Indigenous commercial R&D in advanced ceramics – Retrospect and prospect*

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A review of the status of various products developed by indigenous R&D and other commercialization attempts in the area of advanced ceramics over the last several years in the country is presented, with particular reference to electronic ceramics, because this segment forms the bulk of the advanced ceramic markets. Various issues related to commercial R&D are recapitulated, such as the differences between terms like invention and innovation and technical and product development, etc. Different types of R&D with their stakes and time scales are also discussed. In view of the above ideas and in the context of liberalization, the future prospects for indigenous R&D in the area of advanced ceramics in our country is reviewed.

Although R&D in advanced ceramics and related components has been going on over the last 20–25 years in the country, its requirements towards competitive commercial needs have not been systematically studied and understood. With the dwindling government funding for R&D and with the increasing emphasis towards product-oriented applied R&D, this issue is becoming increasingly significant in recent years. In addition, the onset of liberalization and globalization policies in the country adds an additional challenge to the indigenous R&D, which has to gear up to the exacting global standards. Therefore, the indigenous R&D is somewhat at crossroads of either facing the danger of extinction or gearing up substantially to the ever-increasing demands on it. It is, therefore, relevant to review the different commercial R&D efforts (R&D in defence, space and atomic energy are excluded) in the country in this area, examine critically the factors for success or failure of these efforts, understand the strengths and weaknesses, identify the gaps in our knowledge of product development and related commercialization issues and analyse the future scope in this area in the context of the fast-changing economic scenario in the country.

Markets for advanced ceramics: World and Indian scenario

The commercial interest in any field depends upon its markets. The markets for advanced ceramics can be divided broadly into two areas, viz. electronic ceramics and structural/engineering ceramics (Table 1). The figures indicate that bulk of the markets[1] are for electronic ceramics, a scenario which would continue for another 10–15 years. The table shows that the Indian markets (nearly 75 million dollars) are less than 1% of the world markets. This is nearly 7% of the markets for South Korea[2] (~ 1000 million dollars), which is one of the very fast developing economies in Asia. (It is interesting to note that the population of South Korea is nearly 7% of that of India.) The substantially larger markets in South Korea are mainly due to the boom in the electronics industry, which accounts for nearly 90% of the above markets.

The small indigenous markets give a caution that the investments in R&D are to be made rather discretely keeping the global markets also in view to be able to derive significant commercial benefits. It is also to be understood that considering the heavy investments already made by the advanced countries as well as to some extent by the developing countries in this area, only a very well thought out and highly focused R&D can result in economic benefits. As a corollary, the poor growth of the R&D in this area in our country may also be assumed to be due to the paucity of substantial indigenous markets so far. It is also to be remembered that India spends less than 1% of its GNP on R&D as against the advanced nations, which spend[3] in the range of 2–3%. Also, government spending accounts for most of the R&D spending in India, which is not so in the advanced countries.

Retrospect

Electronic ceramics

Analogous to the world trend, the Indian market's trend for advanced ceramics is largely dominated by electronic ceramics and, therefore, the R&D efforts and investments were also more in this area. R&D efforts towards product development in this area started at NPL, New Delhi, as early as 1960 in the fields of ferrites and ceramic capacitors. Both products have been commercialized. The ferrites were commercialized by Central Electronics Ltd. (CEL), Gaziabad, and the ceramic capacitors by Bharat Electronics (BE), Bangalore, both being public sector companies. This experience, particularly the latter, only helped to show the deficiencies in our product development and commercialization skills and did not seem to result in major economic benefits. (Bharat Electronics had discontinued the process very shortly after the commercial production started and went in for an imported technology.) Some of these deficiencies (well-known by now) are poor skills in mechanization and volume production, poor designing for quality and robustness into the products and failure of tailoring the products to customer requirements and making them cost-competitive.

Table 2 shows the typical products of indigenous R&D in the area of electronic ceramics that are currently in the market. The table also displays the particular organizations which developed/productionized the product, approximate period of their development,

*Paper presented at the 81st Session of the Indian Science Congress, Jaipur, 1994

Table 1. Advanced ceramic markets* (approximate markets in millions of dollars)

Type	World[1]	South Korea[2] (1988 projections)	India[3]
Electronic	9000	~900	66 (2000 M Rs)
Structural/ engineering ceramics	1200	~100	10 (300 M Rs)
	~10 200	~1000	76

*1992 figures.
[1]Ceramic Industry Magazine, Aug. 1993.
[2]*Am. Ceram. Soc. Bull.*, 1988.
[3]Author's estimates.

