Technology Commercialization as Driver for Economic & Social Development – Indian Experience

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Abstract

Technology development and commercialization are important activities for enhanced productivity, growth and international competitiveness of the industry. Often Indian policies concerning Science & Technology (S&T) or Research & Development (R&D) discuss only the input parameters like expenditure on S&T or R&D in terms of GDP or some output parameters like papers published or patents filed. However, a key element for measuring the impact in economic or social terms should be the extent of commercialization of newer technologies. The article provides an insight to technology commercialization initiatives especially among the Indian small & medium enterprises (SMEs). The article attempts to delineate various technology development & commercialization experiences as evidenced in TIFAC programmes. With the objectives of promoting key technologies in the country and towards facilitating SME-led technology development efforts in early stages of the innovation chain, TIFAC had initiated a few programmes of national importance on ***home grown technology, advanced composites, bioprocess & bioproducts*** etc for promoting public-private partnership for generating market-driven projects with potential applications in areas such as ***chemical, bio-medical, pharma & nutraceuticals, transportation, tourism*** etc. The article brings out a few case-studies of successful technology development projects with significant and measurable impact on partnering industries by improving their turnover and profitability.

Introduction

The process of technology commercialization is culmination of a dynamic network of agencies interacting in a specific economic/industrial area under an institutional infrastructure and involved in the generation, utilization and diffusion of technology. This paper attempts to provide a few examples from the large number of successful technology commercialization projects promoted by TIFAC from mid-1990s. These projects were mostly implemented through Small and Medium Enterprises (SMEs). However, several stake holders and knowledge providers were brought together by TIFAC. The involvement and extent of networking with the stakeholders depends on the sectors to which the products belong, their technology status in the country, market potential, regulatory mechanisms (including standards, certification needs etc.). Certain experiences were also a pointer for expertise available with the established industry sector helping in commercialization of novel technologies by SMEs.

The technology commercialization, the key driver for growth and profitability in an economy, is the ultimate outcome of several complexities. Effective contributions from various stakeholders namely, industry toying with the technology, extraneous sources for knowledge support, new resources as raw materials, novel methods of production, inspection & certification needs and most importantly, involvement of the users and/or the market feedback are critical components for the successful commercialization of a technology. However, the problems become acute in rapidly changing technological and economic environment. Many innovations that do not succeed are often potentially good ideas but liable to be rejected due to budgetary constraints, lack of available skills or poor fit with current goals of the organization. Hence, failures should be identified and screened out as early in the process as possible.

The small & medium enterprises (SMEs) play a significant role in Indian industry. Today some SMEs are investing in R&D in order to compete globally. SMEs enjoy more flexibility, better ability to adapt themselves and they are better placed to develop and implement new ideas. Their simple organizational structure, low risk and higher receptivity are certain merits favouring them to be innovative. SMEs help in the socio-economic advancement in the developing country while further facilitating the achievement and streamlining the objectives relating to employment generation, low investment and significant export earnings with a capacity to develop appropriate indigenous technologies and high contribution to domestic production. In India, they constitute over 26 million enterprises and employ nearly 60 million people, next only to agriculture. Nearly 40% of total exports and 45% of the industrial production in India are contributed by SMEs. It is estimated that SMEs account for 90% of industrial units in India and 40% of value addition in the manufacturing sector[1]. Technology development and commercialization have been key to their survival and success though access to and availability of technologies by Indian SMEs from publicly funded R&D/S&T institutions, academia or large-scale industries, has been quite limited[2]. Finance has been recognized as an important driver for innovation process for the SMEs and the cost of funds should be attractive enough for them for investing in projects involving technological risks. They are often beset by multi-faceted problems, which include the following:

- inadequate infrastructure facilities
- availability of skilled labour
- access barrier for the market
- in-house technical & managerial capabilities
- long product development cycle
- extraneous knowledge support
- lack of adherence to standards & certification
- internal resistance to change….
- cheaply available foreign imports
- longer payment realization cycle from clients

In order to avoid such problems and effect a seamless technology development process for subsequent commercialization, the requirement of a well-defined strategy had strongly been felt by the Government of India. Over five decades of planned development have elevated India to a stage, where the country demonstrates some remarkable strength in modern technologies for achieving development goals. There exists a chain of national laboratories, specialized R&D agencies in defence, atomic energy & space, Indian Institutes of Technology (IITs), National Institutes of Technology (NITs), universities & other academic institutions of higher learning, which are capable of providing world-class expertise, technically trained manpower and technology support to the industry. The institutes have been pursuing application-oriented research, which led to amassing an excellent knowledge pool. However, the extent of knowledge flow from such centres of excellence to the industry for its actual exploitation for the prototype development and reaching out to market has been rather limited. Various policy interventions were directed and organizational structures along with the fiscal incentives were designed by the Government from time to time to bridge the gap[3]. However, unless each element of this complex process is clearly understood and attended to, the degree of success becomes very limited. This explains lack of accessibility and transfer of knowledge to SMEs as noted in the NISTADS report referred above.

2.0 Technology Commercialization – Approaches Based On Public-Private Partnership

Keeping in view of its critical need, ***Technology Information, Forecasting and Assessment Council (TIFAC)*** had conceptualized a unique knowledge networking mechanism in India for facilitating novel technology commercialization for the key sectors of economy. TIFAC was established in 1988 as an autonomous organization under the aegis of Department of Science & Technology, Government of India. Towards facilitating SME-led technology development efforts in early stages of the innovation chain, since 1992 TIFAC had embarked upon a few programmes of national importance on ***home-grown technology, advanced composites, bioprocess & bioproducts*** etc. The programmes were conceptualized with the basic premise of promoting ***public-private partnership*** for generating market-driven projects with potential applications in areas such as ***chemical, electronics, biotechnology & bio-medical, pharma & nutraceuticals, transportation, tourism*** etc.

The policies in TIFAC programmes were oriented for ensuring an active involvement of the industry in the entire process of technology development. This complex process adopted by TIFAC had been studied and referred to as ***'Technology Intermediation'*** in a book[4]. Based on the world experiences, a few successful experiences and large number of failures in India, it was realized at the outset by TIFAC that successful technology development model should be **industry centric**, keeping the industry at the heart of all the actions namely, product conceptualization & design, assets creation for prototype development & in-house testing and finally large-scale replication for wider induction. This called for extraneous knowledge support from the leading centres of excellence across the country and brought the industries closer for technology absorption, development & dissemination. The knowledge partner provided design support to the industry in terms of engineering drawings, advice on raw material selection, fabrication process, testing etc. for successful development of the prototype. The programme involved faculty members from the renowned institutes such as IITs and scientists from national labs.

In order to reduce technology development cycle, the programmes involved key persons from the user groups, certifying agencies etc. in the project monitoring mechanism for effective project management, technology support, product evaluation etc. The project review team provided a right mix of expertise on design, process, machine/equipment, testing & quality assurance. Such user driven project monitoring has been the cornerstone of project management initiatives by TIFAC and it has greatly helped in improving the market reach of products and their commercialization in the shortest possible time. Thus, the projects were more focused with clear time bound objectives and most of them were completed with successful product development and deployment.

With the modified priorities in the programmes, the financial support was extended directly by TIFAC to the industries on repayable basis. The major thrust was on generating market-driven projects with potential applications in sectors such as railways, telecom, building & construction, healthcare, bio-medical etc. With this change in focus, industry's participation was intensified and many new projects with novel applications were initiated.

TIFAC generally adopted a two-pronged approach for such technology innovation programmes. The tri-partite arrangement involved the knowledge partner (usually public funded research labs/academic institution), the industry partner implementing the project and TIFAC as the facilitator by providing soft development finances. In some cases for SMEs with strong in-house knowledge base, a bi-partite arrangement was worked out between the industry and TIFAC for technology development & demonstration projects[4].

With the financial support from TIFAC, the industries had set up advanced fabrication system in-house and testing & quality control facilities for manufacturing products meeting the international standards & quality norms. This greatly contributed to the capability improvement for the industry and generated confidence among the users in product acceptance. In some cases, the industry partners have achieved strong and profitable growth (+10% to 30% of sales increase per year generating 10% to 40% of return on capital employed).

3.0 Home Grown Technology Programme

The programme on **Home Grown Technology (HGT)** (1992-2005) was initiated by TIFAC with a view to support the Indian industry to achieve competitive strength through technological innovation. HGT encompassed a diverse set of projects on technology development towards commercialization. Many of the projects involved technology transfer, wherein some of the cases, TIFAC had funded the R&D institutions (*technology generator*), while in other cases the SMEs (*technology recipient*) were funded. Another group of projects involved technology development through in-house efforts by SMEs, followed by commercialization. While the financial and intellectual investments were moderate in quantum, substantial impact in terms of technology deployment, users' acceptance and export market were achieved. The total contribution to the national exchequer by excise duties, income & sales tax and foreign currency earnings were substantially higher than the meager financial support extended for technology development. HGT was regarded as a highly successful attempt for technology development & absorption towards its conversion into marketable processes and products.

