From Concept to Commerce: The Challenge of Technology Transfer in Materials

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Introduction

Many millions of dollars are invested annually in materials science research and development in U.S. universities. Both the universities and the sponsors, either government or private industry, have enormous incentives for the R&D efforts to become commercial. For private industry a successful development means new or improved products or processes and ultimately more profits. For the government, successful materials development can lead to improved hardware or operations efficiency and lower costs. For a university the payoff can be more than economic.

Ideally, successful commercial development leads to royalties paid to the universities in the form of the most precious of assets — unrestricted or flexible income. Students and faculty can benefit from the additional income, both privately, depending on university policy, and through their departments. However, benefits can also accrue in the form of experience and knowledge gained while participating in the technology transfer process from university to corporation. Students who take part in such efforts gain invaluable experience in preparing and defending patent applications, designing and developing prototypes, and they are exposed to economic and legal issues that are seldom taught in the classroom. They become more valuable graduates. Taking part in a technology transfer case history is a far more effective form of learning than reading about it.

These benefits to a university are offset by a number of potentially negative factors. The space, time, personnel, equipment, and deadline pressures involved in commercialization are often beyond the capabilities of a university program. However, these limitations may not be realized until the effort has begun, and it is costly to stop in midstream, as is discussed below.

Thus, university administration and faculty are faced with a dilemma. On one hand, patents, royalties, and commercialization contracts appear to be one of the few solutions to the ever increasing need for new income and especially flexible income at a university. On the other hand, the personnel, experience, or physical resources are seldom available at a university to achieve commercialization efficiently or effectively. The most common solution to the dilemma is an arm's length licensing of the technology. This solution has its own perils and is often difficult to control and enforce. This article examines the relative merits of the alternative routes for commercialization based on the requirements for effective technology transfer. It is based on my personal experience with the commercialization of several medical, dental, optical, electronic products,[1] combined v consulting experiences and discuss on business start-up efforts of var faculty and venture capital friends.

Rate of Technological Change

One of the major difficulties fa today in commercializing new tech ogy is the accelerated rate of tech ogy change.

Man's progress is often measure technological change. These steps shown in Figure 1a, are usually mar by changes in materials. From pre-his to the present day, the information tent embodied within each new clas material has dramatically increased. knowledge required to control fire drafts and clay to make earthenw pottery was many times greater than used to make implements from nat materials such as bone, wood, or fl As ceramics and manmade materials w born, mankind was changed foreve

This was the seminal change of civil tion. The birth of ceramics was immen more significant than just having be bowls, jars, and pots. It was the change leading to man's control *over* ture rather than accepting living *with* ture. The irreversible change of clay ceramics, or natural into unnatural, t had profound philosophical implicati

The knowledge necessary to w purify, and alloy metals built prog sively upon that developed by the e potter and led to the Bronze Age Iron Age. Each age, thereafter, built gressively upon the earlier until stag tion in western civilizations occur during the Middle and Dark Ages. H ever, following the Renaissance and onset of the Age of Science, the kno edge content associated with the de opment of new materials increased a exponential rate or more (Figure 1).

Technological Half-Life

An important consequence of t rapid increase in the rate of change i ever *decreasing* technological half-life new developments (Figures 1b and At one time, advances in new mater might have lasted for thousands, o least hundreds, of years. Today, the span of growth of a new developm from concept to production through ra expansion and then to maturity and slow growth of a commodity (Figure is measured in decades.

By the 21st century, a technolog half-life may only be a few years or l Many fields of materials are already past their technological half-lives. Glass containers, structural clay products, whitewares, refractories, and enamels are all examples of ceramic industries where growth seldom exceeds the growth in the GNP, if at all. Ferrous metals, copper, etc. are also at the maturation end of their technological lifetimes. For some materials, stagnation has set in and the growth curve has a negative slope. The technological half-life for these products was in the range of 30 to 40 years. Most of the R&D efforts in these fields past their technological half-life consists primarily of the small evolutionary steps required to just maintain their positions as slow-growth commodities.