Table 2. Typical electronic ceramics products developed indigenously and currently available in the market

Product	Organization	Development period (approx.)	Approx. cost of finished components[3] (Rs/kg)	Market status
Soft ferrites	CEL	1960–1970	×	Okay for some indigenous markets
Varistors	Elpro Intl, Pune**	1982–1986 (4 years)	~10×	- do -
Thermistors	BE, Bangalore (PTC/CTV)*	1986–1992	~100× (high-end products)	- do -
	Thakarsons, Pune (NTC)*	N.A.		- do -
	Translektra (heater PTC)	N.A.		Position not clear

*Prior exposure to an imported disc ceramic capacitor technology.
**Developed by a group who had a substantial exposure in similar manufacturing plants abroad.
N A. Not available.

and their current market status. Commercialization of ferrites was started by CEL, based on NPL know-how. The efforts were started without any prior manufacturing base and therefore the product development times were rather long. Requirements for high-end applications such as high-frequency ferrites for electronics and telecommunication markets do not seem to be fully met. After this effort, quite a few companies in the private sector have gone in for foreign collaboration to produce soft ferrites in the country.

The next product which is successfully commercialized and currently in the market is the varistor from Elpro International. The product has been developed for the Indian markets largely with indigenous machinery, by people who had exposure to similar plants abroad. Moreover, they had the benefit of the manufacturing base of lightning arrestors (based on ZnO) which M/s Elpro had earlier set up with collaboration from General Electric Company, USA.

A fair amount of indigenous technology was successfully developed for different products in the thermistor family. While Thakarsons, Pune, have successfully commercialized the NTC thermistor, Bharat Electronics, Bangalore, has done so for a relatively more challenging product, viz. the PTC thermistor for the colour picture tube degaussing. The process for the latter involves developing techniques for doping ppm levels of dopants in the ceramic homogeneously, reproducibly and inexpensively, designing the compositions for manufacturability, designing of the process to maintain high purity all through the processing steps, and designing an appropriate and inexpensive sintering technology to achieve the required properties and microstructure on a manufacturing scale. More recently, Translektra Domestic Products, Bombay, has announced successful commercial development of the PTC device for the mosquito-repellent heater market (newspaper announcement). The exact status of this effort is still not clear.

The Thakarsons and the BE group had a prior exposure to an imported ceramic capacitor production line, which was helpful in evolving the production technology for the thermistors. The Translektra group also apparently had some amount of prior manufacturing experience.

From the above case studies, the factors for commercial success of product development are inferred[4], as shown in Table 3. The table shows different R&D efforts that did and did not result in successful commercialization. The case studies include the NPL process for ceramic capacitors, the BE process for piezobuzzer and for PTC, and the fine particle technology of TIFR. In cases where the different criteria for commercial success were not met (Table 3), the outcome was poor. It is interesting to note that the different drawbacks associated with the piezobuzzer process of BE were nearly the same as those of the NPL process for ceramic capacitors, although the former was attempted nearly 20 years after the latter. This observation clearly indicates that the absence of planned effort to fill up the gaps or make up for the weaknesses in the total process of commercialization of R&D over the years has led to failures. Mostly, the R&D component (technical development component) is overemphasized and the manufacturing and marketing components are not given adequate attention in the total product development process.

In addition, all the products which could be successfully commercialized had a fairly simple fabrication technology, viz. the dry pressing process. Some involve, additionally, spray drying and screen printing processes, which are also relatively simple. Therefore, suc-

Table 3. Factors for commercial success of product development

Factors for commercial success	Ceramic capacitors (NPL know-how supplied to BE)	PZT buzzer (BE)	PTCR process (BE)	Fine particle technology (TIFR, NCML)
Low-cost raw materials	OK	OK	OK	Not OK
Cost-effective process/product with respect to market needs	Not OK	OK	OK	N.A.
Low capital costs	OK	OK	OK	N.A.
SPM capability	Not OK	Not OK	OK	N.A.
Implementation of quality concepts	Not OK	OK	OK	N.A.
Company's business objectives	Fits	Does not fit	Fits	No commercial tie-up
Commercial outcome	Not OK	Not OK	Appears OK	Not OK

N.A. Not applicable.
NPL, National Physical Laboratory.
TIFR, Tata Institute of Fundamental Research.
NCML, National Chemical & Metallurgical Laboratory.
SPM, Special-Purpose Machines.
PZT, Lead Zirconate Titanate.
PTCR, Positive Temperature Coefficient Register.