A recent programme review report[5] by a panel of experts on comprehensive assessment of HGT programme provides important insight regarding the process of funding, direct taxes paid by the companies (in addition to their return of the financial assistance received from TIFAC) and their production volumes, which are a rough indicator of employment generated. The aforesaid report also points out the need for more liberal approach to the enterprises, which face several problems in the early commercialization phase. Higher success rates along with improved socio-economic benefits could be ensured by careful and sympathetic handling of the enterprises. The report gives recommendation in this direction.

The report mentions the following:

Quote

- The HGT programme (1992-2005) was the first of its kind for supporting the technology development in the R&D domain and was a pilot programme and a precursor for other programmes that had come up in later years.

- 71% projects had industry involvement and 30% of them were start-up companies. 80% of the projects achieved objectives and 27% projects had good impact on the recipient in terms of technology capability.

- A sample study of 15 successful projects (who fully returned the financial assistance) reported a turnover of Rs.7.88 crores during 1998-2011. Contribution to exchequer through taxes amounted to Rs.80 crores which was more than the entire programme outlay. This also resulted in significant employment generation.

- HGT experience of funding public institutions was not encouraging and most of their projects failed at the commercial level and returns were poor. Routing funds through industries with professional and stringent monitoring would have yielded better results.

Unquote

Total number of HGT projects that were finally funded after series of screening and necessary compliance with the procedural requirements of TIFAC had been **79.** Of this **27%** were fully commercially successful with significant impact on the recipient. On the overall, **80%** of the projects were successful but not fully commercialized. Out of the entire spectrum of projects, two case-studies on development of products belonging to diverse fields are described in the following sections:

3.1 Isolation & characterization of probiotics and formulation of synbiotic preparations

Pro (for) biotics (life) are defined as live microorganisms, when taken in sufficient amount orally, they benefit the host gut environment by improving its microbial balance. Changing food habits, chronic gastro-intestinal disorder, stress, prolonged antibiotic treatment, environmental factors lead to disturbance or even loss of natural microbial gut flora and force a need to take probiotic therapy. The largest group of probiotic bacteria in the intestine happens to be lactic acid bacteria, of which Lactobacillus acidophilus is found in yogurt with live cultures. In humans, probiotic products impart several health benefits, which include enhancing the immune system, and reducing intestinal pathogens, by secreting anti-microbial chemicals and by inhibiting their adhesion to the intestinal lining. This results in an improvement of intestinal function by normalizing the microbial flora, thereby, reducing constipation and improving intestinal mobility, treatment of diarrhea, improved nutrition through the enhanced digestion of vitamins, minerals and amino acids and their absorption through the intestinal walls. The activity of the probiotics can be increased appreciably when they are administered in combination with other supplements and additives. These formulations of probiotics with other non-digestible food supplements (pre-biotics) are called as synbiotics.

The titled project was launched in July 2003 in partnership with ***M/s Hi-Tech Bio Laboratories, Pune*** to develop novel, host specific probiotic and synbiotic formulation in five different areas viz. human healthcare, veterinary, poultry, aquaculture and agriculture. The project was completed with the following milestone achievements :

- Pure cultures of probiotic bacteria originated from normal flora for human, poultry, cattles that exhibit all the required characters for a good probiotic organism.
- Probiotic formulation - large-scale biomass production of a characterized probiotic organism in dry form/ powder, which exhibit all the required characteristics of a good probiotic organism
- Synbiotic formulation; an effective combination of probiotic organisms originated from normal flora of a host and prebiotic preparation of medicinal plants prepared as per Ayurveda.

In humans, probiotics can be used for gastric and intestinal illness, alcoholic liver disease, to enhance both specific and non-specific immune responses, to provide relief for lactose intolerance and to reduce bouts of diarrhea, for blood pressure control, reduction in total cholesterol and triglycerides. They can reduce cancer risk, may down-regulate the hypersensitivity reactions with food allergies and reduce allergy.

In cattle and poultry, probiotics can have growth promotion effect, give better milk yield and fat content, impart healthy skin and improved hair coat etc. In aquaculture, it makes the aquatic environment clean and safe, makes the gills of the shrimps & fish sturdy, and increases the dissolved oxygen in the pond. Hi-Tech Bio Laboratory's strains are isolated from India and more suitable to Indian system.

The industry partner had developed a cost-effective, low-temperature drying process, which was better than lyophilization for the survival of probiotic organisms in the host. The company carried out extensive research for the development of host specific probiotic formulations for human healthcare, poultry and veterinary applications. Synbiotic formulations, developed under the project utilize knowledge of the ayurvedic medicinal theories in the formulations to stimulate growth of probiotic microorganisms in the gut. Thus they act as good stimulators of the gastro-intestinal flora. The ayurvedic ingredients for the fermentation and probiotic formulations were proven to be very successful. Further, the stability of the formulations was enhanced by the process employed for drying of the microbial suspensions used in the probiotic system. Normally, the cultures are dried by the technique of lyophylization (drying of cultures under vacuum at temperature ranging from -18^0 C to -30^0C). The equipment required for this technique is expensive with high operating cost. Further, the viability of the cultures under freeze drying conditions was low. The freeze dried cultures would need to be kept under cold conditions in order to preserve their viability. So the company devised a novel technique of low temperature drying, wherein the cultures were dried at temperatures between **4^0C** to **10^0C**. Less harsh conditions of drying in this case increases the viability of the microbial systems, thus giving better yields.

The costs towards equipment and drying of the products were thus substantially reduced. However, the biggest advantage was that the products could be kept at room temperatures without affecting their stability. Thus the technology becomes highly suitable for countries like India, where maintaining cold chain is difficult or sometimes impossible. Thus, the technology helped in cost reduction, which offered direct benefit to the consumers.

The company developed a whole range of novel products, utilizing innovative technologies in the field of probiotics with significant advantages over the existing products. The technology of probiotics for all applications has been commercialized by Hi Tech Bio Laboratories (HTBL). The commercial formulations are being marketed by HTBL in bulk form to many pharmaceutical companies for the human healthcare sector. HTBL has also launched a veterinary product for cattle under the brand name, “GAI GRASS”.

The project was completed and commercialized in 2006-07 with the production of 20 MTPA. The total revenue generated from the product has been in the order of **Rs.45 millions** annually with the product worth **Rs.10 millions** has been exported till date.

3.2 Manufacture of heat pipe based heat sinks

Heat pipes are very efficient heat conductors by offering an effective method of transporting heat over a given distance. They can transfer heat more efficiently and evenly than solid conductors such as aluminum or copper because of their lower total thermal resistance. In a heat pipe, the evaporation-condensation cycle of a working fluid in closed loop is used to transfer heat from the source to the sink. A heat sink is a device which carries heat from an object and dissipates it to a surrounding fluid medium (such as air) with the help of fins (to increase surface area in contact with fluid). It does this continuously so that the object being cooled can function properly. A heat pipe comprises three basic components viz. container, working fluid and the wick or capillary structure. The heat pipe is filled with a small quantity of working fluid (water, acetone, nitrogen, methanol, ammonia or sodium). Heat is absorbed by vaporizing the working fluid. The vapor transports heat to the condenser region where the condensed vapor releases heat. The condensed working fluid is returned to the evaporator by gravity, or by the heat pipe's wick structure, creating capillary action. Both cylindrical and planar heat pipe variants have an inner surface lined with a capillary wicking material. The heat-pipe based heat sinks are configured for applications in power electronics devices like diodes, thyristors, field effect transistors etc.

Heat pipes can be designed to operate over a very broad range of temperatures from cryogenic (< -243°C) applications utilizing titanium alloy/nitrogen heat pipes, to high temperature applications (>2000°C) using tungsten/silver heat pipes. In electronic cooling applications where it is desirable to maintain junction temperatures below 125-150°C, copper/water heat pipes are typically used. Copper/methanol heat pipes are used if the application requires heat pipe operation below 0°C.

