SUCCESSES AND GAPS IN OUR METALLURGICAL R&D EFFORTS

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Foreword

I am delighted to present the report: 'Successes and Gaps in Indian Metallurgical R & D Efforts”. It is known that in spite of our excellent accomplishments in metallurgy, in terms of wootz Steel, bronze icons, gold and silver ornaments, famous zari works of ancient India, zinc smelting and refining, rustless iron pillar, etc ; the country was importing most of metallurgical products needed for infrastructure such as railways and thermal power plants, at the time of independence. India has progressed, in a significant way from 1947. We are the fourth largest producer of steel in the world and are able to produce the steels and alloys needed for our strategic and other demanding programmes. It is also true that increasing quantity of finished metallurgical machineries and components are still being imported .Our capacity to export finished components rather than the ores without any value addition needs to be enhanced multifold. Thus there are gaps, challenges and opportunities. Indian National Academy of Engineering entrusted the task of chronicling the developments and do the critical analysis to three experienced fellow metallurgists. Shri K K Sinha, Dr. R. Krishnan and Dr. V. Ramaswamy have put dedicated efforts to bring out a valuable report, of much value to the country. The report was discussed in a detailed manner by Dr. Srikumar Banerjee and other experienced metallurgists to ensure comprehensive approach to this important subject matter of national importance.

The discerning readers shall find that sufficient focus and commitment to meet the challenges with right resources has led to successes. Quality and capability of leadership has always mattered. The successes relating to materials and manufacturing in nuclear, defence and space programmes are a testimony to this deduction. The government has also tried different types of motivational approaches through support, awards and recognitions. This report brings out another key message that, we might have succeeded in producing the best metallic products, but most of the quality control and analytical instruments required for this purpose have been of imported origin. Approaches for realizing successes, cannot be generic but a few lessons namely pursuit of objectives with purpose inspite of difficulties, availability of right resources, proper leadership with right mindset, appropriate policies, etc. are key to bridge the gaps and convert challenges to opportunities.

I wish the readers a fruitful reading and request them to provide the Academy with valuable inputs.

My gratitude to the authors, Dr. Srikumar Banerjee and all those who contributed to the important report.

Baldev Raj

PREFACE

Dr. P. S. Goel, the then President of the Indian National Academy of Engineering while addressing the convenors of the various sectional committees of the Academy in August 2010, mentioned that the 12th Plan documents of the GOI are under preparation. He pointed out that while the export revenues have shown an increasing trend, the import has not shown any decrease. On the contrary, it has only risen over the years and the gap between export and import does not appear to shrink. At the same time, he mentioned that considerable R&D efforts are also on in several fields and finding funds for well thought projects has not been a problem. In addition, at present, unlike in the earlier days, there is no constraint on provisioning of foreign exchange either. Does that mean that our R&D efforts have not yielded tangible results?

The above remarks pointing towards suitability/ inadequacy of our R&D efforts, prompted me to propose a study on 'Successes and Gaps in our Metallurgical R&D Efforts" and I am thankful to the Council of the Academy for granting this study. The objective of this study is to prepare an in depth analysis of the relevance of the goals set, the efficacy of the resources deployed, the commitment of the concerned agencies and any other factors that generally lead to the success or otherwise of R & D efforts. The study would cover major successes achieved and the factors that contributed to it and also why some of the efforts failed to meet the desired goals. It would also reflect areas where R&D efforts have been successful but the technology transfer to industry has not taken place. What could be the possible reasons for this were also to be pointed out. Finally a recommendation is to be made to make our R&D activities more effective/productive.

Obviously, this is not a one man's job. Even at the time of submission of the proposal, I thought of seeking the assistance of Dr. R. Krishnan, FNAE and former Director of GTRE. After the proposal was accepted, I approached him formally to be a partner in the study. He readily agreed and I can only say that his participation in the study has been of great value. Dr. Krishnan also pointed out that as both of us are not fully familiar with the steel sector, we should have a member knowledgeable about that field. He suggested that Dr. V.Ramaswamy, FNAE, former Executive Director of RDCIS could be a good choice and Dr. Ramaswamy readily agreed to assist us as a member of the committee. Later, INAE issued a directive to restrict our study to non-ferrous materials only, as another study on 'Impact of R&D in the steel sector' had already been initiated. Having already carried out some studies in the ferrous sector, it was decided to incorporate those findings also to a limited extent.

After an initial round of discussions between ourselves, we felt that it is necessary to have face to face interaction with as many researchers (leaders) as possible, whereby it would be possible to understand their ethos and attitudes towards R&D. Accordingly, we visited as many laboratories and establishments as possible, to get first hand information required for our study. We had also spelt out our purpose/objectives to them in advance so that they can address the issues straight away. In this context, some scientists very willingly submitted all necessary information. In several other cases, after our visit, when we sought further information, it was not readily forthcoming and we had to draw our own conclusions. It was also decided that we should interact with as many academicians as possible to get their views and we succeeded fairly well in this exercise. We also met with scientists who had held top positions in the scientific department and had guided many projects, and we found their opinion very helpful in arriving at final conclusions.

I thank the Secretariat of INAE in giving us all necessary support. We have enjoyed conducting this study and writing this report. We do hope the readers also enjoy reading this report. I am very grateful to Dr. Srikumar Banerjee, Ex-Chairman, DAE, and other members of the peer review committee of INAE for critically going through the draft report and for making suggestions and providing inputs in making this report comprehensive. We sincerely hope that the suggestions made here would receive due consideration of the authorities concerned in various organisations.

K. K. Sinha
Convenor

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EXECUTIVE SUMMARY

1 The genesis of this report, “Successes and Gaps in Metallurgical R&D Efforts” is due to an address by Dr. P. S. Goel, the President of the Indian National Academy of Engineering to his council and sectional committee coordinators. He said that everywhere China dominates. Their products are cheaper and readily available. Our country has been encouraging scientists and engineers and has also set up national centres of excellence. But what is the impact of R&D on our overall economic performance? He said that we need to assess this discipline-wise and this report covers aspects related to metallurgy.

2 Research and development are two different entities. Research can continue without any consequences on economic performance of a country. Researchers, by and large, are not concerned about whether their research work has led to any tangible products, processes or improvements in existing ones. Invariably, whenever a new invention is made elsewhere in the world, our researchers jump into the band wagon to publish as many papers as possible in that novel area. This has been the case in areas like rapid quenching, bulk metallic glasses, high temperature superconductors, nanomaterials, carbon nano- tubes, graphene etc. At the same time, researchers and developers elsewhere are trying to find out what are the possible applications or uses of such discoveries and work towards exploiting them. This requires a conscious and cultural change in our attitude. While government provides large scale funding, there is no clear cut demand of what is expected out of it. This needs a corrective action, if the end results are desired to be different. These are dealt with in Chapter 2. It is also pointed out that metallurgy is gradually becoming more science oriented with academic institutions getting to adopt materials engineering as part their curriculum.

3 Chapter 3 deals with in-house R&D departments in the government sector like the Departments of Defence Research, Atomic Energy and Space. Defence R&D laboratories have been established primarily to assist the armed forces of the country, particularly in developing new systems and products. These are often compared with imported goods and timely availability of these has been another major concern. DMRLas a metallurgical lab has succeeded to a considerable extent in meeting several requirements of the Services and has indigenised many materials. Development of brakepads, investment cast DS and single crystal blades for jet engines and naval steels are some noteworthy examples.. In the Atomic Energy sector, because of the embargoes imposed, the indigenous R&D had to rise to meet the challenges faced for total indigenisation and has done extremely well. The R&D carried out at BARC has helped in setting up the Nuclear fuel Complex and the heavy water plants that supply the requite quantities of fuel and the heavy water for the entire nuclear programme. An important difference in the programmes of the DAE and the DRDO is that the user and the designer are the same in the DAE while the user, the specifier or the qualifier and the producers are all different entities in the case of DRDO with their attendant problems of being on the same plane. The situation in case of Space Dept. is more or less similar to that of DAE. . DOS have specified their requirements for materials and components and have indigenised several products with the assistance of Indian industry and other R&D laboratories, that include setting up infrastructure facilities at the manufacturing sites.

4 The Council of Scientific and Industrial Research has established several laboratories over the country since independence as their initial mandate was to help in finding suitable

applications of regional raw materials, the exception being some of the National Laboratories, like the National Physical Laboratory, National Chemical Laboratory and the National Metallurgical Laboratory. Other regional laboratories were added later on and many have changed their names as they have moved away from their original concept. In this context the NML has done a lot of work on a national basis, serving truly as a national facility, particularly to meet the demands in mineral beneficiation and materials testing. Their component testing laboratory and their expertise in residual life estimation has been fully utilised by many service sectors. CGCRI has also risen to the occasion to meet the demands of special glasses and refractories for the strategic sectors and has progressed well in the fibre optic side. Activities of many other regional labs appear to have moved away from their original goal of regional resource utilisation to carrying out interdisciplinary research and developing advanced processes, with no particular mandate of developing any specific product. Some details have been provided in Chapter 4.

5 Many of the private industries have their own research, engineering and development units, as they have to solve their day to day problems. At the same time energy saving and cost reduction are of great concern for the these industries. In this context, TRDDC at Pune stands out as an excellent example which not only caters to Tata group of companies, but also carries out work for other industries as well. They have developed expertise in modelling and simulation techniques and are able to come out with appropriate solutions with very little enhanced scale experimentation. Of course, this necessitates extensive data logging and associated instrumentation for appropriate modelling. Other industries have kept a low key on their R&D efforts, especially due to commercial interest. Chapter 5 covers the above subject.

6. R&D in public funded institutions is dealt with in the next chapter. There are separate R&D laboratories like the ARCI and NFTDC, while there are other R&D units attached to production centres. Midhani is more of a prototype PSU under Defence Production & Supplies Department, which caters to needs of specialised materials for strategic applications for nuclear, space and defence programmes. The manufacturing facilities at Midhnai are relatively of small scale and consequently, Midhani loses out on economies of scale, in cost comparison, particularly after globalisation. HAL Foundry & Forge has done well in absorbing technologies developed by R&D laboratories and in addition it carries out its own innovations. Similar is the case with BHEL and Rail Wheel Factory. Their R&D activities essentially cater to the requirements of their main factory.. ARCI is a separate laboratory funded by DST but it did not appear to have any specified objective of serving any industry. As a strategy for easier transfer of technology it was found to have set up a technology incubation Centre. But, it must be pointed out that not all technologies claimed to been developed, have successfully been transferred to industry. In comparison, NFTDC appears to meet their budget from the projects that they get. Consequently, they tend to innovate more to keep costs down and have built excellent equipment for solving their problems. If there could be a greater collaboration between R&D Centres of the various production establishments their cost effectiveness or output might have been greater.

7. Chapter 7 gives in brief some details about what needs to be done in some important areas of research. With increasing emphasis on energy savings and waste disposal problems, greater attention needs to be paid to achieve optimal benefits. International collaboration that exists in the aluminium sector should be thought to be extended to other sectors as well.

8. The crux of the report is in Chapter 8 which deals with recommendations. With regards to metallurgical/materials engineering curriculum, process metallurgy has become a neglected area and this needs to be remedied soon. Particularly, if one were to look for alternate and cheaper routes of processing of energy critical materials, including the rare earths, it requires immediate action. Academicians also may have to develop a different mindset to see how best their research outputs can lead to improvements in processes or in the production of new technologies. Modelling and simulation along with integrated computational materials engineering could be special subjects for metallurgy students. Other recommendations are made in brief in this chapter.

9. In summary, there is no denying that there is enough talent in the country to tackle and succeed in the developmental activities for materials and components. This is evident from the achievements in the nuclear, defence and space sectors. May be this has happened out of necessity, coupled with the spectre of facing denial of technologies. However, if this can lead to success in these sectors, why does it not occur in other areas as well? Should not this be pondered over?

10. This report is intentionally kept brief, so that people concerned and interested would read it in full, appreciate the success stories in government scientific departments, government supported laboratories, and also the R & D initiatives of public limited as well as private companies who are concerned with immediate or short term solutions. The recommendations made are in no way to be taken as a criticism. The committee felt that if some of the recommendations are adopted, it may lead to more tangible results.

1. INTRODUCTION

1.1 Metallurgical Engineering, unlike other branches of engineering borders between basic sciences and conventional engineering like civil, mechanical and electrical engineering. The uniqueness of metallurgical engineering is that it is not a system development subject, but all systems need metals, alloys and materials. You need materials to withstand the strength requirements and environmental conditions which could be harsh; you need materials that are light and strong so that payload fraction could be increased in flights and spacecrafts, etc. All the systems engineers turn to metallurgists and material scientists to meet their requirements. It is also heartening to mention that metallurgists have not let down the country. Of course, this is a statement often made by late Dr. Raja Ramanna whenever he referred to the nuclear programmes of the country. Another thing that is often said about metallurgists is that they are a coherent and friendly community and that they are always willing to help each other. It is hoped the future generations would continue to uphold this spirit.

1.2 When we took this task of writing a report on 'Successes and Gaps in our Metallurgical R&D Efforts', we thought that it would be easier to write about the success stories, but it would be rather difficult to talk about gaps and failures, partly because people do not like to talk about failures, leave alone owning them. It should be emphasized here that we are not talking about failures in achieving our research and development goals, but we are more interested in failure in converting our research outputs into useful tangible products for use of the society at large. We need to analyze what are the contributing factors for the failures and suggest possible remedial measures. Similarly, there are some significant gaps in our research activities, which need to be addressed. Everyone knows that the area of electronic materials has not received the attention that it should have. We shall highlight some of these later, based on the inputs we have obtained.

1.3 To begin with, there is the academic community that is more interested in research per se. They are more motivated towards publications of their work in reputed international journals rather than tackling the so called 'mundane' problems of industries. There are R&D establishments within the Departments of Atomic Energy, Space and Defence which are more interested in solving the problems they encounter or they would be encountering. In addition, the Council of Scientific and Industrial Research had established several laboratories to meet the requirements of the industries in different regions of the country and for effective utilisation of regional raw material resources. Depending on the environment, attitude and the available technical manpower, some laboratories have concentrated more on basic research, while others have paid greater attention to product development. On the other hand, industries look for proven and well established technologies for quick successes and better return on investments (ROI) and feel that these can be achieved more easily with imported turn key technologies. There is nothing wrong in importing technology to get a head-start, but there is an urgent need to assimilate and adapt that technology to make use of indigenous raw materials, to improve production, to reduce energy consumption and to bring down the costs. If our R&D has helped in achieving some of these objectives, then it can be said to have achieved success.

1.4 The committee has visited several establishments in the last four months or so, met with the top executives and R&D directors and managers of these establishments and discussed in detail several aspects pertaining to the task on hand. It interacted with the academic community as well as it interacted with the scientists who were Secretaries to the Scientific Departments of the Government, to get a broader perspective.

1.5 Having collected the basic material for the report, the next task was how to present it to the Fellows of the Academy and others. After some deliberations, the committee decided on the following groupings so that some coherence would emerge when it comes to making the final recommendations. Thus, the report deals with R&D efforts in metallurgy in the following categories.

(a) Academic Institutions

(b) In-house R&D in DAE, Defence and Space

(c) CSIR Laboratories

(d) R&D in Private Sector

(e) R&D in Public Sector

(f) Sector-wise Assessment in Ferrous, Non-ferrous, and other Metals

(g) Successes, Gaps and Recommendations

1.6 After due deliberations, the committee decided that the report should be brief, so that interested people would read the report in full to derive the benefit from the efforts put in. If one desires to learn more about certain programmes or institutions, their websites are available. Further, elaborating on the gaps or the failures at great length is not the right thing to do any way. Again brevity in listing out the recommendations is a necessity, as otherwise it may not yield the desired results. It was also the decision of the committee to collectively acknowledge all who have contributed to our efforts rather than assigning each idea or concept to individuals except where necessary.

2. ACADEMIC INSTITUTIONS

As Pandit Nehru spearheaded the industrialization of the country in the 1950s, the planners rightly envisaged that the country would need a large number of engineers, including metallurgical engineers. A few Indian Institutes of Technology and subsequently Regional Engineering Colleges now rechristened as National Institutes of Technology were established. All of them have done well and are doing well. Compared to only 4 institutions that catered to undergraduate programme in metallurgy in 1950, there are over 30 institutions offering undergraduate metallurgical and materials engineering courses today. According to a recent CSIR, NISTADS report, the total number of metallurgy BTech, MTech and PhDs coming out of premier institutes such as IITs, NITs, BHU, Bengal Engineering and Science University (BESU) and Jadavpur University (JU) are 421, 196 and 42 respectively in 2010. Several private engineering colleges have been set up during the past few years to offer degrees to young professionals aspiring to excel in their selected areas of interest. It is ironic however that this year, 25 to 30% of the available seats in engineering colleges in Maharashtra and Tamil Nadu remained vacant. Several reports on the state of engineering education have highlighted the severe shortage of qualified faculty. Even in IIT's on an average 25 to 30% of the faculty positions are not filled. Situation in other private colleges is even more pathetic. It is also to reckon that none of the private engineering colleges offer degrees in metallurgical engineering, particularly in core metallurgical engineering areas. Unless we take corrective actions at a national level, the higher engineering education in metallurgical engineering in the country will lose its relevance so far as the Indian industry and Indian R&D is concerned. The mismatch between what is being taught and what kind of skill sets are needed to maintain our competitiveness globally in mineral, metal and materials engineering field, is steadily growing. It is not surprising therefore that new innovative means of developing human resources with relevant skill sets are being thought of. All premier R&D organizations in the country, that is, DAE, Defence, Space and now CSIR have established universities of their own so that they can train the human resources commensurate with their needs.

2.1 Metallurgy or Materials Science?

In the discussions with the academic community, it was pointed out by a senior professor that the best service that they have done to the industry is by providing good metallurgical engineers, who have helped set up several factories and supervise the production operations. However, Prof. A.K. Lahiri, in the Indian Institute of Metals Daya Swarup Memorial Lecture - 2010 had expressed some reservations about this. He has stated in his lecture that there is an overemphasis of pure science aspects in the way the subjects are taught in the under graduate metallurgy courses except for process metallurgy. This situation has got further exacerbated with metallurgical engineering departments getting rechristened as materials engineering with additional load of science based courses at the cost of basic engineering subjects . Lahiri has put it bluntly by stating that 'we are not producing metallurgical engineers at all'. As a result, many of the metallurgical industries do not prefer to hire metallurgy graduates as their first choice. He laments that the present objective of research is tuned to publishing papers in peer reviewed journals. The situation is similar in industrial R&D departments also. His statistics show that Arcelor Mittal which produces 160 million tonnes of steel per annum has 1400 researchers and their total number of publications in the period 2007-09 is 161 only. On the contrary, an Indian steel plant which produces less than 15 million tonnes of steel has research staff of about 200 but their publications number 210 in the same period. This status of metallurgical education in the country needs to be addressed critically.

2.2 Graduate and Doctoral Programmes

One academician stated that topics for most PhD theses have no relevance to any direct applications. In many cases, the work is more of data generation than getting an insight into the materials behaviour or processes. As a consequence, some doctoral degree holders even find it difficult to get jobs in their fields of specialisation. This is not unique to our country. In a recent article in Nature (472, 267, 2011) entitled 'The PhD Factory', it is stated that the number of PhD degree holders in the OECD countries grew by 40% every year between 1998 and 2008, because the number of educated workers was considered to be indicative of economic growth. Today, the doctorate degree holders are confronted with a dwindling number of academic jobs and the industrial sector is unable to take up the slack. It is also pointed out in the same article that the quality of graduates in China and India is not consistent. The number of PhD degree holders in China is increasing at an alarming rate, with some 50,000 graduating across all disciplines in 2009 but, the main problem is the low quality of many graduates. In 2004, India produced around 5,900 science, technology and engineering PhDs, a figure that has now grown to about 8,900 a year. It is anticipated that this number will go up to 20,000 by 2020, according to T. Ramasami, Secretary, DST. There are few academic opportunities in India for doctorate degree holders. But, according to the Planning Commission's report, about 2 million additional seats in higher education are to be created in the 12th plan period. The same NISTADS report indicates a shortage of about 950 PhDs in materials engineering alone in the academic sector for the year 2020. Better-paid industry jobs used to be major attractions, but this number is also dwindling. But, the basic problem one faces is the employability or unemployability of fresh undergraduates and graduates in our industries and R&D institutions. It is also mentioned in the NISTADS report that out of the undergraduates and graduates coming out of premier institutions, about 60% 0f the materials engineers are absorbed in non-core companies. In the remaining about 35% are absorbed in manufacturing sector in core companies. Several private engineering colleges have been set up during the past few years to offer degrees to young professionals aspiring to excel in their selected areas of interest. It is ironic however that this year, 25 to 30% of the available seats in engineering colleges in Maharashtra and Tamil Nadu remained vacant. Several reports on the state of engineering education have highlighted the severe shortage of qualified faculty. Even in IITs on an average 25 to 30% of the faculty positions are not filled. Situation in other private colleges is even more pathetic. It is also remarkable that none of the private engineering colleges offer degrees in metallurgical engineering, particularly in core metallurgical engineering areas. Unless we take corrective actions at a national level, the higher engineering education in metallurgical engineering in the country will lose its relevance so far as the Indian industry and Indian R&D is concerned. The mismatch between what is being taught and what kind of skill sets are needed to maintain our competitiveness globally in mineral, metal and materials engineering field is steadily growing. It is not surprising therefore that new innovative means of developing human resources with relevant skill sets are being thought of. All premier R&D organizations in the country, that is, DAE, Defence, Space and now CSIR have established universities of their own so that they can train the human resources commensurate with their needs.

2.3 Applied Research

The requirements of industries are in finding solutions to their production problems. By and large, the academics are not interested in tackling these, as these will not fetch them any recognition in the academic circle. However, there are a few faculties who are very passionate about solving industries' problems, but they are a minority. In this context, it was pointed out that the work on formability diagrams by YVRK Prasad, bacterial leaching and bio-remediation by KA Natarajan and modelling and simulation studies by AK Lahiri (all from IISc) are very commendable. Of course, there are similar examples in other institutions also.

We were told by another academician that the 'link' between academic institutions of excellence and industry is missing. While an academic institution's responsibility is to train students and come up with new ideas and concepts, making use of them to produce industrial products etc. is rarely done (and can't be done) in academic institutions. However, it should also be pointed out that Indian industries have a long-standing culture of importing the required technology and as such there is not much emphasis on developing indigenous technologies, except in strategic sectors, where the embargoes prevented technology import. Basically Indian industries do not trust what Indian researchers have accomplished and are hesitant to accept indigenous technologies. At the same time, it is also a fact that a few problems faced by the industries do get solved by academicians when there is a personal rapport.

2.4 P Balaram's Views

The general opinion is that universities and institutes of excellence are established for research, and not for development of new industrial processes or products. P. Balaram, Director, Indian Institute of Science in his recent interview published in the Times of India dated April 3, 2011 is quoted: "IISc deals with knowledge and if the knowledge generated by the academia is used to make a car that is fine. But IISc would not get into the business of making cars". He is perfectly right in saying that IISc would not enter into making products. Balaram stated that the products of his institution are people and knowledge and it is those people trained by IISc who have built other establishments and made them a success. There is no doubt that there are several examples where basic research and publication of results thereof have led to important applications benefiting industries.

