Chapter 6:

Conclusion
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Nanotechnology supports both unparalleled opportunity and unprecedented challenge for commercialisation. As nanotechnology has moved from laboratory to industrial manufacturing and commercialisation taking place through distribution network, huge potential for human and environmental exposure exists hence commercialisation of nanotechnology have become an priority and reality of today’s world economic statistics and indicators of nanotechnology is further challenged by the broad range of technologies and products encompassed within the term “nanotechnology,” both in terms of current products and applications and even more in terms of future generations of products.

6.1. Identifying India’s Nanotechnology Focus Areas

The focus areas are defined based on the selection criteria keeping in view nanotechnology objectives of India defined in earlier chapter as follow:

- Areas where existing research is of high quality and output should be built up.
- Maximise joint venture with existing infrastructure and industrial base with local and international collaboration.
- Areas with substantial pre-existing infrastructure and resourcing investment must be given priority.
- Shortlist corporate and countries with opportunity for resource sharing and collaboration with India and those that offer unique collaboration potential across the world.
- Identify themes which resonate with national priorities (e.g. Make in India economy, green zone).
- Focus areas should be evaluated and updated on a predetermined schedule (every 3-5 years). This approach represents best practice and it helps keep research priorities relevant and has a selection bias towards areas that meet/exceed expectations;
- An advisory group comprising representatives of industry, academia and government, both Indian and foreign, should be tasked with monitoring and evaluating the focus areas and identifying new ones as appropriate; and
- The focus areas should be underpinned by responsible development of nanotechnology

<table>
<thead>
<tr>
<th>Market</th>
<th>Comment</th>
</tr>
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<tbody>
<tr>
<td>Semiconductors</td>
<td>Strong industrial base as global power centre for Si-semiconductor is migrating to Asia; Existing public infrastructure can be readily utilised for market-driven research, possibly with minor upgrades in the mid-term</td>
</tr>
<tr>
<td>Medical devices and diagnostics</td>
<td>Several technical focus area options have deep applicability in this market; Industrial base more likely to engage in co-development</td>
</tr>
<tr>
<td>Pharmaceutical</td>
<td>Requisite level of commitment is too expensive to make; global landscape is cluttered and nanotechnology-driven solutions are largely unproven</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>Makes up a large share of total Indian industry with strong applicability of all technology focus area options; broad definition will require strong focusing influence of super-customers</td>
</tr>
<tr>
<td>Food</td>
<td>Large component of India GNP, mostly indigenous enterprise; nanotechnology research in this sector requires significant application development which companies might not have an appetite for</td>
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The India needs to focus on basic requirement which will help to move from developing to developed nation. Nanotechnology has the potential to impact all these basic sectors. These can be stated as under

- **Water**: Clean water
- **Food**: Packaging materials, Sensor
- **Energy**: Magnets, LED, Hydrogen production, Light materials for vehicles, catalyst for combustion in vehicles, Solar panels
- **Environment**: Photo catalyst materials for degradation of pesticides and organic contaminate materials in water

**Healthcare**: Nanomedicine, Diagnostic tools

<table>
<thead>
<tr>
<th>Areas</th>
<th>Indian Industries</th>
<th>Applications</th>
</tr>
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<tbody>
<tr>
<td>Energy</td>
<td>Industrial nanotech United nanotechnology &amp; NEI cor.</td>
<td>Nanotechnology based materials for energy saving Nanotechnology based lithium ion battery electrode material</td>
</tr>
<tr>
<td>Water</td>
<td>CSIR, IITs &amp; Tata company</td>
<td>Nanotechnology based water filter</td>
</tr>
<tr>
<td>Biotechnology</td>
<td>National research development corp. Biomix network</td>
<td>Calcium phosphate nanotechnology for non-viral gene delivery Nanotechnology based biotechnology tools</td>
</tr>
<tr>
<td>Textiles</td>
<td>Bodal chemicals Arvind brands</td>
<td>Dyes for textile industries</td>
</tr>
</tbody>
</table>
6.2. Prospects of nanotechnology for developing countries like India;