The technology for manufacturing of heat pipe based heat sinks was developed by the ***International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad***, a state-of-the-art R&D facility in advanced materials and associated processing technologies. ARCI had set up a pilot plant for manufacturing of heat pipe based heat sinks at ARCI Technology Park, Hyderabad. Technology transfer included leasing the complete manufacturing set-up, providing standard operating procedures for the entire process and rendering complete training to the operating personnel. The technology was scaled up by ***M/s Capri Cables Pvt. Ltd., Hyderabad*** under a project launched in October 2003. The project aimed at setting up a pilot manufacturing facility of heat pipes with a capacity of 40,000 units per annum. ARCI provided continuous technical guidance, R&D support, characterization and testing services to the entrepreneur. The company channelized its efforts for commercialization of heat pipe technology basically for two major applications for *heat dissipation* and *energy recovery*. Heat pipe based heat sinks find wide-ranging applications in areas such as telecom industry, refrigeration, air-conditioning, waste heat recovery, power electronics etc.

During the project implementation, the project advisory & monitoring team involving experts from IITs and user groups played a major role and their suggestions enabled the company introduce better design and manufacturing techniques for production, cost optimization, saving of raw materials, and better performance. The team also helped in re-designing fins & tubes spacing for tailored applications, and suggesting a contoured profile in the aluminium block to optimize heat transfer & save material cost etc. The company manufactures both *forced convection* and *natural convection* driven heat sinks. Wattage dissipation of these heat sinks ranges from 10 to 10,000 W depending on the requirement and size constraints. While each heat sink designed by Capri Cables is tailor made to suit specific needs and preferences of each customer, efforts were made to create an optimum product of high quality, performance and efficiency. The project has been a very successful example of private-public partnership[3]**.**

The heat pipes, developed under the project, were fully commercialized in 2009 with the production of **10,000** heat pipes in 2009-10; **45,000** in 2010-11; and **43,000** in 2011-12. The product generated revenue of **Rs.7.90 millions** in 2009-10; **Rs.36.00 millions** in 2010-11; and **Rs.35.00 millions** in 2011-12.

4.0 Advanced Composites Programme

Composites have proved to be worthy alternatives to other traditional materials in the high-pressure and aggressive environmental conditions of chemical processing. Besides superior corrosion resistance, composite materials exhibit excellent fatigue performance, good resistance to temperature extremes and wear. Continuous advances in the manufacturing technologies and associated performance of composites have diversified their range of applications leading to significant growth in its market acceptance. Increasingly enabled by the introduction of newer polymeric matrix and high performance reinforcement fibres of glass, carbon and aramid, the penetration of these advanced materials forms has witnessed a steady expansion in uses and volume. The increased volume has resulted in an expected reduction in costs. High performance composites can now be found in such diverse applications as armouring designed to resist explosive impacts, fuel cylinders for natural gas driven vehicles, windmill impellers, industrial drive shafts, support decks of highway bridges and even paper making rollers. The tailorability of composites for specific applications has been one of its greater advantages such as imparting low thermal conductivity & low coefficient of thermal expansion, high axial strength & stiffness etc. Concerted efforts are directed towards the development of innovative and cost competitive materials, which can improve performance and reduce maintenance cost while increasing reliability and improving safety.

As a follow-up of an in-depth sectoral analysis[6] coupled with a detailed technology assessment exercise, composites were identified as an important performing material in India with a wide array of applications touching a large number of people from different walks of life. The increasing demand for materials with higher strength-to-weight ratio has led to the cognizance of composites. The ***Advanced Composites Programme (ACP),*** launched by TIFAC in 1993, aimed to promote various composite applications. In view of the application potential of composites, a fast paced indigenous product development & its induction was felt necessary for the key sectors. Other aspects such as usage of natural fibre in composites, development of new fibre & resin system, recyclability/reusability of composites and their effective disposal were also addressed under the programme. The programme, completed in 2011, has been an attempt to enhance the utilisation & application of composites in various sectors and to improve upon the laboratory-industry linkages towards technology development & commercialisation.

Under the Advanced Composites Programme, **44 projects** were launched and more than **30 products** were developed successfully. An appropriate technology support, attractive project financing mechanism and user oriented product development approach immensely helped the industries in expanding their technology capabilities and market presence. The programme paved the way for ushering in composite applications in the domestic market as well as for promoting business avenues abroad. The industry partners for the programme achieved strong and profitable growth (+10% to 30% of increased revenues per year generating 10% to 40% of return on capital employed).

The programme made a visible impact on **Indian Railways** by developing composite products having direct relevance to the sector. **11 projects** were launched focusing composite applications especially for railways including ***gear-cases*** for diesel & electric locomotives, ***axial-flow fans*** for diesel locomotives, ***sleepers*** for railway girder bridges, ***modular toilets*** for passenger coaches, ***FRP doors*** for passenger & EMU coaches etc. These products after meeting the stringent technical and safety requirements were inducted by the railways, thus enhancing the confidence levels in the industries as well as R&D establishments. The complete composite ***interiors for railway coaches*** and composite ***interiors for diesel loco driver's cabin*** with the help of IDC/IIT-B were developed for improving the users' comforts.

Towards reaching immediate succour to the earthquake affected people of Gujarat in 2001, the programme contributed to the national efforts of re-building & rehabilitation by constructing around **400** *low-cost semi-permanent shelters*, **128** *composite toilet blocks*, *class-rooms for the schools* etc. made of jute-coir composite & bamboo mat veneered rice husk particle boards supported on steel structures with the roof overlaid with terracotta tiles in Kutch. Building upon the experience in Kutch rehab project and towards a token intervention to rehabilitate livelihood of the tsunami affected people, a project was taken up by TIFAC in January 2005 for the construction of **39** *community sheds* made of natural fibre composites and distribution of **55** *composite fishing boats* in Nagapattinam district of Tamil Nadu[7].

In view of the development of a novel composite application and its acceptance by the users, efforts were directed for large-scale replication of activities by a wider cross-section of composite industries. Under the aegis of Advanced Composites the early projects of Bamboo based composites were also nucleated; this activity was later spun off as National Mission on Bamboo Applications. In this paper, case-studies of five key products developed under the programme for the Indian industry are mentioned below:

4.1 Composite interiors for driver's cabin in diesel locomotive

Indian Railways had always welcomed new developments for its rolling stock, which could offer improved performance, low maintainability, reliability, safety and cost effective on life cycle basis. There are two driver seats (positioned as a mirror image) on the long hood section of the diesel locomotives. The driver's cabin has provision for tool kit, almirah, instrumentation/control panels etc. and it appears too cramped. The Indian Railways had been seriously contemplating ways and means for an ergonomic improvement of driver's cabin interiors for diesel locomotives along with allied aesthetic appeal. In fact, TIFAC's success in developing the composites toilet with better aesthetics and ergonomics had triggered an interest in Indian Railways for developing further such applications. The railway officials approached TIFAC in taking up the project with design and development support from IIT-Bombay. Due to the interest by Indian Railways in modernizing the interiors for driver's cabin, a team of experts from IIT-B, TIFAC, railway officials and the industry partner had detailed discussions on the design approach and various features to be incorporated in the driver's cabin for diesel locomotives.

The project was launched in September 2003 under the Advanced Composites Programme in partnership with ***M/s. Black Burn Co. Pvt. Ltd., Kolkata***. The Industrial Design Centre (IDC) of IIT-Bombay extended knowledge support in terms of prototype design & development, preparation of various design drawings, assistance during fabrication of full-scale prototype etc. For a user oriented development approach, the experts from Railway Board, RDSO, DLW, DLMW and Western Railway were inducted in the project review & monitoring activities. Development of driver's cabin interiors focused on retrofitment considering the large fleet of diesel locos in the country.

The new design[8] of the cabin as evolved addressed appropriate paneling, comfortable seats, clear visibility, proper arrangement of gauges, provision of space for tools & kit boxes for better operator comforts etc. The problems of heat and sound insulation were also addressed while developing the cabin interiors. In addition, the safety features such as increase in roof height inside the cabin, scientific illumination of the cabin, ergonomic placement of various instruments, indication regarding driver's attentiveness were also incorporated in the driver's cabin.

The design of interiors comprising wall & roof panels, flooring, console panel etc. was carried out based on human body clearances, space requirement for ingress & outgress, tool box, drivers' belongings etc. The side panels & console panels were given an off-white granular granite finish. The roof panels were painted white to improve the interior light condition. A cupboard was provided at the short-hood side to accommodate tools and other accessories.