While one may argue on the issue that academia should not delve in product development activities, there cannot be any question about the relevance of research to meet industrial and societal needs. Everyone is concerned about global warming and finding out ways and means of energy conservation. All of us are concerned with green house gas emissions and with the world population increasing, concern for water conservation has become a topic of utmost importance. Developed countries have drawn roadmaps for energy critical elements as a priority item for R&D. It would be very appropriate if the institutes of excellence concentrate as well on such problems and find solutions that can be applied for societal benefit. This is not to say that it is not being done now, but a greater focus is required at all levels.

2.5 K S Krishnan's Views

In this context, it would not be out of place to mention the views of Sir K. S. Krishnan, a revered physicist of our country. In a recent biography (K S Krishnan, His life and work, by

DCV Mallik and S Chatterjee), it is mentioned that according to Krishnan, while pursuit of science was a noble goal in itself, he placed application of pure science to industry was a corollary that he seldom thought about. However, his visit to Europe in 1940 made him think about the benefits of application of science to industry and enhancement of quality of life in the West. As such, in his Krishna Rajendra Jubilee lecture in 1941, Krishnan stated that there is an intimate relation between fundamental research and industries. To quote from his above lecture, "in order that fundamental research may reach industries, we naturally need a large group of scientific men, fully equipped with the available knowledge of the fundamental sciences, who will apply them for industrial purposes- that is ad hoc researchers, who will take up problems that are of importance to the industries and tackle them. Probably the best representative of ad hoc research is Edison. In fact, the strength of ad hoc research depends on the support it derives from the fundamental side …. Fundamental research in the long run is likely to be much more helpful to the industries than ad hoc research". These profound thoughts made as early as in the 1940s should have been viewed seriously.

The situation as it exists today is not flattering. One of the industrialists stated that researchers are not ready to take up specific mission oriented and time bound projects in metallurgy. The needs of the industry for R&D in metallurgy usually relate to material development, process development, trouble shooting, failure analysis etc. The response required is mostly immediate and the time span given is rather short. We also heard from another industrialist that a project to develop a better material was given to a well known researcher in an academic institute of excellence, but it had to be short-closed as the interest shown by the researcher concerned and the progress achieved were far from satisfactory. There is a need for organizations to give greater credit to scientists who work along with the industry to solve problems and develop materials or processes. It is felt a radical change in attitude is necessary for the interactions between academicians and industries to be mutually beneficial. It was also opined that if R&D projects are taken up in collaboration with the industries, which have either short term / long term interest and with some investment from the industry as a stakeholder, transfer of technology would be successful. Later, we came to know that the present Director of NML is trying to follow this model in the wake of complaints regarding unsuccessful transfer of technologies. One only hopes that audit does not come in the way.

2.6 Increasing Awareness

It is pertinent at this stage to bring to the attention of readers the situation as it exists in the USA. In a study conducted by the US National Academy of Engineering on the 'Impact of Academic Research on Industrial Performance' published in 2003, it is said that the role of academic research has changed over the last 25 years in that there is a growing awareness of academic research to industrial innovation and performance. Universities have become directly involved in the commercialisation of their research. Another important aspect to consider is that in the US, multi-disciplinary research and intermingling of people and ideas are encouraged. That usually does not happen in India. It is necessary to encourage integrated research for achieving greater progress.

2.7 MNCs and Academic Institutions

Another interesting observation made during the discussions is that American industries like Boeing and General Motors are approaching centres of excellence in India to work on futuristic research for them. They are not bothered about the return on investment at this stage. A senior Fellow of an MNC in India said that they are happy with the front end research being carried out in some Indian institutions which have a good number of highly qualified personnel. They have excellent facilities, which the industries cannot afford to establish for their exclusive use. The availability of highly skilled motivated students in these places is another factor that draws multinationals. Pre- emptive research prior to technology development is made use of by these MNCs' India Centres. Interactions with high quality academics help them in keeping up to date a healthy knowledge repository. Obviously, intellectual property rights are shared between the two, whenever a project comes to fruition. Another senior professor stated that working for MNCs is also attracting good students for the institutions. The question that one may ask is, if our national centres of excellence can do such great work to attract attention of MNCs, what prevents them from doing it on their own and for our own country? Why do we have to share our IPRs with MNCs? If a material for Boeing's dream liner and beyond is developed by us (our institutions), it would not go unnoticed by the MNCs. It is pertinent to point out here that in a recent Royal Society report 'Knowledge, Networks and Nations: Global Scientific collaboration in the 21st century' published in March 2011, Sir Llewellyn Smith, Director of Energy Research at University of Oxford (Prof. G. Mehta from IISc was a member in this committee) points out that unless focused efforts are made on capacity building in emerging nations to make their research institutions more effective partners in their own developmental efforts, they would end up as "research labs" for scientific superpowers. In fact the collaborating laboratories should be able to tap the knowledge base of their counterparts so as to benefit national research base. It cannot be a one way affair. Our institutions of excellence need to analyze these aspects more deeply and take appropriate actions.

2.8 Technology Incubation Parks

Another aspect to be taken note of is that the academicians are often constrained in carrying out their research on a bench scale. There is no facility for testing their know-how on a pilot plant scale, before adoption by industry. As a consequence, industrialists are sceptical about utilizing this kind of (untested) know-how. As an illustration, let us take the case of Indian iron ores. It is well known that Indian iron ores contain more alumina and silica which pose serious problems in blast furnace operations. Bio-beneficiation work with minerals such as hematite is known to have resulted in significant surface-chemical changes. Through bio-pre-treatment, it is possible to selectively separate alumina and silica from iron oxide either through flotation or selective flocculation. The research was carried out on a bench scale and results were published. But, one needs the patience and cooperation of the concerned industries for pilot scale testing, which was not forthcoming. We were told that a fair amount of success had been achieved on the use of biotechnology with gold ores at the Hutti Gold mines, because of a collaborative project 'Setting up of a demonstration bioreactor plant for bio-treatment of refractory gold ores and concentrates at Hutti gold mines'. The results showed that the yield of gold and silver increased considerably after bio-treatment.

2.9 Better Documentation Needed

Another major factor for the research output not being put to use is the poor documentation of the work done by our researchers. This also affects them when a comparative evaluation of the processes or products they have developed, is made. This needs to be addressed carefully, but at the same time it has to be realised that we cannot impose ISO culture on researchers here. It was also pointed out that scientists so far have not been thinking about patenting their innovations, but they are only keen on publications to get peer recognition and awards. However, this is gradually changing now. It was mentioned that there are patent marketing groups in the country which assist innovators to commercialise their innovations. In this context, a reference was made to the innovation centres being set up by the Department of Science and Technology. It is understood CSIR also has taken up this task.

2.10 Build Institutions around Great Researchers

An important point to be noted is that centres of excellence and basic research thrive solely on the reputation of the leading researchers in the centres. This was the principle that Homi Bhabha had put into practice when he started the Tata Institute of Fundamental Research and the Atomic Energy Establishment Trombay. This is the principle on which the Max Planck Society and Institutes were founded after the World War II. Since inception Max Planck Institutes have produced 17 Nobel Laureates and published over 13,000 papers. One of the objectives of MPIs is to promote projects at the interface between applied and basic research. To facilitate transfer of technology, they have also set up a Max Planck Innovation GmbH., to bring patents and technologies to the market and to assist people in setting up new companies. While we have similar methodologies, we have not met with as much success as the Germans have, possibly due to lack of focus.or methodology.

2.11 R&D Funding in Metallurgy

NISTADS report (July 2011) also had made a comparison between R&D funds by public and private sectors along with FDI in the metallurgical industries. See table below reproduced from their report. It is seen that the annual growth rate from 2003 to 2010 in public funding has been around 4%, while that by the private sector is 10 times more. It appears that there is no dearth of funding for R&D in materials engineering.

2.12 R&D investment by Public/Private Sector and FDI in the Metallurgical Industries

Year	Total no. of Ph.D. produced	AGR (%)	R&D Investment (Public Sector) (Rs. in Crore)	AGR (%)	R&D investment (Private Sector) (Rs. in Crore)	AGR (%)	Total FDI (Rs. in Crore)	AGR (%)
2003	440		90.26		104.43		146	
2004	513	16.73	85.62	-5.14	131.83	26.24	881	503.42
2005	997	94.26	89.02	3.97	142.87	8.37	6540	642.34
2006	1048	5.07	92.58	4.00	201.45	41.00	7866	20.28
2007	2024	93.18	96.28	4.00	284.04	41.00	4686	-40.43
2008	2235	10.44	100.14	4.00	400.50	41.00	4157	-11.29
2009	3825	71.11	104.14	4.00	564.70	41.00	1935	-53.45
2010	3314	-13.34	108.31	4.00	796.23	41.00	5055	161.24
Projection for future 10 years								
2011	3816	15.13	111.07	2.55	684.83	-13.99	5948	17.67
2012	4308	12.89	114.62	3.20	759.95	10.97	6438	8.24
2013	4826	12.02	118.17	3.10	835.07	9.88	6928	7.61
2014	5393	11.75	121.72	3.00	910.19	9.00	7418	7.07
2015	5886	9.14	125.27	2.92	985.31	8.25	7908	6.61
2016	6378	8.36	128.82	2.83	1060.42	7.62	8398	6.20
2017	6826	7.02	132.37	2.76	1135.54	7.08	8888	5.83
2018	7363	7.87	135.92	2.68	1210.66	6.62	9378	5.51
2019	7845	6.55	139.47	2.61	1285.78	6.20	9868	5.22
2020	8324	6.11	143.02	2.55	1360.90	5.84	10357	4.96

2.13 Research Priorities

Contributions from applied academic research are very important to industry. Today, in the US academic researchers and their research infrastructure are directly involved in the development of industrial tools, prototypes, products, and production processes, as well as in delivery of products and services. Individual companies have also greatly benefited from university-based research to solve discrete practical problems. University-based research centres, with industrial participation, have become another important venue for applied research as well as more directed basic research of value to industry. Applied research through multidisciplinary collaboration among science, engineering, and/or medical faculties is a unique strength for the academia. But, as published in a recent article in Nature (12th May 2011) ambitious targets of multi-disciplinary projects get lost as the products unfold and it is the pull of the heavyweight 'science for its own sake' and economic agenda that crush wider intentions. It states that society is not willing to consider any knowledge to be inherently good if its benevolent image cannot be sustained (example: nuclear power). Our major fund givers have to take this into consideration. The notion that public and stakeholder participation can help define research priorities regarding quality and relevance of deliverables is not being taken for granted. Will such a situation not arise in India also in near future?

3. R&D IN DEPARTMENTS OF DEFENCE, ATOMIC ENERGY AND SPACE

The Departments of Atomic Energy, Defence and Space of the Government of India all have major metallurgy activities. While we could visit BARC, IGCAR and DMRL we have not had time to visit the laboratories of the Department of Space, and as such our analysis with respect to Space department is from the literature made available to us. Right at the outset it should be pointed out that in the Department of Atomic Energy (DAE), apart from basic research, applied research is carried out mainly to satisfy the needs of DAE and in particular that of the fuel production unit, the Nuclear Fuel Complex, Heavy Water Plants and the Nuclear Power Corporation of India Ltd (NPCIL). Here, it is to be noted that the researcher and the end user are all within the same department. This has led to a better understanding and appreciation of the needs of each other. But, in the case of Defence R&D, the researcher and developer is from one department, the production agency is from another while the user is altogether a different entity. Coordination, understanding and appreciation between the three agencies require a lot of give and take. The normal procedure for the DRDO staff is to interact with the Services to evolve the Qualitative Requirements (QR) of the systems to be developed in conjunction with the concerned laboratories of DRDO. Invariably, the Services require a product that would encompass a combination of the best performance parameters in all the systems that exist at that point of time worldwide. It may be even theoretically impossible to meet such requirements. However, such tough QRs are evolved and imposed on the DRDO laboratories and with tight time schedules, sometimes dictated by finance people. More often than not, cost and time overruns have become inevitable. On top of that, with threat perceptions changing, the QRs also get modified and consequently there is a further delay.

3.1 DEFENCE METALLURGICAL RESEARCH LABORATORY

3.1.1 DMRL Unique in DRDO

The Defence R&D Organisation, which is mandated to assist the three Services, has been more oriented to developmental activities pertaining to systems and components than in carrying out basic or applied research. Major portion of the funds made available to the laboratories is utilised for developmental activities and user trials than in research. The Defence Metallurgical Research Laboratory is however an exception in that it has also evolved as a centre of excellence for metallurgical research. This is amply evident from the number of papers published in peer reviewed journals and in the number of awards and recognitions DMRL scientists have got over the years. At the same time, it is gratifying to see that it has placed considerable emphasis on developmental activities as well. A brief account of the activities of DMRL is given in the following paragraphs.

3.1.2 Brakepads

The country has a large number of Russian aircrafts and brakepads in them need to be replaced periodically. Indian Air Force found it difficult to procure them from Russia in time and posed this problem to DMRL. The laboratory rose to the occasion and developed these brakepads by reverse engineering. The technology was transferred to HAL, Bangalore where these are now manufactured routinely. HAL has gone ahead and has developed brakepads for other aircrafts also. This is a very creditable work and the country now meets its requirements from indigenous production.

3.1.3 FSAPDS

Fin Stabilised Armour Piercing Discarding Sabot (FSAPDS) sounds very complicated and it is so. But, based on basic research and pilot plant studies carried out in powder metallurgy of tungsten, DMRL had established a full scale facility for the production of FSAPDS at Tiruchirapalli, Tamil Nadu. This plant was later transferred to Ordnance Factory Board of the Department of Defence Production and Supplies. The uniqueness of this plant at that time (late 1980s) was in it being a robot controlled facility and the first of its kind in the government sector. It is hoped that this has led to better capacity utilisation of the plant over the years.

3.1.4 Armour Technology

The armour steel, named jackal steel, was primarily developed for use in BMP and T72 tanks. SAIL is now producing this steel. Cost reduction has been achieved by the continuous casting technology instead of the ingot route. Body armour technology has been transferred to Midhani for production. Armour technology has been continuously evolving at DMRL to take care of the changing threat perceptions. Armours have moved away from rolled homogeneous steel plates to high hardness steel and from monolithic to composite configurations containing a variety of materials such as ceramics, metals, polymers and FRP/GRP. Newer armour concepts such as explosive reactive armour and dynamic armour have also emerged in recent years.

3.1.5 Steel for Naval Ships

Indian Navy is known to be proactive in supporting and absorbing indigenous technologies. This is true from the acceptance of various sonar systems developed at NPOL, torpedoes from NSTL and materials of construction from DMRL and NMRL. Based on the R&D studies carried out at DMRL on equivalent grades of hull steels from the former Soviet Union, technology for production of DMR-249A steel has been established through SAIL. Within five years of commencement of this work, Cochin Shipyard Limited (CSL) placed bulk orders on SAIL during late 2004 for the supply of DMR-249A steel for construction of the very first aircraft carrier. Through continuous casting and controlled rolling, the steel has been made cost competitive with respect to import options. Subsequently, technology for production of another grade of steel, DMR-249B has also been established. CSL placed bulk orders on SAIL during 2008 for supply of DMR-249B steel for the construction of the aircraft carrier.

3.1.6 High Strength Steels

Strength to weight ratio is of major concern for materials usage in aero-space applications. A new ultra high strength, high fracture toughness low alloy steel designated DMR-1700 was developed as a candidate material for booster motor casings. The motor casings fabricated through external agencies have been successfully pressure tested. DMR-1700 promises to be an attractive substitute for 250-grade maraging steel for motor casings, particularly as the cost of DMRL-1700 is about one third of that of 250-grade maraging steel which is currently used for such applications.

3.1.7 Investment Casting

Investment casting has been an age old technology in our country right from the intricate bronze and panchaloha castings of images of Gods carried out by the lost wax process. Thus, development of directionally solidified and single crystal blades from high temperature nickel base alloys for jet engine applications may be considered as an extension of our ancient technology. But, it is far more complicated than producing idols, because the turbine blades need to meet the operational requirements at high temperatures and at high speeds. This necessitates complex internal cooling passages. The ceramic core technology required for creating these internal passages developed at DMRL is a marvellous technology. After a pilot plant operation, the technology was transferred to HAL for production. As a spin off, investment cast equi-axed blades for land based turbines have also been made and supplied to BHEL and NTPC for possible applications in their thermal power plants. Unfortunately, there is no marketing wing to follow up with these agencies to complete the loop. It would be advisable for R&D departments to have a marketing wing for utilising the spin-off technologies for civilian applications.

3.1.8 Titanium Sponge Production

Another successful story apart from promoting indigenous technologies is in bringing in technologists to assist the organisation. This is illustrated in setting up of the titanium sponge pilotplant of DMRL. DMRL had not delved much in extractive metallurgy prior to setting up the titanium plant. Hence, it brought in the scientist who had worked in this area from DAE to set up a 3 tonne per batch Ti sponge plant. Based on this experience, the technology has now been transferred to KMML, Kollam, Kerala to set up a 500t/y plant that has been commissioned recently. This programme is supported by Department of Space. As an offshoot, the anhydrous magnesium chloride which is a by-product is to be converted into magnesium metal for recycling in the plant. A multi polar cell operation on a pilot scale for magnesium recycling has also been carried out at DMRL, based on the earlier experience gained on monopolar cell in association with CECRI.

3.1.9 Titanium Alloys

Ti-29A, a near alpha titanium alloy production technology was co-developed with Midhani which will be producing disks of this material using the DMRL isothermal forging press. This activity shows good cooperation and understanding between a production agency and a research establishment.

While titanium alloys are capable of operating only at moderate temperatures up to 600oC, the intermetallics of titanium are capable of withstanding much higher temperatures. DMRL successfully developed orthorhombic titanium aluminide for gas turbine applications and has jointly patented it with SNECMA, France. The Ti_3Al forging stocks are made at DMRL and blade forgings are carried out at HAL.

3.1.10 Aluminium Alloys

Al-Li alloy development was started in DMRL at the most appropriate time when the user interest was high. Al-Li alloys made at DMRL were used in various satellites to replace 2000 series Al alloys, while alloys produced on industrial scale in collaboration with Russia and HAL, Bangalore and cleared by airworthiness agencies, found only a limited use in LCA. Su-30MKI parts made of Al-Li alloys are being manufactured at HAL, Nasik under Russian collaboration. Though plans to indigenise these alloys at industrial scale in collaboration with NALCO had progressed substantially, the same did not materialise due to poor demand at home and abroad. There appears to be resurgence in the usage of Al-Li alloys in various aeronautical programmes across the globe once again. ADA and DMRL are closely examining the feasibility of using Al-Li alloys for new aircraft programmes.

3.1.11 Rare Earth Permanent Magnets

Samarium-cobalt magnets were developed and a pilot plant for the production of magnets was established. TOT did not take place as the market was very limited. In the case of Nd-Fe-B magnets, while DMRL developed the requisite know-how and also transferred the technology, production could not be started as import option was cheaper. DMRL had developed a few more technologies for the civil sector, but no TOT took place. As a policy guideline, it may be necessary to carry out a market survey before developmental work for civil sector is started.

As stated earlier, DMRL is in an unenviable position because the user and production agencies are different from that of the developer. But, as in the case of DAE, whenever there is a denial of products and technology or considerable delays in getting supplies (as in the case of brakepads), DMRL has risen to the occasion and met the requirements. One thing that needs to be emphasised here is that the basic and applied research at DMRL has been the main stay of their successes.

3.2 BHABHA ATOMIC RESEARCH CENTRE

Bhabha Atomic Research Centre has done pioneering work in nuclear materials right from its inception. Conversion of yellow cake into metallic uranium, extraction of thorium from monazite, plutonium from irradiated fuels etc. have all been carried out successfully. These have been converted into fuel elements for research reactors. Later, R&D was started on uranium oxide and mixed oxide fuel elements for our power reactors and the technology was transferred to the Nuclear Fuel Complex for establishing full scale plant operations, which included zirconium technology right from separating hafnium from zirconium and going through the various steps of melting, casting, extrusion, etc. to produce different types of end products. It should be mentioned here that the very first challenge in nuclear metallurgy was taken up by Dr. Homi Bhabha when he decided that half the required metallic uranium fuel elements for the CIRUS reactor would be made at AEET, the then name of BARC. The Canadians, with whose collaboration this reactor was being built laughed at this idea and joked that the fuel would behave like the Indian rope trick. But, the metallurgists did this job successfully and the indigenous fuel withstood twice as much irradiation as compared to that of the Canadian fuel. Presently, the Materials Group of BARC is involved in R&D in materials pertaining to Pressurised Heavy Water Reactors (PHWR), Fast Breeder Reactors (FBR), Advanced Heavy Water Reactors (AHWR), High Temperature Reactors (HTR) and Accelerator Driven Subcritical Systems (ADSS). R & D work is carried out right from lab-scale up to demonstration stage in several cases.

3.2.1 Processing Uranium Ores

Processing trials of uranium ore from Tummalapalle deposits at Andhra Pradesh using an innovative alkaline pressure leaching process has been successfully completed. A technology demonstration pilot plant has been set up at Jaduguda to scale-up the studies carried out on bench scale. The richest uranium ore in the country is found in Gogi in Karnataka and a flow-sheet for extraction of uranium values has been worked out.

3.2.2 Purification of Materials

Purification of materials and compounds and production of metals of different types including powder metallurgical products have been the other important activities at BARC. R&D work carried out on the production of very high purity materials lead to setting up the Special Materials Plant at NFC. Refining the nuclear materials to specified purity has been achieved by solvent extraction, iodide refining, molten salt electro-refining and electron beam processing.

3.2.3 Rare Earths

A few of the rare earth compounds have been separated and purified from the stock obtained from the beach sands. Rare earth based phosphors have been synthesised and evaluated for their spectral properties and quantum efficiencies. Cerium and lanthanum metals have been prepared by fused salt electrolysis.

3.2.4 Composites

Development of carbon-carbon composites has been initiated for potential use as fuel tubes of Compact High Temperature Reactors (CHTR). This includes carbon fibre reinforced carbon, carbon fibre reinforced silicon carbide and SiC fibre reinforced SiC composites. Chemical vapour infiltration technique has been adopted for this. SiC is a candidate protective coating material for CHTR. BARC has developed and successfully implemented a novel method of immersing a heated graphite sample in a bed of fluidized silicon for the above work.

3.2.5 Instrument development

BARC has always been working on development of instruments, partly due to import restrictions. They have recently designed and fabricated a spark plasma sintering facility. It has been used for the production of boron carbide, zirconium boride etc. They could achieve theoretical density in all these cases.

The technology for glass to metal seals, ceramic to metal seals and glass-ceramic to metal seals have also been perfected. Lead silicate, borosilicate and sodium aluminium phosphate have been developed for low temperature sealant applications. High temperature sealants have also been developed for specific applications.

3.2.6 Novel Processing Methods

Microstructure characterization of products developed by novel processing routes has been an on-going activity. The routes used are melt spinning, bulk metallic glass (BMG) formation, laser near-net shape forming and synthesis of shape memory alloys. Corrosion studies on Zr based BMGs have shown better corrosion resistance. They are found to have higher mechanical strengths also. Ni-Ti shape memory alloy ferrules have been developed and supplied to Aeronautical Development agency for use in the Light Compact Aircraft Tejas. The TOT for this shape memory alloys has been carried out to Hindustan Aeronautics Ltd, which has set up a plant for production of these components. Porous Ni-Ti shape memory alloys find applications as prosthesis material.