Materials science, in the broadest sense, has been equally seminal in the birth of this technological explosion as it was in the birth of man's first technology. The rapid rate of change in information content of new materials parallels the rapid rate of information transfer within society. The two rates are interconnected and lead to the autocatalytic explosion of technological development shown in Figure 1c.

Without the technology of high performance insulation and dielectric isolation, microencapsulation and packaging, high storage capacitors, ultrahigh purity crystal growth, chemically doped semiconductors and many more, there would be no microelectronics or information processing field today. The next major expansion in microelectronics is very likely to involve high T_c ceramic superconductors, which require the application of advanced ceramic processing technology to produce useful products. Recent developments in high temperature ceramic matrix composites and transformation-toughened ceramics indicates that this field is at the threshold of revolutionizing high temperature structural applications of materials. Carbon-carbon composites are already making a major impact on aircraft structure and turbine design. The development of bioactive ceramics, glasses and glass-ceramics and molecular control of polymer surfaces has begun to revolutionize biomaterials and many areas of medical and dental treatment. Likewise, recent advances in solid state lasers, sol-gel derived optics, quantum confinement, and nonlinear optical materials are beginning to yield important advances in optical based communications and information processing systems.

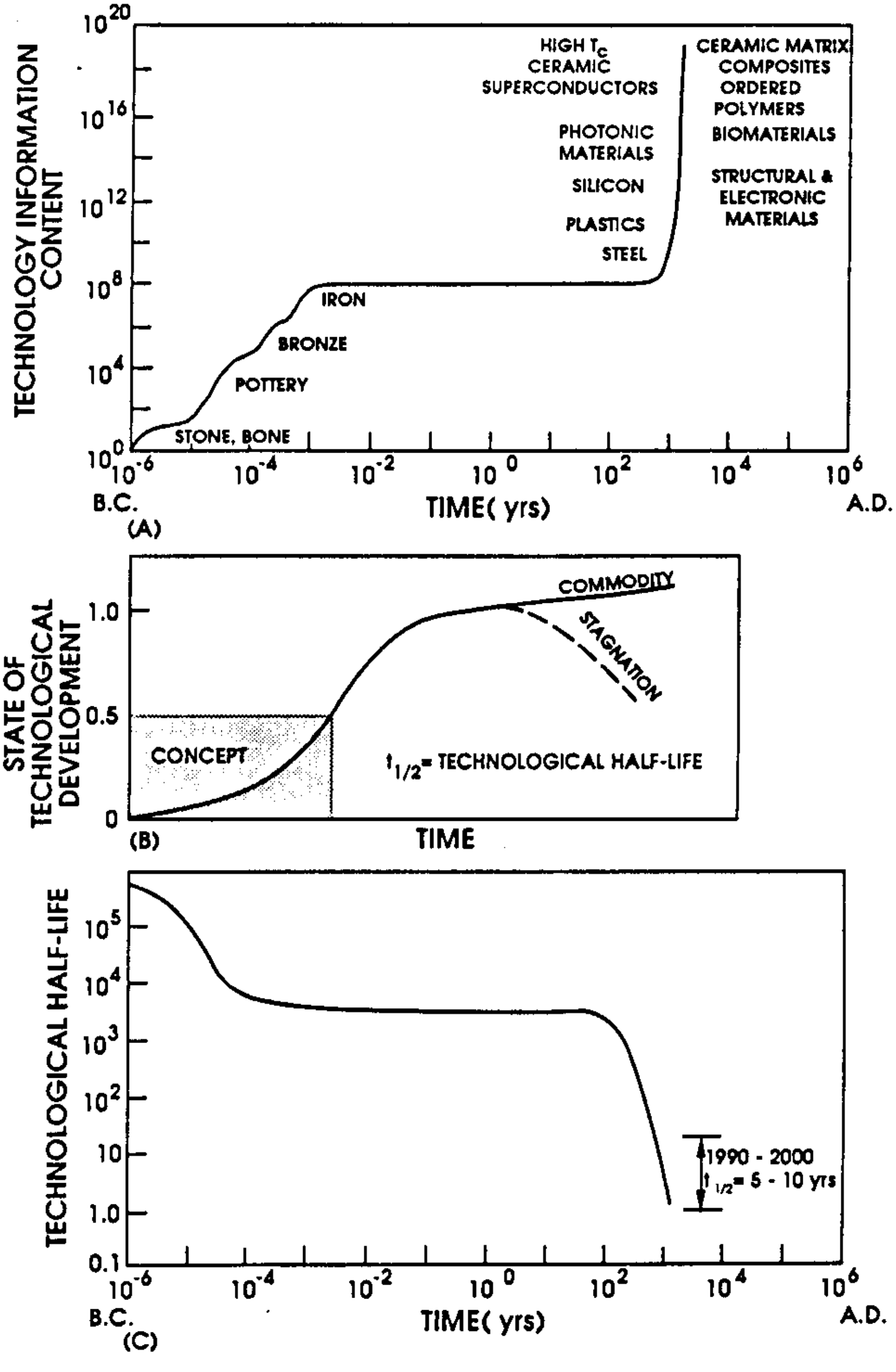

Figure 1. The (a) rapid change in materials technology and (b,c) its effect on technological half-life.

Thus, the fields of superconducting ceramics, ceramic matrix composites, toughened structural ceramics, multifunctional polymers, biomaterials, and photonic materials are all at the earliest stages of their technological lifetimes. Thus $t < T_{1/2}$ for these new materials. However, the rapidly decreasing value of $T_{1/2}$, Figure 1c, for *all* technological developments makes it progressively more difficult to project a technological

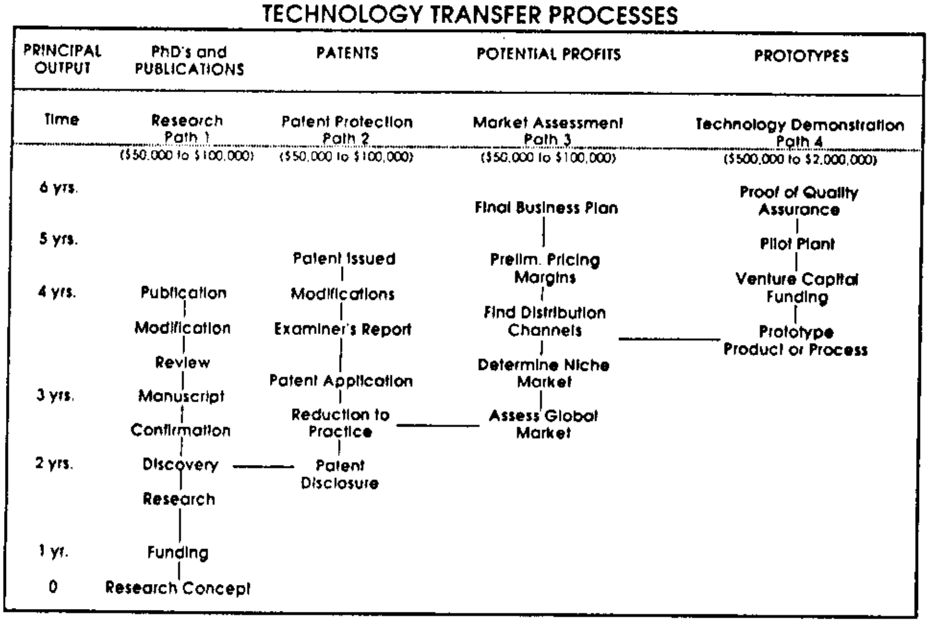

Figure 2. Four primary pathways required for technology transfer.

half-life for any singular new development, even ones as exciting as those listed above.

Technological Transfer

The uncertainties of technology transfer make it difficult for materials science and engineering programs to meet the challenge of rapid change within a university. Technology transfer is often considered to be like death and taxes, i.e., inevitable. In fact, the technology transfer process is both long and complex. Figure 2 summarizes the many steps involved in bringing a research idea from concept to commercialization.

