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A Framework for Materials Product Innovation: Promoting Musso
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Introduction
This article was written to summarize and promote the concepts of Dr. Christopher Musso (bio is here [http://esd.mit.edu/people/alumni.html#musso]), as put forth in his 2005 dissertation, Beating the System: Accelerating Commercialization of New Materials which can be found here [http://esd.mit.edu/people/dissertations/musso.pdf]. A chapter-by-chapter synopsis is found at the closing of this document as Exhibit 1: Highlights from the Text.

Background
Contacts at three Fortune 100 materials companies recommended reading Beating the System: Accelerating Commercialization of New Materials, the February 2005 dissertation of Dr. Christopher Scott Musso. Having spent the past two years commercializing electrospinning, the dominant method for production of nanofibers, the recommendations all came in the context of marketing advanced materials. Since 2006 I've also been working on the Committee on Forecasting Future Disruptive Technologies overseen by the National Research Council. Many of Musso's arguments are relevant to technology forecasting. The approach, tone and methodical nature are similar to that of Eric Von Hippel's The Sources of Innovation.[1]

Musso has clear applications for anyone working in or around materials science or for those who are involved in technology forecasting. Studies of materials science have significant application to the Nano, Industrial, Cleantech or Energy ("NICE") technology sectors.

Dr. Musso's paper is valuable for three reasons; (i) it is quantitative – the author gives real numbers, backed by the source data wherever possible; (ii) it is evidence-based – Musso bases his work on decades of materials innovation in the plastics industry; (iii) it is focused exclusively on materials. This focus on materials is significant given the increased focus on NICE technologies. NICE technologies impact industries which are vastly different than information technology, which has been the dominant area of venture capital investment over the past three decades.

Materials Are Unique
These four points come verbatim from Musso's text (page 17) and they are the clearest discussion of how materials are different from other industries.

1. "Materials come early in the value chain." Early in the value chain means far away from retail customers. To win with materials, you'll need to be comfortable with an industrial sales process, know how to navigate committee-style purchase processes and vet whether or not your prospects can transition into real customers. Dealing with industrial customers, rather than retail, dramatically shrinks the number of prospects – there aren't hundreds of shots on goal, you'll be lucky to have dozens.

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[1] Von Hippel, Eric. The Sources of Innovation. (1988). Available for download here: http://web.mit.edu/evhippel/www/sources.htm

2. "Materials are difficult to change." "Iterate, iterate, iterate" is the mantra of web service start-ups. Such iteration for materials is expensive, time-consuming and often not possible. New materials have a diverse range of properties that are often notable only on an empirical basis, creating long discovery processes for management and customers alike.

3. "Materials are versatile." A novel new material has many potential applications. Whereas an end product is designed for a specific market, a new material often has many applications and must instead be ruled out of new applications. The new material often finds its market by being ruled out from others, rather than being ruled in.

4. "Materials are functionally fungible." If a material does the same job as another material, with outperformance along select dimensions, or with better cost; the old material will be usurped despite its service to the industry. There is little loyalty from a materials customer; better performance or cost will quickly drive replacement of an existing material.

Six Essential Factors for Materials and NICE Technologies

1. Insertion vs Penetration. Musso states clearly that materials face two challenges; insertion into an application, and subsequent penetration into an application. While the act of insertion echoes the themes of early adopters in Moore's Chasm Model, it provides an important distinction for those working in this area.[2] Insertion is the act of getting someone to include a material in a new application. Penetration is the act of winning that application and becoming the material of choice. Musso provides numerous examples that the factors that make for easy insertion are different than those that make for long term penetration.

2. Materials framework: Enabler, Platform, Substitution. If we evaluate the difference between insertion and penetration, we can start to look at end market applications differently. Enabler markets are those that have a high speed of insertion, but which might not be the kind of robust markets needed for long term success. Examples are the Hula Hoop and highway reflectors, which provided certain plastics easy markets to enter which had not previously existed. Since the markets were new, and were enabled by the materials, they were easily won. Platform markets are the markets which allow a material to gain market transaction; they allow the material to scale, engineers to learn their capabilities and customers to accept their presence. It is only after the platform phase that substitution markets can be addressed – the material can pursue areas where they have superior cost or performance to existing materials.