The space between drivers control stands was increased considerably to facilitate free movement of personnel and height adjusted to ensure eye ball contact between driver & assistant. Openable hatches were provided below the console table for access to the cables, gauges and other mountings. The roof comprised of two arched panels on either side and a central panel to accommodate lighting fixtures with shadow light. The set of wires/cables feeding the two console panels were laid below the floor. Indian Railways had been using PVC covered compressed resin impregnated wood (Compreg) overlaid on the steel structure for flooring. This was covered with a heavy-duty, anti-skid, abrasion resistant synthetic material for flooring. While the flooring material suited the purpose well, it was quite expensive. The floor suffered from the problem of dust accumulation. Under the project, the floor of the cabin was made in three-piece modular sandwich panels with rigid PU foam core supported on existing metallic structure and covered with anti-skid type liner. The modular type floor design helped in accessing underneath for maintenance. Wide openable hatches were provided at the long-hood side for fitment of various MCBs/switches/knobs, gauges and other accessories. The cabin interiors were designed to provide high elegance without any sharp edges and to provide maximum comfort to the users. As the vibration dampening is an inherent property of composites, sidewall cladding and air space at the outer steel shell contributed effectively for achieving noise attenuation as well as heat insulation. The life expectancy of composite interiors would be around **15-20** years under normal usage conditions with minimum maintenance.

Two sets of composite interiors were fabricated and the drivers' cabins of two diesel locomotive (WDM-2A) were furnished at Ratlam loco-shed of Western Railway in 2006. The users' feedback from the field trials for diesel locomotives furnished with composite interiors was quite encouraging. The diesel loco maintenance unit from Ratlam loco-shed inferred that the newly furnished diesel loco driver's cabin had created quite a conducive workspace.

The project was completed in **November 2006** and commercial production of loco interiors started in 2007-2008. The Company initially had supplied limited composite interiors for diesel locos in Southern and South Eastern railways. Based on their satisfactory performance, the company has now been supplying the composite interiors regularly for diesel locomotives for Indian Railways. Since then **100 locomotives** have been retrofitted @ approximately **25 locos per year** recording the revenue of **Rs.17.50 millions** annually. The product has also been introduced in new electric locomotives being built by BHEL, Jhansi. **50 electric locomotives** were retrofitted in 2012 with the composite interiors costing **Rs.500,000/-** per loco thus generating the revenue of **Rs.25.0 millions**.

4.2 Composite houseboat for tourism

Houseboat is a recent innovation positioned as the unique attraction for tourism industry in Kerala, a southern Indian state. A houseboat is traditionally made of resinous wood and it takes 8-10 trees (70-80 years old) to build one. Apart from denuding the forest cover, building a traditional houseboat is extremely manpower intensive and nearly 40 man months of skilled labour are required to shape it up. The wooden hull is highly prone to decay due to its continuous contact with water calling for regular tarring of the hull and frequent outages of the houseboat. The superstructure outer surface thatched with woven bamboo mat requires replacement every year due to an excessive fungal attack in a moist environment. Thus the cost of maintenance becomes quite prohibitive for the houseboat and for the tourists to enjoy that 'ultimate in luxury', the cost of occupancy rises! No attempt was earlier made so far to use composite to make hulls for house-boats in a scientific way. Composite has been established as the ideal material for marine vessels and structures due to their corrosion resistance, easy mouldability and maintenance free service.

The development of ***composite houseboat***[9] was taken up as a project under the Advanced Composites Programme of TIFAC in December 2004 in partnership with M/**s. *Samudra Shipyard Pvt. Ltd., Cochin*** for improved aesthetics, boat stability, comfort level and maintainability using advanced fabrication methods**.** A multi-agency approach was adopted for seeking expertise in hull design, testing, fabrication assistance, design of superstructure, interiors, amenities etc. ***NGN Composites-Chennai***, a consulting agency working in composites technology development, had assisted in mechanical design & fabrication of hull, deck & superstructure. The ***Dept. of Ocean Engineering*** of ***IIT-Madras*** had provided hydrodynamic design of boat hull, bulkheads, ballasts and conducted the necessary tests for boat stability. The ***Industrial Design Centre (IDC)*** of ***IIT-Bombay*** had extended design support for developing a superstructure with improved space utilization, aesthetics and ergonomics of the living area with the detailed design of bedrooms including design of panels, partitions & other interiors. The important milestone of IDC's contribution has been modular design approach of the entire superstructure. The Department of Ocean Engineering & Naval Architecture-IIT, Kharagpur had provided necessary technical guidance while monitoring the project right from the beginning. As the project dealt with the development of house boats for tourism sector, senior professionals from the Department of Tourism (Govt. of Kerala) and also the leading tour operator for house-boats were involved as experts in the project monitoring.

The sandwich hull with polyurethane foam core was fabricated in composite. The decking for the houseboat has always been a problem area with a whole lot of wooden planks being used in the conventional ones. This problem was addressed by using moulded composite gratings. The entire superstructure was made into five modular parts requiring only three moulds for fabricating the half modules. The superstructure was configured to accommodate two bedrooms each measuring 4.00 m x

3.50 m. The houseboat components such as the hull, deck and superstructure consumed about **19.20 MT** of composites, thus making it one of the largest composite products in the country.

A 104 HP Cummins diesel engine used for the propulsion system was housed inside the hull with anti-vibration mountings. An acoustic barrier in the form of high resilience foam was used in the engine enclosure for a noise free operation. A 10-KVA DG set was installed inside the hull for the power back-up when the engine is not in operation as the boat is anchored during the night. Polymer concrete ballasts weighing 1.50 tons were added inside the hull to improve boat stability. Three bulkheads were provided in the hull to isolate hull puncture and water leakage. The project was completed successfully in April 2006.

Initially the tour operators were skeptical about the material of construction for the houseboat and it took almost two years for them to opt for the houseboats made of composites. In the first five years' of construction, the Company had developed and delivered 25 boats to the users. The houseboat with two bedrooms was priced at **Rs.6.00 millions** each and the one with the premium quality and three bedrooms costs about **Rs.10.0 millions**. With the first houseboat supplied by Samudra Shipyards now in service for over eight years, the stake holders are convinced with the quality and maintenance free nature of this material. Thus, the company has experienced a steady growth in orders over the last five years. The company has order in-hand for the supply of **10 houseboats** till April 2014.

The composite houseboat had been a small step in technology development but this would go a long way in saving the environment. Involvement of the multi-agency expertise and a user-oriented approach were instrumental in reducing the product development cycle limiting the entire exercise to less than one year. While boat building in India has been a traditional activity, it is now important to introduce new materials such as composites and processes such as vacuum infusion technique. With vast pool of technical expertise available in naval architecture in the leading academic institutes in India, boat building could be an important business opportunity for the industries. India is an emerging market for leisure activities with higher disposable incomes per family. With very long coast lines along the peninsula, large natural inland water bodies and long rivers, development of composite boats of various forms & functions in India would certainly assume importance and attract investment in the near future.

4.3 Development of artificial limbs for physically handicapped

In developing countries like India, road accidents inflict grievous injuries to people. Loss of a limb by amputation can be a traumatic experience for such accident victims. Other factors such as congenital defects, bone deformities and constricted bone growth also add to the number of physically challenged people in our country.

Advances in the science of prosthetics burgeoned after the World Wars, when large numbers of people needed artificial limbs. New lightweight materials and better mechanical joints were introduced after the wars. Prostheses are usually sold as components so that someone who has an above-the-knee amputation would be able to choose legs, knee and foot units depending on their individual needs.

For centuries, wood and leather were the only materials for prosthetics for artificial limbs but today's physical therapist has a much wider range encompassing advanced plastics & carbon fibre, which are much stronger, lighter and more durable. In India, commonly used artificial legs are exoskeleton type made of high-density polyethylene. These artificial limbs are more of a cosmetic replacement rather than a functional one. Though these appear like natural limbs, they cannot impart normal gait to a person. While, the imported endoskeleton types of limbs are available in India, they are very expensive. On assessing the scenario towards improving design, functional needs & aesthetics of the artificial limbs in India to cater to societal needs a project on developing ***endoskeleton type below the knee composite artificial limbs***[10] was launched in June 1999 in collaboration with ***Mohana Orthotics & Prosthetic Centre, Chennai*** with technology support from ***IIT-Madras*** and ***Madras Institute of Technology,*** Chennai. The consultants helped in design, prototype development and complete testing of composite limbs. The product was developed and tested for accelerated life span within two years of project implementation. Extensive field trials were also undertaken for assessing the users' feedback.

A complete evaluation of individual components and also of the entire endoskeleton assembly for compressive & bending strength was carried out. A simulated endurance test was conducted for 5-year service life of the artificial limb considering average stance duration of **0.5 seconds** for normal gait and three hours walking time per day thus testing the limb for **39.42 million cycles** to simulate its lifespan of **5 years.** The project was completed successfully in March 2001.