3.2.7 Corrosion Studies

Corrosion studies are of great importance and relevance in nuclear field. BARC has carried out extensive studies on stress corrosion cracking in a variety of stainless steels under different environments. Oxidation and hydrogen pick-up behaviour of Zr based alloys and flow accelerated corrosion of carbon steels have been studied in detail. They have established all the requisite facilities for these studies. Studies on inter-granular stress corrosion cracking of stainless steels in simulated reactor conditions have been carried out and the problem of making the stainless steels resistant to irradiation has been approached by different routes.

3.2.8 Phase Transformation & Structure Property Correlations

Phase transformation and structure property correlation studies have been the main theme for the Metal Sciences Division. These studies have been carried out in a variety of Zr and Ti base alloys, nickel base alloys, specialty steels, intermetallics and amorphous alloys. These studies have helped in solving some of the problems the production agency faced in meeting the requirements of properties.

3.2.9 Computational Materials Science

Computational materials science is another area of interest for materials scientists. These include sequence of phase transformation in Zr-Al-Nb alloys and Ni-Mo alloys. Occurrence of short range order and long range order in TiAl intermetallics has also been carried out by Monte Carlo simulations. Computational materials science activity should be pursued to identify possible candidate materials for diverse applications with better properties than existing ones in the nuclear field. This would save considerable costs and time.

3.2.10 Mechanical Behaviour

Studies on mechanical behaviour of metals have centred on zirconium base alloys. These are hot deformation, fracture and fatigue behaviour, hydride and hydrogen embitterment, superplasticity and creep. As is expected, these are correlated with microstructures in these materials. Understanding the relationship between texture and mechanical properties is another area of interest. Processing maps for optimisation of parameters for hot working, cold working and annealing have been worked out and these are used at the Nuclear Fuel Complex for preparing the flow-sheets for production of components for the nuclear reactors. How dynamic recrystallisation gets affected by different alloying additions is another notable research carried out. Hydride/Deutride embrittlement and delayed hydrogen cracking of Zr alloys, which are safety related issues for PHWR systems have been fully studied to avoid such occurrences. Visco-plastic self consistent approach has been used to model deformation characteristics of magnesium and zircaloy-2 for strain path optimisation of pilgering and cold drawing operations at NFC.

3.2.11 Beryllium Plant

Beryllium powder is as toxic as plutonium and handling this has to be done under controlled conditions in glove boxes. Because of its low density and high specific strength, beryllium alloys find several applications, particularly in the aerospace sector. The Department of Space had special requirements for beryllium and beryllium alloy components. BARC readily took up the challenge of setting up a beryllium pilot plant to produce beryllium powder and consolidated by sintering. Thereafter, components were also machined under careful conditions so as to contain the toxic beryllium powder from escaping into the atmosphere. There is now a renewed interest in another Be alloy, called Lockalloy, by the Department of Space and BARC is gearing up to produce this alloy.

3.2.12 NDT and QA/QC Evolution

Nuclear technology requires stringent quality control measures in every step, including manufacturing, assembly, etc. There was not much of awareness of non-destructive techniques or quality control/ quality assurance methodologies in the Indian industries. In some case, even the instrumentation had to be developed ab initio. These were all successfully developed at BARC and the culture of QA/QC was instilled into private sector companies which were manufacturing components for the power reactors in the country. As a consequence, the country can be proud of meeting and maintaining the strictest quality control measures in their operations.

3.2.13 Post-Irradiation Examination

Another notable success of BARC is in carrying out studies on irradiated materials, which require specially protected hot-cells and remote handling techniques. It was difficult to import master slave manipulators and remotely operable systems to be used with in the hot-cells. BARC successfully gained expertise in this technology, including development of manipulators, getting the shielding windows from CGCRI and training a host of scientists and technicians for carrying out various remote controlled operations. These studies have helped in predicting the life of reactor structural components and fuel assemblies with greater reliability. This is certainly a very significant achievement about which BARC can be really proud of.

3.2.14 Collaborative Efforts

BARC is collaborating with IIT Bombay for texture and micro-texture studies, with IISc, Bangalore for microstructure characterisation, with Jadavpur University for high temperature electron microscopy and with RDCIS for hot deformation studies with their Gleeble set up. These collaborations have benefited the participating organisations.

3.2.15 Spin off Technologies

Several technologies developed essentially for the nuclear programme are utilised as spinoff technologies to cater to the needs of other specialty sectors. One such activity is reported here. The Atomic Fuels Division with its long standing expertise in the fabrication of metallic uranium fuel for research reactors has mastered diverse forming technologies such as rolling, extrusion, swaging, drawing etc. As a spin off technology AFD has developed the fabrication technology for Nb-Ti based low temperature superconducting cables. Two types of cables were fabricated in the recent past and delivered to VECC, Kolkata and IPR, Gandhi Nagar for their use in the superconducting cyclotron and the superconducting Tokamak respectively. For application in the Variable Energy Cyclotron Centre, the multifilamentary cable required consisting of 500 Nb-Ti filaments of 20-25 micron diameter with a spacing of 5 micron in a copper matrix and soldered in U-grooved rectangular OFHC copper channel. About 500m single length of soldered conductor was successfully fabricated and delivered – which met the design specifications of a critical current value of ~ 2.5 x 105 Amps/cm2 at 5 Tesla field and at 4.2K.

For the superconducting Tokamak, at Institute of Plasma Research, a novel design of the Cable-in-Conduit-Conductor (CICC) was required. The CICC consists of 0.80mm dia Nb-Ti strand containing 492 filaments each of less than 25 micron size with Cu to superconductor ratio of 1.15:1 having a twist pitch of 12.4mm and with 0.80mm dia copper wire. These wires are twisted with particular cabling scheme, wrapped with 25 micron SS304 tape and jacketed with 30mm x 30mm x 1.50mm thick square cross section SS316LN tube by swaging. Sufficient void fraction is required for flow of liquid helium which is ensured by cabling and jacketing. An online CICC fabrication facility has been developed which consists of triangular cable insertion system, orbital welding, swaging and coil winding machine. Already 100m length of 30kA Nb-Ti based CICC was fabricated and delivered to IPR. Recently work has been initiated towards development of Nb3Sn based multi-filamentary superconducting wire using Internal Tin (IT) process.

The progress and successes achieved by BARC are partly due to the denial regime imposed on the country. It was 26ealized that there is no alternative other than doing things indigenously. Regular inflow of trained man-power through the training school programme, which is now in its 55th year, could be another factor for the successes. But, if a comparison is to be drawn between DAE and DRDO, it is seen that while DRDO is more oriented to system/product development, BARC has concentrated more on basic and applied research. A suitable combination of both is essential and it may lead to greater tangible output.

3.3 INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH

IGCAR is established to carry out research and development work pertaining to fast breeder reactors. It is a singular success for the DAE metallurgists in identifying mixed uranium carbide-plutonium carbide as the fuel for the FBTR in place of the conventional mixed oxide fuel. About 1000 pins of mixed carbide fuel have been irradiated to a burn-up of 155 GWd/t since the research reactor was commissioned in 1984. This is in spite of the fear of the sceptics who expressed doubt about using carbide fuel in fast raectors. It is gratifying to note that the Fast Breeder Test Reactor continues to operate efficiently. Life extension studies have shown that it can be operated for 10 more full power years. At present, the reactor is operating at 18MWth capacity. FBTR is used to evaluate the irradiation behaviour of Prototype Fast Breeder Reactor (PFBR) test fuel subassemblies, and to study the irradiation behaviour of structural materials etc.

3.3.1 Non-Destructive Testing

When one mentions about the metallurgy programme at IGCAR, one immediately associates it as a centre of excellence for Non-Destructive Evaluation (NDE). Almost all the available NDE techniques are developed and put to good use at IGCAR. Recently, gamma scanning of the irradiated FBTR fuel pins has been carried out for understanding the in-reactor behaviour of fuel pins, especially the fission product distribution. Flow induced vibration of subassemblies is a cause for concern. It is necessary to assess the vertical position of fuel subassemblies in sodium. An ultrasonic sensor operating in the pulse echo mode is developed to detect the axial growth of subassemblies. During circumferential welding of steam generator (SG) shells, spatter of weld metal, fusion of shell with tubes etc are likely to occur. There is no standard NDE technique available for examination of such defects. Remote field eddy current testing was found to be suitable for inspection from the tube side. This was coupled with ultrasonic techniques to develop a reliable technique for detection of welding induced defects during the manufacture of SGs. There is no doubt that IGCAR has emerged as a centre of excellence for NDE in the country.

Austenitic stainless steels are ideal core component materials for fast reactors. Apart from good radiation resistance, these have excellent void swelling resistance. IGCAR has used the basic AISI 316SS and suitably modified its composition to get a higher Ni to Cr ratio. In addition, the silicon content has been increased to a certain extent and Ti added in amounts that are a small multiple of the carbon content in the steel. Titanium binds part of the dissolved carbon to form TiC precipitates. The TiC–matrix interfaces serve as sinks for the radiation induced point defects and thus contribute to the enhanced swelling resistance. This indigenous development of the D9 alloy is a very creditable work first carried out by computational engineering and later experimentally verified.

Modified 9Cr-1Mo steel is the material of construction for steam generators and candidate materials for wrapper and clad tubes for future sodium cooled FBRs. This modified steel is no exception to the ductile to brittle transition phenomenon observed in all ferritic steels. Studies at IGCAR have shown that controlled addition of boron improves the resistance of this steel to Type IV cracking. As a result it is possible to increase the design life. This is an important study which has a lot of potential applications.

The inherent superior void swelling resistance of ferritic/martensitic steels up to a dose of 200dpa has made the 9-12Cr steel very attractive clad tube material. However, it suffers from poor creep strength above 873K. Oxide dispersion strengthening is found to be a promising method of enhancing the creep strength. Improvements in properties are achieved by using nanoparticles of yttria along with the formation of complex Y2Ti2O7/Y2TiO5 oxides. Efforts are on to increase the creep strength of this material equivalent to that of D9 alloy.

3.3.2 Welding Technology

In the present PFBR design, a number of weld joints are required. Though the material of construction was the carbon steel (AFNOR A48P2) with guaranteed through thickness ductility, lamellar tearing was encountered during welding. Hence, butt welded joint between plates of different thicknesses was developed and was cleared by NDE techniques. This has also shown the way to use conventional ASTM A516 Grade 65 steel instead of the special grade A48P2.

3.3.3 Ferro-Boron

The feasibility of using a commercial grade ferro-boron (Fe-15 to 17 wt% B) in fast reactors was established. This was as a result of the study conducted on the compatibility of ferro-boron with D9 alloy which is used as a clad. It was shown that the material can be very safely used under typical service conditions.

The metallurgy programme at IGCAR is focused on developing materials and technologies for sodium cooled fast reactors and associated fuel cycle.

3.4 VIKRAM SARABHAI SPACE CENTRE

Vikram Sarabhai Space Centre (VSSC) at Thiruvananthapuram has been entrusted to develop materials for space applications. These materials must fulfil a combination of conflicting requirements to meet the severe environmental conditions and mission demands. The essence is in developing materials with higher specific strength and stiffness to increase the payload fraction. Thus, over the years VSSC has embarked upon indigenous development of well known high performance materials like M250 grade Maraging steel, aluminium alloys, titanium alloys and magnesium alloys. Most of their efforts are in utilising the R&D laboratories and industries in the country to achieve their desired goal.

3.4.1 Maraging Steel

Maraging steel is a low carbon, iron nickel martensitic steel that in the presence of other alloying elements such as Co, Ti. Al and Cr gets strengthened by precipitation of a number of intermetallic compounds. The distinct characteristics of this steel are high strength with excellent toughness along with high dimensional stability, ease of fabrication and simple heat treatment. Engineers form VSSC, Midhani, and SAIL (RSP) produced the first vacuum induction melting ingot followed by double vacuum arc refining (VAR) process. VAR ingots were homogenized in two stages and later forged into blooms for ring rolling and slabs for plate rolling. Plate rolling was carried out at RSP. The plates met all the property requirements. As ring rolling facilities were not indigenously available, the same was carried out at M/s Krupp Steel in Germany. This is elaborated elsewhere in this report. Maraging steel produced successfully satisfied all the requirements for use as motor-case for the PSLV and GSLV flights. It is heartening to note that motor cases for the next generation launch vehicle, GSLV MK3 capable of launching 4T satellites have also been manufactured.

3.4.2 ESR Steel

Electroslag refined 0.3C-Cr-Mo-V steel has been developed with attractive properties for use as motor case material for S139 booster. All processing and fabrication parameters have been established. Use of this steel would lead to considerable cost saving compared to M250 maraging steel cases.

3.4.3 Aluminium Alloys

Some of the critical components made of aluminium alloys for space applications include inter stage rings, liquid fuel tanks, liquid engine components, cryogenic engine components etc. To achieve complete self reliance in high strength aluminium alloys such as AA 2014, AA 2219, AA 7075 and AA 6061, ISRO undertook an ambitious indigenisation programme in active collaboration with various industries such as BALCO, HINDALCO and INDAL. For the production of Al alloys of aerospace quality, state of the art facilities/techniques for inline refining like SNIF (Spinning Nozzle Inert Floatation) degassing, Ceramic Foam Filtering (CFF) and automatic casting lines were made use of to achieve the required cleanliness.

3.4.4 Development of AA 6061 Forgings and Infrastructure Development

AA 6061 forgings were successfully produced by controlling hydrogen and also by carrying out stress relieving using a hydraulic press and not a hammer, as is done conventionally. ISRO also started developing infrastructure for metallic materials. The first such infrastructure was ring rolling and allied facilities for realization of seamless rings up to 5.5 m set up at M/s. Bay Forge, Chennai and heat treatment and finishing facilities at BALCO. The equipment added at BALCO included a 2500T plate stretcher, 2 Hi flat rolling mills along with leveller and cold working drop bottom furnace (electrically heated) for solution treatment. The whole line can deliver range of sheets and plates with thicknesses ranging from 1-100 mm width up to 1500mm and length ranging from 5000 mm to 9000 mm.

3.4.5 Titanium Alloys

Titanium alloys have unique properties like high specific strength, good corrosion resistance to liquid propellants and good fracture toughness. Ti-6Al-4V has been the main workhorse alloy for the Indian space program. ISRO has developed a strong technology base for closed-die forging, plate forming, ring rolling, machining, diffusion bonding and superplastic forming of Ti- 6Al-4V alloys. This alloy has been used for high pressure gas bottles and propellant tanks. Extensive studies were carried out to optimize electron beam welding (EBW) technology necessary for realizing the hardness. Using diffusion bonding, a transition joint between Ti-6Al- 4V and SS 304L was developed successfully. For subzero applications up to 90 K, purer version of this grade called Ti-6Al-4V ELI (Extra Low Interstitials) is used where impurities like oxygen, hydrogen and iron are controlled to retain sufficient toughness at the operating conditions.

3.4.6 Ti -3Al -2.5V Alloy

The upper stage of advanced Indian launch vehicle required 118 mm OD x 1.6 mm wall thickness seamless tubes. Seamless tube of such large OD to wall thickness ratio is not available even through import. The processing technology for the above with Ti-3AL-2.5V alloy was developed through hot extrusion and cold pilgering route in association with NFC, Hyderabad.

3.4.7 Titanium Aluminides

TI3Al (Alpha 2) and TiAl (Gamma) have received a lot of attention for elevated temperature applications. Powder metallurgical processes based on pre-alloyed and elemental powder techniques are being investigated for near-net shape processing. Elemental powder metallurgical technique based on Reaction Synthesis (RS) is particularly attractive for less ductile intermetallics like aluminides of nickel and titanium. RS processed billets with duplex microstructure gave tensile strength of about 400 MPa at $800^{o}C$.

3.4.8 Magnesium Alloys

Magnesium with a density of 1.748 g/cc is the lightest structural metal and alloys of magnesium combine light weight with other attractive properties like good strength, stiffness, high damping capacity, low thermal stress modulus and excellent thermal diffusivity.

3.4.9 Casting AZ92 and ZE41 Magnesium Alloys

The alloy AZ92 developed was for 3 Axis gate gyro mounting block for SLV3. The technology for preparation of moulding sand with the addition of sulphur and boric acid as inhibitors was developed. Moulding, gating and casting technologies were established. ZE41 alloy containing zinc, rare earths and zirconium as alloying elements has improved elevated temperature strength, superior weldability, castability and conductivity compared to conventional AZ series of alloys. This is a difficult alloy to cast due to low liquid solubility, tendency for precipitation and compound formation and very low recovery. Alloying with rare earths increases the difficulty in processing of the alloy. By carefully controlling all processing parameters ZE41 magnesium alloys were processed.

3.4.10 ZK 30 Rolled Rings

Substitution of aluminum alloy pay load adapter (PLA) with magnesium alloys could lead to substantial weight reduction. It is essential to have large sized billets for production of these rings and such large billets are invariably produced by direct chill (DC) casting to obtain the desired microstructure. Large DC casting facility for magnesium alloys is not available in the country even today. DC billets of 365 mm diameter were imported from M/s Magnesium

Electron Ltd UK. These billets were successfully ring rolled by M/s. ECHJAY Industries, Rajghat with the required dimensions, mechanical properties and ultrasonic quality.

3.4.11 Magnesium – Lithium Alloys

Magnesium-lithium alloys are the lightest structural metallic material with a density of 1.35-1.60 g/cc. This alloy is very difficult to produce since lithium is a very reactive material. ISRO has successfully mastered melting and casting of this alloy using inert atmosphere. It is now possible to melt up to 20kg of this alloy and the developed alloy (Mg-9Li-7.5Al-1.2Sn) gave stable properties up to 1000^{o}C.

VSSC has successfully collaborated with several industries and R&D laboratories to develop critical special purpose components for launch vehicle applications. This example of financing and setting up infrastructure facilities to develop indigenously the requisite materials is worth adopting, wherever it is necessary.

3.4.12 General Comment

In-house government R&D establishments appear to have risen to the occasion and met the challenges faced in 30ndigenizing the processes and products. At the same time it may be noted that there is considerable delay in execution of several projects in all scientific departments. The reason for this has to be critically examined. Further, the government departments have the advantage of not bothering about return on investments, which the private sector always keeps in mind. The major problem faced by these establishments is that the graduates coming out of universities are not readily employable and they need to be put through a rigorous orientation course equivalent to a post graduate study. This has certainly helped the DAE. Dept. of Space has followed suit and CSIR with its recent academic study programme will also benefit to a certain extent.

4. CSIR LABORATORIES

4.1 NATIONAL METALLURGICAL LABORATORY

The National Metallurgical Laboratory, Jamshedpur celebrated its diamond jubilee in 2010. In the words of its present director Srikanth, 'Research at NML up to the mid 80s was driven by self reliance, conservation of foreign exchange, indigenous technology and use of indigenous resources'. NML focused on R&D in steel to start with. A pilot LD converter was operated for the first time. Nickel free austenitic stainless steel was thought of for the first time. Subsequently, utilization of lean grade iron ores and non-coking coal attracted its attention. NML was well known for its mineral beneficiation activity. The coal washing circuits at Tata Steel and the chalcopyrite beneficiation flowsheets at ICC Ghatsila and Mallajkhand were developed at NML. Country's first commercial sponge iron plant was based on the technology developed at NML. Later, ferroalloys smelting facility and development of aluminium conductors to replace copper were the other major activities in the 1970s. A 250 tonne/year magnesium extraction plant following Pidgeon process was set up in 1972. The 500 TPY fluorspar beneficiation plant at GMDC, Kadipani commissioned in 1971 and the Electrolytic MnO2 plant of 1000 TPY capacity at MOIL, Nagpur are from NML. The only commercial magnesium production in India was based on NML's technology. NML had established a Central Creep Testing Facility in the early 70s. The fluorspar beneficiation plant of Gujarat Mineral Development Corporation at Kadipani and the electrolytic manganese dioxide plant of Manganese Ore India Ltd (MOIL) operating even today are outcomes of NML technologies. All these were pioneering R & D works at that point of time. At the same time, innovative basic research was not neglected. Nitrogen stabilized austenite and liquid metal structures were commendable basic research activities. NML had developed a pilot scale extraction facility for metals from sea nodules. NML's Component Integrity Evaluation Programme had provided yeoman service to several industries. NML had developed column flotation technology. Corrosion inhibitors developed and commercialized by NML are widely used by the Indian Steel Plants. Newer activities pertain to advanced high strength steels, biomaterials, utilization of metallurgical and mineral wastes, processing of lean grade ores and secondary resources, NDE sensors and devices for structural integrity assessment and nano materials. The following elaborates further on some of the major activities.

4.1.1 Ferro-alloy Development

NML has made outstanding contributions to the country's ferroalloy development program, both on low carbon ferroalloys using the aluminothermic route as well as the high C ferroalloys through the electrothermal process. A 500 KVA submerged arc pilot furnace was commissioned in 1962 which was extensively used to develop technologies for various ferroalloys such as ferrosilicon, silico-chrome, ferrochrome and ferromanganese from indigenous raw materials. Major commercial ferroalloy producers in India today have benefitted in many ways from these pursuits at NML. Ferro Alloys Corporation Ltd. (FACOR) is a pioneer in submerged arc electric smelting for production of high carbon ferromanganese. When FACOR approached NML to undertake smelting trials with different raw materials to produce ferro-alloys, NML readily came forward to assist them. The pilot smelting experience gained at FACOR helped it to set up a 12MVA furnace for high carbon ferrochrome and silico-chrome production. FACOR also undertook an investigation on a special electrode of dense carbon aggregate developed by NML and found that it was as good as what they were using till then.

4.1.2 Sponge Iron

NML played a significant role in developing a ‘Direct Reduction Technology’ for producing sponge iron with solid fuel like non-metallurgical coal. This formed the basis of the first commercial sponge iron plant of India in 1975. NML’s assistance in setting up sponge iron and ferrovanadium facilities for Orissa Industrial Development Corporation is note worthy. It is on account of the continuous input from the R & D fraternity and sustained interest of the entrepreneurs that India is a world leader to day in the field of sponge iron production.

4.1.3 Hydro-metallurgy for Zn

NML had developed a technology for extraction of zinc by the hydrometallurgical route for Hindustan Zinc Ltd. In this process, nitrogen was used as an inert gas to prevent oxidation of zinc, and in a once through mode rather than recovery and recycling. This pushed up the cost of conversion and HZL gave it up.

4.1.4 Column Flotation

Column flotation technology for the beneficiation of sillimanite was successfully developed and demonstrated first at the Indian Rare Earths plant in Orissa. Today it is commercially operating with consistent recovery and grades, both at Chatrapur and Chavara. Further two more commercial columns one for limestone beneficiation at Salem has been operational for more than 2 years now and a commercial barite beneficiation plant has been very recently commissioned at IBCL, Mangampet. The feed pump was getting clogged frequently. An analysis by NML and IREL identified the root causes and corrective measures were taken to get the desired results. This is a good contribution by the NML to IREL.