3. Serendipity's Demotion. When working with a new material there are frequent discussions about the ideal market. These discussions usually include faith in serendipity; that the ideal application or market lurks around the corner, and that rather than focusing on execution, time should be spent on additional application development. Musso's research shows that the likelihood of finding the lucky market is low. For 34 plastics in application, only 1 was to find its largest market in an area that had not been previously considered. The largest markets for 33 of 34 new materials were identified in the early days of the materials' development. As a corollary, enablers were important,

[2] Moore, Geoffrey A. Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Customers (2002).

and only 2 plastics of 34 were immediately inserted into the markets that would go on to be their largest application. There is always a fear with a new material that there must be relentless innovation to create options to enter previously unidentified new markets; this is wasted time. Given a large range of experts evaluating potential markets, it is likely the best markets for the material have already been identified.

4. The 20 Year Rule. Common materials wisdom states that it takes 20 years for a new material to reach widespread adoption. Rather than challenge this rule, Musso took it as a given and looked for ways to shorten this time period. He broke out delaying concerns by whether or not they were technical concerns or supply chain challenges. Technical challenges were more significant, causing a delay of 11 years, three times longer than the typical supply chain delay of 3.7 years.

5. Cost Doesn't Matter. Musso found that when looking at insertion factors, what mattered was that the cost must be feasible, not necessarily cheaper. For the 34 plastics that entered a new market, "81.25% were equal to or higher [the cost of the material they replaced]." (Chapter 4, pg. 71).

6. Importance of Community. Community, often touted as the core to new IT products, was equally, if not more important, to the materials science community. Musso saw this area being driven by transaction costs. Community creates credibility around the material, reduces the fear of failure for an engineer working with a material, reduces learning costs, and per Musso, "The goal of all insertion strategies is to minimize the switching costs faced by manufacturers who are potential adopters of a material."

Finding Enabler Markets

If you are working with a new material or NICE technology, Enabler markets are key. They keep your business alive, allow you to demonstrate your capabilities, create time to address production concerns, and as noted allow the community of customers to learn about your capabilities. In Chapter 6, Musso notes six key characteristics of an Enabler end application.

1. "[The new] Material offers unique value." An enabler market currently has an unmet need; the problem is currently not fixable. In this scenario, any solution, regardless of its inexperience or cost, has a chance. This is the defining element of an enabler market.

2. "Simple value chains." Enabler markets sit closer to the end customer than most materials supply chains; they have a simple path to execution. The industrial customer may be vertically integrated, or the supply chain may be simple. They allow the value of the new material to be quickly captured and production issues smoothed over.

3. "Develop the materials value chain = Learning." Customers in the Enabler market want and need the new material; they have a history of pushing the envelope and are not easily scared away. Hiccups that would derail a more hesitant customer are surmounted, because the Enabler customer places a value on the learning process. This has the further balance of encouraging transparency from the new material organization.

4. "Fault tolerant applications." The enabler market has a lower penalty for failure than a conventional materials application. Risks of lawsuit, death, explosions or massive product recalls are low.

5. "Visible to adjacent, attractive markets." The new material's accomplishments in the enabler market must be readily observable and transferable to the larger platform and substitution markets that the new material will eventually target.

6. "Must be profitable for the application manufacturer." Enabler customers aren't charities – they may have higher margins made possible from the new material than any other potential application. Indeed, it is their ability to exploit a previously unexplored application made possible by this new application that allows them to be an early adopter of the new material.

VC and Materials: Not an Ideal Combination
Early on in the document, Dr. Musso lays out some of the basic reasons that VC investing in materials (and therefore the NICE technologies) is unlikely to be significant or attractive.[3] Musso's basis for this assertion is that the relative returns are simply too high and that the initial capital outlay, estimated to be $10,000,000 or more, is also too great. While I agree that the constraints around capital are legitimate, having surveyed many early stage investors, there appear to be other contributing factors as to why a VC partnership might not be suited towards this market.

Most VC firms are oriented towards the end market applications they service. Over the past decade, many VCs have developed expertise around retail software applications, often known as web applications. Other firms have shown expertise around telecommunications, pharmaceuticals and the electronics industry. Across most firms, domain expertise has been the most common point of differentiation; this allows for more opportunities to make money in an industry and easier marketing to those Limited Partners who invest in VC funds.