The indigenously developed artificial limb has high modulus, long-term dimensional stability, high fatigue resistance, long-term bio-stability, excellent abrasion resistance and bio-compatibility. The unique design of this composite limb permits walking, cycling, climbing and even driving a vehicle by a person physically challenged otherwise. A whole lot of innovative technology inputs from the knowledge partners were instrumental in developing a user friendly & world-class artificial limb with excellent market potential in India and abroad.

Such indigenously developed below-knee artificial limb cost maximum Rs.6,500/- only against Rs.40,000/- for the imported ones. The endoskeleton type below-knee artificial limb, developed by Mohana Orthotics, was awarded the prestigious **National R&D Award 2001** by Department of Scientific & Industrial Research (DSIR), Govt. of India. TIFAC had been instrumental in promoting the product among various limb fitting clinics & hospitals as well as by procuring them in large numbers for their distribution to earthquake victims of Gujarat. 350 such endoskeleton limbs for distributed to the earthquake victims at Bhuj @Rs.6500/- per complete limb including polyurethane foot.

Currently, each composite endoskeleton limb without the PU foot costs about **Rs.11,000/-** and with PU foot is sold at **Rs.12,000/-** by Mohana Orthotics. The patients fitted with endoskeleton limb have experienced good results and some of them have come back to Mohana after a few years only for the foot replacement. The firm delivers about **3-4** endoskeleton limbs for patients in a month (about **40-50 limbs per year**) thus generating a revenue of **Rs.6.00 lakhs** annually. Mohana faces stiff competition from the endoskeleton limbs currently being imported from China & Taiwan costing around Rs.20,000/-.

4.4 Filament wound composite pressure vessels

Composites are anisotropic material with the fibre orientation bringing in directional strength of the composites. Filament winding is the technique, which attempts to impart uniformity of strength in composites in different directions. The filament winding technique for composite fabrication has been used to develop cylindrical and spherical pressure vessels, pipe lines, oxygen & other gas cylinders, rocket motor casings, helicopter blades, large underground storage tanks (for gasoline, oil, salts, acids, alkalis, water etc.). The filament winding offers high speed and precise method for placing many composite layers. The process is not limited to axis-symmetric structures; prismatic shapes and more complex parts such as T-joints, elbows may also be wound on machines with appropriate degrees of freedom. The laminate structure is reproduced on the winding machine exactly as guided by high-end software programmes like CADWIND, CADFIL etc. Given the strength requirements, the fibre lay-up on the mandrel is generated by the software for filament winding system. Mechanical strength of the filament wound parts depends on composition of material and very much on process parameters like winding angle, fibre tension, resin chemistry and curing cycle.

Considering huge applications potential of filament wound composite pressure vessels[11], the project was launched in March 2002 in partnership with *M/s. Kineco Pvt. Ltd., Panaji* and technology support from IIT-Bombay. The project aimed at developing filament wound pressure vessels for the following applications:

- Undercarriage composite tanks (450 mm dia. with 2.00 bar operating pressure) for AC passenger coaches for water supply to the toilets for Indian Railways
- Two sizes of pressure vessels (500 mm & 600 mm dia.) for water treatment application; operating pressure : 3.50 bar

All the above vessels were designed as per **BS 4994**. For fabricating composite pressure vessels with dished/hemispherical ends, the need for a multiple axes filament winding facility was found essential.

As an integral part of the project, development of a ***multiple axes CNC filament winding facility*** was taken up by ***CNC Technics Pvt. Ltd., Hyderabad*** for the first time in the country. Within a short period of 8 months, 4-axes (with one additional X-axis) CNC filament winding system was designed, developed, fabricated and installed at Kineco, Panaji. The system has the following unique features :

- The filament-winding machine is powered & controlled by SIEMENS 840 D control system.
- Pressure vessels/pipes with diameter ranging from 50 mm – 4.00 mts can be wound on the system.
- Length of the job being wound can vary from 1.00 mts – 9.50 mts
- While the first spindle can wind diameters ranging from 50 mm – 1500 mm at high rotational speed, the second spindle can rotate diameters up to 4.00 mts at relatively slower speeds. The second spindle can hold component and mandrel weight up to 6.00 tonnes.
- The unique design of the cross axis allows the winding pattern to be unaltered from 50 mm – 4.00 mts dia
- The main filament winding carriage feeding the impregnated glass fibre moves at a very high speed of 60 mts per minute
- The creel stand for fibreglass rovings accommodates 24 spools and has adjustable mechanical tensioning device at its spool. The tension can be accurately controlled for each roving.
- The drum type resin bath with micrometric adjusting doctor's blade can control resin pick-up accurately. Top wetting rollers assure proper wetting of rovings and squeeze blades remove excess resin. A temperature controller and a hot water pump controls the resin bath temperature within $\pm 2^0$ C enhancing the pot life of epoxy resins
- The CNC control system is enclosed in a fully sealed panel, which has a piggyback air conditioner and can work in any environment.

- The multi-axis filament winding system is equipped with CADWIND software to facilitate various design configurations of composite parts.

The air-conditioning unit in the railway passenger coaches is located in the space atop the toilet beneath the roof of the coach. Hence, there is no space availability for the toilets for overhead water tanks and they are installed under the carriage. Each coach is equipped with two such water tanks with the capacity of 450 liters per tank. A low pressure (1.20-1.50 atm) air supply to the undercarriage tanks helps the water flow into the toilets. Using the 4-axes filament winding system, undercarriage composite water tank module, comprising two tanks, were designed & fabricated. LDPE liner was used as an inner mandrel for the pressure vessels with sufficient thickness to withstand the winding tension. The tank fixing arrangement was designed to allow both retrofitting and fitting to new coaches. Two tanks were mounted to the coach under frame with a specially designed SS 304 fixing arrangement. In addition, a sacrificial polypropylene shield was provided underneath the water tanks so as to protect them from ballast hits during train movement.

While the existing module comprising two water storage tanks (SS316) weighs 265 Kgs., the composite module weighed 205 Kgs. Hence, a total weight saving of 120 Kgs. was achieved for two such modules per coach. These composite tanks also found to be cost effective.

The undercarriage water tank module developed for railway passenger coaches is the most critical product in terms of safety. In case of its detachment from the chassis, there could be a catastrophic failure for the entire train. Keeping this aspect in mind, Indian Railways had carried out detailed radiographic tests etc. on the module support structure. The tank module underwent a series of other safety tests specified by RDSO before its clearance for fitment to the passenger coach.

The project for development of composite under-carriage water tanks was completed in December 2003. But the railways desired to have a prolonged test for their performance evaluation. The composite tanks, fitted to an AC III-Tier coach of Mumbai-Jaipur Express at the Lower Parel Workshop of Western Railway, had completed actual field trials of around one & half years and this was concluded successfully in October 2005.

Kineco has so far supplied over **90 units** of composite pressure vessels (2.5 m ID; operating pressure: 6.0 bar) to various customers such as Pentair-Goa, IDE Technologies-Israel over the last five 5 years generating a revenue of ~ **Rs.42.00 millions**. These vessels are used for water filtration & treatment plants. In addition, Kineco has bagged an initial order for supply of **100 sets** (200 nos.) of under carriage water tanks to Indian Railways for their AC coaches; the order value amounts to **Rs.57.00 lakhs.** The Indian Railways would place repeat orders to Kineco after the initial one is completed within the stipulated delivery schedule.

The Advanced Composites Programme was instrumental in developing the indigenous capability of designing & fabricating a sophisticated CNC controlled 4-axes filament winding system while actually targeting at composite pressure vessels. Staring from 2002, when the first filament winding system was developed & delivered under the TIFAC project for Kineco, CNC Technics has so far designed and manufactured **145** filament winding machines with different degrees of freedom. The most laudable achievement of this indigenous development has been export of over **50** filament winding systems to **19 countries** around the world. CNC Technics has generated a total business of around **Rs.1100 millions** till date.

4.5 Filament wound composite pipes for oil & gas industry

With technology innovations and developments in processing industry, composites have become an attractive solution for the oil & gas industry. The glass-reinforced epoxy (GRE) piping system offers complete solution for offshore environment against highly corrosive fluids at various pressures, temperatures, adverse soil and weather conditions (especially in oil exploration, desalination, chemical plants, fire mains, dredging, portable water etc.). GRE piping system can withstand the detrimental effect of brackish water when expelled under pressure from fire mains.

Internationally, composite as a material has proven its use in piping systems, grids & gratings, platform structures, pressure vessels etc. Composite pipes & pipe-fittings are widely being used for cross-country transportation of water and hydrocarbons. In fact, internationally nearly 1200 Kms. of composite pipelines have been in operation for water & hydrocarbon services for the oil & gas industry. These pipelines are being designed & fabricated as per the internationally prevailing **American Petroleum Institute (API) standards**.