4.1.5 Eco-friendly Furnace for Foundries

NML had developed an eco-friendly cokeless cupola for foundries, particularly for the Taj Mahal area in Agra. This was based on CNG instead of conventional coke. However, this technology was not readily adopted by the foundry cluster because of the non-availability of natural gas. In addition, the foundry owners were shy of adapting newer technologies. Possibly a governmental and societal intervention even before the beginning of the project and participation of the foundry operators at different stages may have been helpful.

4.1.6 Blast Furnace Productivity

The main objective of the project on blast furnace productivity maximisation was to characterise the process dynamics in a blast furnace. NML had developed models to capture and predict the process phenomenon occurring in different zones of the blast furnace. Lack of operational data was a great handicap. To overcome this, a ‘Real Time Process Simulator’ was developed for online monitoring and prediction of internal process dynamics. At TISCO, the productivity of blast furnace G increased from 2.04t/m3/d to 2.46t/m3/d because of the inputs from NML. At Bhilai Steel Plant, the blast furnace productivity was enhanced from 1.6 t/m3/d to 1.88 t/m3/d upon implementation of the RTPS system.

4.1.7 Structural Integrity Assessment

Over the past two decades, NML has developed a range of softwares, test protocols, sensors and devices for structural integrity assessment and residual life evaluation of materials and components used in power plants and petrochemical industries. These include minimally invasive mechanical property evaluation devices, NDE sensors and devices based on ultrasonics, magnetic and acoustics which have been implemented extensively in the industries.

4.1.8 Methodology

NML's success in its R & D activities is possibly on account of 70% of its programmes being user oriented. They carried out exploratory projects to pursue excellent scientific work, leading to innovative thinking and high value publications. They also advocated thrust area programmes which consisted of very large, long duration externally funded projects. The third area consisted of interactive projects, interfacing with industries to produce quantifiable monetary benefits to the industry concerned. NML focused its attention on outputs and time overruns, and at the same time in satisfying the customers. However, several other technologies that have been developed at NML are not yet 33tilized33lized. In addition to a marketing wing to look into the problems seriously, to see how the efforts can be 33tilized by the industries, a comprehensive analysis of the techno-economics and impact analysis is essential for a larger conversion to commercialization.

4.2 CENTRAL GLASS AND CERAMICS RESEARCH INSTITUTE

The CGCRI at Kolkata was among the first labs set up under the CSIR along with NPL at New Delhi, NCL at Pune, NML at Jamshedpur and CFRI at Dhanbad. It is currently engaged in six high priority technology sectors including materials, minerals, communication and photonics, energy and environment. Metallurgical activities require ceramics and refractories for many of its activities and the committee felt that it would be desirable to include these in our studies.

4.2.1 Glass Technology

Specialty glass windows of different dimensions required for remote handling of radioactive materials are supplied by this institute to the Dept. of Atomic Energy. CGCRI has also developed a glass frit for nuclear waste fixation. Nd3+ doped phosphate laser glass is another material for strategic applications. Anti- bullet armour plates/shields and jackets for army are other developments for strategic sector applications. They have also developed glass coatings for plasma display panels. Nano-structured materials are developed for glass and plastic substrates for abrasion resistant, antireflective and hydrophobic applications. These have been commercialized. Hybrid nano-composite coatings on plastics have been developed for scratch resistant applications. Advanced Surface Technologies at Gurgaon is manufacturing this material and coated lenses are being marketed.

4.2.2 Non-Oxide Ceramics

In non-oxide ceramics, carbon fibre reinforced SiC composites and reaction bonded silicon nitride have been developed and supplied in requisite quantities for strategic applications. CGCRI has developed a pulp casting technology, which is cost effective and very simple and is used for fabrication of porous SiC tubular shapes for hot gas cleaning applications. Cutting tool inserts made of SiAlON for grey cast irons and nickel base superalloys have been developed. Fabrication process for silicon nitride balls for use in hybrid bearings with ceramic balls and steel races has been established and the product has undergone successful testing.

4.2.3 Refractories

In the refractories sector, a cost effective plasma route has been developed for production of magnesium aluminate bricks. Refractory products from Indian bauxite have been developed and properties compare favourably with those of imported material. Hydration resistant sintered lime and lime refractory developed by CGCRI are being produced at OCL, Orissa. It is expected to replace dolomite refractory in the long run. It may also be mentioned that the great strides the Indian steel industry has made in terms of quantity, range and quality would not have been possible without adequate support of appropriate refractories and these products have been continuously upgraded by R & D inputs from government establishments as well as private sector industries. Whether it is high density alumina products or porous refractory bricks for filtration of molten metal to remove coarse inclusions, the users are able to obtain them from indigenous manufacturers.

4.2.4 Fibre Optics and Photonics

Fibre Optics and Photonics Division has developed and demonstrated some of the specialty optical fibres for commercial exploitation. Through continuous innovation and R & D, erbium doped fibre (EDF) has been commercialised for use as optical amplifiers in communication network. The products are being produced by an industry regularly. Fibre Bragg grating based sensor devices have been demonstrated successfully for strategic and civilian use. Another area of significant achievement is in fabricating photonic crystal fibre for use as wide-band supercontinum light source. Polarisation maintaining fibre and fibre laser are being developed and fabricated for various applications. While significant strides have been made, there are a few shortcomings. Most of the raw materials and components are being imported. There are not many photonic industries in the country to take up this work. Future activities are focussed on fibre lasers, Bragg grating sensors, hollow core photonic crystal fibre and plasmonic metamaterials. This group maintains active and effective collaborations with industries and academic institutions in India and abroad.

4.2.5 Bioceramics

Several ceramic implants have been successfully developed and commercialised. These include:

- hip implants
- eye ball
- bioactive coatings for orthopaedic and dental implants
- porous drug eluting scaffolds and bone filler materials
- drug eluting injectable bone cements
- controlled drug delivery systems for osteomyelitis

- nano anti-cancerous drug delivery system and
- rapid prototyping technology for custom specific bio medical implants.

Here again, further emphasis is needed in modelling for design optimisation and precision machining and fabrication facilities for complex geometries is needed. Collaboration with other laboratories as well as with industries may be beneficial.

4.2.6 Fuel Cells

In the energy and environment sector, solid oxide fuel cell has attracted the attention of CGCRI. Single cells of varied dimensions have been fabricated using simple and inexpensive techniques such as tape casting and screen printing. Stabilized zirconia with 8 mol% yttria is the electrolyte, while 1.5 micron porous anode (Ni-YSZ) provides the mechanical support on one side and with successive 10 micron thick layers of La (Sr) MnO2, (LSM)-YSZ cathode functional layer and a 50 micron thick LSM porous cathode layer on the other side. These single cells have yielded a current density of 1.5- 2.0 A/cm2 at a cell voltage of 0.7 at 800o C.

4.3 INSTITUTE OF MINERALS AND MATERIALS TECHNOLOGY

The Regional Research Laboratory, Bhubaneswar, now rechristened Institute of Minerals and Materials Technology (IMMT) was established in 1964. Over the years, IMMT has developed considerable expertise in process and product development activities in minerals engineering and materials technology.

4.3.1 Hydro and Electro Metallurgy

Hydro and electro metallurgy have been of interest for IMMT for several years. A process for recovery of cobalt from superalloy scraps has been successfully carried out and a 100 tpy plant has been commissioned by M/s. Rubamin Pvt. Ltd. at Baroda. S. K. Enterprises, Kanpur has put up a plant for recovery 250 kg/day each of copper and zinc from spent catalysts based on know-how received from IMMT. High purity cobalt is produced by HZL at Debari, also based on IMMT know-how. Process for recovery of copper, nickel and cobalt from polymetallic sea nodules has also been successfully completed.

4.3.2 Mineral Processing

The mineral processing deals with problems related to processing of lean and off-grade ores. Energy efficiency and environmental effects are of great concern. A process for beneficiation of low grade iron ore fines for pelletisation has been developed for Jindal Steel and Power Ltd. At the request of the cement plant of Birla Corporation Ltd. at Chanderia, low grade lime stone beneficiation was carried out. RDCIS, SAIL was the beneficiary in getting details on beneficiation of iron ore lumps and fines. Design and installation of a beneficiation column for antimony was successfully carried out for Cheminco Chemicals Ltd., New Delhi. A pilot column has been installed at Essar Steel, Kirundal for recovery of additional iron values from tailings. In addition, there are a number of other technologies developed by IMMT waiting to be exploited.

4.3.3 Modelling and Simulation

Process instrumentation, measurement, data acquisition and control are essential in any process related activity. IMMT has not only concentrated their efforts in this area, but also in carrying out modelling and simulation studies for developing bench scale prototypes. Modelling of a multiple hearth furnace for reduction roasting of chromite ore burden to extract nickel has been carried out for GTZ, Germany. Technische Universitat, Clausthal, Germany has been a beneficiary for hydrodynamic modelling and simulation of a pulsed sieve-plate extraction column. IMMT had also participated in the design, development and commissioning of a 4t/h continuous billet heating coal fired furnace for a re-rolling mill of Orissa Industrial Development Corporation at Hirakud.

4.3.4 Advanced Materials Technology

In advanced materials technology, IMMT aims to develop suitable processes for preparation of strategic and industrially important materials and conduct exploratory research on development of futuristic materials. It has designed and developed transferred arc plasma reactors for melting, smelting, carbide synthesis etc. and extended non-transferred arc in-flight plasma reactor for dissociation of minerals and spherodization of materials. Some of the successful developments are: setting up a 30 kg/h pilot plant for production of synthetic rutile, pig iron and high purity iron oxide from ilmenite concentrate using thermal plasma technology, production of rare earth colorants under NMITLI programme, optimisation of plasma parameters to reduce energy consumption for plasma melt separation of TiO_2 rich slag and pig iron from metallised pre-reduced ilmenite for IRE Ltd. Mumbai.

IMMT has done considerable work in minerals and materials processing technologies. They have also successfully transferred technologies to private sector agencies and it is heartening to note that full scale plants are operating based on the indigenous technology developed by IMMT. At the same time, there are a sizable number of technologies that are waiting to be absorbed by entrepreneurs.

4.4. NATIONAL INSTITUTE OF INTERDISCIPLINARY SCIENCE & TECHNOLOGY

The NIIST, formerly the Regional Research Laboratory, Tiruvananthapuram, is truly an interdisciplinary establishment and has rightly been renamed now. However, we are concentrating in this report on minerals and materials areas only. NIIST has been carrying out research in the following areas.

- Characterisation of beach sand minerals processing and marketability
- Development of novel and environmental friendly processes for minerals
- To assist mineral industries to improve efficiency and productivity
- Scale up studies of the processes developed

4.4.1 Rutile

NIIST has successfully completed a pilot plant for the production of high grade synthetic rutile. This was extended as a pilot plant study for synthetic rutile, pig iron and pure iron oxide through a plasma route, a project sponsored by NMDC. They have also produced titania rich slag by melt separation of iron from the pre-reduced ilmenite using a thermal plasma process. While this work was carried out with Kerala beach sands, similar studies were also carried out with Andhra beach sands. They have made a comparative study of Chavara and Cox Bazaar (Bangla Desh) ilmenites as a collaborative exercise.

4.4.2 Novel Materials

The Ceramics group is exploiting sol-gel technology to develop novel materials and processes for commercial and strategic applications. Nano structures and coatings, novel superconducting and magnetic materials, materials for wireless communication and eco friendly building components are other areas tackled by the ceramics group.

4.4.3 Light Alloys

Research and development of light alloys and composites have been carried out at NIIST, since its inception in 1978. The requirement of lightweight materials with high-performance for various engineering applications in the areas of aerospace, automotive, nuclear, defence, energy and general engineering has led to extensive R&D efforts in the development of Al and Mg alloys, metal and polymer matrix composites and functionally graded materials.

In aluminium alloys work was centred on indigenisation of specialised Al alloys for GSLV and PSLV programmes of ISRO. For aluminium conductors, rare earth addition was shown to be beneficial. Semisolid processing of Al alloys for automotive applications was another area where considerable work has been carried out. In metal matrix composites, development of liquid metal stir casting and campo-casting were studied in great detail. Development of low thermal expansion coefficient composites for space applications was also carried out.

4.4.4 Modelling and Simulation

The Modelling and Simulation Group at NIIST has developed' Virtual Casting' software for simulation of casting solidification and defect prediction. This has been copy-righted and licensed. Know-how for design of rotary kiln of 350 tpd for production of high grade synthetic rutile has been transferred to industry, based on 37odeling studies carried out.

4.5 CENTRAL ELECTROCHEMICAL RESEARCH INSTITUTE

The CECRI founded in 1948 is one of the early institutes set up under the CSIR. It was located at Karaikudi, Tamil Nadu because of the push given by Dr. Alagappa Chettiar, a well known industrialist and philanthropist at that time and with enthusiastic support from Pandit Nehru. The Institute has been carrying out work in corrosion science and several electrometallurgical studies. Some highlights of achievements pertaining to metallurgy are given below.

4.5.1 Electro-Hydrometallurgy

The electro-hydrometallurgy work pertains to recovery of metals and metal values from primary and secondary sources with a focus on energy conservation, by-product recovery and pollution abatement. The technologies developed range from recovery of chromium from chromic acid bath, recovery of gallium by an amalgamation process, electrolytic manganese dioxide for batteries, electrolytic iron powder etc. Current activities relate to development of bipolar cells for electro-winning of copper, nano platinum coated titanium electrodes, and development of process for electro-reduction of CO_2 to useful organic chemicals.

4.5.2 Electro-Pyrometallurgy

The electro-pyrometallurgy work aims at developing noncarbon anodes for eco-friendly aluminium production, production of high purity calcium in a single stage fused salt electrolysis with improved electrolyser and preparation of novel materials by molten salt electrolysis. It was shown possible in a laboratory cell to produce aluminium metal and oxygen from Al_2O_3 using stable cermet anodes (Patent Nos. 34/D/2003 and 35/D/2003). This group is also working on electro-refining to produce super pure aluminium from commercial purity Al and operates a 2000A electro-refining cell by two layer non-alloying technique. Development of an economic electrolytic process for production of Ti metal and Ti-Al alloys as well as electro-winning of magnesium metal from sea bitterns are ongoing studies.

4.5.3 Polymer Electrolyte Fuel Cell

In the year 2004, CECRI was selected as one of the nodal laboratories for R&D on hydrogen-based fuel cells under the New Millennium Indian Technology Leadership Initiative. In a short span of two years, CECRI has developed and demonstrated self-sustainable polymer electrolyte fuel cell stacks for portable power applications, clearly establishing its capability to fructify a concept into product. Based on this noteworthy contribution, cutting-edge R&D on hydrogen-based fuel cells and next-generation lithium batteries have been taken up and considerable progress has been made.

4.6 ADVANCED MATERIAL AND PROCESS RESEARCH INSTITUTE

This institute at Bhopal is one of the late entrants to the CSIR family. It was established as a Regional Research Laboratory of CSIR and now it is known as Advanced Materials and Processes Research institute. Major areas of interest are light weight metallic materials, metallic and polymer based composites, functional materials and nano materials. Utilisation of industrial wastes such as red mud and fly ash is also tackled by AMPRI.

4.6.1 Al alloy Composites

Aluminium alloy composites, particularly with graphite and SiC particles have been thoroughly studied. Material synthesis was carried by vortex technique as well as in-situ techniques. Brake drums for automotive vehicles have been made with Al-Si alloy reinforced with 10 wt. % SiC particles. These brake drums showed improved braking efficiency and reduced friction heating as compared with conventional cast iron components.

4.6.2 Magnesium Alloys

Flux less melting technique was adopted to produce magnesium alloys. Alloys like AZ91, AZ31 etc. have been made by this route and fully characterised. Processing maps have been developed for these materials for reducing rejection rates.

4.6.3 Aluminium Foams

AMPRI has developed a novel technique to produce open cell Al foam using melt route. Al syntactic foams reinforced with fly ash cenospheres have been synthesized using liquid metallurgy route. These foams attain 25-45% porosity with energy absorption capacity of 30-50 MJ.m-3 and crushing strength 45-150 MPa. They have potential applications in vibration control, electromagnetic shielding, energy absorption casings, light weight sandwich panels etc.

4.6.4 Component Development

Several engineering components have been developed jointly with Bharat Heavy Electricals Limited (BHEL) Bhopal and other industries. Different components developed under the programme include FRP gear case for locomotives and hybrid packing rings for railway bogies. Another category of components has been developed for hydro-generators and related applications in power generating plants. They include 'V' block, hopper, air baffle, oil vapour seal, conformable pipes, asbestos-free brake pad, thrust bearing pad etc.

4.6.5 Simulation

Elasto-plastic finite element simulation of sheet metal bending process has been carried out to predict spring back. It is a major failure mode and plays a significant role in designing a die for any sheet metal forming process. The study is very useful in designing pressure vessels, LPG and petrol storage tanks etc.

4.6.6 Waste Utilisation

Zinc industry waste anode mud contains 50-60% MnO_2 and 5-15% PbO_2. A process has been developed for recovery of manganese values as $MnSO_4$ and lead values to make lead chromate pigment.

4.6.7 General Comments

When product development is said to be in the realm of CSIR laboratories, establishment like Fraunhofer Institutions in Germany comes to mind. These are Germany's largest application oriented research institutions and their research efforts are geared to meet people's needs in sectors like health, security, communication, energy and environment. CSIR laboratories were presumably set up with similar objectives initially, to help the regional sectors, to see how best the available natural resources could be put to use for economic development of that region but the outcome has not been commensurate with what was expected. Of late, these laboratories are also moving further towards carrying out more of basic research than applied work, to get peer recognition through paper publishing, getting higher citation indices and consequent rewards.

The CSIR with its unique multidisciplinary strengths covering a wide spectrum of science and engineering disciplines needs to develop strong intrainstitutional scientific knowledge networks to offer multidisciplinary research capabilities of high commercial relevance. Such a knowledge network needs to be equally nurtured by an equally enduring public-private partnership during scale up and technology commercialization phase. There is thus a need to evolve appropriate multidisciplinary project management models based on heterarchial leadership structure.

5. R&D IN PRIVATE SECTOR

5.1 TATA RESEARCH DEVELOPMENT & DESIGN CENTRE

Many major private sector companies have established inhouse R&D centres to solve their day to day problems and to take care of their mid-term as well as long term plans. The Tata Research Development and Design Centre (TRDDC) at Pune, a division of Tata Consultancy Services Ltd. (TCS) established with a mission 'To apply existing knowledge for the benefit of our industry and our people' as spelt out by JRD Tata is unique in the sense that it not only caters to the Tata group of companies, but also assists in solving problems of other industrial units as well. Perhaps, it is the only centre for research by design in the country. They have used their domain expertise along with their experience in modelling and simulation to improve design and to optimise manufacturing processes. Some of the accomplishments of the Process Engineering Innovation Lab of TRDDC in the area of minerals and metals research are summarized.

5.1.1 Energy Related

Energy is a significant part of any production process and considerable attention is required in reducing its consumption not only from an economic point of view but also from the environmental aspect. This requires a critical look at the sensors and control systems without which no meaningful process analysis, optimization and control can be carried out. In addition, raw materials also pose a great challenge because of their changing nature with different beneficiation efficiencies and attendant waste management problems.

TRDDC has been working on model based solutions for steel plants. They aimed at improving process and energy efficiency in several areas beginning from beneficiation, extraction, refining, casting, deformation, heat treatment and finally the products. By focusing on productivity, energy and quality, while keeping emissions under control, they have delivered quantifiable benefits to the industry.

5.1.2 Beneficiation Studies

Alumina rich iron ore slimes are of great concern in our country and TRDDC has developed a model based on Density Functional Theory (DFT) to design highly selective reagents for the beneficiation of iron ore slimes, in particular with respect to reduction of alumina. They have also experimentally validated their model.

In the beneficiation of minerals, design and optimisation of grinding, flotation and dewatering circuits are the key to achieving success. TRDDC has designed and implemented a plant wide supervisory control software tool for enhanced plant performance. This was a first of its kind in Indian minerals sector, a technology demonstration project, sponsored by Ministry of Mines and Department of Science and Technology, undertaken in collaboration with Hindustan Zinc Ltd (HZL). Process optimization was carried out through mathematical models for simulation and optimization, software tools for computer-aided process design, simulation and circuit synthesis. This exercise led to an increase in recovery from 87.3 to 90.1 % for zinc while maintaining the same concentrate grade of 54.4%. It was also accompanied by reduction in recirculating load in grinding circuit, control in size fractions and almost total elimination of alarms. All these resulted in substantial savings for HZL. In coal beneficiation, with appropriate reagent design and selection, TRDDC showed on a bench scale, the ash content could be brought down from 15% to 8% and this was tested at Tata Steel's Bokaro Coal Washery.

TRDDC has developed a rigorous Molecular Modelling (MM) based framework for designing flotation reagents for processing difficult-to-treat ores. Several novel reagents have been developed by the lab based on this approach for processing mixed sulphide-oxide base metal ores, beneficiation of dolomite rock phosphate ore, separation of fluorite from gangue minerals, recovery of wolframite from slimes, coal flotation etc.

5.1.3 Modelling and Simulation Studies

TRDDC developed an integrated iron ore sintering model for enhancing the productivity by optimising granulation and sinter bed permeability. Based on the recommendations derived from this model and with in-house research and development efforts, Tata Steel improved its sinter plant productivity to more than 40t/m2/day from the previous 30t/m2/day. TRDDC has also developed an optimization and simulation tool Virtual InduratorTM for induration of iron ore pellets. This tool contains soft sensors for pellet quality and for parameters of the pellets and gases on the moving grate, and an optimization algorithm to optimize the throughput while keeping the pellet quality parameters within desirable specifications. Implementation of this tool resulted in increasing the throughput of iron ore pellets by 3% in one of the pellet plants in India. This tool has also been implemented for advanced model predictive control in a Brazilian pellet plant. The major problem faced was lack of reliable data, because many sinter and pellet plants are neither well instrumented nor have documented data. On-line characterisation of materials is another problem area.

In coal based Direct Reduction Iron (DRI) production, accretion inside the rotary kiln is a major cause of concern. TRDDC developed a software tool DRIKSTM, Direct Reduced Iron Kiln Simulator package to enhance kiln campaign life by reducing rate of accretion and for minimizing coal consumption. The recommendations derived from the model along with other in-plant optimization strategies taken up by Tata Sponge helped in increasing the kiln campaign life to more than 300 days (from previous 180 days) and in reducing the coal consumption by more than 5%.

In secondary steelmaking, TRDDC has developed and utilised computational fluid dynamics based models to come up with online advisory system for real time control of ladle furnace operations and effected 20% reduction in production time and 5% reduction in aluminium consumption. In continuous casting, by a thermomechanical modelling, they were able to predict defects in the strand as a function of process parameters and were able to reduce cracks by 80% in a bloom caster and increased speed by 20% in a thin slab caster.

Wire drawing also attracted their attention and by thermomechanical modelling, they were able to predict the mechanical properties and problems associated with multi-stage wire drawing. Not only did it enhance the die-life, but it also reduced energy consumption by about 9%.

5.1.4 Waste Utilisation

TRDDC has converted toxic mining and industrial waste into eco-cements. Eco-cements were made from fly ash and steel plant wastes, BGML tailings sands, fertilizer chalk waste, red mud (aluminium refineries), municipal incinerator ash, spent pot lining waste from aluminium refineries. The Alinite cement developed has properties comparable to that of Ordinary Portland Cement (OPC). But large scale production did not take place due to several constraints.