As we've seen earlier in this market, success in materials investing is based on finding success in Enabler industries, which are difficult to identify. If Enabler markets are diverse, ill-defined and often exist only conceptually, then it would be difficult for any set of partners, let alone a VC fund in pursuit of 10 year returns, to identify them and make a business of finding them.

Despite these concerns, constructing a team to focus on these markets could create attractive return possibilities. Teams with similar target investment market and operational challenges exist in the pharmaceutical and life sciences industries. Whereas many VC groups are loosely knit confederations of readily available individuals, constructing an investment team for this market would require a long term commitment and focus on assembling a uniquely pedigreed team.

Unlikely to Disrupt
Musso references the work of Clayton Christensen, author of The Innovator's Dilemma on disruptive technologies several times. Musso states that disruptive technologies are those that move through the supply chain quickly and find Enabler markets the most rapidly.

For those materials that don't quickly fall into their enabler market, or in which the enabler market has minimal societal impact, it is unlikely that they will be considered disruptive; these slow developing materials take too long and lack the surprise that is so common with disruption. As we look back to the

[3] Dr. Musso makes one mistake when accounting for the portfolio effect in VC returns. He notes that a VC would need to make four investments to get one liquidity event and mistakenly multiples the rate of return by 4, rather than the exit amount. This leads to his ~1,000,000x target exit multiple, whereas a ~400x would suffice. Both are high, much higher than any admitted target exit multiple of even aggressive VCs.

key challenges to materials innovation, they are unlikely to cause disruption, as they must be broadcast widely, take long times to adopt and require a good deal of learning costs before they become widespread.

Closing Thoughts

There is much in the popular press about NICE investing and entrepreneurial focus in this space. Many heading into the area are new to materials, industrial sales and hard technology engineering. These industries are vastly different than the IT industry which has been the primary focus for entrepreneurship over the past decade. We see with Musso's work that the materials industry is different than would be expected from the industry's own conventional marketing wisdom. Applying Musso's dissertation to product innovation in materials science could have significant impact on operators and investors alike.

Next Steps: Read the Source Document

While putting together this synopsis has been helpful in clarifying my own learnings from Musso's document, it is no substitute for the actual paper. I highly recommend reading the source material and hope that he has opportunities to expand upon the concepts he has outlined. It is my hope that documents like Beating the System: Accelerating Commercialization of New Materials and this synopsis will help to standardize product commercialization steps for NICE technologies in much the same fashion that the IT development and web application industries have codified their product and marketing methods.

Exhibit 1: Highlights from the Text

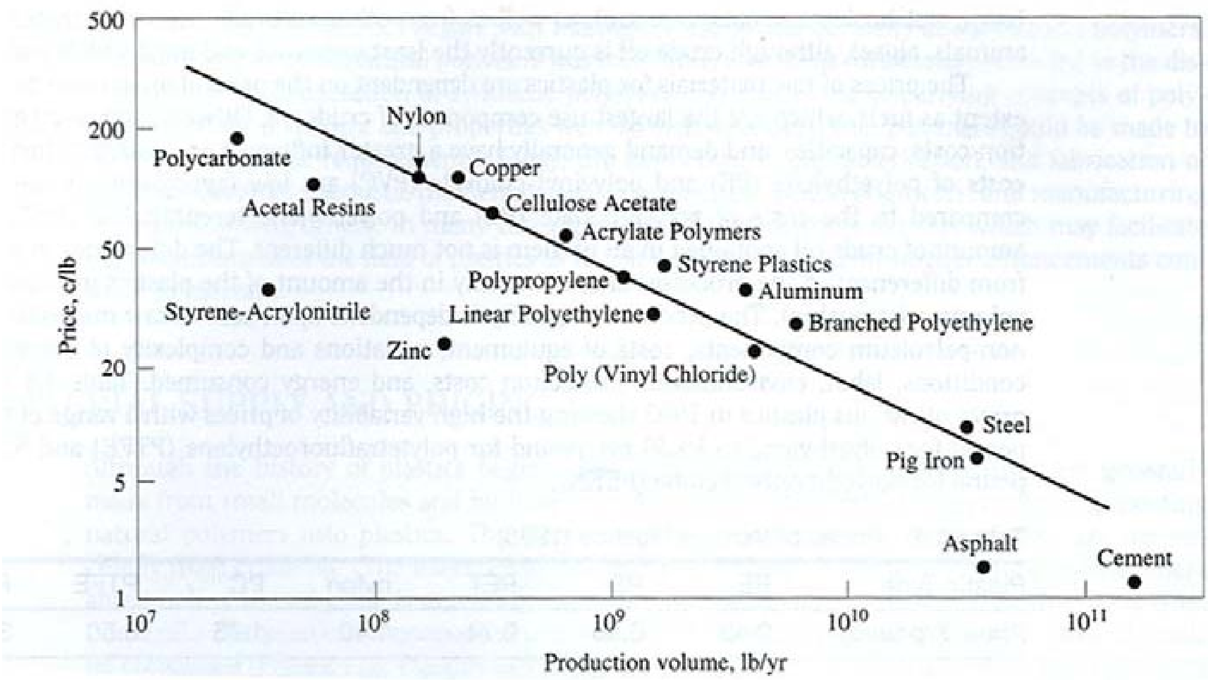
The following notes are a synopsis of the work of Dr. Christopher Musso.