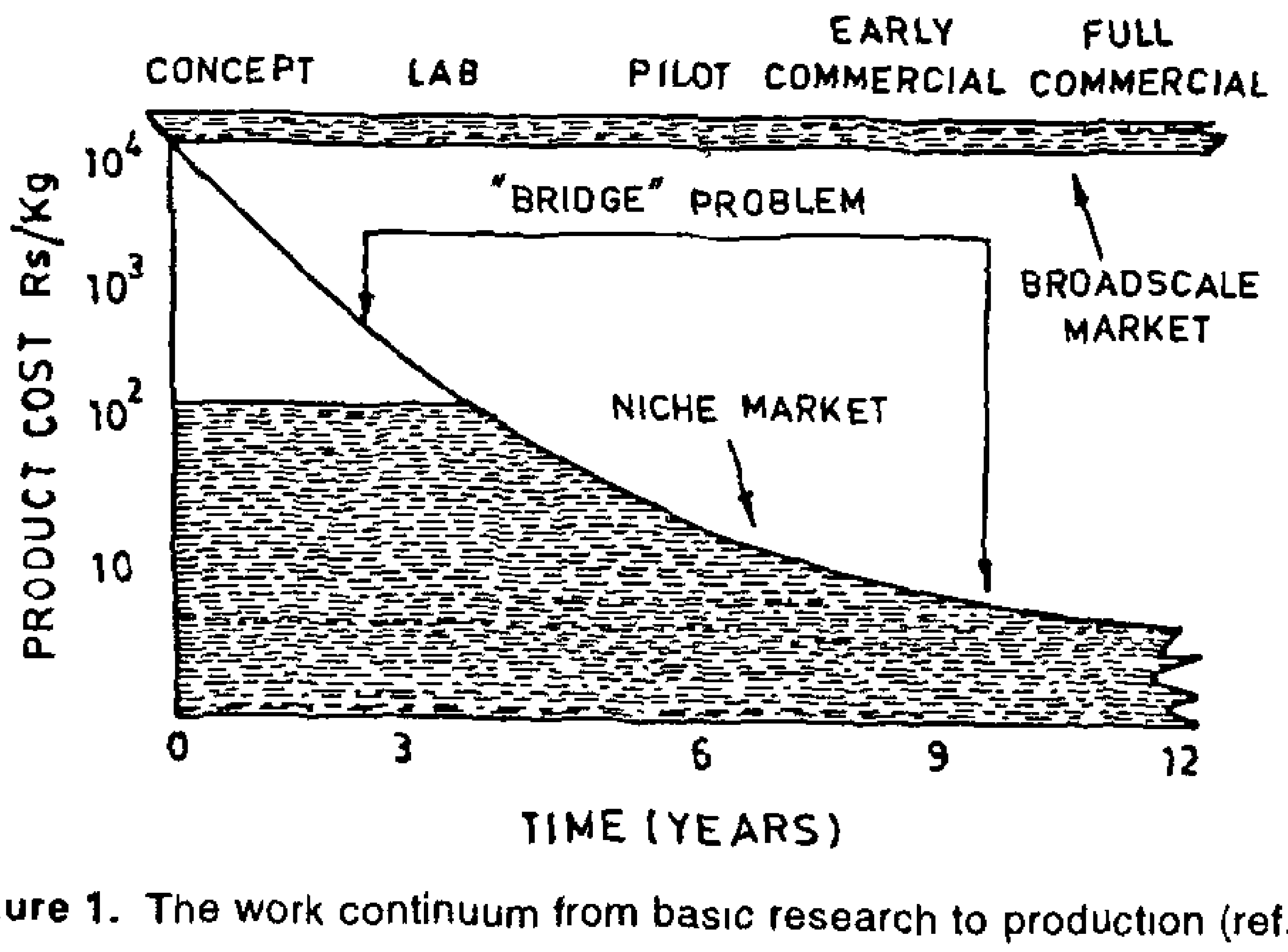

Figure 1. The work continuum from basic research to production (ref. 5).

cessful commercialization of indigenous R&D has been possible so far only in the case of fairly simple fabrication technologies. Secondly, success rate was high only when there was some prior exposure to some well-developed imported manufacturing processes existing abroad.