5.1.5 Life Cycle Analysis

Detailed life cycle analysis carried out by TRDDC for automotive and aerospace sectors is worthy of mention. Steel for high end applications require VIM and VAR treatments which are the most energy intensive processes and by utilising scrap, it has been shown that energy consumption and CO2 release can be brought down by 40%.

5.1.6 Computational Materials Engineering

Steel industry has been introducing new alloys for automotive applications to improve the product performance and to meet the challenges posed by other materials. Introduction of new and improved alloys such as Advanced High Strength Steel (AHSS) requires enabling technologies to reduce the costs and lead times for development. The concept of "Through Process Modelling" which enables use of sophisticated mathematical models to predict the evolution of microstructure and properties during the production of sheet metal, can be used to build a suitable platform to facilitate production of new grades of steel sheets to meet the requirement of downstream processes.

Integrated Computational Materials Engineering (ICME), an integrated systems engineering approach is expected to (a) reduce the time and cost of discovery and development of materials and their manufacturing processes, and (b) enable faster development of products augmented with richer material information. Development of a comprehensive IT platform that facilitates this through the integration of models, knowledge, and data for designing both the material and the product is a need of the day. TRDDC-TCS with its experience in both the domains of materials engineering and IT is developing a platform for ICME named PREMΛP - Platform for Realization of Engineered Materials and Products conceptualized for this purpose. PREMΛP is envisaged to be a platform for discovering and concurrently designing new materials, manufacturing processes and engineered components. The platform will have tools to enable Decision Support Problem (DSP) construct for a manufacturing process design and component design, multi-disciplinary optimization, informatics & data mining, and knowledge engineering for discovery & use of prior knowledge. Currently, two major problems involving steel dealing with (a) development and production of steel mill products meeting stringent requirements of quality and cost and (b) integrated design of gears by linking up manufacturing processes and mechanical design, are being executed on PREMΛP along with the platform development.

These illustrative examples suggest that TRDDC is a suitable model for replication in the country as an excellent system for carrying out result oriented research by proactively seeking industrial partners.

5.2 R & D at TATA STEEL

5.2.1 The Beginnings

Tata Steel has the distinction of being the first company in India to establish a corporate centre for R&D, way back in 1937. This was a natural corollary to the vision of the founder, Jamsetji Tata, who foresaw an aspiring India with strong homegrown industries, self-reliant in technology. This Research and Control Laboratory is to play an important part in the progress and development of the steel industry in India and in the training of research workers in the metallurgy of iron and steel.

5.2.2 Assimilation of knowledge

At the time of its formation, it was viewed that the laboratory would carry out investigations on the methods of manufacture, costs reduction, fuel economy etc. The researchers were to collect material from foreign technical journals and compare results in every phase of operation with those obtained on similar steel works abroad. Till the late 1990s, the Research and Control Laboratory was engaged in quality control, process development, testing and certification, product development, product services, failure investigation and refractory technology. To support these activities, it had several state of the art analytical and research facilities.

5.2.3 Technology Group and R&D & Scientific Services

Tata Steel always believed that research is an indispensable activity in the quest for staying ahead of times and is an essential prerequisite for the progress and prosperity of the company. Since 2001, many organizational changes have been made in the Technical Departments to meet the current challenges of the growing steel market. At present the company has two departments 'Technology Group (TG) and RD & SS (Research and Development & Scientific Services)'. They together address the short term and long term requirements of the divisions and customers in all areas spanning from raw materials to finished products. The creation of Technology Group has helped R&D to focus on fundamental research and long term requirements. TG also facilitates the commercialization of the innovative work. Since the acquisition of Corus, the research projects in terms of number and quality have achieved international standards and the improvements are mainly due to good integration activities between European and Indian laboratories. The growing performance of Tata Steel in high-end market segments such as automotive and construction is attributable to the development of several new products for the first time in India and also in setting up research facilities for the characterization of materials. Steel grades up to tensile 600 MPa have been commercialized and high strength steel with nano carbide precipitation having strength values of 800 MPa is under commercialization. The research activities indicate that in about five years' time, steel grades up to a tensile level of 1400 MPa may be produced. With the advent of new facilities such as 'pelletizing unit' and TSCR (Thin Slab Casting and Rolling), new process and product development would receive increasing attention. The company plans to carry out research on 'Electrical Steel' and API grades in near future. The research in the area of raw material beneficiation is to achieve higher yield and lower product gangue which are essential for improving efficiency in blast furnace operation. Researches in the area of agglomeration and coke making for increased quality of sinter, pellet and coke have helped in improving the blast furnace operation in respect of coke rate, furnace productivity and overall cost of iron production. Research in the area of rebars for the improvement in UTS / YS ratio and corrosion resistance needs a special mention. The main role of RTG (Refractory Technology Group) is in providing knowledge and information based services related to refractory applications in iron and steel making. Waste utilization and environment related research are likely to yield handsome results in the near future. The company in its endeavour to disseminate steel related knowledge publishes a technical journal which goes by the name ‘Tata Search’.

5.2.4 Major Challenges

Tata Steel believes that the journey hitherto travelled in research is insignificant as compared to what needs to be done still. According to them, two major challenges facing steel related research are:

- Shortage of human resource for research
- Absence of design and manufacturing facilities to commercialise successful research

5.3 R & D in ESSAR STEEL

5.3.1 New and Uncommon Technologies

Research & Development in Essar Steel has a special significance because the company has adopted relatively new and uncommon technologies for iron and steel making, such as Corex and gas based DRI in combination with CONARC, uniquely configured thin slab casters etc. The product mix includes very high strength line pipe steels for petroleum industry, plates for pressure vessel applications, quenched and tempered plates for Defence sector, mining and other heavy duty applications.

5.3.2 Tangible Output

The R&D setup works in complete coordination with the operating technologies aiming at tangible deliverables. It uses modelling and process simulation extensively and concentrates on new product development apart from conventional iron & steel making.

Some of the successes are listed below:

- Using Coal fines - Approximately, 30% fines are generated in handling coal for Corex. In Essar, a process was developed to produce briquettes from coal fines which can withstand high temperature and reaction with gas in the Corex. A briquetting plant of 0.25 MTPY capacity is likely to be put in place.
- A method of cleaning the ceramic filter used for dewatering of iron ore slurry was developed for offline cleaning and regeneration of clogged ceramic plates which enhances its performance and life at an estimated saving of 9.5 crores a year.
- Under the zero waste initiatives, R&D has developed a pelletisation process to recycle effluent sludge through the sinter plant.

5.3.3 Modelling & Simulation

In the modelling and simulation area, the tasks accomplished are:

(a) Blast furnace model for optimum carbon rate using the concept of Rist diagrams. This model is used online to understand the effect of different raw materials and process conditions on carbon rate.

(b) Water modeling of CSP tundish for optimum location of tundish furniture. This model is used to reduce the skull volume and improve product quality.

(c) Optimization of batch annealing time for medium carbon steels to predict optimum soaking parameter led to a reduction in annealing cycle time by 6 hours. This led to a reduction in fuel and gas consumption by 11% per cycle.

5.3.4 Future Goals

Future goals of R&D at ESSAR pertain to

- Continued thrust on R&D in iron ore – there is a long term plan to put a state-of-the-art beneficiation laboratory.
- Setting up coal & coke research facilities – presently such work is being outsourced.
- Emphasis on energy/environment related R&D including solid waste conversion/utilization and green house gas emission.
- Continued thrust on 45odeling and simulation – developing and retaining talents in this area.

5.4 JINDAL ALUMINIUM LIMITED

Jindal Aluminium Ltd. has pioneered the aluminium extrusion industry in India. It started its operations with a press of 1500 MT capacity and with addition of 4 more presses with capacities up to 2200 MT and ultramodern features, Jindal Aluminium has emerged as the largest extrusion facility in the country. With the addition of the 6th press of 4000 MT capacity, the production has exceeded 75, 000 MT per annum. It provides its customers a wide variety of extrusions up to a maximum width of 460mm. Jindal accounts for more than 35% of India's production.

With an amazing 5000 varieties of extrusion profiles, Jindal is able to provide the best solutions to its customers in the building and construction industry. The most popular alloys are the AA6063 and 6061. It has also produced extrusions in the 2000 and 7000 series of aluminium alloys.

Jindal has been able to develop in-house machinery and was able to implement hot log shear, hot log casting and log heating technologies. Jindal has been able to export its quality goods to USA, UK, Germany etc and it has the distinction of indigenously developing several critical sections like heat sinks, aircraft and rocket sections etc. It had also developed fuel tubes for nuclear research reactors. The 12.64 MW wind power generator has made it self-sufficient in terms of its requirement of power and shows the companies concern for environment.

Research effort at Jindal is largely devoted to creating new finishes and developing new processes to exploit aluminium's versatility and has established a state-of-the-art R&D facility particularly in die design and manufacturing. The company is not hesitant in investing in high quality product. It has developed its own in-house R&D without any external assistance.

5.5 KENNAMETAL INDIA LIMITED

5.5.1 Early Days of Tool Industry

The tungsten carbide cutting tool industry in our country is as old as machining industry. Most of the R & D related to this industry have been conducted in western countries that also have setup their manufacturing plants in India, under collaborative agreements, by supplying know-how along with required equipment. Prominent among these were the India Hard Metals, Sandvik India and Widia (India). As the machining industry expanded in scope and size, the market for the cutting tools increased rapidly in different parts of the country. This created room for many players and wholly Indian companies like Rapicut, Indicarb and Powder Metals and Alloys all came up. Obviously the technology was not too complicated, yet aspects of recovery, quality and reproducibility dictated viability in the market. The most essential ingredients like tungsten ore, cobalt powder, tantalum carbide etc had to be imported. Vital equipment like hydrogen reduction, carburising, and vacuum sintering furnaces, automated presses for pressing precision parts with accuracy were also of imported origin. Hence, the Indian manufacturers had to concentrate on following the SOP provided by the collaborators and improving the productivity in order to stay in the market. As the technology matured, newer sophisticated equipment were required; cash flow requirements dictated functioning of these companies and except Sandvik Asia Ltd. all the carbide companies have undergone changes in ownership.

For studying the sintering (liquid phase sintering) behavior of tungsten carbide – cobalt systems, a number of studies were undertaken by Indian researchers at IIT, Bombay and IIT Kanpur, to find a substitute for cobalt which is an expensive imported material. But, cobalt was almost an ideal material which just could not be replaced. There is another material TiC which is harder than WC and if this could be sintered to high density, it could replace WC. The Indian company M/s. Indicarb Ltd. started working on this premise under collaboration with Adamas Carbide Corporation of USA. After a great number of trials, it discovered that nickel with small amounts of molybdenum can be a good sintering aid for TiC, to replace cobalt totally; but the sintered product lacked the toughness or impact resistance of WCcobalt combination. Thus, the prospect of (indigenously available) TiC replacing WC was dashed. However, another method of taking advantage of high hardness of TiC in metal cutting and wear applications came to the fore. That was by imparting a thin coating of TiC or TiN over the WC, by the well known CVD or PVD processes. The TiC and/or the TiN layers were not only harder than WC but even behaved as better lubricants, which improved the metal cutting performance considerably. It was later demonstrated that alumina coatings also have equally good performance provided the first intermediate layer of TiC is uniform and adherent. The process of CVD or PVD has developed so well over the years and the equipment design so perfected, that Japan has made it mandatory to employ either TiC, TiN and/or Al2O3 coatings on all WC parts and components, for it increases the tool life by a factor of 4 to 8, thereby reducing the quantity of import of tungsten or cobalt to that extent.

For metal removal or grinding applications other materials like silicon carbide, alumina and/or cubic boron nitride (CBN) have been developed, which find extensive use as grinding wheels or brazed/tipped tools; but the development of these materials has been totally nonindigenous. In India, M/s. Grindwell Norton and M/s. Wendt (India) have pioneered the efforts. Likewise for slicing and polishing granite and marble slabs/tiles which has become a very viable industry recently, diamond impregnated tools are required which are made by a powder metallurgy (hot-pressing) process. The technology and the associated machineries are all imported and Indian R & D if at all was only trying to duplicate the efforts. It may be of interest to the inquisitive readers that though the first man-made diamond process was patented around 1955 by M/s. DeBeers of USA, and attempts to duplicate the same by Indian researchers did not succeed, today, nearly 90% of the world's requirement of man-made diamonds for cutting and abrasive applications is met by China.

5.5.2 Kennametal Efforts

Reverting back, Kennametal (formerly Widia) is one of the leading producers of cutting tools for metal cutting, metal forming, and mining and special purpose machines in the country. Against a demand of 1000 t/yr of cutting tools, Kennametal supplies about 30% of the total requirement. It concentrates on alumina/silicon nitride coated products, while cubic boron nitride tools and wheels are handled by their competitors, M/s Wendt India. Taegu Tec of Korea is another company that has also set up a tungsten carbide cutting tool facility at Bangalore.

New grade tools for finish turning of steels suitable for machining at cutting speeds up to 500 m/min have been successfully developed by Kennametal. This development has increased productivity due to higher cutting speeds. Tungsten carbide rolls are used for producing thin steel sheets for the construction and/or packaging industry. New grade of cutting tools were designed with modified binder system to improve thermal conductivity, corrosion resistance, fracture toughness and abrasion resistance. The binder is a type of mixture consisting of chromium and nickel along with cobalt.

Kennametal has its own Research, Development and Engineering unit and most of the problems are solved in-house. They have all the requisite facilities. Once in a while, when they have ventured to look for alternate materials like fibre reinforced ceramics, the academic community did not deliver the desirable results. They also tried some collaboration with RDCIS for development of rail wheel machining, but did not succeed due to terms of agreement. Another aspect that was mentioned by Kennametal was that imported equipment worked trouble free without any difficulty in controlling the parameters and in maintenance. Indian counterparts fared badly in this area.

Kennametal is one of the industries that are not worried about Chinese competition, because when people want quality products, they preferred Kennametal-India products. Remaining closer to market and concentrating on delivering quality products appeared to be the motto of Ms. Kennametal for sustenance in an intensely competitive market.

5.6 SANDVIK ASIA PRIVATE LIMITED

Sandvik Asia Pvt. Ltd. is an Indian subsidiary of Swedish Sandvik Group and commenced its operations at Pune in 1960. A dedicated research centre for materials R&D was inaugurated in February 2008. This is a satellite laboratory directly connected to R&D laboratory in Sweden. The focus is on modelling and simulation of various manufacturing processes for Sandvik Materials Technology. The modelling techniques employed include ThermoCac and Dictra for thermodynamic modelling, large plastic strain finite element analysis (FEM) and computational fluid dynamics (CFD). A microstructural characterization laboratory is also set up including field emission scanning electron microscope. The total manpower dedicated to materials research in

Sandvik Asia is 15 including 4 PhDs and 6 MTechs. The research carried out is monitored by a research council. The R&D expenditure for the year 2011-12 is about Rs.4 crores.

The major achievements from these R&D groups are given below:

- CFD simulation of gas atomization process for better understanding of the process in order to optimize the parameters to obtain powders of required quality
- CFD simulation of various types of furnaces including gas heating and resistance heating furnaces to optimize the heat treatment processes and also aid in designing new furnaces
- Development of databases for thermodynamic calculations
- Computational thermodynamic calculations for development of advanced austenitic stainless steels and hyper duplex steels
- FEM simulation of 3D extrusion, wire drawing, closed die forging for optimization of process parameters to achieve better product quality . FEM simulations for new product development for oil, gas and aero-space applications
- Structure property correlation of advanced austenitic stainless steels for applications in Ultra Super Critical (USC) boilers
- Development of new grades of cobalt powder
- Development of special cutting tool products
- Kanthal fibrothal heating and insulating systems

The processes at Sandvik Asia are zero effluent discharge processes. A good amount of research is dedicated to sustainability. A very good example is establishing a global centre for recycling of cemented carbides and drill bits for tungsten. We also develop more efficient processes by modelling and simulation techniques to increase energy efficiency. This resulted in Sandvik being recognized for inclusion in the prestigious Dow Jones Sustainability World Index (DJSI World).

5.7 ADITYA BIRLA SCIENCE AND TECHNOLOGY COMPANY LTD.

Aditya Birla Science and Technology Company (ABSTC) is the corporate R & D hub for the Aditya Birla Group and its vision is to be a world class R & D organization focused on achieving technological excellence in its businesses. It is based in Taloja, Mumbai and has a technology centre, laboratories, scale-up facilities, modelling and simulation capabilities, analytical services and a knowledge centre which also functions as the Group’s patent cell. ABSTC is also engaged in partnering with external institutes, laboratories, universities and government entities to develop and commercialize technologies related to the group businesses. Since its inception in 2006, ABSTC has built a strong core pool of researchers with both horizontal platform-centric research and vertical business-aligned domain capabilities. Till date, ABSTC has worked on more than 100 technology development and commercialization initiatives leading to over 55 patents being filed.

Technology platforms are broad areas of research for organizing the research effort and growing in-depth expertise and may combine several technologies, multi-disciplinary developments and process, product and application needs. Platforms of research at ABSTC include aluminium smelting, copper pyro-metallurgy, metal downstream, materials & minerals, fibres & textiles, chemistry & catalysis, chemical & process engineering, simulation & CAE, advanced process control, analytical sciences & technology.

Areas of focus for ABSTC in metals and materials area are listed below:

Aluminium: ABSTC works along the entire aluminium value chain including alumina production, aluminium smelting and downstream processing of aluminium and penetrating new markets in building, construction and transportation sectors.

Copper: The focus is on capacity enhancement and higher yield through process debottlenecking, improving production sustainability and minimizing environmental impact.

Carbon Black: From a fundamental understanding of the carbon black reactor, ABSTC provides insights to improve production yield, consistency of quality and expand the product portfolio through reactor design modification, enhanced process control and process parameter optimization.

Fibres: The Fibre Science Laboratory works in collaboration with the Group's fiber business to develop and support new value added products and technologies for cellulose and acrylic fibre.

Working collaboratively with customers, ABSTC developed processes and products include:

- Development and formulation of consumer products such as Kara and Puretta wipes
- New materials based on innovative alloys, particulate aluminium matrix nanocomposites and fibre cement blends
- Novel technology to incorporate property – modifying constituents into fibres and yarn processes
- Advanced technology for optimizing feed, capacity debottlenecking and reduction of energy intensity via development of innovative designs and control strategies for aluminium plants
- New process control strategy and design for capacity debottlenecking and higher yield in copper plants
- New carbon black reactor designs utilizing optimizing combustion flow patterns resulting in increased conversion and higher quality product
- Synthesized a soft sensor based on-line decision system for metallurgical processes
- Maximized recovery of by-products from waste streams aiming at zero-effluent plants
- Exceeded global benchmarks in attaining desired specifications of key raw materials

- Invented an approach allowing step-change reduction in cost of Al/Al welding
- Developed an electrically conductive coating that aids in resistance spot welding of aluminium.

As we move into the era of specialized products, ABSTC's experience in bringing new ideas to our customers significantly enhances their learning curves. The ability to diffuse product and process innovation across businesses makes ABSTC a valued partner and thought leader.

6. R&D IN PUBLIC SECTOR

6.1 MISHRA DHATU NIGAM LIMITED

Mishra Dhatu Nigam is a public sector unit of the Department of Defence Production and Supplies. It was set up by the great visionary metallurgist, R. V. Tamhankar. He conceived this as a refractory and rare metals and superalloys plant, mainly to meet the demands of the defence, aero-space, atomic energy and civil sectors. He had envisaged production of a vast number of alloys, but the facilities established could make these specialty materials in small quantities. In fact, Midhani should be treated more as prototype production facility. As a result, the economies of scale of operation were not available for the products produced at Midhani. But, the contributions of Midhani are noteworthy particularly in supplying maraging steels, nimonic alloys, titanium alloys, special steels etc. for strategic applications. Consequently, the company got enormous support from the Departments of Space, Defence and Atomic Energy. It would not be out of place to mention the R&D support provided by Defence Metallurgical Research Laboratory and its co-location made it easier for Midhani to get requisite help from the laboratory. it has come out of difficult periods. Midhani’s output was 2000 tonnes in 2009-10 and it is likely to double in a short while.

6.1.1 Maraging Steel

When the success story of Midhani is to be mentioned, it is but natural to talk about maraging steels. While our neighbour has to procure this material stealthily for their centrifuge programme, Midhani was able to produce this alloy indigenously. Of course, this material, its composition and properties were all available in literature. But, when it comes to indigenous production for the first time, it is the experience that counts. A case in point is the production of rings for our space programme. Initial problem was to make an ingot of the requisite size, as large scale melting facilities were not available. This was overcome by melting two ingots and welding them together, which was remelted and forged. Later ring rolling and heat treatments were to be done at Krupps in Germany. Two initial rings made there successfully met all the requirements and everyone was elated. But, later when the full supply of 16 rings was to be rolled, the same Krupps did the job, but properties fell short of requirement. DMRL was brought into the picture and a careful analysis by them showed that the precipitates were coarser than in the first two cases. A review of the working revealed that a large number of hot rolled rings were stacked one over the other and as result, the cooling rates differed and consequently, precipitate coarsening had taken place, thereby degrading the properties. Reheat-treating of the rings based on R&D inputs from DMRL was carried out and everything fell in place.

6.1.2 Electro Slag Refining

Another feather in the cap for Midhnai is in bringing Electro Slag Refining (ESR) technology. It was well known that the armoured tanks of Hitler’s forces in the WW II failed because of the brittle steel used in the manufacture of tanks. The Russians who had captured the tanks analysed the steels and found large inclusions in the steel. Then, they developed the ESR technology to produce cleaner steel. Brahm Prakash as Chairman of the Review Committee for collaboration agreements of Midhani, suggested that Midhani procure an ESR unit. This led to successful production of gun barrel steels required by the Ordnance factory, and other cleaner steels required by the nuclear industry and space programmes.

Way back, Midhani started production of 15CDV6, a French steel, for applications in rockets for the Dept. of Space and now is working on a modified 15CDV6 alloy with improved properties. As already mentioned, Midhani today manufactures the world's best maraging steel, a critical component for fuel enrichment centrifuges, missiles and space rockets. Midhnai is now in the process of developing a high strength MDN 400 alloy.

6.1.3 Meeting Aero-Space Requirements

Midhani also produces titanium gas bottles by a super-plastic forming technology provided by DMRL. Commercial purity titanium and a host of specialty alloys for aerospace applications including the equivalent of Ti834 are being manufactured and supplied. Superalloys equivalent to Inconel718, HastelloyX, Inconel X-750 and superweld82 electrodes for welding are routinely manufactured and supplied. Alloy C-103, an Nb-10Hf-1Ti alloy is now developed and supplied to VSSC. Shape memory nitinol and a wide variety of brazing alloys are also supplied to VSSC/DRDL.

BT-9, a titanium alloy required for Sukhoi fighters is made and supplied. It is gratifying to note that 13 different alloys for Sukhois are manufactured by Midhani. Isothermal forgings of IMI685 for Kaveri and Adour engines are manufactured and supplied in requisite quantities. When 49 MIG aircrafts were down for want of BT-91, an aluminium alloy, Midhani took the challenge and supplied the material in record time.

