



## Developing an Enduring Manufacturing Infrastructure

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### Introduction

An enduring manufacturing infrastructure requires a persistent competitive edge. A workforce that understands how to identify and implement ideal manufacturing technologies is the only way to achieve it. Process manufacturing technologies (as opposed to product manufacturing) provide the best opportunity to create that persistent advantage as it requires an intimate knowledge of exactly how to create the product, which requires a core group with the proper skills. The key is to create such skilled professionals and at the same time develop foundational manufacturing techniques to start providing tools.

The biggest hurdle to process manufacturing start-ups are the relative lack of relevant tools and techniques. Therefore, due to time or financial constraints, most new ventures in this space make technical compromises that lock them into a path that limit their probability for success. In many instances, the venture is hemmed in by a lack of the training to identify and create process/equipment solutions that would circumvent the constraints. Concurrently, there are many foundational technologies the ventures could utilize except they do not yet exist. Developing foundational technologies will provide near-term benefits to the manufacturing base, and educating the technical workforce will create a long-term resource with which to creating the manufacturing infrastructure regardless of market requirements. Educating technical professionals to define the technical challenges, drive solutions, and create new foundational manufacturing technologies is therefore a critical approach to laying the groundwork for manufacturing success.

Rapid and enduring progress and success occurs when both equipment development and process manufacturing are run by the same people. Case in point is the rapid success of the semiconductor industry which was in large part due to having equipment development and process manufacturing under one roof. As Jack Yelverton of Fairchild Semiconductor said of their work in 1958, "There were challenges and problems everywhere. You had to build the equipment that you needed to make these transistors. It was a whole, brand new world that nobody had been there before." [1][1] In the early days, the specifications were simple and equipment was low-cost; it required mostly the imagination, technical depth, and attention on detail to create the equipment and set-up the line. Such tight integration continued from the 1950s through the 1980s, and corresponds to the most rapid innovation. As the industry matured and requirements for precision and throughput started to outweigh

those of raw performance, integrated circuit manufacturers banded together through development of specialty equipment manufacturers (Lam Research and Applied Materials) as well as industrial consortia (Sematech and IMEC). The key in duplicating the semiconductor industry's early success is comprehensively train professionals to develop these new manufacturing technologies regardless of the requirements. Since it is impossible to predict what technology will be required for a given industry this flexibility is crucial.

The second key is to develop relevant foundational manufacturing technologies. Identifying such technologies requires analysis of several nascent manufacturing fields and identifying common technical impediments to ideal production. One example is inert atmospheric manufacturing. Materials that show the most promise of revolutionizing many new fields are moisture and oxygen sensitive. Unfortunately, equipment today to manage these environments do so by compromising cost, throughput, product geometry, and/or capital investment. Equipment that break these constraints would be underpin proliferation of several manufacturing industries, including organic electronics, batteries, pharmaceuticals, organic LEDs, and organic photovoltaics. One analog of this is the development of vacuum equipment, which saw its heyday from the 1930s through the 1980s. During this period a great deal of effort went into developing the components of high quality manufacturing equipment. Improvements in pumping, sealing, improved attainable vacuum levels, were originally created to support the vacuum tube industry, but it also dovetailed into the semiconductor industry's requirement for improved purity for its processes. Therefore, focusing in this area would be a fruitful vehicle for both training and improving a foundational technology.

Since industry and market needs are inherently difficult to predict, the key to success is to train the workforce with enough depth in the fundamentals of problem solving, and select technical challenges with enough breadth to be applicable across a wide number of manufacturing opportunities. The proper depth of problem solving is to frame the technical challenge, define the requirements, and drive the technical solution regardless of what it may be, and to maximize technical training by defining the technical solutions of the program such that it is foundational. There are many technical issues that afflict multiple fields, so selecting wisely maximizes market relevance for technical deliverables.