Indian composite industry has the required capabilities for developing products & applications catering to highly growing indigenous oil & gas sector. There exists a huge demand in ONGC for the use of composite pipes & pipe-fittings for hydrocarbon transportation, water & other effluent injection, effluent transportation etc. At present, most of these demands are being met by procuring composite products from overseas, as there are no Indian manufacturers to supply such composite pipes & pipe fittings as per the international standards. Presently, either hand moulded or other old moulding techniques are being used by Indian fabricators. Not only excess material is consumed in such fabrication processes, it also results in failures and frequent replacement of the components. This called for understanding various technology aspects of composites applications in oil & gas sector and to develop the product as per API norms with improved quality meeting customers' needs.

In line with the requirement of growing business for composite pipes in oil & gas sector, the project[12] was launched under the Advanced Composites Programme in August 2006 in partnership with ***M/s. EPP Composites Pvt. Ltd., Metoda near Rajkot.*** The project aimed to design GRE pipes as per API 15 LR by using 4-axis CNC filament winding system. Using advanced fabrication technique such as CNC filament winding results in considerable weight saving with reduced material wastage and would cater to the exact strength requirements.

Getting API-15LR has been a lengthy and rigorous process warranting complete documentation at each and every step including maintaining total QMS system as per API requirement. This warranted detailed assessment of testing requirements and procurement/development of specific test equipment tailor made for the purpose. All the testing equipment needed to be calibrated as per the standard norms and the whole facility needed to be approved by API from USA after clearing the third party inspection by reputed agencies. API standards 5B and 5B1 for tubing, threading and gauging of pipes and design standard AWWA M-45 for composite pipes were followed. The design template for buried pipes as per AWWA M-45 was also finalized using MathCAD software.

The list of routine and type tests to be followed as per API is as follows:

Routine Test

S No.	Mechanical Property	Test Method
1.	Bust Testing	ASTM D 1599
2.	Mill Pressure Test (1.5 * Design)	API 15LR
3.	Axial Tensile Strength	ASTM D 2105
4.	Hoop Tensile Strength	ASTM D 2290
5.	Hoop Tensile Modulus	ASTM D 2290
6.	Axial Tensile Modulus	ASTM D 2105
7.	External Collapse Pressure	ASTM D 2924
8.	Initial Stiffness Factor	ASTM D 2412

S No.	Physical Property	Test Method
1.	Specific Gravity	ASTM D 792
2.	Density	ASTM D 792
3.	Co efficient of thermal Expansion	ASTM D 696
4.	Barcol Hardness	ASTM D 2583
5.	Degree of Cure	API 15LR
6.	Glass Content	API 15LR
7.	Resin Content	API 15LR

Long Term Type Tests

1. Long Term Hydrostatic Design Basis (HDB) Cyclic Pressure Test as per ASTM D 2992

2. Long Term HDB Static Pressure Test as per ASTM D 2992

3. Long Term Beam Bending Modulus as per ASTM D 2925

The API audit certifies the product and its manufacturing facilities at a specific location. EPP Composites had created the necessary testing and manufacturing facilities for the complete range of GRE pipes as specified in API15 LR with pipe diameter of 25 - 600 mm, pressure ranges of 10 - 70 bar for a pipe length of 4.5/6/9/12 m and temperature range of – 65° C to 120° C. These included 4 axis CNC filament winding system, fully automatic hydraulic extractor unit, CADFIL software for accurate winding, hydro testing machine for pipes & couplers, 12 m long curing oven, ultimate axial tensile strength testing machine, parallel plate crush test, impact resistance etc. in addition to the long term cyclic and hydrostatic (internal & collapse) pressure testing machines. The entire test (type & routine) had been carried out for the samples as per API guidelines including long term static & cyclic hydro testing.

The short-term & long-term hydrostatic and/or cyclic loading tests as per ASTM D 2992 were critical requirements for API. Such special purpose equipment were designed and developed indigenously for the first time in India and this had been a milestone achievement for the project. The short-term tests were conducted on 12 m pipe length over 1.0 min at 1.5 times the design pressure. In long-term test, 1.0 m pipe lengths were subjected to 2.0 times the design pressure for minimum 5000 hrs. In addition to above, API recommends long-term cyclic loading test for min. 10,000 hrs or 15 million cycles. The test encompassed exposing a minimum of 18 specimens of pipes or fittings or both to cyclic internal pressures @ 25 cycles/min and at different pressures. Elevated test temperatures were obtained by circulating hot water through the specimens.

The equipment design for the hydraulic burst & collapse tests for composites pipes was based on the test methods described in ASTM D 1599 & 2924. The test method prescribed loading a specimen to failure or a predetermined minimum level, in short-time interval by means of continuously increasing internal hydraulic pressure while immersed in a temperature controlled environment. The test method establishes short-time hydraulic failure pressure of reinforced thermosetting resin pipe or fittings. Same test set-up could also be used for carrying out collapse pressure test by applying hydraulic pressure external to the pipe in an enclosed shell. Data obtained by this test method are of use in predicting the behavior of pipe, tubing, and fittings under various conditions of temperature, time, method of loading and hoop stress similar to those used in the actual test.

In order to bring the right expertise to get appropriate design inputs to develop pipelines for various applications, key senior officials from the industry dealing in pipelines such as **Gujarat Water Supply & Sewerage Board, ONGC,** Engineering & Construction Group of **Larsen & Toubro** etc. were involved in the regular project reviews. It had been an excellent effort over four years in obtaining the API certificate by EPP Composites and the Advisory & monitoring Committee had extended full support and guidance in accomplishing the project objectives. The project was successfully completed in November 2011.

On successfully carrying out all the necessary tests and the detailed audit performed by API, EPP Composites received API certificate (API spec Q1 and API spec 15 LR) in October 2011 for composite pipes & fittings for pipe dia. up to 24" and operating pressure up to 1000 psig. EPP Composites has been the first in South Asia and 17th in the world to have the API -15 LR certification for composite pipes.

Global epoxy based pipe demand had been estimated as 216,000MTPA while India has an annual requirement of 4.6 MT of GRE based composite pipes with annual growth rate of 9%. 12^{th} Five-year Plan has estimated the requirement for 18,000 Kms. of pipes with an investment of US$9.00 billions.

EPP Composites has the necessary facility for producing **15 kms. per month** of API pipes with dia ranging from 25mm to 600 mm. EPP has received an order in August 2013 from Kalpataru Power Transmission Ltd., Gujarat for supply of **28 Kms.** API grade composite pipes for ONGC. These pipes would be priced @**Rs.1395.60/- per meter** thus generating revenue of **Rs.4.00 millions** from the order.

5.0 Bioprocess & Bioproducts Programme

Bioproducts derived from sustainable bio-resources are receiving much attention due to the potential impact of these technologies in terms of environment friendliness. The bioprocesses are low energy intensive operations, which optimally utilize bio-resources and enhance rural economy coupled with employment generation etc. Considering the above, the ***Bioprocess & Bioproducts Programme*** of TIFAC was launched as the major technology initiative at the national level. The programme catalyzed technology development & demonstration activities in pre-treatment, processing and conversion of biomass to fuels. Development of active pharmaceutical ingredients (API), chemicals and other value-added products with a view to optimal utilization of bio-resources were also attempted. The programme also aimed to promote indigenous technology capabilities in the sector with the involvement of wider cross section of stakeholders in the national & international arena.

Under the programme, 10 projects were supported. Initially a few projects were launched based on the 'industry-centric' technology development model with the financial assistance directly extended by TIFAC to the industry partners. Later on due to changed TIFAC policy, research laboratories and academic institutions were funded on grant-in-aid basis with industry partners sharing the project cost to a limited extent in a few cases. This was primarily for the projects related to knowledge generation as well as for transferring technology to the industry partner.