6.1.4 Weld Consumables

Development and supply of consumable arc welding electrodes for welding the AB grade steels for Arihant submarine and other ships of the Indian Navy is another creditable achievement.

6.1.5 For Nuclear Industry

Midhani is now working on supplying SS403 end fittings for the 700 MW PHWR reactors of NPCIL. Midhani also has produced a Low Activation Ferretic Martensitic Steel, a material urgently required by the International Thermonuclear Energy Reactor (ITER) project. This steel must have very low activation, allowing it to be placed in a highly radioactive environment without itself becoming highly radioactive. The ITER authorities are presently evaluating it. For the PFBR, a 500MW breeder reactor being built at Kalpakkam, Midhani is supplying the D-9 alloy, developed by IGCAR.

6.1.6 To Keep Costs Down

The major problem is to keep the costs down, as in several cases, imports have become cheaper. At the same time, Midhani needs to augment its equipment and machineries. One way of keeping the cost down, according to the present CMD is to buy reconditioned high value equipment and machineries, and the competent authorities may have to look into this proposal. At the same time if Midhani could increase the capacity utilization of some of its costly imported machines in the cold rolling and wire drawing areas, its fixed costs would be reduced with consequent reduction in its cost of production. A note worthy attempt in this direction has been made by Midhani recently, by making a 10 ton ESR melting furnace indigenously for its enhanced production of special steels. An interesting point in this context is that with the help of

IIT Mumbai, a small scale private sector firm at Hyderabad has successfully made a 500 kg ESR furnace thru which it is able to remelt and recycle tool steel grade steel scrap, a noteworthy achievement towards conservation of imported materials like tungsten, cobalt, molybdenum etc.

6.2 HINDUSTAN AERONAUTICS LIMITED – FOUNDRY & FORGE

In the initial briefing to the committee, it was stated that HAL F&F has a strong manufacturing base and a mass production culture. They have cashed on these strengths to supply various components for the aerospace sector, and they were happy to acknowledge the support received from established R&D laboratories. They also felt that there is a greater need for R&D support, which was very heartening to note.

6.2.1 Production of Aero-space Components

In association with DMRL, Foundry & Forge has developed brakepads for several military and civil aircrafts. Brakepads for Su30, Hawk, MIG29 (Naval Version) and Saras aircrafts have been developed in-house and produced. They have also developed Super Waspalloy turbine disk forgings. They have established production technology for high pressure compressor discs of titanium alloys for Adour engines by near isothermal forging. When it was difficult to import shape memory alloy components for the LCA, in association with BARC, they developed the ferrules and have now put up a plant for production of SMA components. Again with the help of DMRL, they have developed castings for turbine rotor and stator in CM 247LC alloy for jet fuel starter for LCA, and pilotless target aircraft engines. Directionally solidified blades for Adour engines are another notable achievement.

6.2.2 Aluminium Alloy Development

Apart from using the indigenously developed technologies that they have obtained from DRDO laboratories, they have also developed several in house technologies. They have optimised heat treatment parameters for aluminium alloy AA2219 and a couple of 7000 series of Al alloys, AA7449 and AA7049.They have developed sintered iron components for starter generator of Intermediate Jet Trainer (IJT) aircraft.

6.2.3 Why imports still continuing

Midhani, a Defence PSU has developed various aerospace materials and got them certified. HAL Foundry & Forge has used them and users have accepted them. But, with 53lobalization, import option has become cheaper and thus HAL is not in a position to use indigenously developed materials, that too from another unit within the same Department of Defence. Some solution has to be found out. Apart from that, the main issues that need to be addressed, according to them, are timely completion, costing mechanism and consolidation of requirements.

6.3 BHARAT HEAVY ELECTRICALS LIMITED – CORPORATE R&D DIVISION

The R&D Division of BHEL caters to a wide variety of requirements of BHEL and their customers. Their thrust areas in metallurgy include creep and structural studies, fatigue and fracture mechanics, non-destructive testing and evaluation, alloy development, residual life assessment of power plant components and failure analysis.

6.3.1 Gas Turbine Buckets

Gas Turbine buckets are made of IN738 superalloy. The main aim of indigenous development is to be independent of suppliers' whims and fancies.

This alloy has been developed, hot isostatically pressed and heat treated. Further, about 50% of scrap generated during bucket casting could be recycled. The billets have been ultrasonically tested, and subjected to microstructure and mechanical property evaluation. 250kg batches have been produced and supplied for evaluation. Investment casting technology for bucket production has also been perfected.

6.3.2 Ni-Hard Rolls

Development of Ni-hard bowl mill rolls with nano/ micro particle additions has been completed. Rolls with 0.1% nano size tungsten carbide powder are being manufactured. Supplies are to be effected to Vijayawada and Raichur TPS for performance evaluation. With anticipated improvement in roll life, BHEL hopes to regain the lost business opportunity.

6.3.3 NDT and Residual Life Assessment

Phased array ultrasonic testing has been established for turbine blade root cracks detection and also by magnetic particle inspection (MPI). This saves the cycle time of Residual Life Assessment (RLA) studies of turbines by about 5 to 7 days. This has already been used at Ramagundam and Vijayawada power stations. Pulsed Phase Tomography**,** a unique method of non-contact inspection for refractory coatings without removing the sample has been successfully tried in other BHEL units.

6.3.4 Super Critical Power Plants

Modification of steels required for super critical power plants to overcome present drawbacks is a problem of immediate concern. Indigenous manufacture of directionally solidified gas turbine blades are also taken up. Damage mechanics analysis would be carried out on super critical power plants. Failure analysis and RLA studies would be carried out as and when required. BHEL R&D would take the help of other R&D establishments and production facilities in the initial phases of the above mentioned studies.

6.3.5 Surface Engineering

In the surface engineering area, development of a laser hardening process to combat droplet erosion of turbine blades has been successfully completed. Development of HVOF coatings on hydro turbine components to combat silt erosion is another success story. Other major works carried out include nanocrystalline coating on boiler tubes, slurry erosion and corrosion resistant coatings for oilfield gate valves and twin wire arc coatings to combat high temperature erosion. Development of thick thermal barrier coatings on gas turbine liners has also been taken up.

6.4 NUCLEAR FUEL COMPLEX

6.4.1 Integrated Fuel Manufacturing

The Nuclear Fuel Complex (NFC), established at Hyderabad during 1969-'73, is even today considered as the only Integrated Fuel Manufacturing Facility in the world for PHWR type nuclear power stations. The Nuclear Fuel Complex started commercial production of the PHWR fuel bundles in 1973. The initial capacity of the plants was aimed at producing about 100 tonnes of the PHWR fuel per year. However over the last four decades, owing to many modifications in the processes, design changes and backed up by periodic capacity augmentation, it has been possible at present to increase the fuel production capacity to about 650 tonnes per year. NFC is the first organization in the world to manufacture thin walled seamless Calandria Tubes of 134 mm OD x 1.4 mm WT in Zirconium alloy. Though their competitors abroad are trying to manufacture seamless calandria Tubes, it is understood that they have not yet succeeded.

This was possible due to constant in house R&D efforts with periodic support from BARC. It may be mentioned here that the country is presently operating 18 PHWRs and 2 BWRs and all the finished fuel requirements of these operating reactors have been met continuously from the NFC. It may be emphasized here that the technology to manufacture the nuclear fuel assemblies, right from the stage of making nuclear pure uranium and sinterable grade UO2 powder to dense sintered pellets of UO2 with desired microstructure, and the technology to make hafnium free zirconium metal and zircaloy components there from, were all developed at BARC on a pilot scale and was transferred to NFC along with the engineers and scientists who worked for the project. Some of those senior engineers were also present at the meeting with the INAE team who shared their experiences in up scaling the production batches and in improving the quality or reliability.

6.4.2 Titanium Production

An analogous technology, similar to that of zirconium, is that of titanium. During the mid-'70s, a pilot plant for the production of titanium sponge in 100kg batches by the Kroll Process was demonstrated at NFC, Hyderabad. Starting from rutile, facilities were created for the production of titanium chloride, its purification and subsequent reduction with magnesium and vacuum distillation to isolate pure sponge were all successfully established.

6.4.3 Meeting Hafnium Needs

Another strategic material is hafnium, which is a by-product in zirconium metal production. Nb-Hf is a requirement for our space programme and hence, NFC is setting up a 3t/y plant for Nb production, while C-Met is commissioned to produce hafnium. Midhani would carry out the consolidation process. This alloy equivalent to C103 was studied in detail at IGCAR, Kalpakkam.

6.4.4 Zr-Nb Pressure Tubes

Another notable outcome R&D work at NFC is that of heat treated Zr-Nb pressure tubes, in place of the conventional cold worked Zr-2.5 Nb. This process leads to increased in reactor radial creep resistance. Development of pressure tubes through a forging followed by pilgering route is expected to yield significant improvements. In this context it was also brought out that the user NPCIL is proactively asking NFC to carry out this work, which is heartening to note.

6.4.5 Incoloy Development

Incoloy800 is another steam generator tube material for the 700MW applications. This work of bending the alloy 800 tubes at NFC was taken at the insistence of L&T on a global competitive basis. Successful trials have been carried out to produce 23m long tubes and bending them in to a U shape and NFC is confident of meeting the time schedule also.

6.4.6 Machinery Development

In the manufacturing area, NFC has developed its own pilger mills, sintering furnace, vacuum annealing furnaces, electron beam melting furnaces, end cap welding machines and ultrasonic tube testing machines. They have collaborated with private and public sector agencies in this area. They have also developed the process technology for production of seamless square and hexagonal thin walled hollow zircaloy sections. It was pointed out that R&D successes are often achieved when you collaborate closely with the industries that you are working with. In case of imported machineries, it was found necessary to develop the spare parts needed for maintenance of the equipment, as other wise the cost of spares is hiked by the original suppliers. When import options are denied, the agencies concerned are able to meet the requirements, because of the focused attention of all concerned. NFC also successfully executed an order received from the International Atomic Energy Agency for design, manufacture, supply, erection and commissioning of a fuel end cap welding unit to the Turkish Atomic Energy Authority.

6.4.7 Spin-off Technologies

NFC has developed truss rod assemblies in titanium half alloy for GSLV. Small diameter tubing of 6 to 25 mm OD were developed and manufactured for Light Combat Aircrafts (LCA) for use as hydraulic tubing, wherein, the impulse test results confirmed the superior quality of NFC tubes over imported tubes. Thin walled tubing in aluminium alloy AA 2219 were produced in a number of sizes for cryogenic application for use as propellant feed lines for liquid oxygen and liquid hydrogen. Developed and produced large diameter thick walled tubing in maraging steels for use as missile casing and gun barrels.

NFC has also manufactured seamless tubes in several sizes in titanium alloys PT1M and PT7M and stainless steels SS 321 and SS 316Ti for use in nuclear submarine. NFC, in collaboration with IGCAR, ARCI and DMRL, manufactured seamless tubes through powder metallurgy route in oxide dispersion strengthened steels. In addition to the manufacture of seamless tubes with circular cross-section, technology was developed to produce tubes with hexagonal and square cross-sections. It was also established that tubes with different geometries on the inside and outside surfaces can be manufactured through pilgering. NFC has also developed the manufacturing technology for producing seamless tubes in 304H (Cu) and Inconel 617 grades for use in advanced ultra supercritical boilers.

6.5 ADVANCED RESEARCH CENTRE INTERNATIONAL

ARCI at Hyderabad is an R&D establishment under the Dept. of Science and Technology, set up with a view to developing unique, novel and technoeconomically viable processes that could be transferred to industries. The thrust areas of ARCI are nanomaterials, engineered coatings, ceramic processing, laser processing and fuel cells.

6.5.1 Nanomaterials Technology

In nanomaterials, it is gratifying to note that ARCI is interested in developing applications oriented research and development activities. It has successfully developed and transferred technology of nanosilver suspensions for antibacterial applications in textiles. Nanosilver modified ceramic silver candle filters for drinking water applications and high performance varistors based on nanocrystallline zinc oxide powders are two other important successful applications.

6.5.2 Surface Engineering

ARCI is well recognized as a centre for excellence in surface engineering. The successful transfer of detonation spray coating, micro-arc oxidation and electro-spark coating technologies are commendable. The coating of electrically insulating material on long lengths of conducting foils is a very notable application. Work on thermal barrier coatings and nanocomposite wear resistant coatings are of importance, but possibly these require expensive coating systems. Functionally gradient coatings with varying hardness by tailoring microstructure appear to be another important area of application.

6.5.3 Laser Processing

The Centre for Laser Processing of materials was set up to develop laser based materials processing technologies for industrial applications. Degradation of various components in power plants takes place. With suitable surface modifications, life of these components can be extended. Tungsten carbide reinforced NiCrBSi metal matrix composites cladding was carried out on SS310 components. The laser clad samples were twice as erosion resistant as compared to unclad samples. Laser hybrid welding is another area of interest at ARCI. For this the existing CO2 laser is integrated with pulse MIG system and trials are being carried out to see the effects of various parameters.

6.5.4 Sol-Gel Technology

Due to the depleting reserves of zinc globally and due to toxicity associated with hexavalent chromium, focus is on use of alternate coatings on steel for corrosion protection. ARCI has developed an organic-inorganic hybrid nanocomposite coating derived from a UV polymerizable organically modified sialane precursor in combination with zirconium-n-propoxide. Improved corrosion resistance of mild steel was observed.

6.5.5 Transfer of Technology

ARCI has got a technology incubation park that assists entrepreneurs to carry out initial studies on the processes, before establishing the same at site. In addition, they have a centre for technology acquisition, and transfer of technology to the industries. These are very necessary for R&D to succeed. While this incubation park is expected to assist in quick transfer of technology, it was also stated that some of the entrepreneurs who have taken technologies have not been that successful in implementing the process. They continue to seek ARCI assistance free of cost.

Possibly a little more attention is to be paid in selecting the partners for transfer of technologies. This strengthens our view that a good marketing wing with experienced professionals may be the need of the hour. If one considers the case of nanosilver candles Vis a Vis other products in the market, how does the cost compares- is it cheaper both from the initial cost as well as the cost of maintenance? This also needs some critical thinking, even before embarking on the project.

6.6 NONFERROUS MATERIALS TECHNOLOGY DEVELOPMENT CENTRE

NFTDC sprang up as a result of a novel initiative of the Department of Mines. This centre is under their administrative control. NFTDC is an autonomous R & D institution formed as a result of collaboration between DMRL and four PSUs (HCL, HZL, NALCO and BALCO). It is interesting to observe that even though each of the above named institutions have their own independent R & D facilities, it was considered desirable to form another institution to carry out inter-disciplinary applied research. The story of growth of R & D in India has been essentially an exercise between concepts of a need based research on one hand and a holistic approach aiming at advancement of knowledge base (which earlier used to be in the realm of universities) and at the same time seeking adequate autonomy for the author organizations. Though born out of such a hybrid concept, the NFTDC has kept its focus on need based research by imbibing the character of self financing, unlike many other research institutions in the country which are operating mostly as over-heads with no relationship to what is being imported into the country or how to enhance the export potential of the nation.

6.6.1 Equipment Development

The stress of NFTDC has been to build capability, both in terms of equipment such as vacuum melting, centrifugal casting, micro-wave sintering, electron beam welding, plasma spraying etc and to develop capability for specialized applications of technology such as metalceramic brazing or pack rolling. Presently in its twentieth year of existence, the NFTDC is interacting with and obtaining research projects from Navy, Air Force, Departments of Atomic Energy and Space as well as from private sector organizations. Since it earns its revenue for both capital and operational needs, it has to be necessarily proactive towards finding solutions for its existing and prospective customers. Some of the technologies developed by NFTDC are production of molybdenum-disilicide, thin foil rolling, thermal sprays, high energy battery materials, recovery of valuables from copper wastes generated in copper plants etc.

6.6.2 Automobile Sector

NFTDC has taken up a project for development of motors of different capacities for their automobiles. It has started as an ab-initio exercise and a complete analysis of the components of motor and with the aid of design tools have optimised the dimensions of various parts. Successful completion of this project would certainly give the deserved recognition to the motivated researchers at NFTDC.

Having visited both ARCI and NFTDC, it is but natural to draw a parallel between the two. Though both are supported by the GOI, ARCI has built up its strength with bought out equipment and initially with imported technology. On the contrary NFTDC appears to rely on building its own equipment and believes in learning by doing things. An admixture of the two may be beneficial for both the laboratories.

6.7 R&D CENTRE FOR IRON AND STEEL

Most of the research and development activities at RDCIS have been confined in reducing the cost of production (58.3% of the total costs) development of value addition (7.2%), quality improvement (7.2%), cost reduction (8.2%) and development activities (19.1%). These figures are for projects undertaken in 2010-11 at SAIL RDCIS Ranchi. Some of the successfully completed R & D projects which have bought benefits are enumerated below.

6.7.1 Formable Quality Steels

High Strength Formable Quality (HSFQ 450 grade) steel was developed at Bokaro using innovative alloy chemistry with 0.03-0.04% Nb and 0.2-0.3% Si which resulted in superior formability properties in terms of elongation (32%). Addition of Si in HSFQ led to ease of casting, increased flowability, better desulfurization during secondary refining and reduction of cost. These steels exhibit a very fine ferrite grain size of 2.8-3.5 microns in HR coils. These steels have been used in the manufacture of high pressure cylinders.

6.7.2 Inclusion Control

Suitable process technology has been developed for the manufacture of steel plates having guaranteed through thickness ductility in the Z direction for use in off-shore platforms. This is due to modification of sulphide shape and using thermomechanical processing and microalloying to yield fine ferrite grain size.

6.7.3 Reduced Energy Consumption

RDCIS has designed and constructed a normalizing furnace for plate mill of Bhilai steel plant which ensures efficient combustion. PLC-based furnace control and reduced heat loss resulting in substantial fuel saving. It has also designed and introduced energy-efficient ignition system in the sinter machine 2 of Durgapur Steel Plant which reduces the specific heat consumption by 54% and increased production rate by 1.5%. Refractory consumption was brought down by about 60%.

The above are some typical examples of successfully completed R & D programmes over the years. The R & D has to concentrate on developing steels for the auto sector and it is imperative to develop high-strength interstitial-free steel and advanced high strength steel with improved formability and flange making ability. In addition, the steel makers have to ensure close compositional control and cold-rolling with close tolerance and minimum thickness variation.

6.8 RAIL WHEEL FACTORY

6.8.1 Indigenisation of Rail Wheels

Indian Government decided to set up a Rail Wheel Factory in Bangalore since Durgapur Steel Plant and Tata Iron and Steel Company were unable to meet their requirements. Railways had to import the wheels to meet their operational needs. The cost of import was high and in addition, it was also time consuming. Thus, the Government of India decided to set up a new specialised production unit for the manufacture of rolling stock wheels and axles. It was based on the assumption that the DSP and the Rail Wheel Factory should be able to meet the Indian railways requirement fully for standard wheels and axles, so that import could be stopped.

6.8.2 Forge or Cast?

Two technologies were available for the manufacture of wheels. Forging route used by European Railways while casting method was adopted be American Railways. Initially, the forged wheels were manufactured by the Kapurtala Rail Coach Factory. After carrying out an exhaustive study regarding latest technological trends, and equipment available for the manufacture of wheels, Indian Railways decided to adopt the casting technology developed by M/s Griffin Wheel Company, USA. The cast wheel technology was found to be superior in terms of productivity and cost of production as compared to forged wheels.

6.8.3 Microalloying

Electric arc furnace has been used for melting of the pedigree scrap generated within the railway workshops. The entire process of melting, casting under controlled pressure, pouring into graphite moulds and different heat treatment operations to develop optimum micro- structure with a view to obtaining the desired mechanical properties has been automated. This enabled RWF to ensure optimum production and rigid quality control and minimum workers fatigue. In case of axles, a precision long forging machine capable of a high rate of production supported by specialised machining centres was procured. Automated machines to surface finish the axles in stages to the desired profiles and finish have been employed. The final pressing of the wheels to the axle is undertaken be an automatic machine with the preset limits of interference, tolerance and close control of pressing pressure. Thus, a precisely engineered product with little scope for human error has been ensured. It is planned to increase annual production capacity to 200000 wheels and 75000 axles from the present level of 115000 wheels and 65000 axles. High level online integrated management system (IMS) has been deployed. IMS is a decision support system which helps in increasing production, duly maintaining quality and controlling inventory levels. Recently they have developed a micro-alloyed (V, Mo) cast steel wheel with superior properties and a patent is obtained for this technological development in 2006. Three furnace operations have been started in Dec 2007. They have successfully absorbed the imported technology for cast wheel production and upgraded this with the introduction of micro alloyed steels. So far, not a single wheel has failed within the expected lifespan. Modern quality control techniques have been successfully employed to assure quality wheel and axles.

An interesting observation is that they have never felt the need to involve or interact with any academic institutions or R&D laboratories in the country. They said that they take help of Central Power Research Institute, Bangalore and some local analytical companies for carrying out chemical analysis as and when required, apart from interacting with their parent R&D organization, RDSO, at Lucknow.

7. SECTORWISE COMMENTS

7.1 IRON AND STEEL

Steel industry is growing at a rapid pace in India to meet the demand for different applications. In 1990, the Indian steel industry had a production capacity of 23 million tonnes which rose to 43 million tonnes in 2005. In 2010, the capacity rose to 60 million tonnes. According to the steel policy of the government, it is envisaged that the country would be producing 120 million tonnes by 2020 (doubling the capacity in the next 10 years).

7.1.1 Improvements in Quality

In comparison to the quality of steel produced in 1960s, today's requirements demand a dramatic change. This has led to an increased understanding of the complex processes of blast furnace iron making, LD steel making, electric arc furnace melting and the role played by slag in removing impurities. Steel makers rose to the challenge of producing steel at competitive costs. By inventing new steel making methods to produce quality steel and with advanced processing methods such as thermo-mechanical processing and controlled cooling, it was possible to control the microstructures that led to improvements in properties. This was made possible with the introduction of sophisticated analytical instruments which enabled one to find the role of fine carbide precipitates in imparting strength and also in providing insight into the effect of harmful inclusions such as sulphides, oxides, etc. Secondary refining methods such as ladle metallurgy, vacuum argon decarburization, argon oxygen decarburization, vacuum oxygen decarburization and compositional adjustments by argon blowing, were developed and in use now in integrated steel plants to produce cleaner steels. Continuous casting technology has been introduced to control solidification behaviour to minimize segregation and surface quality.

7.1.2 Indian Context

In India, the following technological routes are used for the production of iron and steel:

- Coke oven – blast furnace, basic oxygen furnace/twin hearth furnace using coking coal and iron ore (lumps and sinter as basic inputs for steel)
- COREX- basic oxygen furnace with non-coking coal and iron ore lumps
- Direct reduced iron/arc furnace/ induction furnace using natural gas/non-coking coal and iron ore lumps and pellets
- Blast furnace, electric arc furnace using iron ore lumps and coke
- Mini blast furnace/energy optimizing furnace using coke and iron ore lump and scrap
- Stand alone gas/coal DRI furnaces using iron ore lump/pellets and natural gas/noncoking coal for direct reduced sponge iron
- Stand alone electric arc furnaces and induction furnaces using steel scrap and sponge Iron

Over the years the older plants have been modernized and the cost of production has been brought down. After globalization, the steel industry has been adopting technological up61 gradation, energy optimization, along with improved pollution control and safety measures.