There are four primary paths in achieving technology transfer, each with a distinctly different principal output:

Path	Output
Research	PhDs and Publications
Patent Protection	Patents
Market Assessment	Profit Potential
Technology Demonstration	Prototypes

All four paths must occur in order for a concept to become a commercial success, i.e., to become a product which can be produced and sold in the marketplace with a reasonable return on investment. Each technology transfer path has a time line which is governed by the serial sequence of steps indicated in Figure 2.

Although a specific length of time is indicated for the steps shown in Figure 2, in reality the distribution of times is unique for a given product and organization. However, the time lines shown in Figure 2 tend to skew toward the short end of the distribution and so can be used as a good measure of effective technology transfer. If time increments are longer than those shown, there is likely to be a problem somewhere in the organization.

In practice, the length of time for each of the four paths shown in Figure 2 is close to being optimal. It is seldom possible to decrease the length of time required for either the research, patent protection, market assessment, or technology demonstration phases of a new product, assuming that the product involves substantially new technology. Improvements in previously existing processing or products take perhaps a third less time in the technology demonstration phase because the pilot plant facilities already exist. However, the time lines for R&D and patent protection are nearly invariant, regardless of the level of innovation being pursued. Also, experience shows that it is seldom possible to short-circuit any of the individual steps in Figure 2 without suffering expensive delays later.

Figure 2 shows technology transfer as four parallel paths. It is optimal to pursue all four paths in parallel, rather than in sequence, for several reasons: (1) shorter cumulative time, (2) feedback of information between paths, (3) maintenance of momentum, and (4) lower total cost.

If it is possible to pursue the four technology transfer paths in parallel, as shown in Figure 2, then the cumulative time for a successful technology transfer process is approximately six years. However, if it is necessary to complete each path prior to commencing the next, the cumulative time is more than doubled to 12 years. Often this is the case because the costs associated with patent protection and technology demonstration are usually considerably larger than research costs. Consequently, new layers of management become involved in the decision making process as one moves from Path 1 > 2 > 3 > 4. Since the project costs of Paths 2-4 are substantially higher than usually budgeted in universities, the time required to evaluate the project and also the number of people required to evaluate go up proportionally. The probability of approval goes down proportionally.

A combination of factors often leads to a long serial technology transfer process. The major impedance step in the serial process is the transfer from Path 3 > 4. The level of financial commitment goes up by a factor of 10 at this point. However, cost is not the only barrier in moving from Path 3 > 4. Personnel, management, and facilities are equally important factors.

In order to achieve a demonstration of the technology (Path 4) it is essential to create a team composed of the scientist(s) who originated the discovery, engineers capable of scaling-up the technology and experienced in designing the requisite equipment, along with technical staff, and management. Experience, skills, attitudes, responsibilities, and temperaments differ greatly among such a team. Consequently, considerable time can be invested in achieving an acceptable schedule, plan of action, budget, and commitment to "make it work."

Most of the time the technology will not work in the demonstration scale without a number of trials. Consequently, feedback of information from the technology demonstration team to the science team and vice versa, i.e., Paths 1 > 4, is essential. However, by this time creative scientific personnel will have already moved on to other interests and are not enthused about returning to an "old" project when problems arise. The net effect is a lengthening of Path 4. These difficulties can arise whether the technology transfer effort occurs within the university or with an "arm's length" licensing agreement between the university and a corporation.

In most cases the funds to pursue a Technology Demonstration project will not be approved without completion of a marketing and commercialization study, Path 3. The marketing analysis will attempt to project: cost/benefit ratios, capital required, size of market, time to reach the market, percentage of market penetration, competitive position of the new technology, lead times over the competition, profit margins, effect on existing corporate products, etc. Most university science and engineering departments do not have the staff or experience to make this analysis.