Out of the aforesaid **10 projects**, 9 of them were successful in meeting all the technology milestones as stipulated. Two industry partners have productionized the technologies developed (*active pharmaceutical ingredients*) on a regular basis. The project on development of L-arginine, an important drug molecule, exceeded the yield as initially targeted under the project. The results have been encouraging enough for the industry partner to invest in scale-up and commercialization of the technology. One more industry partner did produce a few batches of the product (*stevioside as zero-calorie sweetener*) but could not sustain the production due to shortage of raw material (stevia leaves). The project on *detoxification of jatropha seedcake* was completed very successfully with a lot of promise of converting toxic seedcake wastes into value-added animal fodder. In the event of jatropha based biodiesel production taking off in a big way in India, the technology developed would be very useful in utilizing large quantum of the waste seedcake. Two other projects launched with the academia in partnership with the industry on *enzymatic peeling of potato* and use of *aloe vera extracts for control of diabetes* are in the advanced stages of completion. However, the results obtained so far in both the projects appear highly promising for their commercial exploitation by the industry. Another project on setting up the *Centre for Biofuels* in partnership with the National Institute for Interdisciplinary Science & Technology (NIIST), Trivandrum truly has been an exercise in promotion of pedagogy, creation of a seat of advanced knowledge and training. An important milestone of the project has been identification of surplus biomass in India for their exploitation based on nationwide survey. The crucial process steps such as pretreatment and hydrolysis for the identified biomass (six types) for ligno-cellulosic (LC) ethanol have been completed at the laboratory scale. The LC ethanol pilot plant with a capacity of processing 80 kgs of biomass per day has been set up at NIIST. Validating the laboratory results and establishing the viable technology steps at the pilot plant level would be attempted under Phase-II of the programme. Some of these success stories have been described in detail in the following case-studies:

5.1 Enzymatic conversion of racemic molecules for stereospecific active pharma ingredients (API)

Chiral intermediates and fine chemicals are in high demand both from pharmaceutical and agrochemical industries for the preparation of bulk drug substances and agricultural products. Thus the production of single enantiomers of chiral intermediates has become increasingly important in case of pharmaceuticals. The single enantiomers can either be produced by chemical or chemo-enzymatic process. **Three** low-volume, high-value active pharmaceutical ingredients by biosynthetic route were developed under the project[13] on optimization of process parameters, launched in November 2007 in partnership with ***M/s Hi-Tech Bio Sciences India Pvt. Ltd. (HTBL), Pune***. While HTBL was involved in process scale-up, technology demonstration & product marketing, they also had tie up with other institutions for knowledge support in terms of molecular biology work, enzyme expression studies, development of membrane reactor system for enzyme recycling, kinetics and immobilization of enzymes.

The following molecules were developed for the first time in India under the project:

- **11-hydroxy Canrenone :** an important intermediate for the manufacture of eplerenone. The hydroxylation at 11 position of Canrenone cannot be performed chemically and calls for biotransformation.
- **Eplrenone :** an aldosterone antagonist used in the management of chronic heart failure. It is similar to spironolactone and is specifically marketed for reducing cardiovascular risk in patients following myocardial infarction.
- **S Indolene 2 carboxylic acid :** an important chiral intermediate in the manufacture of pharmaceuticals such as perindopril and similar long-acting ACE inhibitors

The technology development activities were monitored by a team of experts inducted from academia, pharmaceutical industry and a leading financial institution making a significant difference. The innovations involved in the project were development of economical & sustainable sources of enzymes, isolation of fungal isolate & development of process for bioconversion of steroids, use of molecular biology tools for over expression of enzymes and their utilization. HTBL carried out basic studies on some of the economical and sustainable sources of enzymes, especially from some of the agricultural produce. The bioconversion involved use of either purified enzymes or fermentation for carrying out the desired conversion reactions. The enzymatic bio-conversions used in the project have been proven to produce better results. These methods are highly versatile, economical and also chemo-, regio- and stereo-selective. The major advantages of using enzymatic conversions are as the enzymes are chiral catalysts and hence are often able to produce optically active molecules that can be used as building blocks for the preparation of homo-chiral compounds. Further, the reactions can be carried out under very mild conditions of temperature, pH, and pressure, thus avoiding the use of more extreme conditions, which could cause problems with isomerization, racemization, epimerization, and rearrangement. Most importantly, the biocatalysts can perform transformations that are difficult to emulate using more traditional organic chemistry. Further, the enzymes or microbial cells derived therefrom can be immobilized and reused for many cycles.
The synthesis of 11- hydroxy canrenone utilized monoxygenase enzymes present in certain fungi for in-vitro transformation of the steroid canrenone into its 11 α-hydroxy analogue. The process steps for 11-hydroxy canrenone involved preparation of the innoculum, growth of fungal culture in defined fermentation medium, addition of canrenone to the fermentation broth & downstream processing of the fermentation broth and then purification of 11 α-hydroxy canrenone from the fermentation broth and cell mass. After purification of 11 α-hydroxy canrenone, it was converted chemically to Eplerenone

The total estimated demand for 11-hydroxy canrenone is in the range of 3 to 4 MTPA, which is being imported at around **Rs.40-45,000 per Kg.** The present domestic demand for eplerenone is around 2 MTPA costing about **Rs.300,000/- per Kg**. The total estimated demand for S-Indoline 2 -carboxylic acid is estimated to be more than 25-30 MTPA with a price tag of **Rs.20,000/- per Kg**. The pilot plant has successfully been set up by the company for production of aforesaid three molecules for **50 Kgs. per month** capacity and it has been in regular operation since April 2010. HTBL have produced ~ **200 Kgs.** of products till date. The sales turnover from the product has been ~**Rs.60 lakhs**. It is expected that the indigenously developed product & technology platform would enable development of other advanced products in the future.

5.2 Development of prostaglandins by bioconversion

Prostanoids are chemical/biochemical precursors and chemical derivatives of prostaglandins having application in diverse human conditions namely, labour induction, congenital heart disease, primary pulmonary hypertension, treatment of glaucoma, breeding management, prevention of NSAID-induced ulcers, healing of gastric/duodenal ulcers etc.

Prostaglandins are unsaturated carboxylic acids, consisting of a 20 carbon skeleton that also contains a five member ring. The prostaglandin and its advanced intermediates are optically active compounds. Hence one needs optically pure **4R-hydrodroxycyclopent-2-ene-1-(S) acetate**, the building block for prostaglandins, with high chemical purity (>98 %), which can only be obtained by biotransformation.

Biotransformation[13] is always desirable as a green choice wherein the required reaction/s and selectivity are achieved avoiding the use of environmentally unfriendly chemical reagents in a multi-step sequence to achieve the same target conversion quicker, cleaner and to products, which are chemically and optically purer. The biotransformation process either uses microorganisms, whole cell biomass of desired activity or isolated purified enzymes. The process of biotransformation for developing active pharmaceutical ingredients (APIs) is quite tedious as the screening and identification of suitable enzymes from a wide variety of strains are required to convert the substrate into the desired product. Currently most of the important pharmaceutical intermediates are being imported. Hence, establishment of these processes by biotransformation would create a platform in future for the manufacture of other products with similar chemistry. The other advantage would be the possibility of making these products economical, compared to the present market price, and affordable to the Indian industries.

The National Centre for Industrial Microorganism at ***National Chemical Laboratory (NCL)-Pune,*** India had been granted a US patent for the identification of the specific strain of microorganism and its efficient use in the biotransformation of racemic molecules to prostaglandins. Based on laboratory studies at NCL, excellent results were obtained using the mesodiol diacetate as the substrate leading to optically pure 4-(R)-hydroxycyclopent-2-en-1-(S)-acetate with high yields.

Hygeia Labs, ***Pune*** a knowledge driven company tied up with NCL for licensing the aforesaid process for technology demonstration of prostaglandin intermediates under a project, launched in August 2008 with financial assistance from TIFAC. Hygeia aimed to develop the process on pilot-scale to produce at least 50 kg of biotransformed product. The project involved growing of yeast cells in 200L fermenter to get active biomass which in turn was used to manufacture **4R-hydroxycyclopent-2-ene-1-(S)-acetate** from meso-cyclopent-2-en-1,4-diacetate using whole microbial cells as enzyme source. Processing of the bio-transformed product, 4-*R*-hydroxycyclopent-2-ene-1-(*S*) acetate further to intermediate components of prostaglandin (PG) was then carried out by Hygeia Laboratories. The conversion of biotransformed product to prostaglandin intermediates involving a few chemical steps was standardized at lab scale to get the final product with good yield by Hygeia. The technological implications of the innovative process included (i) using a cheap whole cell culture and (ii) carrying out bio-transformation in a fermenter in high concentrations, which lead to commercial feasibility.

The prostaglandins have good market potential not only in India but also at the international level. Biotransformation trials were carried out for pilot plant scale. The global demand for prostaglandins and prostaglandin intermediates are expected to increase. Currently the market for advanced intermediates for maternal health care products alone is ~ USD 500,000. Further, there exists a good demand for veterinary care and other application areas.

The project was successfully completed in July 2010 with the development of the product. Hygeia has supplied the product intermediate at small quantities (~**5 Kgs.** priced at **Rs.5.00 millions**) in the domestic market. The firm has also been working on developing some other advanced intermediates of prostaglandins for higher price realization.