Thus, the newer steel making units set up in the late 1990s have adopted newer technologies like COREX iron making, combined blowing in basic oxygen furnace, DC arc furnaces, twin-shell arc furnaces, oxygen lancing electric arc furnaces, thin-slab caster, etc

7.1.3 Performance of Indian Plants

The technological performance of Indian steel plants, however, is much lower than that of the advanced countries:

- Coke rate of 450-550kg/thm in Indian blast furnaces is higher than international norm
- Energy consumption is 7-8Gcal/tcs compared to 4-5Gcal/tcs abroad
- About 30% of the cost of steel is in energy, whereas it is less than 25% abroad
- Indian plants generate 1.5-2 times more slag and dust, 15 times more waste water and 4-5 times more waste gases
- Only approximately 30% of India's steel is by secondary refining
- 40% of slabs and plates produced are through ingot casting
- Meagre advanced instrumentation and automation

Indian steel plants have to ensure consistency in the production of steel, heat-after-heat with close compositional control. Proper practice of tundish metallurgy is necessary to arrive at the cleanliness needed for producing steels for specific applications.

In the power sector, cold-rolled grain oriented (CRGO) steel is required for transformer applications. Currently, Rourkela Steel Plant produces 75,000 tons of CRNO steel like M-45 and M-47. RSP is producing only limited amounts of M-43 although it is most required. Efforts should be made to enhance the production of CRNO grade M-43. This requires making cleaner steel with minimum inclusion content and dissolved gases and also hot-band annealing furnace.

7.2 ALUMINIUM

India is ranked fifth in world's bauxite reserves with deposits of about 3 billion tonnes but our share in world aluminium production is just about 3%. In spite of its easy availability, ease of fabrication and its relative lower cost (compared to copper, nickel or stainless steels), the per capita consumption has been quite low (around 1 kg per year), in comparison to 3 kg in China, 10 kg in Taiwan and around 25 kg in the US. Production of aluminium is carried out by electrolysis and thus is highly power intensive. Consequently, one looks for cheaper electric power either in the form of hydroelectricity or captive power plants. It is predicted that in the coming decades, most of the primary metal production would take place in China and India. Production facilities in developed countries are likely to be closed down.

7.2.1 Technological Improvements

While the existence of aluminium was known way back in 1808, the first commercial production of the metal took place only after 46 years. The same Hall-Heroult process is followed even now and no process innovation has taken place since then. At the same time, some process innovations have brought about improvements in the production of aluminium and subsequent processing through ingenious R & D. Some of these innovations relate to treatment of the molten metal by degassing and filtration to take care of inclusions and porosity, direct chill casting of ingots for extrusion or rolling instead of pouring in moulds, improving strength through age hardening process after addition of certain alloying elements, and use of high speed rolling mills or high capacity extrusion presses for mechanical working. Deployment of instruments for process monitoring, aiming at consistency through quality control, advent of TIG welding for joining and radiography of welds for evaluation of quality have expanded the application of aluminium from cladding of nuclear fuels to fuselage of aircrafts, from electrical cables for transmission of high voltage power to storage vessels for petroleum, and from material of construction for yachts to window frames for high raise buildings. Further, processes like back extrusion to magnetic force forming are expanding the horizon of applications of aluminium for containerization and jacketing. Amenability of its surface to anodizing and powder coating is making the material suitable for decorative applications too. However, there are certain hurdles or barriers which may have to be overcome or circumvented through appropriately prepared 'road maps' for improving the technology of aluminium production, waste utilisation and increasing the use of alumina ceramics.

7.2.2 Recycling Cheaper

Recycled metal requires significantly less amounts of energy for manufacturing of primary aluminium. In fact, the recycling of aluminium scrap requires only 5% of the energy required for primary smelting, which is astoundingly lower, considering that power is such a high cost component in primary metal production. However, one has to be careful to avoid cross contamination. Can revert material be used for use in aerospace sector needs to be addressed by scientists and certification authorities.

7.2.3 Aluminium Consumption

Major aluminium consumption is in power, transportation, consumer durables, packaging and construction sectors. Of these, power is the biggest consumer (44%) followed by infrastructure (17%) and transportation (about 10% to 12%). However, internationally, the pattern of consumption is in favour of transportation, primarily due tolarge-scale aluminium consumption by the aerospace sector.

The EU is likely to introduce stricter CO2 emission requirements for automobiles which will inevitably boost demand for aluminium. Aluminium is lighter than steel, so its wider use in the automotive industry will make cars more efficient. However, a composite sandwich of aluminium with polymers would be a better option and intense research is required to find a suitable material.

7.2.4 Aluminium Alloys

Extensive R&D efforts in alloy development have led to a series of alloys with better properties. Differing thermo-mechanical treatments have added further improvements in properties. As mentioned earlier, aluminium castings find applications in petrol engines and in wheel bases of automobiles. Different kinds of fluxes to remove porosity, gaseous fluxes to remove suspended oxides and novel filter elements have come into existence as a result of applied research. An aluminium beryllium alloy with 38% Be known as Lockalloy has an elastic modulus equivalent to that of steel. This is lighter than aluminium and titanium and at the same time has better ductility than beryllium. It is several times stiffer than aluminium, magnesium or Al based metal matrix composites. This alloy finds use in satellite components, avionics packaging, aircraft/missile systems etc.

Al-Li alloy is a relatively newer development. Considerable interest was shown by aerospace industries all over the world, and Defence Metallurgical Research Laboratory and other academic institutions have carried out considerable developmental work, but due to economic downturn, this alloy has not received as much attention as it deserved. But, things are likely to change and there could be revival of interest in the near future.

Apart from conventional uses of aluminium, newer and innovative research has led to novel applications to provide power and drinking water to remote villages, as reported by Purdue University researchers. The aluminium alloy contains gallium, indium and tin. Immersing the alloy in freshwater or saltwater causes a spontaneous reaction, splitting the water into hydrogen and oxygen molecules. The hydrogen could then be fed to a fuel cell to generate electricity, producing water in the form of steam as a by-product. The steam would kill any bacteria contained in the water, and then it would condense to purified water. The potable water could be produced for about $1 per gallon, and power could be generated for about 35 cents per kilowatt hour of energy. The unit, including the alloy, the reactor and fuel cell, might weigh less than 100 pounds.

7.2.5 Aluminium Powder

Aluminium powder was previously imported for the manufacture of fireworks, rocket propellants and slurry explosives. Arasan Metal Powders near Sivakasi in Tamil Nadu has taken great strides in taking this technology of powder production forward by their own R&D and with assistance from international research centres. They make atomised aluminium powder, aluminium paste and pigment grade powders.

7.2.6 Environmental Concerns

Production of 1 tonne of metal requires 2 tonnes of alumina while production of 1 tonne of alumina requires 2 to 3 tonnes of bauxite. This process leads to the generation of 2 tonnes of red mud, 10 tonnes of fly ash and 21 tonnes of CO2. The environmental problems posed by these wastes are a source of concern to the aluminium industry. It is seen that nearly 40% of fly ash is being used in cement plants and for masonry works. But, application of red mud has not met with much success so far and still remains an area to be tackled. Because of the large demand for power and also the huge requirements of land for dumping red mud, only major players like Hindalco, Nalco and Balco have survived. Vedanta is trying now to come in a big way.

7.2.7 JNARDDC

Jawaharlal Nehru Aluminium Research Development and Design Centre was established by the Department of Mines, Government of India specially to address the problems faced by the aluminium industries. They are developing a technical data bank on laterite and bauxite deposits in the four southern states of India. As a nodal agency for the Asia Pacific Partnership on clean development and climate, JNARDDC has undertaken the project management of bauxite residue, the red mud. The main aim of the project is to reduce energy consumption, protect environment and put in efforts to utilise waste. JNARDDC is also carrying out simulation and computer aided die design for complex extrusion profiles with a view to lowering the metal discards and reducing rejection ratio with consequent improvement in productivity.

It is heartening to note that Asia-Pacific region countries have joined together to pool their expertise to solve some of the problems faced particularly in the energy and environment sector. The flagship projects include research and development, pilot plant studies, demonstration projects, deployment activities and best practice dissemination.

Aluminium production generates large quantities of perflurocarbon (PFC) due to 'anode effects', when the dissolved alumina content in the cell drops too low. As a result the electrolytic bath itself undergoes electrolysis. Reducing the frequency and duration of anode effects not only reduces the green house gas emissions but also improves energy and process efficiency. As a result of this APP partnership programme, the technology and practices for PFC reduction have been implemented in member countries.

There is a strong case for looking at alternate routes for metal production. It is worthwhile to pool expertise in several countries to find the best practices for follow up leading to reduced energy consumption and effective waste management.

7.3 MAGNESIUM

Magnesium is the eighth most abundant element in the earth's crust and its resources are widely spread all around the world. It occurs mostly as carbonates, oxides, sulphates and chlorides generally in combination with other elements. In addition, sea-water is an abundant and a perennial source containing approximately 0.13% of Mg in the form of sulphates, chlorides etc. Despite its wide availability, the metal is expensive due to many complex and energy-intensive processes involved in its extraction.

7.3.1 Uses of Magnesium

Magnesium alloys have a very high strength to weight ratio, an essential requirement for the manufacture of aircraft, space and automotive components. It is worth mentioning that well over 50% of magnesium produced today is utilized exclusively for the manufacture of aluminum alloys for a variety of structural applications. Its use as a nebulizer for the production of spherical graphite iron, as a desulphuriser of iron in steel making, as a reductant in the production of reactive metals such as titanium, zirconium and uranium, for cathodic protection of ship hulls and underground pipelines, etc. are some of the other applications.

7.3.2 Production of Magnesium

Bulk of the magnesium produced in the world today is by one of the following three processes:

- Fused-salt electrolysis of anhydrous/partially dehydrated magnesium chloride (MgCl2651.5H2O) produced from either sea-water or sea-bitterns (a byproduct from the commonsalt industry)

- Ferro-silicon reduction of calcined dolomite at 1100-12000C in nickel-chrome horizontal reactors under vacuum. (Process developed by Pidgeon during 1941-'44)
- "MAGNETHERM" process, an improved version of the Pidgeon process which enables semi-continuous production of the metal in the form of a solidified ingot. (Pidgeon Process, on the other hand, is essentially a batch process producing no more than 22-25kg of metal in the form of a crystalline crown per batch per reactor.*)*

7.25 Yet another process named "The Bolzano Process", a further variant of the Pidgeon process, was developed by SIAM in Italy using internally heated reactors that can produce up to 2000kg of distilled magnesium metal per batch.

7.3.3 Present Status on R &D and Production

NML's Contributions: Development of the Pidgeon process on a laboratory scale using Indian dolomite was started in late 1950s at the National Metallurgical Research Laboratory. Based on the satisfactory results obtained, they designed a 250TPY pilot plant which became operational by 1972. Technology was transferred to M/S. Southern Magnesium and Chemicals Ltd. and a 600TPY plant was set up in Andhra Pradesh. Despite several teething problems, this plant could reach a production of 400TPY by 1990 after incorporating many changes in the retort loading and unloading practices. At that point of time, Nuclear Fuel Complex considered procuring their magnesium requirements from them but the levels of iron and aluminum impurities were above the limits specified. It is unfortunate that this plant had to finally close down because import options became cheaper.

7.3.4 CECRI's Contributions

Around the same time, the Central Electro Chemical Research Laboratory, Karaikudi (CECRI) started an intensive R&D programme on magnesium production technology from sea bitterns by the "Fused Salt Electrolysis" process. CECRI flow-sheet involved purification of the sea-bittern, followed by spray drying to obtain hydrous magnesium chloride. CECRI designed a unique 'Mono-polar Cell', using cylindrical graphite anodes and operated the same successfully for some time. Encouraging results obtained on the lab-scale experiments led them to design a 75TPY capacity pilot plant.

CECRI transferred their technology to Tamil Nadu Magnesium Metal Ltd (TMML), a unit of The Tamil Nadu Industrial development Corporation (TIDCO). A commercial scale plant of 600TPY capacity with sea-bitterns as raw material was set-up by TMML at Valinokkam village near Ramanathapuram. For this plant, CECRI designed a 30KA mono-polar cell based on their earlier experience with the 8KA cell. Very high levels of humidity that prevailed almost throughout the year at this location resulted in rapid pick-up of moisture by the spray dried magnesium chloride which necessitated very frequent replacement of the graphite anodes in the cells. This also led to a very steep increase in specific energy consumption. An expert committee made some valuable suggestions and helped TMML to design a completely leak-proof cell to avoid moisture ingress into the cell during operation and also designed a pilot-plant for converting the hydrous spray-dried magnesium chloride into totally anhydrous magnesium chloride with dry HCl gas in a heated fluidized-bed reactor, a process that has been adopted by Norsk-Hydro in Norway. The HCl vapour coming out of the reactor is re-dried with

Conc.H_2SO_4 and then re-circulated. Unfortunately, by the time this equipment could be fabricated, TIDCO decided to close down the TMML plant due to techno-commercial reasons.

7.3.5 DMRL's Contributions

A program for the development of technology for large scale commercial production of titanium was undertaken by DMRL during early 1980s. Initial attempts were to develop the Kroll Process for the production of titanium sponge in 2000Kg batches. It was realized quite early that economic production of titanium depends to a large extent on the availability of an in-house electrolytic plant for recycling the anhydrous magnesium chloride byproduct from the Kroll Process. Utilizing the experience and expertise developed by CECRI, a 30KA monopolar cell was designed with several improvements for making the cell leaktight. Yet another major improvement attempted was to use molten anhydrous magnesium chloride as the feed material instead of the solid hydrous feed material that CECRI had used in their work. With these improvements the cell life could be prolonged and a specific energy consumption of about 18kWh/kg could be achieved. With a view to further improving the specific energy consumption and increase the space-time yields, DMRL continued their R&D work on the design of multipolar cells for magnesium production. Specific energy consumption in the range of 13-15kWh/kg could be obtained.

Realizing the economic importance of recycling the byproduct magnesium chloride in both titanium and zirconium sponge production plants, a decision has been taken recently to set up two technology demonstration and optimization facilities one at Kerala Minerals and Metals Limited, where very shortly a 500TPY titanium sponge plant, based on the technology developed at DMRL will go into commercial production and the second at the Zirconium Complex at Pazhayakayal, near Tuticorin wherein a 250TPY capacity zirconium sponge plant has recently become operational. The capacity of the Pazhayakayal facility will, however, be expanded to also reprocess the byproduct $MgCl_2$ from NFC's 400TPY capacity zirconium sponge plant at Hyderabad.

It is imperative to develop technologies on a pilot plant scale for the production of anhydrous magnesium chloride from sea-water and byproduct seabitterns. It is necessary to evaluate fused-salt electrolysis of anhydrous magnesium chloride on large industrial scale multipolar cells. It would be good to develop the "Magnetherm" process on a pilot plant scale by reviving the existing facility at NML.

7.4 RARE EARTH ELEMENTS

Rare Earth elements have been in the news because of proposed squeeze by China and consequent rise in prices of these elements. Rare earth metals have proved to be a welcome addition in steel industry in grain refining to impart better properties to steels. They are used in consumer goods industries, petroleum refineries and the automobile sector (catalytic convertors). Wind turbines need praseodymium, neodymium and samarium for their magnets. Lighting industry requires lanthanum, cerium, europium and terbium in phosphors. High temperature superconductors require REs. High temperature coatings require yttria. Erbium is a key element for optical fibre technology. This illustrative list shows that modern technology in India as elsewhere will depend on REs. In India we have the resources of rare earths mainly in the monazite beach sands and this is occurring along with thorium and uranium. Extraction of radioactive free rare earths has thus become a costly proposition. However, BARC had carried out the requisite process know-how for the separation of rare earths and the Indian Rare Earths Ltd., a Dept. of Atomic Energy Undertaking has set up a plant for the production of rare earths.

7.4.1 Indian Production

As is the case in other areas, Chinese have dumped rare earths at a very low cost everywhere and IRE's products could not compete with this, thanks to globalisation. IREL has produced only 35 tonnes in 2010, according to the annual report of DAE. The thought of stockpiling of REs did not occur to anyone earlier. With the Chinese curtailing export by 30% this year, and possible more in later years, developed countries had to fall back on their reserves.

7.4.2 Waste Recycling

Considering the fact that natural resources of rare earths are limited, efforts must be made to extract RE from electronic wastes. Developed countries have already started on this exercise. Concerted efforts from laboratories such as BARC, IMMT, Bhubaneswar and NML, Jamshedpur are needed to develop this recycling technology. IMMT and NML are already executing a joint project on recovery of non-ferrous metals from placer deposits. They should be persuaded to focus on extraction of REs. India must also study the geological formation of rare earth compounds and carry out a detailed exploration in hereto unexplored areas.

7.4.3 Worldwide Requirements of Rare Earths

The current estimate for worldwide requirements of REs by 2014 given below will surely need to be modified. But, new and strategic applications will arise in India. As part of its sustainable and low-carbon growth energy requirements, the country will go in for hybrid and electric vehicles. The batteries used in these vehicles depend critically on REs. The most popular hybrid to-day, Toyota Prius, requires 10-15 kg of lanthanum and 1 kg of neodymium per battery. Terbium and dysprosium are added in smaller quantities to preserve neodymium's magnetic properties at high temperatures.

Rare earths and strong magnets are inseparable. In a recent article in Nature (April 2011), it is stated that the two main problems faced here are magnet strength and cost. While the strength of available magnets doubled every decade or two, it stalled in the 1990s. And in the past two years, the cost of the rare-earth elements that are essential for advanced magnets has shot up. The price of neodymium oxide jumped from US$17 a kilogram to $85 a kilogram in 2010 alone. As mentioned earlier, an electric car carries a few kilograms of rare-earth elements, and a 3-megawatt wind turbine uses about 1.5 tonnes. Demand in the US leapt from 30,000 tonnes in the 1980s to 120,000 tonnes in 2010 (which was met in part by depletion of national stockpiles), and is predicted to hit 200,000 tonnes by 2015, according to Gareth Hatch, founder of the Technology Metals Research consultancy**.**

7.4.4 DMRL'S Contribution

Realising the importance and necessity, DMRL has taken up R&D programmes since 1980s for the indigenous development of rare earth permanent magnets and standardised the powder metallurgy route for production of SmCo5 (17-18 MGOe), SmCo17 (24-26MGOe) and NdFeB (34-36 MGOe) magnets. This home grown technology is exploited to develop specialty magnetic components for several strategic programmes of the departments of Space, Atomic Energy and Defence. DMRL has recently started an R&D programme on SmCo17 magnets having (i) a low (< 100ppm) temperature coefficient of remnance, (ii) higher energy product (28-30 MGOe) AND (iii) high temperature capability (4000C).

7.4.5 Thermax, Pune

Thermax's R&D is focused on waste-to-energy products. Besides the conventional wastetoenergy products such as steam-fired absorption chillers, Thermax is working on hydrogen based heat-pumping systems which are ideal for using waste-heat for comfort cooling. These products are not only green but also disruptive in nature. The heart of any hydrogen based heat pumping system is the alloy that absorbs hydrogen. Hydrogen absorbing alloys such as LaNi5 are ideal for deploying in hydrogen based heat-pumping systems. Known for a long time as the best alloys for hydrogen absorption with appropriate characteristics, the actual deployment of LaNi5 alloys in an industrially viable product is dictated by the availability of rare-earths metals which form a major constituent of the raw material.

7.4.6 Conservation of Rare Earths

This calls for better management of resources. To start with mining activities, wherever possible should be intensified. It also becomes necessary to better manage their consumption. Crucial is to reuse and recycle wherever possible. It pays to recycle, as rare earths in electronic gadgets has risen so much that their concentration in computers is higher than in mines. In this context, innovative technologies need to be encouraged, as shown in the next paragraph.

The same article in Nature talks about 'next-generation' magnets that could solve both problems at once. This is based on nanotechnology. Combining nanoparticles of rare-earth magnets with nanoparticles of cheaper magnetic materials, it is possible to develop super-strong end-products. Governments keen to invest in energy-efficient technology, and scared by a global crunch in the rare-earth market, have started to pay attention to magnetics research. India cannot lack behind in this area.

Permanent magnets get their pulling power from the orbits and spins of unpaired electrons, which tend to align with an external magnetic field and stay that way when that field is taken away. Newer magnetic materials with complex crystalline structure help to keep the spins pointing one way. The dream is to unite the magnetic punch of something like iron–cobalt with the stability of, for example, a NdFeB magnet. That should be possible by combining nanoparticles of the two, packed so closely that neighbouring electrons influence each other and keep their spins aligned. In theory, a nanocomposite could reach an energy product of a whopping 960 kJm^{-3}, with rare earths making up just 5% of its weight, compared with 27% in a normal NdFeB magnet. But making such a composite is extremely difficult. The rare-earth nanoparticles aren't stable as they react with oxygen, which ruins their magnetic properties. One has to think of some innovative ideas to succeed. Rare earths offer enormous challenges to metallurgists and material scientists.

7.5 ELECTRONIC MATERIALS, DEVICES AND INDUSTRY

Presently, India is a small player electronics industry. The global electronics industry is ~ US$1.75 trillion and India currently accounts for about 2.5% of this. As per the Department of

Information Technology (DIT)'s Annual report 2010-11, the demand for electronics hardware in our country is projected to increase from US$ 45 billion in 2009 to US$ 400 billion by 2020. As against this, the production (supply) is projected to grow from US$ 20 billion in 2009 to US$ 104 billion by 2020. It means by 2020 the electronics import bill is estimated to exceed that of oil!

The electronic devices are fabricated using multilayered thin films grown on suitable substrates amongst which silicon is most widely used. The first silicon single crystal boules were made in 1950s and nowadays have gone up to diameters of 300 mm, with a possible enhancement to 450 mm. About 98% of the commercial processing is based on silicon. The silicon technology is well matured and moving towards *22 nm and below* technologies, in accordance with the Moore's Law.

GaAs, InP, Sapphire, SiC, and GaN substrates are strategic and useful for making optoelectronic devices and high-power/high-frequency electronic devices capable of functioning at high temperatures and withstanding high breakdown fields. The combined market size of these substrates is of the order of US$1 billion in 2010 and accounts for < 2% of foundry volume. In the recent years, the major thrust is on *flexible electronics, molecular electronics and nanoelectronics*. R&D's focus is now on new materials (viz., conducting polymers, carbon nanotubes, graphene, nanowires, organic materials, nanomaterials, self-assembled materials, high-k gate dielectrics, high-mobility channel materials, anisotropically conducting interconnect materials), new issues (extreme ultraviolet lithography for the sub-20 nm technology in DRAMs, scaling and abruptness of shallow junctions), novel technologies (integration of III-V devices with CMOS for realizing *system-on-a-chip,* 3D integrated circuits, beyond-CMOS technology) and futuristic devices (multifunctional devices based on convergent technologies, flash memory, quantum computers, low-dimensional electronic devices such as single photon sources, single electron devices, spin devices).

Our country is importing single crystal substrates, all the high purity materials and electronic grade chemicals used for processing, epitaxial growth/device processing equipments, packaging & testing equipments and several technologies of consumer electronics and IT products. In this context, our infrastructure base is negligibly small and even a single commercial silicon foundry does not exist! Our electronic industry today is where China was in early 1990s! Notably, Taiwan holds 65% of the world silicon foundry revenue.

