic *Lewia* sp. improved the efficiency of polyaromatic hydrocarbon removal by *F. arundinacea*[29]. There is an estimate of over 300,000 species of land-dwelling endophytes and using these directly to treat accumulated toxic waste is a big step towards the holistic way for nutrient cycling.

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