The greater the advance of the new technology, the more difficult it is to make these marketing and commercialization assessments. Therefore, the better the technology the greater is the risk and the longer is the time required to pass judgment that it should be supported to enter Path 4, and become a Technology Demonstration Program. One dominant mode of dealing with a high risk decision is to postpone it. Again, the effect is to lengthen the initiation of Path 4 and the overall technology transfer time line.

Thus, there are two primary difficulties in pursuing Paths 2, 3, and 4 entirely in parallel: (1) the 5 to 10 increase in cost of moving from prototypes to pilot-plant scale operations, and (2) the need to complete market assessments before large budgets can be approved. Consequently, the staggered parallel paths (2 > 3 > 4) shown in Figure 2 are required by economic realities.

The cumulative time for a staggered parallel technology transfer program (t^{P}_{tt}) is approximately six years; for a serial technology transfer program (t^{s}_{tt}), approximately 12 years. It requires a very high level of organizational efficiency and substantially greater risk to reduce these figures to shorter times. It is extraordinarily easy for the time lines to lengthen.

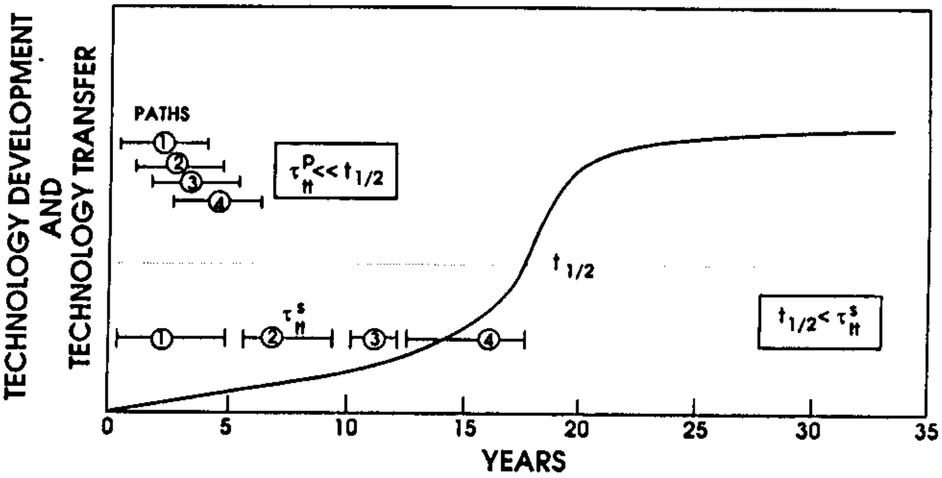

Figure 3. Comparison of parallel vs. serial technology transfer paths with technological development curve.

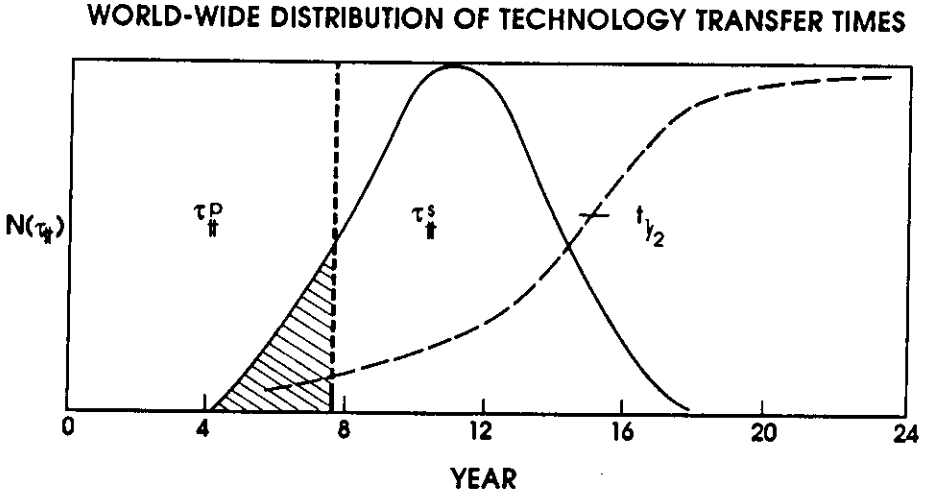

Figure 4. Distribution of technology transfer times compared with technology development curve.