The experts identify the top 10 nanotechnology applications desired would be:

1. Energy: There was a high degree of unanimity in ranking this area number one.
2. Agriculture: Researchers are developing a range of inexpensive nanotech applications to increase soil fertility and crop production and help eliminate malnutrition.
3. Water treatment: Nano-membranes and nano-clays are inexpensive, portable and easily cleaned systems that purify detoxify and desalinate water more efficiently than conventional bacterial and viral filters.
4. Disease diagnosis and screening: Technologies include the "lab-on-a-chip", which offers all the diagnostic functions of a medical laboratory.

5. Drug delivery systems: Technologies include Nano-capsules, dendrites (tiny bush-like spheres made of branched polymers) and "buck balls" (soccer ball shaped structures made of 60 carbon atoms) for slow, sustained drug release systems.

6. Food processing and storage: Improved plastic film coatings for food packaging and storage may enable a wider and more efficient distribution.

7. Air pollution remediation: Technologies include nanotech-based innovations that destroy air pollutants with light.

8. Construction: Technologies include nano-molecular structures to make asphalt and concrete more resistant to water; materials to block ultraviolet and infrared radiation.

9. Health monitoring: Nano-devices are being developed to keep track of daily changes in physiological variables such as the levels of glucose, carbon dioxide, and cholesterol without the need for drawing blood in a hospital setting.

10. Disease vector and pest detection control.

6.3. Key Issues for Nanotechnology in India

Since the last decade, there are continuous positive developments in nanotechnology R&D and commercialisation in India; there are a number of critical issues requiring attention. These include:

India risks being left behind

    Nanotechnology progress has moved beyond early stage of scientific research to applications development and commercialisation. Most countries around the world are investing significant funds into nanotechnology R&D, which include new entrants like Bulgaria and Albania. India needs to maintain at least its existing level of funding to stay competitive in the race of nanotechnology across the world.

India’s critical focus on effective use of resources

    Nanotechnology’s cross-disciplinary nature tempts spreading resources across multiple areas. India should ensure that resource allocation should focus on a few strategically-significant applications, instead of a non-
discerning funding model. Such a strategy will maximise India’s chances of generating increased economic impact.

India needs a national policy of resource allocation in nanotechnology

Resource allocation should be explicitly channelled to commercially viable opportunities until a working “market mechanism” for prioritisation evolves. The priority research applications areas should be developed so that we are able to drive the demand of customer in the field of nanotechnology. Driving priorities in research and development towards viable applications identifying these opportunities is a critical step and should be undertaken in a consultative fashion.

Nanotechnology can be a natural enabler for innovation

The cross-disciplinary nature of nanotechnology can be a booster for the increased collaborations and will thus impact the economy. As discussed, nanotechnology will impact every core Indian business sector deeply and will be a strong driver for technology upgrade of existing enterprise.

Lack of Regulatory Standard and Body

There is no clarity on the standard of regulation due to interdisciplinary nature of nanotechnology. Various Government departments are involved and thus there is no uniformity in the regulation process. Since the outcome of nanotechnology products is not still clear and there is no clarity about toxicity and environmental hazards involved which make regulatory standards stringent and the regulatory body has no defined standard.

Unavailability of skilled Human Resource

There is lack of awareness of nanotechnology among common public and thus the career in nanotechnology is not as common as other disciplines. There is unavailability of skilled and trained engineers and scientists to take ahead nanotechnology to next level. As nanotechnology is been moving
towards commercialisation the various courses at diploma and graduate level are been introduced by various universities to promote nanotechnology.

**Diverse demographic can be good**

India’s demographics diversity can, and should, be turned into an advantage through sharper focus, more efficient use of funds, fewer commercial obstacles, rapid prototyping and testing and higher quality standards.

**India should be an intelligent follower**

The governance and commercial exploitation of nanotechnology in India can benefit from starting with a relatively clean slate but at the same time being able to learn from best practices of other nations. India can learn from the experience and mistakes made by market leaders.