Beating the System: Accelerating Commercialization of New Materials By Christopher Scott Musso Submitted to the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Technology, Management, and Policy at the Massachusetts Institute of Technology February 2005

Chapters and Highlights

1. Beating the System (pg. 15)
    - 1.1. Materials industry is a very broad classification.
    - 1.2. Definitions of a material = "Anything for which an engineering drawing does not exist" to "The substance or substances out of which a thing is or can be made."
    - 1.3. Unique aspects of materials
        1. Materials come early in the value chain
        2. Materials are difficult to change
        3. Materials are versatile
        4. Materials are functionally fungible
    - 1.4. Market pull (other markets) vs technology push (materials)
2. Review and Commentary of Relevant Literature on Materials (pg. 25)
    - 2.1. Risk factors – "Time to market risk"
        1. The 20 year challenge
        2. VC analysis (page 28)
    - 2.2. Traditional materials marketing wisdom
        1. Large initial markets
        2. Substitution based on superior value
        3. Special focus on lower costs
            - 2.2.3.1. Great graphic of production volume vs cost for all materials (pg 31):

Figure 2.1: Graph of production volume v. cost. Note that this graph does not take into account the relative density of materials.



4. Investment Methodology for Materials ("IMM") page 32

2.3. Obstacles to Commercialization
1. Production / technical obstacles
   - 2.3.1.1. Appropriability
   - 2.3.1.2. Production capacity
   - 2.3.1.3. Market identification
2. Value chain obstacles

2.4. Applicable General Innovation Theories
1. Schumpeter – Dominant Design, 1943 – page 38
2. Christensen – Disruptive Technology

3. The Pattern of Materials Commercialization (pg. 45)

3.1. Materials industries do not follow conventional life cycles "Iterative cycles are very difficult to develop" – pg. 45

3.2. Traditional wisdom holds that placement = penetration

3.3. Musso bifurcates insertion and penetration

3.4. Plastics industry survey

3.5. Expectations if 'common' wisdom were correct
1. Largest markets came quickly after initial development
   - 3.5.1.1. Page 53 histogram

Uniform Quick Insertion

A histogram of the elapsed time between commercialization of the major plastics and their insertion into major applications is shown in figure 3.1.

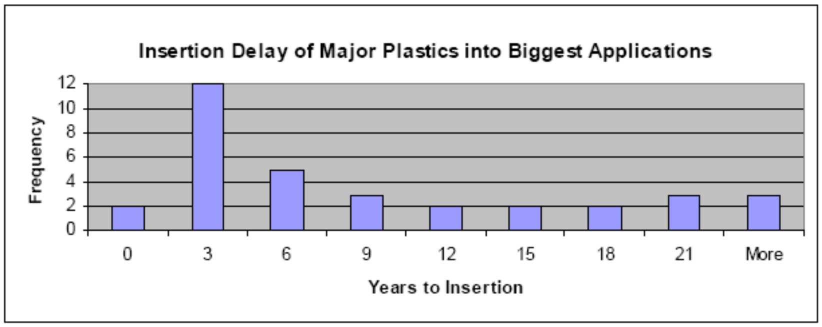


Figure 3.1: Histogram of time elapsed between introduction of new materials and their insertion in biggest applications.