The Problem

Comparing Figures 1 and 2 identifies a serious problem. For a given field, as $T_{1/2}$ decreases it approaches t_{tt}. Consequently, when $T_{1/2} \leqq t_{tt(i)}$, a development program will have reached its technological half-life before it is even out of the pilot plant stage. This is indeed possible because of two factors: (1) There are an exponentially growing number of alternative developments being pursued simultaneously; and (2) there is a distribution of t_{tt} for each alternative. This competitive situation is illustrated in Figure 3, where the time curves for serial t_{tt} and staggered parallel t_{tt} are compared with the technology development curve.

Consequently, development alternatives with a short t_{tt} will enter production and rapidly achieve market dominance while competitive developments are still within Paths 3 and 4 in the technology transfer process.

As indicated previously, any given technology transfer program is in fact competing with many other programs worldwide. Each program will have a characteristic value of t_{tt}. The distribution of t_{tt} is compared in Figure 4 with the technology development curve. It is apparent that only the programs skewed to the short end of the distribution will share in the rapid growth and rapid return on investment.

Thus, efficiency of technology transfer and speed of response to new developments become the major factors for commercial success.

This is a dramatic change from the

past (see Figure 1a) when proximity or quality of resources, size or skill of manpower pool, cost of energy, size, proximity to markets, availability of capital, or government subsidy were the dominant factors for success of a business.[1-3]

The materials industry in the United States and Europe receives fairly poor marks in recognizing and responding to this challenge of rapid change. There is relatively little effort in evidence that the traditional materials industry is accelerating technology transfer processes. The emphasis remains on large plants with large capital investment and very slow response times to change. The investment in basic processing R&D is far lower than required to maintain parity in rapidly developing technical areas. There is in general too little freedom, imagination, and flexibility in R&D directions.

The Solution (Perhaps)

Most importantly, there are very few long-range R&D and technology transfer collaborations between materials firms, universities, and the U.S. government. A few such programs have been organized but in general they do not have sufficient funding or personnel or industrial commitment to have a major impact on this problem.

However, collaborative programs are a step in the right direction. Existing programs should be doubled or tripled in size and a minimum of 5 to 10 new advanced materials R&D programs should be established with interdisciplinary faculty, staff, and students involved. However, I submit that for such interdisciplinary programs to be successful they must be organized to pursue all four technology transfer paths in an optimal staggered parallel manner.

This requires that budgets be approved with sufficient funds to pursue Paths 2, 3, and 4 without long and costly delays. It also means that such programs should have market analysis teams associated with the program from the start in order to minimize the Path 2 > 4 delays. The critical size and budget for such an integrated enterprise is a factor of five larger than most collaborative programs in existence. As a result, most so-called collaborations seldom, if ever, move past (1 > 2) in their payoffs. Path 3 is seldom organized and Path 4 is commonly pursued through licensing arrangements with little incentive to utilize university expertise. The "Not Invented Here" syndrome stifles progress even if there are corporate benefits to move quickly through Path 4.

Conclusion

In the age of ever decreasing technological half-lives, it is extremely important to utilize all available resources to bring about the rapid commercial utilization of technology developed in universities. If the United States is determined to compete in the worldwide market for high-tech products, then it must realize the full benefits of collaborative means of product development.

This requires recognizing the economic requirements *and* risks of technology demonstration projects. It also requires organizing university programs so as to share those risks among corporations and/or venture capital firms. The cost of sharing those risks is to decrease the potential financial returns on the technology to the university. The cost of not sharing the risks, or delaying the decision, is to lose the competitive race to those organizations that are organized to do so. "Time is money" is a proven axiom in the business world. It is often a foreign concept in a university. Only when universities recognize that rapid time lines for technology transfer are as valuable as the technology itself will we be able to compete effectively in the worldwide technology race. The prognosis at present is doubtful.

Acknowledgments

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