In strategic electronic materials and devices, our country achieved important milestones due to the policy initiatives aimed at self-reliance. The Semiconductor Complex Limited (SCL) and the Society for Integrated Circuit Technology and Applied Research (SITAR) are engaged in the development of Application-Specific Integrated Circuits (ASICs) based on CMOS technologies. The Gallium Arsenide Enabling Technology Centre (GAETEC) is an integrated GaAs foundry known for the *space qualified* MMIC technologies. DRDO, in particular Solid State Physics Laboratory (SSPL), has established the important III-V and II-VI epitaxial thin film technologies, GaAs MESFET/HEMT technology for microwave frequencies up to 40 GHz, and launched the GaN HEMTs program. Currently, there are plans to upgrade GAETEC and the existing MEMS facilities, and to set up a Gallium Nitride foundry. SSPL is also working on silicon based MEMS technology development and a foundry is being established at SITAR. ISRO has developed several types of electro-optical sensors for satellites and launch vehicles. Among the public sector enterprises, Bharat Electronics Limited (BEL) and Electronics

Corporation of India Limited (ECIL) are playing major roles in the production of systems for defence, space, nuclear, civil aviation, information & broadcasting and telecommunications.

By recognizing the importance of the electronic materials, devices and industry, Government of India had launched several policies, such as Microelectronics Development Programme in 1980s, New Industrial Policy 1991, and New Telecom Policy. Some outcomes are listed below:

(a) Creation of electronic hardware parks and special economic zones which attracted several multinational companies. However, the investments are mostly confined to the consumer electronics/IT hardware assembling, industrial, automotive and medical electronics.

(b) The government's measures to promote semiconductor foundry in the country did not attract the big market players. For example, the governmentbacked *'Hyderabad fabcity'* project (30,000-wafer processing capacity per month involving US$3 billion investment), has not progressed well, although the MOU was signed in 2007.

(c) Public-funded programs have been initiated for developing core R&D capabilities, technologies and trained manpower in the country. The recent initiatives are on nanostructured materials, wide band-gap semiconductor devices, non-silicon based device technologies, photovoltaics, information storage, energy storage, phosphors, chip components, flexible electronics, sensors, device packaging, MEMS based sensors and actuators, optically active polymers etc. R&D infrastructure has been created in selected research centers and academic institutes (viz., IITs, IISc, TIFR, DST, DIT, CSIR & DRDO laboratories, SAMMER, C-MET and other premier universities in the country) for the epitaxial growth of II-VI/III-V devices, SixGe1-x devices, e-beam lithography processing and ion-implantation reactors.

(d) Announcement of the Draft National Policy on Electronics 2011, with key points: (i) setting up of 200 electronic manufacturing clusters with worldclass infrastructure and building on the emerging chip design and embedded software industry to achieve global leadership and a turnover of US$55 billion by 2020, and (ii) establishing the National Electronic Mission aiming at promoting *'Brand India'* in Electronics (Indian Economic Survey 2011-12).

Indian electronics sector is lagging much behind our neighbours and we do not have high impact IPRs/products/technologies in this important arena. Even in high-technology areas, we have not made any India-made world-class product. It is high time to recognize the major concern that our electronics import bill is likely to outweigh oil bill by 2020, if corrective measures are not taken.

7.6 MINERAL EXPLORATION

Minerals are precious natural resources of any country—nonrenewable in nature and limited in quantity. In our country, the per capita consumption of most minerals like copper, lead, zinc, aluminum and related products, like steel, fertilizers, etc. is one of the lowest. The demand for various metals and minerals will grow 4-5 times over the next 15 years. With the existing mineral potential in India, the current contribution of the mining sector in the GDP is

2.1%. The mining sector needs to play a major role if India has to realize the potential growth of 9% per annum in the coming years. The importance of the sector in the growth of GDP in mineral rich countries indicates the ample opportunities that are available for India on account of its vast mineral potential but insufficient exploration. Considering the fact that it takes 10-15 years of gestation time to convert a mineral discovery into a producing mine, more intensified exploration activity is the dire necessity of the day.

India has a favourable geological milieu and is well endowed 94 with mineral resources which are yet to be fully explored, assessed and exploited because of non-adoption of advanced techniques. Most of the exploration activities in the country are of conventional type (based mostly on geological data) with restricted input from geochemistry, geophysics and remote sensing. Geologically, India has a tremendous potential for targeting deep-seated and concealed mineral deposits.

The Peninsular region is the most important domain so far as mineral resources are concerned. Metallogenic provinces as well as various mineral deposits in India are mainly concentrated in the peninsular region. The Phanerozoic and Tertiary sequences contain coal and lignite. The Holocene and Quaternary sediments have presence/concentration of gold, tin, diamond, etc. in riverine placers and monazite, ilmenite, rutile, etc. in beach placers.

7.6.1 Status of Mineral Deposits in India

GSI, MECL and State DGMS, over the years have developed core competency in systematic geological mapping and mineral exploration by following the traditional and conventional method. Near exhaustion of surface and shallow surface deposits stresses on the need for probing deep seated mineral deposits with infusion of state of the art equipments and machineries by the exploration agencies. In this era of mobile mapping resorted to elsewhere in other Geological Surveys, GSI is carrying out mapping with Brunton Compass. There is an absence of remote sensing study on lineament for structurally controlled epigenetic mineral deposits.

Inadequacy of latest analytical instruments with lower detection limits has hampered accurate analysis of geochemical samples for fruitful interpretation of anomaly zones. There is a lack of applicability of geochemical surveys particularly in collection of gas (nano-gas collection) for identification of sulphide deposits and energy resources.

In deposit modelling, GSI has to start application of computer based multivariate statistical analyses, interpretation based on multi-thematic and multidimensional modelling in order to establish characteristic inter-relationships of various parameters that lead to mineral modelling. Such modelling will effectively prognosticate the concealed/ deep seated deposits. In baseline geoscience data generation, GSI is yet to apply methodologies such as hyperspectral remote sensing and geomorphological mapping for prognostication and identification of mineralized zones.

Airborne magnetic surveys are effective in delineating major structures which may control the locations of epithermal gold deposits. Radiometric surveys may detect potassium enrichment accompanying this alteration. Filtering and image-processing techniques are particularly useful in enhancing magnetic and radiometric data to reveal subtle structures and alteration systems. Airborne Surveys completed so far show variations in scale of data collection.

Mineral	**Abundant**	**Adequate**	**Deficient**	**Scarce**
Metallic minerals (ferrous)	Iron Ore	Chromite (Metallic) Mangnese	Chromite (Refatory)	Nickel Tungsten Cobalt Molybdenum
Metallic minerals (non ferrous)	Bauxite (metallurgical)	Zinc	Bauxite (chemical grade), Copper, lead	Antimony Gold PGE
Industrial Minerals	Dolomite. Gypsum, Limestone, Mica	Graphite	Aspirite, Rock Phosphate, Kyanite	Sulphur Potash
Precious Stone				Diamond Emerald Sapphire Ruby

With the development of several sophisticated geophysical ground survey instruments and improved data processing & interpretation software, geophysical investigation techniques need to be modernized at par with the latest global trends. Some of the surveys such as magnetotellurics (MT), borehole resistivity tomography and borehole gravity and spectral IP surveys are not yet adopted by GSI.

In this context, it is appropriate to quote from 'Mining Industry in India' published by India Infrastructure Research, New Delhi. "The mineral potential in India has not been explored fully due to low spending in exploration activities. According to Global Consulting firm McKinsey, the current exploration spending in India is US$ 15 per sq. km as compared to US$ 124 per sq km in Australia and US$ 118 per sq. km in Canada. India till date has explored less than 10% of its mineral resources as against almost 100% geophysical and geochemical surveys in countries such as Australia, There are thus ample opportunities for mining exploration and development companies in India and abroad., Potential areas of exploration thrust include gold, diamond, copper, lead, nickel, cobalt, molybdenum, lithium, silver, platinum group of metals, rare earths, rock phosphate etc."

A viable and sustainable exploration strategy should include:

- Adaptation of the state-of-art technology to explore deep seated/concealed deposits.
- Intensive search for new mineral findings based on baseline data generation by GSI and other agencies. Complete NGCM and National Aeromagnatics and Hyper Spectral Mapping of OGP by end of XIIth Plan and rest of the country by end of XIIIth Plan.
- Intensive search on National priority for minerals in which the country is deficient or scarce.

- The strategy requires application of different advance techniques for regional and detailed exploration. The technological gaps are to be met through acquiring state of the art technology and equipments and IT applications.

To achieve the goals of large scale prospecting and optimal mining, large investments will be required together with the latest technologies in prospecting and mining. To enable the use of state-of-the-art exploration techniques, scientific mining and optimal use of minerals through ore dressing and beneficiation technologies, it is necessary not only to promote research and development in minerals but to simultaneously establish appropriate educational and training facilities for human resources development to meet the manpower requirements of the mineral industry.

8. SUCCESSES, GAPS AND RECOMMENDATIONS

8.1 SUCCESSES

The committee visited as many establishments as possible. It had also discussed with scientists who had held top positions in the Government. While elaborating the works of the various establishments in the earlier chapters, the successes have been elaborated, while gaps have been noted in passing. However, it was felt that it would be good to summarise in a few paragraphs, the significant achievements before proceeding further.

The general opinion of the committee, after visiting with various establishments and holding discussions with several technocrats, is that if the objectives and deliverables are clearly spelt out, the outcomes have been commensurate with the effort and money spent. The country has been exploring an open policy towards R&D and allowed enough freedom to the various organizations to choose their methodology to be followed. The inputs as well as the outputs were varied. Some excelled, while others did not. Wherever government aided institutions were concerned, often one heard about cost and time overruns. But, a serious analysis has not been carried out to find out the causes for these delays. It is always not lack of knowledge or technology. Given the global competitive environment, the country with all its ups and downs, has today attained 4th position in crude steel production in the world, It is the largest producer of sponge iron spite of belated start. It is also the fifth largest producer of aluminium and it exports even copper products in spite of having inadequate mineral resources. India makes its nuclear fuels and missiles. On the other hand the country imports practically all its requirements of tool steels and even the shaving grade steels. It attempted making CRGO steels long ago, but it gave up; Because of inadequate stress on mineral exploration and using outdated techniques it lacked in finding enough sources for rare earths and energy critical elements. Some of these gaps are not necessarily due to technological reasons, but economic or geographical factors could also be attributed. There is however a great need for a critical review to establish the basic causes and to suggest remedies.

Another fact that has been brought to our notice is that while our labour is chaeap, we are not able to compete in international markets, especially against China. Today apart from science and technology, the entire ecosystem related to productivity, availability of funds or land, cost of power and a myriad other external factors contribute to the total cost of the final product. It is for these reasons the country lagged behind in the production of doped tungsten for use as filaments in incandescent bulbs or nickel free heating elements, in spite of making an early start. When we compare these with the Chinese situation, we find that they have single mindedly pursued the objective of achieving excellence in any field that they have chosen to work on. The technological approach they have adopted is worth examining. Taking steel as an example, they started with what is called ‘basic research on new generation of steels’ in 1998.They demonstrated that in low carbon low alloy steels, through grain refinement, homogenisation and purification, the yield strength can be increased from 200 to 400 MPa and then from 400 to 800 MPa and the ultimate tensile strength from 800 to 1200 or even up to 1500 MPa. Likewise their ‘basic research on alumminum’ achieved the breakthrough of reduced energy consumption after ‘de-siliconisation’ of the bauxite ore by flotation. These are a couple of examples where focused research has yielded invaluable results. We are not decrying our efforts, because we also have some success stories, but that number has to grow much more to get the desired benefits for our growth in GDP. We shall elaborate these in the following paragraphs.

8.1.1 Nuclear Metallurgy

R&D in nuclear metallurgy has been a phenomenal success. Whether it is making metallic uranium fuel for our research reactors at BARC or making the uranium oxide fuel bundles for the Pressurised Heavy Water Reactors (PHWR) at the Nuclear Fuel Complex, the DAE can be rightly proud of their achievements. This was possible because of the extensive R&D carried out in the extraction, purification, melting and consolidation of nuclear metals like uranium, thorium, zirconium etc. NFC is the only integrated fuel manufacturing facility for nuclear power reactors in the world and it is heartening to note that it has produced over 600 tonnes of fuel last year. The R&D work carried out at BARC has made it possible for the NFC in production and supply of large diameter and thin wall seamless tubes of zirconium alloys in long lengths for the nuclear power reactors. This has also helped in supply of stainless steel and titanium alloys for several applications. It is also to be noted that the flow sheet for the development and setting up of a plant for production of beryllium metal and its alloys, including supply of finished components for the Indian Space Research programmes was successfully carried out at BARC. Successful R&D has also lead to the production and supply of requisite quality components such as boron carbide control rod pins and thoria loaded rods for nuclear reactors. Nuclear programmes require stringent quality control measures and various non-destructive evaluation (NDE) and non-destructive testing (NDT) methods required at different stages of production of diverse components have been successfully developed at BARC. This culture of adhering to strict quality control has benefited different public and private sector agencies in the manufacture and supply of critical components and systems to their customers. Another off-shoot of the work at NFC is the development of high purity materials like gallium, indium, tellurium, gold etc. This has helped in setting up the production facility by the Department of Electronics.

All the above achievements of the DAE may be traced back to the vision of Dr. Bhabha, who had a clear idea of what India should do in the nuclear field. He could assemble competent people whom he believed would deliver the goods. And they did deliver. He also knew that any new organisation could survive only with proper input of trained manpower and with that in view, he started the training school programme, which is still running for over 5 decades and churning out every year over 100 graduates trained in nuclear science and engineering. To keep the scientists happy and reward them for their excellent work, he had adopted flexible complimenting policy, whereby posts could be upgraded to accommodate deserving scientists in higher pay scales. This helped to retain trained manpower. He could do all the above because of the political support that he got from Nehru as the Prime Minister, under whose charge the DAE functioned. Similar was the case with the Department of Space under the leadership of Vikram Sarabhai and later on under the stewardship of Satish Dhawan. But for their imagination and initiative, the DOS would not have achieved the successes that one witnesses today.

8.1.2 Metallurgy in DRDO

Defence metallurgical R&D had not lagged behind. As mentioned earlier in the report, considerable expertise had gone in developing the brakepads for all our defence and civilian aircrafts. Based on the work carried out at DMRL, HAL has put into production all the different kinds of brakepads required for various aircrafts. This is a notable achievement and well recognised. Investment casting is an intricate area. Complications get added up when turbine blades are to be made for jet engines, where these blades operate at high temperatures (almost near the melting point) and high speeds. Incorporation of serpentine cooling passages in the blade to keep it cool under operating conditions is still more complicated as it requires a special ceramic core. Maintaining the tolerances and strengths in thin sections of turbine blades for aerogas turbine jet engines requires a high order of technology. Equally critical is to develop directionally solidified grain structure or developing single crystal blades. All these have been engineered at DMRL and blades have been supplied for the Kaveri engine under development at the Gas Turbine Research Establishment (GTRE). Technology transfer to HAL has also been carried out. This technology would be very useful for the super critical and ultra super critical power plants under consideration by BHEL. Development of special cost effective hull steels for naval vessels has been perfected and tonnage quantities of steel have been supplied to the shipyards for use in Indian Naval vessels. Armed forces are equally happy with the armour development work. Defence metallurgists can certainly be proud of their achievements.

While mentioning about the success stories of DMRL, it would not be out of place to mention that the DRDO had a different origin as compared to that of DAE or DOS. Even before independence, the British have established directorates and inspectorates of metals and materials for quality control and production of small components required for maintenance purposes. Nehru sought the assistance of PMS Blackett to help establishing the Defence research activities in the country and based on his advice, created the Defence Science Organisation by amalgamating all the existing units with diverse qualities. Prof. DS Kothari at the helm of affairs could only initiate small scale activities. DMRL itself was an outcome of merger of a few inspectorates. Another problem that DRDO faced was with respect to recruitment, which was carried out by UPSC, where the Directors did not have much of a choice in assessing the suitability of persons recruited for a particular job. In addition, promotions were vacancy based. Thus, frustration set in among competent workers in not getting proper recognition for their work output. Only when the Government introduced a uniform policy for all the scientific departments, things got improved. DRDO also was permitted to have its own recruitment and assessment centre. Another aspect that is to be mentioned is that the DRDO in general did not develop a research culture. It was tending more towards development activities. In spite of loss of considerable time in the earlier days in rectifying some of these ills, DMRL has come out with flying colours.

8.1.3 CSIR Laboratories

Likewise, contributions of the National Metallurgical Laboratory in the mineral beneficiation sector have been very significant. The pilot plant established for this purpose was extensively used for the analysis of iron ores and lime stones used by TISCO from all their mines. Hindustan Steels Limited also utilised this facility for all their plants. Mined copper ores and phosphate deposits also underwent evaluation at this pilot plant. The statement of Sir Charles Goodeve, Director, BISRA, "I had not yet seen any pilot plant that can stand above the pilot plants in operation at NML" speaks volume about the mineral beneficiation activity at NML. NML had also been the first in bringing in newer concepts. Steel by oxygen blowing in the LD converter, development of nickel free austenitic stainless steels, India's first pilot scale sponge iron processes, and development of aluminium alloy conductors are some of the note worthy contributions.

Central Electro-Chemical Research Institute has carved a name for itself in corrosion evaluation and protection techniques. Their technique for assessing the corrosion of steel reinforcements in concretes and in bridges in particular is well received and adopted throughout the country. Their work on electrometallurgy for the production of aluminium, magnesium etc are also well received.

8.1.4 Private Sector

TRDDC, a unit of TCS in the private sector has done considerable work in utilising their domain expertise with modelling and simulation studies to evaluate the various processes, from the point of view of reducing energy consumption and increasing productivity. The other successes have been listed earlier in the report. It is also to reckon that most metallurgical products are made use of in shapes of castings, forgings, tubes or machined parts which are predominantly manufactured by private sector. Consequently a fairly large amount of R & D efforts are contributed by the private sector, which remain proprietary. The technology of radiography, ultrasonics or eddy current have contributed largely to make the Indian products of world class, which have been assimilated by the Indian technologists very well, though the equipment used for this purposes are largely imported.

8.2 GAPS

8.2.1 Mineral Exploration

During our discussions with P. Rama Rao, he indicated that a major gap has been in neglecting exploration for new resources in the country. As a result, we now face the problem of raw material shortage. According to a US report, the rate of growth of commodity materials in China is ahead by 15 years as compared to India. Reaching the level of China may be difficult now, because not enough attention was paid to exploration. 25 years back, India, Brazil and Australia were top ranking in iron ore resources. China had 49 billion tonnes of ore as compared to India which had only 23 billion tonnes. According to a report by Kirit Parikh, 45% of coal bearing resources in our country is yet to be surveyed. Thus, there is an urgent need for an integrated approach starting from mineral exploration to ending up in finished products. As mentioned earlier, there is an urgent need to modernise the methodology adopted by GSI.

8.2.2 Energy Materials

Rama Rao also mentioned that there should be an intensified activity in the area of energy materials, such as coal, oil, gas and nuclear materials such as uranium, in addition to rare earth elements. Consequent to China imposing restrictions on supply of rare earth elements, every developing country is drawing up a road map to address the status of energy critical elements. India also needs to do the same. It is also important to look into off-shore wind mill farms. Elsewhere, there are such wind mills producing 6 to 10 MW of electric power per mill. In this context, he mentioned that carbon fibre production should be taken up on a war-footing basis. He stated that a single large aircraft that Boeing is building would need about 30 tonnes of carbon fibre and the entire production of carbon fibre in Japan of the order of 60,000 to 70,000 tonnes would just meet only Boeing's demands. This is excluding the needs of strategic/economic needs of the country.

8.2.3 Electronic Materials

VS Arunachalam mentioned that R&D in electronic materials has been a neglected area in the country. He mentioned his own efforts in setting up the Gallium Arsenide Enabling Technology Centre (GAETEC). While small countries in East Asia could set up chip fabrication facilities, India neglected this except for the Semiconductor Complex. If we had excelled in this, this could have been a source of strength for our chip designers, apart from bringing in adequate resources as a service facility. He talked about solar photovoltaics and its market share in clean energy. While amorphous silicon was the preferred material earlier, thin films of copper-indium selenide and cadmium telluride are being increasingly used. Thus, it is necessary to look at energy critical elements seriously, he added.

8.2.4 Micro and Nano Technology

According to V. K. Aatre, we have no problems in dealing with conventional technologies, but, when it comes to advanced technologies, we are nowhere near success. He was citing the examples of smart materials and Micro Electro Mechanical Systems (MEMS). When he attended a meeting on MEMS in China in 2005, he found India was ahead of China, but, today China is at least 5 years ahead of us. They have produced several devices and optimised processes. On the contrary we have only produced research publications. The Government has allocated Rs. 1000 crores for nanosciences research, but, there is a clear bifurcation between science and technology in our country. He said that researchers are trying to change their attitudes and produce devices, but industries are not coming forward to accept these novel initiatives. They take a negative view of hybrid technology in India. A drastic change in attitude is required for R&D to succeed, he said.

8.3 RECOMMENDATIONS

Having brought out some points regarding successes and gaps in our R&D, a few suggestions are made here.

8.3.1 With regards to academic institutions

* Both basic research and applied research need to be carried out

* Proper recognition be given for applied research that leads to innovative solutions to development of newer processes and cost effective materials with better properties and longer life.

* Set up technology incubation centres to assist the researchers to translate their ideas into successful end products

* Ultimate goal of large scale funding is to realise tangible products that are identified

* Documentation of know-how to be given serious consideration

* Process metallurgy as a discipline is becoming extinct and needs to be addressed forthwith.

8.3.2 Regarding in–house Government R&D establishments

*****DAE and DOS to think about adopting project mode of working and monitoring, that DRDO Adopts

8.3.3 CSIR laboratories

***** Bench scale studies with promising results need to be taken up to pilot scale work

* Interdisciplinary/Multi-disciplinary laboratories (NIIST and AMPRI) need better focus in the metallurgy/materials front

* Laboratories should be aware of strategic materials requirements of the country

* Cost effective recycling studies need attention

* More of modelling and simulation studies desirable

8.3.4 Public Sector Undertakings

***** Greater association of public sectors with major R&D labs would be beneficial

8.3.5 General Comments

***** Market survey needs to be carried out before taking up major developmental studies

* Necessary to prepare a list of strategic materials requirement for the country and prepare a road map for meeting the targets

* Batteries and energy storage devices need greater attention

* When technologies are transferred, necessary to collaborate and cooperate with the agencies concerned to achieve the desired results in the shortest possible time frame

* Expertise and skill sets available in various establishments in different fields to be made full use by other agencies

* Movement of senior scientists to other establishments may be beneficial

* Micro miniaturisation taking place in the area of sensors to be extended to metallurgical industries also

* Government to give soft loans for setting up manufacturing particularly for critical materials

* Technological innovation in mining sector a necessity

* Mineral exploration technology to be modernised

* Novel extraction processes for getting by products without enormous production of base metal needs attention

* An authentic listing of products and technologies presently being imported, made available at one place will focus attention on directions to concentrate.. These are some of the suggestions that came to the fore after discussions with several people and agencies. It is hoped at least some of them would be implemented.

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