Thus, successful product development involves a number of issues in addition to mere scientific activity. This aspect is well brought out in Table 4, in which R&D efforts by different institutions in the country on PTC ceramics are indicated[4]. It is clear from this table that in addition to the scientific R&D activity, a number of steps, such as process development, product development, volume production, quality, cost and marketing issues, are required for successful product development. The work continuum from basic research to production is clearly exemplified[5] in Figure 1, which shows the varied efforts put in by the respective organizations involved during the course of commercialization of a product, starting from basic research.

In addition to the above major efforts, commercialization efforts were done on some other PTCs and PZT ceramics with varying degrees of success. For example, the PTCs for motor application were commercialized by a small-scale unit in Pune (although the product needs further substantial R&D for improving its quality and reliability). Likewise, BE, Bangalore, is at an advanced stage of development of the PZT ceramics for sonar applications and dielectric resonators for microwave communication applications. Central Glass and Ceramics Research Institute (CGCRI), Calcutta, appears to be in a similar position for some PTC-based sensors. TRDDC, Pune, is on the threshold of commercialization of ZrO_2 sensors for heat treatment furnaces. The Department of Electronics has invested some money on product-oriented R&D work in electronic ceramics in some of its R&D centres (C-MET). From the above, it is clear that, of late, a fair amount of attention is being bestowed for enhancing commercialization prospects of the respective products in the area of electronic ceramics with occasional successes.

Other advanced ceramics

Apart from electronic ceramics, some R&D efforts were made in other areas of ceramics. For example, a novel fabrication route for fabrication of ceramic foam filter was commercialized by M/s Carborundum Universal, Madras, from a process developed by Tata Research Development and Design Centre (TRDDC), Pune. It is used for filtering of molten metals The process was patented by TRDDC in India. CGCRI, Calcutta, has done a fair amount of work on SiC- and Si_3N_4-based ceramics, particularly by pressureless sintering. But there does not seem to exist significant commercialization attempt of this work.

Ceramic powders

More recently, Associated Cement Co (ACC) R&D Centre at Thane has suc-

Table 4. Status of R&D and commercialization of PTCR ceramics in different institutions in the country

Activity	IISc Bangalore 1977–1982	IIT Madras 1976–1981	IIT Kharagpur 1982–1987	CGCRI Calcutta 1988 onwards	BE Bangalore 1986 onwards
	Institution and periods				
Scientific activity	Understanding of PTC behaviour, chemical route of powder preparation	BHEL/CSIR-sponsored PTC thermistor process development, chemical route of powder preparation	Microstructural effects and complex plane impedance analysis, traditional route of powder preparation	PTC thermistor process development, chemical/traditional route	Microstructural engineering of PTC ceramic, traditional route of powder processing
Technological activity					
Process	No	Yes	No	Yes	Yes
Product	No	No	No	Not sure	Yes
Commercial activity					
Volume production	No	No	No	No	Yes
Quality	No	No	No	No	Yes
Cost	No	No	No	No	Yes

Table 5. SWOT analysis of indigenous R&D for advanced ceramics

Strengths
- Excellent raw material base
- Relatively inexpensive R&D manpower

Weaknesses
- Too diffuse and not largely market-driven
- Too small markets
- Too long development times
- Poor commercialization skills
- Hardly any experience in putting winning products into the market

Opportunity
- Changing government policies
- Advanced engineering ceramics is still an evolving area even abroad

Threats
- Competition

cessfully set up pilot production facilities for the production of high-quality powders of Al_2O_3, ZrO_2, PSZ, $BaTiO_3$, etc. This effort is completely from indigenous R&D and the powders are under evaluation by different prospective customers. Laboratory processes for the development of Al_2O_3 and ZrO_2 powders are also under development at the Ceramic Technological Institute of BHEL, Bangalore. Sol–gel-derived powders were developed by CGCRI and Bhabha Atomic Research Centre (BARC). Naval Chemical & Metallurgical Laboratory (NCML) and Tata Institute of Fundamental Research (TIFR) also have R&D programmes on ceramic powders.

In retrospect then, the indigenous R&D and commercialization in advanced ceramics have so far taken place largely in the area of electronic ceramics. This is entirely due to the prevailing markets, a trend which is similar to that in other advanced and developing countries. Some successes were achieved, particularly when the ceramic fabrication processes involved were relatively simple and when there was prior exposure to some related imported ceramic technologies.