5.3 Process development for production of L-arginine by fermentation

L-arginine, an amino acid considered as the most potent nutraceutical, has numerous functions in the body. It is needed to create urea, a waste product that is necessary for toxic ammonia to be removed from the body. Arginine is considered a semi-essential amino acid because even though the body normally makes enough of it, supplementation is sometimes needed. People with protein malnutrition, excessive ammonia production, excessive lysine intake, burns, infections, peritoneal dialysis, rapid growth, urea synthesis disorders, or sepsis may not have enough arginine. Symptoms of arginine deficiency include poor wound healing, hair loss, skin rash, constipation, and fatty liver. Demand of L-arginine is quite high in national and international market. It has many direct applications in heart disease, wound healing, high blood pressure, migraines, interstitial cystitis. The conventional methodology for L-arginine production suffers from certain drawbacks in terms of less yield and longer production time. Whereas, the fermentative L-arginine production is relatively faster process with improved yields.

The project was launched in March 2010 by TIFAC jointly with ***Jawaharlal Nehru Technology University (JNTU), Hyderabad*** & ***M/s Celestial Labs Ltd., Hyderabad*** as an industrial partner. The project aimed at development of a process for the production of L-arginine from the selected microorganisms. The strain was improved by conventional mutagenesis and recombinant approaches. JNTU had grown mutants for more than ten generations and the mutant organisms were found to be stable. Arginine yields of multi-analog resistant mutant in different media (4 nos.) were studied. JNTU's experiments for reducing expensive beef extract content in the media composition were noteworthy. The experimental results obtained by JNTU at the lab scale (bioreactor volume: 10 lits.) for arginine production (14.92 mg/ml) by using in-house mutant strain were very much encouraging for the industry partner for its scale-up. The scale-up at 150 lits (working volume : 90 lits) was carried out by Celestial Labs at BIT-Mesra using selected efficient mutant strain, optimized media composition and process parameters based on the data obtained from JNTU for arginine production. The average yield of L-arginine obtained was ~16 gms/lits. All the aforesaid technology development activities were monitored by a team of experts inducted from academia, institution of higher studies and a leading energy & petrochemical industry. The project was successfully completed in June 2013.

The global demand for L-arginine has been estimated as **US$1.50 billions per year** with the current market price of **~Rs.3.00 lakhs per Kg**. Celestial Labs plans to set up a production facility for L-arginine with a capacity of **100 Kgs. per year.**

6.0 Conclusion

Various programmes of TIFAC have been unique experiments in technology commercialization in Indian context. Building on the initial experiences, the mechanism of industry-centric technology development had emerged most successful in catering to near-term deliverables. The projects conceptualized following this approach were concluded successfully with products reaching out to the users. The programmes had involved a good number of academicians with excellent expertise in product design & process technology and effectively utilized their knowledge in realizing the applications. The key attributes for the industry centric model such as attractive scheme of financial assistance, technological risk sharing and knowledge-based project monitoring by experts coupled with the market intervention had all helped the projects achieve the threshold of commercialization within a short span.

TIFAC programmes have been catalytic to identification of expertise from academia & research and exposing them to technology/knowledge development activities in SMEs. Some of these academicians or laboratory scientists were later engaged by other industries (not necessarily funded by TIFAC or Govt.) for consultancy services in design & technology development towards adopting newer technologies for commercialization, thus improving the value propositions of the enterprises.

Successful commercialization of technologies requires multiple stakeholders and importantly reduction of risks as perceived by the enterprises faced with financial crunches. The national laboratories or academic institutions often focus on creating linkages related to their expertise only and fail to foresee several other dimensions of the 'technology commercialization network'. These institutions gained from TIFAC programmes by an effective networking while ironing out the complexities of technology commercialization as described here with a few glimpses of processes.

The mechanisms adopted by TIFAC, described as *Technology Intermediation*[4], thus play the key role in assimilating various elements and creating enabling conditions for successful commercialization of technologies. It should be an important element of policy making in developing economies to strengthen the processes of technology intermediation in order to increase the socio-economic impact of investments in S&T/R&D. Technology intermediation could be instrumental in strengthening SMEs leading to their greater contribution to GDP and generation of better employments.

While industry-centric approach[14] appears to be must for successful technology commercialization, it is fraught with certain limitations too. The risk-averseness of SMEs in India and also experienced in most developing countries could be the major constraint due their paucity of disposable funds and competition. Thus the SMEs gravitate to the products with high commercial potential opting for products, which substitute conventional material with newer cost effective ones or different processes etc. Though some advanced technologies have entered the markets of the developed countries in relatively smaller scales, SMEs may not be interested in commercializing those newly (considered at the world level and not India alone) emerging technologies. Another limitation has been that once SMEs have successfully commercialized a product or set of products, they do not immediately pursue developing newer version products with vigour. Lastly, many of the SMEs who have successfully commercialized technologies and secured a profitable share of the total potential market, their aspirations for scaling-up their operations for achieving higher market share are limited.

The latter is primarily due to the limitations of the Indian Innovation System (IIS). Govt. policies towards SMEs, new industries, stability of tax regimes, Govt. purchase procedures etc. are not so supportive for such innovation. Also time periods involved in the plethora of Govt. approvals are long and uncertain to be modelled into a business plan. For more information, *The Global Innovation Index 2012*[15] edited by Soumitra Datta, INSEAD (full report at www.globalinnovationindex.org) may be referred. The Chapter 7 of the aforesaid report on *'Shaping the National Innovation System: The Indian Perspective'* by Y S Rajan brings out the constraints of scale-up. It describes a Chandra-Eclipse of IIS fragility mentioning that unless policy measures and implementation mechanisms are "reformed" to address this crucial scale-up issue, most of the successful technology commercialization efforts will have limited social and economic impact. Even for some limited benefits, TIFAC endeavours and mechanisms in technology intermediation, which lead to a number of successful technology commercialization projects as described earlier in this paper, are useful models to be followed in the coming years in India and other developing economies.

The cornerstone of the industry-centric model along with technology intermediation a la TIFAC, developing an effective networking among the academia/research institutions, standards & certifying agencies as well as the experts from the actual users would continue to play the extremely vital role in any innovation approach for faster knowledge development and user acceptance.

References:

1. Ministry of Micro Small and Medium Enterprises, Govt. of India, msme.gov.in

2. India: Science & Technology 2008, National Institute of Science, Technology and Development Studies (NISTADS), CSIR, full report at www.nistads.res.in

3. Effective Public-Private Partnership for innovation – An Indian Experience, Sangeeta Baksi, Nirmala Kaushik, PR Basak & Soumitra Biswas, presented & published in the proceedings of WAITRO-2008 International Conference on *Turning Technology Innovation into Profit*, Kuala Lumpur, Malaysia, August 12-14, 2008

4. Global Business, Technology and Knowledge Sharing: Lessons for Developing Country Enterprises, N S Siddharthan and Y S Rajan, Chapter 7 & Chapter 9 (Section 9.4), Macmilllan India 2002

5. Report of the Review Committee on Home Grown Technology Programme by TIFAC, February 2012.

6. Performance Materials - Advanced Composites (TMS 036 – Vol. II), 1991 by TIFAC

7. Composites in rebuilding & rehabilitation of Tsunami victims, G Srikanth, S Biswas & S Baksi, Reinforced Plastics, Elsevier (UK), November 2005

8. Composites make train driver's life more comfortable, S Baksi, S Biswas & A Somani, Reinforced Plastics (Vol.51, no.2), Elsevier (UK), February 2007, pp 28-29

9. Composite houseboat helps tourists explore India, S Biswas & G Srikanth, Reinforced Plastics (vol. 50, no.4), Elsevier (UK), April 2006, pp 46-48

10. Artificial Limbs for Physically Handicapped, A Mittal, S Nangia & S Biswas, The Hindu (May 18, 2000).

11. Composites - An Innovative Material for Process Industry, G Srikanth, S Baksi & M Suresh Babu, Conference of Research Scholars and Young Scientists in Chemical Engineering (CRSYS), September, 2004 (pp. 186-192)

12. Certification of Composite Pipes for the Oil & Gas Industry, S Baksi, S Biswas, L Modi, J Shah & SC Lakkad, JEC Composites Magazine, Vol. 73 (June 2012)

13. Biotransformation Technologies for Value-Added Products – Indian Experiences, N Kaushik & S Biswas, International Conference on New Horizons in Biotechnology (NHBT-2011), Trivandrum, November 21-24, 2011

14. Innovation Management - An Indian Experience, Soumitra Biswas & Nirmala Kaushik, Tech-Monitor/APCTT (Sept.-Oct. 2010)

15. The Global Innovation Index 2012, edited by Soumitra Datta, INSEAD (full report at www.globalinnovationindex.org)