Through The Nano-Needle's Eye: Models, Examples, And A Template For The Successful Transition From R&D To Commercialization

Michael O'Halloran

Industrial Design & Construction (IDC)
2020 SW Fourth Avenue, Suite 350, Portland, Oregon 97201, michael.ohalloran@idc-ch2m.com

ABSTRACT

As small-scale technologies emerge and are slated for commercialization, the critical challenge is scaling up prototypes into viable commercial applications. Many new technologies have faced this challenge, and many lessons learned from those experiences can be applied to the diverse fields comprising nanotechnology.

This paper details issues and strategies developed to improve the success of shifting from promising nanoscale research into profitable commercial production.

A key theme in this paper, based on findings from specific case histories involving nanotech research and manufacturing entities, is the contention that advancing nanotechnology research into commercial viability requires a clear understanding of the entire life cycle of technology development. A key target audience for this paper is senior management representatives.

Keywords: nano-technology, R&D, pilot, commercialization.

1 INTRODUCTION

Small-scale technologies (micro and nano) include a wide variety of products and applications. They include new materials or modified materials that may be of use on their own or to modify the bulk properties of existing materials. These include developments such as the use of carbon nano-tubes to build composite "super strength' materials. In other cases, small scale technologies are used to develop new solutions or build up products related to MEMS (or NEMS) devices, sensors, displays, bio-chips, lab-on-chip, microelectronics and so on. Indeed, Business Week recently identified these later applications as those expected to have first significant commercial applications for nanotechnologies.

It is our experience that the "eye of the needle" as it relates to the commercialization of technology is a business problem. If the technology is based on good science, it will be funding, organizational issues and schedule issues that kill the development.

1.1 Types of Commercialization

For the moment I would like to segregate the scope of the topic of transition from R&D to commercialization into two types. Type "A" will be those technologies that transfer cleanly into the commercial world. This is because frequently, once proven, these technologies become integrated into the manufacturing of existing products. The movement of semiconductor manufacturing technology into nano-scale is an example. Newly developed technology, once proven, is inserted into manufacturing processes and the technology steps forward into commercialization. Type "B" will be those technologies that result in the development of new and potentially disruptive products.

This paper is primarily focused on Type "B" technologies. The distinction may not always be clear, but for the moment we will examine the case where new technology is being developed that will result in new products which must be built in new factories. Generally, the nature of such technology-based products is that the associated manufacturing factories are relatively unique, and they are also complex and expensive.

2 THE COMMERCIALIZATION PROCESS FOR NEW PRODUCTS

As nanotechnology development moves forward with new products, experience indicates that the product development will go through a lifecycle sequence moving from R&D through Pilot/Development and into Mass Production (this is true of most complex technology-based development processes).

Figure 1: Formatting dimensions for manuscripts

It is the complexity and expense of the technology and manufacturing process that causes the need for this development model. The significant issues of funding, organizational structure and schedule must be addressed at each phase.

2.1 Funding

Let us begin at the end of the process and work our way backward. The end goal is a viable commercial product being sold in the marketplace for a profit. Millions of dollars, perhaps hundreds of millions of dollars will be invested in the factory. As the technology moves into production we will need additional investment above the pilot level. Our product must be protected by patents, manufacturing know how and/or other barriers to entry such as investment requirements or marketing and distribution channels. Investors like to be aware of as many of these barriers as possible. Prior to investing in the manufacturing plant, investors want to know:

- What is the cost of the product?
- What is the output of the factory?
- What will be the plant cost and cash flow requirements?
- What is the schedule?
- How big is the market?
- What is the selling price?
- Who or what is the competition and how do we keep them away?
- How many staff do you need and where do they come from?

The investors want quantitative (not qualitative) answers to these questions. With an accuracy to within +/-10% to at most +/-25%, they want a business plan. And they want the data to back up the answers. This information normally comes from the Pilot/Development phase of the program.

The Pilot phase is not as expensive as the production phase, but costs can be substantial. Investors ask similar questions when we move to production, but expect less from the answer. They will also be asking questions related to the science; specifically, is it sound?

The important issue to the R&D organization is that the better and more quantitative the answers to investors at both the Pilot and Manufacturing phases, the less risk investors will perceive. The less risk, the faster they will invest, the more they will invest and the less they will seek in return. It is our experience that failure to properly execute the Pilot Phase results in significant problems with obtaining investment, or (worse) significant financial and schedule problems during production.

2.2 Objectives of the Pilot/Development Phase

The pilot phase should use real (commercial) manufacturing equipment in a simulated manufacturing environment to produce commercial product. This will prove the technology within a “product” orientation. It will develop manufacturing run rates and produce product for the development of the marketplace. The objectives of pilot production are:

- Processes are optimized and brought into statistical control.
- Costs are developed.
- Suppliers are developed and pricing negotiated.
- Trial product is produced to seed distribution channels and test markets.

2.3 Organizational Issues

The following model (figures 2, 3 and 4) show the characteristics of the organization as it migrates from R&D to Production. A study of the characteristics indicates the significant scope of change an organization must accept as transitions are made. A stable R&D organization morphs into a pilot organization. Then, after just a short time, the organization morphs again into a production mode. This is exceptionally difficult. Think about the model as a business manager.