SWOT analysis

However, with the increasing liberalization and globalization policies of the government, the future R&D has to be increasingly competitive to be of any relevance and use. Table 5 gives the SWOT analysis of the current indigenous R&D in advanced ceramics. From the table it is clear that the only strength we have, in addition to the basic raw material strength is the relatively inexpensive manpower. The weaknesses are quite a few and the most conspicuous of them all is the lack of adequate skills in process escalation and development of competitive manufacturing technologies.

Different commercial R&D issues

Invention and innovation

When dealing with the subject of commercial R&D, it is useful to recapitulate the difference between the above two terms. While invention can be regarded as a discovery which has hitherto not been existing, innovation is the whole process of moving new ideas, products or services successfully into the economy[6]. Thus, invention is only a part of innovation and it is the latter which results in commercial gains and not necessarily the former.

Technical development and product development

These two terms are rather synonymously used. But it is useful to understand the difference as indicated by Fine[7]. Technical development is purely internal for an organization. For example, in the case of advanced ceramics, it involves development of compositions, relationships between compositions and properties, process design, product design and fabrication, serviceability, product testing under service conditions, safety, appearance, etc. On the other hand, product development involves activities like development of

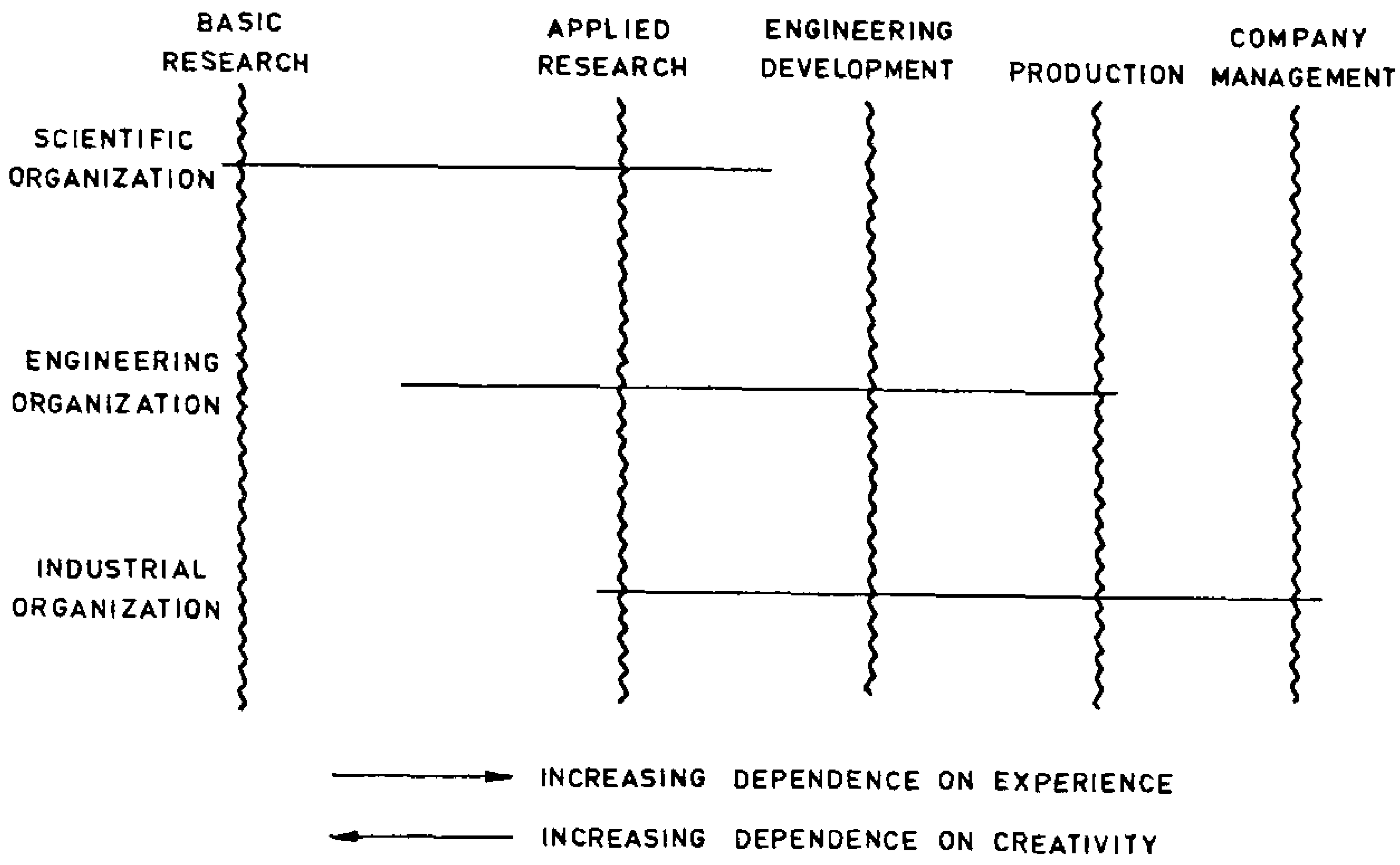

Figure 2. Typical advanced materials learning curve (ref. 9).

Table 6. Success probability of R&D at different stages[10]

Technical feasibility	Marketing decision	Market response
Success	Launch	Success
0.6	0.55	0.4
Failure	Drop	Failure
0.4	0.45	0.6

The final probability of success is 0.6 × 0.55 × 0.44 = 0.132.

ongoing communication between marketing, manufacturing and technology people; it also encompasses other requirements like helping to verify product requirements and assumptions with the customers, helping to assess competitive threats and responses about the product, helping in the design of competitive manufacture and sustainable differential product advantage, etc. Therefore, total product development involves a number of commercial issues in addition to many technical issues.

Customer's priority vs scientists' priority

The customer's priorities[8] are generally cost, size, geometry, delivery and appearance, whereas the scientist's priority is achieving technical excellence in the job he does, for example, imparting as good properties to the ceramic as possible

Costs, time scales, stakes and types of R&D

It is generally acknowledged[9] by companies involved in materials technologies that for every $1 spent on research it will cost $10 to develop a specific product and $100 to even $1000 to take the resulting product to market. The typical time scales involved for converting a concept into full-scale production and the cost of the product at different stages of the R&D and productionization process for a typical advanced material are indicated[9] in Figure 2. The process of concept to pilot production takes nearly 5–8 years and almost beyond 10 years to full commercialization. The product cost keeps reducing gradually over this period.