Interestingly, an academic environment provides many distinct advantages for driving such an effort. The goal of educating, its openness, low-cost of capital, and even its long timeframe make it ideal for several reasons:

1. It steadily trains a large workforce that can immediately move into commercial realm with the fundamental knowledge to work on any problem industry has at that time.
2. It permits rapid dissemination of the IP, *through the trained workforce*.
3. It promotes insight for local and domestic companies
4. It allows simultaneous attempts of multiple solutions for a problem with low investment, and sharing of successes and failures.
5. It tolerates an uneven rate of progress to provide a robust platform as markets evolve.
6. It can be a resource for industrial concerns when dealing with time-consuming issues.
7. These problems will take many attempts (and failures) to solve whether in the commercial or academic sphere, it minimizes private capital loss.

Such as program can be replicated to educate people with a common technical acumen but working on many different foundational manufacturing technologies. There are many foundational manufacturing technologies that need to be developed, a small subset includes:

1. Separation and purification techniques.
2. Controlled atmospheric processing.
3. Surface polishing (roughness control).
4. Hierarchical self-assembly.
5. Customizable fabrication.
6. Resource reduction in manufacturing (materials, energy, waste).
7. Dissimilar and zero-clearance joining.
8. Bio-mimetic structures.

## **An Example Foundational Technology Program**

Developing an ideal production line using foundational techniques would both develop a capable workforce and provide foundational manufacturing techniques on which to build better production equipment. Maximizing technical success and training, the program life-cycle of the program would encompass four stages: 1) line creation, 2) process development, 3) technology creation, and 4) technology insertion. The steps required to successfully develop and carry out the program include:

1. Identify common issues among several emerging and growing process manufacturing fields.
2. Pick a product (not necessarily final product; e.g. electrochromic module, or membrane cartridge.)
3. Design and build a factory with existing equipment and processes.

4. Identify and design the ideal factory and highlight gaps.
5. Design equipment and processes for the ideal factory.
6. Insert ideal equipment into the line to test.
7. Build out the ideal line in parallel with the non-ideal line to compare.

Key program attributes include:

1. Have student do the design and fabrication work.
2. Set goals using it given resources, envision it to be a slow effort.
3. Teach the student the decision-making process.
4. Program technical and education goals shift over time (years) as the factory and needs evolve.

There are two outcomes of this program, 1) an educated workforce that can take on the technical challenges facing manufacturing regardless of what those challenges are or may be, and 2) initial technical capabilities that can be rolled into early-stage process manufacturing efforts in several different markets. The skills that students would develop include:

1. Specify real and ideal products.
2. Specify a process flow.
3. Perform product gap analysis.
4. Perform process flow gap analysis.
5. Evaluate and decide methodology for make versus buy.
6. Specify and design process tools / technologies.
7. Understand how to integrate tools.
8. Debug and improve tools for process technologies.

Resource requirements are flexible depending on the chosen foundational technology and how many students need to be trained. The program can scale depending on resources, the goals shift as the line evolves. Part of this flexibility is working on nascent fields where the performance growth curve is steep. Base capital expenses are normally low for early stage technologies, and can be controlled if technical goals are geared towards developing solutions with that as a constraint. For example, in the case of inert atmospheric manufacturing, starting with a glove-box (or glove-bag) system for small samples, and then driving the equipment development process to focus on system integration and components, rather than building/buying ill-defined or unsuitable systems.

The educational structure could be team project-based that would remain together, lasting 1-3 years. Formal training would encompass the entire life-cycle experience, a team's practical work and goals would be based on the life-stage of the line. Throughout, the

pedagogical approach would be to involve the student in the decision-making process and guide them through doing the decision-making processes required to make informed technical decisions. Early teams would focus on line development and gap analysis; later ones would focus on new equipment and technology development. Team size and duration would depend on the complexity of the technology and program scope. The team would sequentially move through the program, and the program would host multiple teams, with a minimum one team per life-cycle stage.

This model can be propagated to many universities to work on many foundational technologies, thus created a new workforce capable of building their own factories. Graduates enter the workforce in as little as three years from the start of the program, where they can contribute to current issues. With enough programs nationally, over time numbers in the workplace will eventually reach critical mass, and cement the potential for a long-term manufacturing prowess.

### **Footnotes:**

- [1] Randall MacLowry, The American Experience: Silicon Valley, "Jay Last and Jack Yelverton Interview.", WGBH, (2013).