3.5.1.2. 8.5 year mean, 8.2 year standard deviation

2. Earliest applications became very large (corollary of above)
    - 3.5.2.1. First only 2/34 times
    - 3.5.2.2. Only 1/3 of the materials made it into biggest market in < 3 years
3. Negative correlation between insertion time and market size

3.6. Enabler phase and concept
1. Material solved a problem, it made possible something previously impossible
2. Simple applications; Hula hoop, reflective strip (PMMA),
3. Small markets
4. Solved a relatively new problem
5. Killer app, builds credibility, gets the wrinkles out, a good early customer

3.7. Platform phase = key to commercial success

3.8. Widespread substitution

3.9. Page 69 graphic
1. Enabler = 0 – 3 years, Platform = 2 – 7 years, Widespread substitution = 3 – 25years

3.10. Comparison to Kurzweil

4. Insertion Factors (pg. 71)

4.1. Possible reasons for lag between availability and biggest application
1. Serendipity in identification
    - 4.1.1.1. Not so; only the case in 1/34 – polystyrene cassette tapes
    - 4.1.1.2. "The major plastics were proposed as potential suitors for all of the biggest applications earlier than they were inserted into those applications."
    - 4.1.1.3. 4.6 year gap between identification and insertion, 82% identified very early
2. Cost of material
    - 4.1.2.1. "81.25% were equal to or higher"
    - 4.1.2.2. Focus on a feasible price, not a superior price
    - 4.1.2.3. Pg. 78 histogram

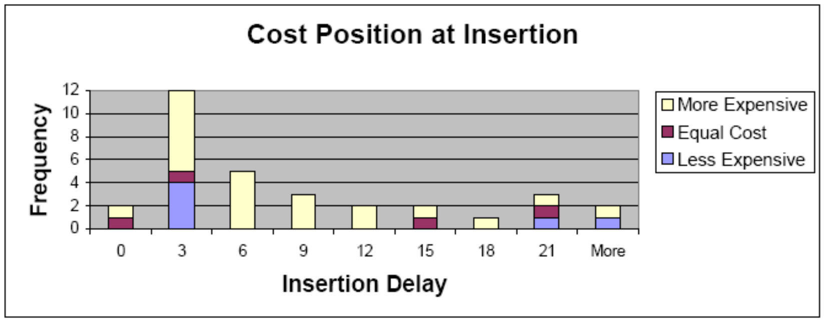


Figure 4.1: Insertion periods of major 1998 applications, showing cost position of entrants.

3. Technically incapable
    - 4.1.3.1. Solved with science and R&D rather than empirical (value chain)
    - 4.1.3.2. 11 year delay, 3x greater than value chain alone
    - 4.1.3.3. Serve as a barrier for addressing other issues
4. Value chain issues
    - 4.1.4.1. 3.7 year delay
    - 4.1.4.2. Page 81 histogram

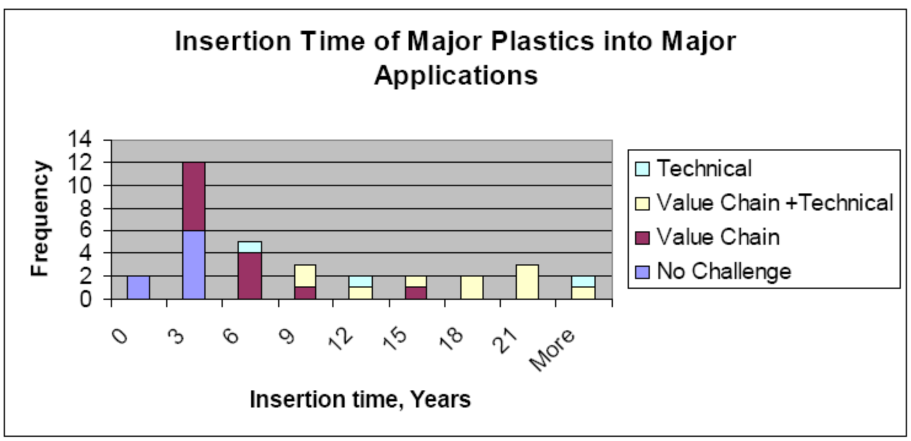


Figure 4.3: Histogram of major plastics divided by value chain and technical challenges.