**6.4. The Importance of nanotechnology in India**

The importance of nanotechnology can be understood by certain facts like the institute involved and major funding agencies and corporate involved.

**The Major funding Agency of India on Nanotechnology**

- Department of Science and Technology
- Department of Scientific and Industrial Research (DSIR)
- Council of Scientific & Industrial Research (CSIR)

**Other funding agencies of India:**

- Department of Biotechnology (DBT)
- Department of Information Technology (DIT)
- Defence Research and Development Organization (DRDO)
- National Program on Micro & Smart Systems (NPMASS)
- Department of Atomic Energy (DAE)
- Indian Council of Agriculture Research (ICAR)
- Ministry of Communication & Information Technology (MCIT)

**Nodal Labs of CSIR on Nanotechnology**

- National Chemical Laboratory, Pune
- National Physical Laboratory, Delhi
Other Potential institutes of Nanotechnology

IIT, IISc, JNCASR, IISER, NISER, Universities, CSIR, Centre of Excellence.

Joint Research collaboration and Networking of Indian Organizations on Nanotechnology

India has international Joint Research collaboration and Networking in the field of Nanotechnology with China Japan South Korea South Africa France CSIR USA Taiwan Russia EU Euro-India Institutes / Organizations Brazil and South Africa Areas in which Indian Researchers are more

6.5. Challenges to nanotechnology commercialisation

The nanotechnology has an immense potential to impact the economy, various sectors and industries and almost all aspects of life. There are huge financial, legal, Social, regulatory, political and ethical challenges to the commercialisation of nanotechnology as follow.

Financial Challenges

1. There is time lag between research and commercialisation. This time factor is detriment for venture capitalists and other sources of funding.
2. Huge funding is required for research and developing applications of nanotechnology
3. Small start up and business houses do not have the capacity to produce products on a large scale.

Infrastructure Challenges

1. There is lack of proper infrastructure such as labs, equipment, measuring devices, and software. The infrastructure needed is very expensive. Furthermore, equipment becomes quickly outdated due to the major advances in technology.
2. The development of nano tools must increase and be more available to universities and new start up businesses.
3. There is no provision for usage of university laboratories and equipment which hurts small businesses that can’t afford this infrastructure.

**Legal Challenges**

1. The patent office takes long time to respond for registered applications due to less clarity.
2. Patent Office does not have enough qualified staff to assess nanotechnology products.
3. Lack of standards and measurements are major hurdle in advancements of nanotechnology and thus delay the commercialisation.

**Social Challenges**

1. There is lack of human resource such as trained scientists, engineers, technicians and researchers.
2. The public perception about nanotechnology products that they are unsafe must be resolved to ensure that public fully understands it’s potential.
3. Public and consumer concern about safety and resulting consumer activism that might inhibit commercial investment in nanotechnology-based products.

**Ethical Challenges**

1. The “Valley of Death” so called is the often fatal interlude between scientific results of the researcher and initial funding for prototyping and commercialisation. This leads scientists to publish results and not to move for commercialisation.
2. Applied research against basic research needs to be encouraged more in universities which can be further commercialised.
3. Safety and toxicity and the effective management of the potential risks of manufactured nanomaterials are also major challenge of commercialisation of nanotechnology.

**Political Challenges**

1. There is a lack of a coherent policy on technology transfer from universities to start-up businesses.
2. Funding has increased at a very low pace which has hindered advancement in research and development.
Financial, Infrastructure, Regulatory, legal, political and ethical issues are the prime challenges to the commercialisation of nanotechnology and hamper it.

6.6 Suggestions to overcome the challenges of commercialisation of nanotechnology

All the prospects of commercialisation are promising a bright future ahead and show that nanotechnology will appear as the technology of century and will pave a way for future advancement of economy. Certain challenges are also growing up to hurdle this commercialisation of nanotechnology in India. A strategy is required to overcome these challenges and promote the nanotechnology in India. The different participants need to plays crucial role as a part of the commercialisation strategy in India are as follow.