The commercial success probability of a general R&D effort at different stages of commercialization is indicated in Table 6. It could be[10, 11] as low as 13%. However, the product success probability in a well-managed product development effort in a typical company in the field for some time could be as high as 65% according to American Manufacturers' Association[12].

High-tech R&D innovations could be categorized[6] into two types. The heavy high-tech innovations (type I) involving high investments and long pay-off periods, and light high-tech innovations (type II) featuring low investments and short development cycles According to Akio Morito[13], the famous Chairman of the Sony Corporation (Japan), success in type II innovations results from a high degree of creativity not only in R&D but also in manufacturing and marketing. The success is all the more striking if all these three functional groups work simultaneously towards the product development goal. This approach is called concurrent engineering, well exemplified by Fine[7] in describing the successful product development efforts of two important products of Corning, viz. the glass laminate system (Corelle) and the K-richeterite glass ceramics (Pyroceram).

The case for profit-making R&D

In India, essentially two types of R&D are being carried out. One is R&D leading to imitative products, largely carried out in the industry for the protected indigenous markets, and the second is the basic R&D in the academic and scientific organizations for generating knowledge and sustaining the country's long-range R&D culture with a somewhat tentative aim of achieving major breakthroughs, although the mechanism of generating income from such breakthroughs is not very much understood. The most profitable R&D, however, as proved repeatedly by the Japanese, is the R&D leading to innovative products from the already existing inventions designed with low investments and short development cycle times (type II). In a globalized economy, one has to learn to do this type of R&D to derive fast economic benefits from the resources spent.

Prospects

Indigenous R&D in advanced ceramics – motivation and scope

In the global scenario, the main motivation for commercial R&D is to establish newer and more lucrative markets While this is the main motivation for countries like USA, Japan and Germany, who have already invested heavily in this area, the motivation for R&D in our country so far appears to be largely not to lag behind in the international scene and to prepare for the future. Right now the Indian markets for advanced ceramics are only too modest and so far we have not achieved substantial success even in electronic ceramics to build further on it for delivering winning structural ceramic products to the market-place. But if an R&D base is developed, it could help in realizing, in due course, the potential of the structural ceramic products as enabling products to gain overall performance and cost advantage in different systems (e.g. as possible replacement of metal parts) Indigenous R&D is, therefore, expected to address itself to such a challenge. The different segments of the markets in advanced ceramics in India are expected to grow in the following order, viz. ceramics for electronic and telecommunication applications, ceramics for the engineering industry, ceramics for use in pollution control (for example, catalytic converters, etc.) and finally ceramics for automotive applications and energy conservation needs