Again, management must answer questions:

- How to hire personnel for a pilot phase and fire them in 2 years?
- Are researchers disciplined enough to work in manufacturing? Will they lose interest?
- Will R&D people or manufacturing people be able to deal with the chaos and urgency of the pilot phase?

R&D Phase

Staff	•Define and demonstrate theoretical concepts in a lab-scale industrial environment. •Technical staff hard science- and research-oriented (80% technologists, 20% engineers). •High degree of individual contribution. •Primary compensation based 90% individual, 10% team. •Focused on discrete events and intradiscipline interactions.
Equipment/ Facilities	•Provide a lab-scale industrial environment for development and prototyping activities. •Uncharacterized tools utilized with non-optimized equipment recipes. •Tool set flexible, portable, and multifunctional. •Work areas decentralized with layout optimized for intradiscipline research and development.
Process, Product, Procedures	•Define individual process steps and confirm initial sequence of operations. •Process variables understood through modeling/simulation and individual step sensitivity studies. •Chemical reactions and scaling parameters understood. •Produce a fully featured and functional prototype. •Initial prototype produced and characterized with respect to key performance variables. •Provide a flexible framework for the coordination of diverse development activities.
Materials	•Provide a basic set of materials specifications including initial sensitivity analysis with respect to intramaterial variation. •Initial experiments done with lab purity materials to obtain highest theoretical properties. •Material alternatives and substitutions freely examined with "decision to use" based on first-order impacts.

Figure 2: R&D Phase

Pilot Phase

Staff	•Integration of developed concepts in a prototype manufacturing environment. •Technical staff balanced (50% hard science- and research-oriented and 50% engineering). •High degree of intrafunctional teams. •Focused on system-level events with balance between intra- and interdiscipline interaction.
Equipment/ Facilities	•Provide a manufacturing-scale environment for initial production equipment burn-in and pilot production. •One-of-each fully sized tools with optimized equipment recipes. •Equipment set user-friendly, repeatable, and functionally optimized. •Layout optimized for efficient manufacturing flow and support area centralization. •Involve vendors in partnership relationships.
Process, Product, Procedures	•Integrate process steps and define manufacturing flow. •Process integration variables understood through sensitivity analysis. •Manufacturing process model defined and characterized. •Produce a fully featured and functional production-worthy product in limited volumes. •Final production product defined framework supporting manufacturing requirements. •Provide a flexible but defined framework supporting manufacturing requirements. •Production support infrastructure defined and implemented.
Materials	•Freeze production bill-of-materials and provide initial intermodule/intermaterial sensitivity analysis. •Define final material purity and compositional requirements. •Determine proper cost vs. performance material trade-offs with 'decision to use' based on first-order. •Develop qualification requirements for vendors and materials. •Involve vendors in partnership relationships.

Figure 3: Pilot Phase

Production Phase

Staff	•Sustain and continually improve the ongoing production operations. •Technical staff 90% engineering and 10% hard science- and research- •High degree of interfunctional teams. •Primary compensation based 40% individual, 60% team. •Focused on system-level events and interdiscipline interaction.
Equipment/ Facilities	•Provide a fully operational manufacturing environment for high-volume •Multiplexed, fully characterized production tool set running stable, frozen equipment •Equipment set fully instrumented, in-situ monitored, and optimally •Layout optimized for maximum output, minimal cycle time, and lowest manufacturing
Process, Product, Procedures	•Running a frozen manufacturing process flow. •Process driven by statistical controls. •Manufacturing process model only changed through continued characterization in incremental steps market-driven demand changes. •Fully characterized products running in high volumes. •Final production product specifications frozen. •Provide a stable, defined framework preventing variation. •Production support infrastructure optimized.
Materials	•Bill-of-materials components optimized for cost reduction and supply •Low cost materials substitutes investigated and qualified. •Cost vs. performance trade-offs controlled tightly. •Vendors become full partners and part of the manufacturing flow.

Figure 4: Production Phase

2.4 Schedule Issues

The R&D to commercialization transition includes many activities. The following time frames are intended to be representative and can vary significantly.

- Negotiation with Pilot investors takes 2 to 6 months.
- Site selection/negotiations for a building or land takes 2 to 3 months (starting from when you have money).
- Conceptual design and permits for a pilot or production facility takes 2 to 4 months (this depends on the facility complexity and location. Code processes vary by state and country.)
- Negotiations with pilot/manufacturing equipment suppliers take 2 to 4 months.
- Delivery of manufacturing equipment takes 6 to 9 months.
- Remodel of a building to accept a pilot or production operation takes 3 to 6 months.
- New construction takes 12 to 15 months.
- Installation and turn of manufacturing equipment takes 1 month.
- Start up and shakedown of "the process" takes 3 to 12 months (this is heavily dependent on preplanning and complexity).
- Negotiations and development of distribution channels takes 6 to 18 months.
- Market development takes 12 months (but this can vary widely).

3 SUMMARY

Technology developments do not "speak for themselves." They require extensive effort, time and money to get to the point where there is an impact on society. The process can seem overwhelming. But, if we focus on the Pilot Phase (the eye of the needle), we can handle the process in manageable parts.