1. Government

1) A strong funding is to be made available by the Government and other funding agencies.

2) Public Private Partnership (PPP) will be ideal model for funding in nanotechnology R&D and commercialisation.

3) Initiative need to be taken to promote nanotechnology as future technology and make public aware of the strength and possible consequences of nanotechnology.

4) A core team of field experts from various government departments, regulators, corporate, academic and industry should be formed to develop a framework for further research and commercialisation of nanotechnology in India. This team should determine priority sectors for research and regulations for nanotechnology.

5) Legislative provision should be made to define regulatory framework and establish regulator for nanotechnology.
6) Tax benefits need to be given to the corporate and industry to compensate the huge cost involved in research work of nanotechnology and for promoting faster commercialisation of nanotechnology in India.

2. Universities and Research Labs

1) The Universities and other research labs should create an environment for nanotechnology and its promises fulfilment for corporate and industry so they continue funding.

2) Regulations and risk assessment and control mechanism need to be developed with the help of core team as discussed earlier.

3) Universities and Research Labs should focus on applied instead of basic research and try for collaborations at national and international level to share infrastructure and IP (Intellectual property) like patents and publications.

4) Technology Transfer Office (TTO) concept need to be developed at universities which will be responsible for transferring technology from university to corporate for commercialisation in the form of patents and IP (Intellectual property).

5) Number of publications and citations should be increased and conferences and seminars need to be organised to create an awareness among public and develop a trust among society and corporate about the bright future of nanotechnology. This will help in attracting funds from corporate houses and industry.

6) Academic Courses need to be designed to develop the required trained and skilled human resources to meet the future demand for commercialisation of nanotechnology in India and across the globe.

7) Infrastructure should be made available to corporate and new start ups so this sharing will help in reducing cost of research for university and research labs and commercialisation cost of corporate for nanotechnology.
8) Best practices by the market leaders like US should be studied as well as shortcoming of similar developing nations should be used as experience and promote a commercialisation of nanotechnology in India.

3. Regulator and Patent Office

1) Regulatory framework based on input of core team need to be designed for better regulation of nanotechnology.

2) The Standards and Parameters need to be defined for nanotechnology so as to regulate nanotechnology industry and safety of society.

3) More skilled staff in nanotechnology needs to be recruited at patent office for faster processing of patent application.

4) A single Regulator need to be established like SEBI for stock exchange, IRDA for Insurance, TRAI for telecomm industry.

5) This single regulator will help to avoid multiple regulator permission and controlling which will make the commercialisation process smoother and faster.

4. Corporate Houses and Industry

1) The corporate must support the research work in nanotechnology with the help of funding and providing infrastructure and promoting in house R&D.

2) Corporate and industry must promote joint ventures at national and international level which will make funding and technology available for commercialisation of nanotechnology in India.

3) Marketing strategies need to be developed for special products of nanotechnology and develop a public awareness about nanotechnology.

4) Coordination with Universities and research labs to be done by means of TTO

5) Industry must focus on applied research and try to acquire patent and IP (Intellectual Property).
5. Society

1) Researcher and Scientist need to educate the society about the benefits of nanotechnology.

2) The conferences and seminars need public participation which will further build a trust of society in nanotechnology.

3) Upcoming students should look toward nanotechnology industry as a career and undertake studies in nanotechnology.

4) Public should analyse the benefit and be aware of the toxicity and hazards associated with nanotechnology instead of avoiding it based on misconception without considering the potential of nanotechnology.

Limitations and Further Scope for Study

This study is limited to the determining prospects and challenges in commercialisation of nanotechnology in India. This research tries to compare the different nations on ranking grid and then nanotechnology vision for India is developed. Sites visits and interview conducted has certain limitation and based on this data interpretation and secondary data, prospects and challenges in commercialisation of nanotechnology in India were identified.

There is further scope for determining regulation and risk associated with nanotechnology in detail and also the upcoming application of nanotechnology which has being commercialised. Market survey for nanotechnology product can be also a part of further study.