Considering the overall scenario, the future scope (perhaps for the next five years) for indigenous commercial R&D in advanced ceramics appears to be in the following directions Development of imitative products with innovative processes, use of relatively inexpensive raw materials, use of inexpensive machinery, development of methodologies for faster R&D development times, and R&D for quality improvements of the currently manufactured products in the country.

Profit-making product development efforts will be the name of the game in the future, requiring a thorough mastery of the complete process of innovation starting from R&D to marketing. In addition to improved processes for the existing products, new products may have to be created (in view of the GATT agreement) to gain substantial commercial benefits of R&D. This means 'technical supremacy' and 'innovativeness' over the competing products from around the world and well-balanced products of high 'reliability' brought as quickly as possible into the market. In addition, this also means good entrepreneurial management for the companies in this business and innovative manufacturing and marketing ideas for the laboratories engaged in this work. In addition, it has also to be kept in mind that competitive advantage is not achieved by technology alone but also by how well it is related to the needs of the customer.

Summary and concluding remarks

Although product-oriented indigenous R&D in advanced ceramics started as early as 1960 (at NPL, New Delhi, for development of ferrites), there have so far been no significant commercial gains from the indigenous R&D efforts. A critical look indicates that there does not exist much planned and comprehensive effort towards this goal keeping in view all the relevant issues in mind for a successful product development effort, viz. R&D, manufacturing and marketing. There appears to be an over-emphasis on R&D or technical development issues, neglecting the manufacturing and marketing issues. Secondly, there appears to be more of a tendency to commit to long-range high-tech innovations (involving high stakes and risks), neglecting the methodology of mastering and thereby deriving the economic benefits from short-range light high-tech innovations R&D in commercial organizations has so far been geared mostly towards imitative products. But, with increased liberalization and globalization of the economy, substantial innovative skills in R&D, manufacturing as well as marketing are required to derive significant commercial benefits from the indigenous R&D efforts. Since advanced ceramics (particularly, structural ceramics) is still an evolving area in the developed countries, there is still hope for indigenous R&D to make a mark in our country. Finally, when we are in the process of getting hooked on to the global markets, it is important to be vigilant about the fact[6] that 'the global game is constantly changing in ways that can land even the largest and ablest practitioners gasping on the shore'.

1. CI Staff Report, *Ceram Ind*, 1993, **43**(8).
2. Jang, S. D, *Am Ceram. Soc. Bull*, 1988, **67**, 1531–1532.
3. *Business World*, 1993, **18**(9)
4. Prasad, V. C. S, *Trans Indian Ceram Soc.*, 1991, **50**(3), 60–62
5. Van Atta, C. M, Decker, W. D and Wilson, T., in *Career Management, A Guide to Combating Obsolescence* (ed. Kaufman, Harold G), IEEE Press, Washington, 1975, pp 122–200
6. Pilditch, J, *Winning Ways*, Viva Books, New Delhi, 1992, p 188
7. Fine, J., *Ceram Eng Sci Proc*, 1992, **13**(1–2), 190–195
8. Ford, R. G, *Ceram Eng Sci. Proc*, 1993, **14**(7–8), 36–39.
9. Sheppard, L. M and Barks, Ron, *Am Ceram Soc. Bull.*, 1993, **72**(4), 89–92
10. Mansfield, E., *Research and Innovation in the Modern Corporation*, W W. Norton, New York, 1971, p 209
11. Prasad, A J, *Technology Policy for Industry*, Allied Publishers, Bombay, 1979, p 77.
12. Jones, J T, *Ceram. Eng Sci Proc*, 1992, **13**(1–2), 217–221
13. Morito, Akio, *Made in Japan*, Fontana, an imprint of Harper Collins Publishers, Hammersmith, London, W68JB, 1988
14. Cantagrel, M, *Am Ceram Soc*, 1986, **65**(a), 1248–1249.

ACKNOWLEDGEMENT The author acknowledges the encouragement and support given by Prof. E. C. Subbarao, Executive Director, TRDDC, during the preparation of this paper

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