4.2. Disagrees with Christensen
   1. Both ignore that there is a firm in the middle

5. The Effects of Value Chain Complexity (pg. 101)
    - 5.1. Major impact is time and conceals the real problems
    - 5.2. Number of parts vs insertion time (page 112)
    - 5.3. Contributing factors
        1. Complexity
        2. Swtiching costs < Unknown switching costs
            - 5.3.2.1. Unknown
            - 5.3.2.2. Multiple
            - 5.3.2.3. Hand-off
6. Towards Faster Commercialization of New Materials (pg. 135)
    - 6.1. "Players in the application value chain rarely have the equipment or knowledge necessary to fully utilize their potential."

6.2. Value chain complexity
    1. Pg. 138 2 x 2 grid

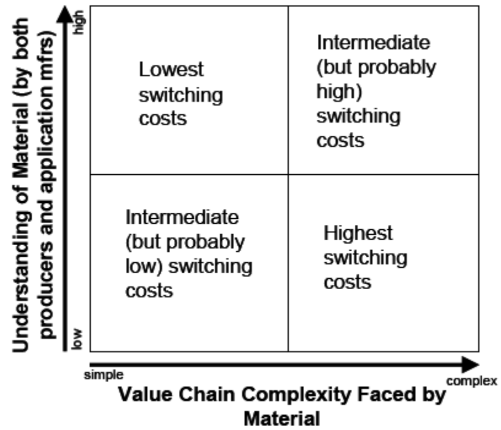


Figure 6.1: Switching cost severity matrix

    2. Levers
        6.2.2.1. Market selection
        6.2.2.2. Integration
        6.2.2.3. Technical development

6.3. Field learning, "was sometimes the only practical way to succeed." – pg. 144 von Hippel

6.4. "The ensuring problem is easy to see: How can producers get validation customers to absorb large learning, liability, and handoff costs for unproven materials so that networks can begin?" The answer is simple: materials producers should carefully choose application markets that are minimally sensitive to these costs, and should integrate forward when those markets are not available."

6.5. 2 x 2 grid – Insertion strategies on page 152

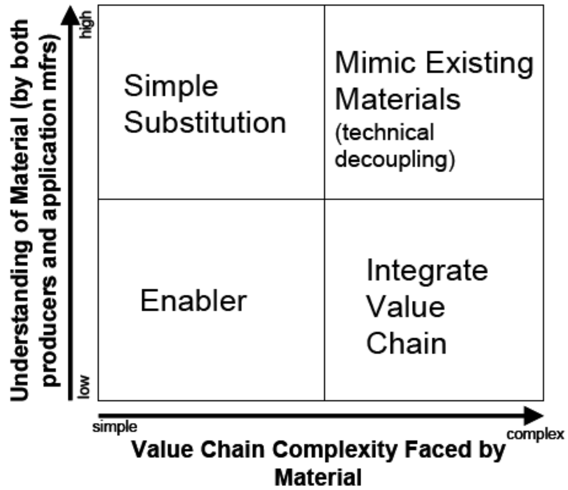


Figure 6.6: Insertion Strategy Matrix for materials

6.6. Selecting enabler applications
   1. Material offers unique value
   2. Simple value chains
   3. Develop the materials value chain = Learning
   4. Fault tolerant applications
   5. Visible to adjacent, attractive markets
   6. Must be profitable for the application manufacturer

6.7. "One job poorly done counteract(ed) twenty jobs well done"

7. Lessons in Competition (Penetration Factors) (pg. 165)

7.1. Technical compatability does not alone create a defensible position

7.2. Value chain can be an obstacle but also a defensive capability
   1. Standards and design
   2. Track record
   3. Understanding and learning
   4. 2 x 2 grid – Insertion strategy map on page 179 (Same as previous)

7.3. Safest position; be the lowest cost material – lowest common denominator

8. Walking Through the Shadow of the Valley of Death (pg. 181)

8.1. "The goal of all insertion strategies is to minimize the switching costs faced by manufacturers who are potential adopters of a material."

8.2. Policy implications
   1. Focus on enablers
   2. Create a materials clearing house
   3. Develop a market for ideas

9. Changing Mindsets (pg. 197)
    9.1. 2 x 2 grid on page 202

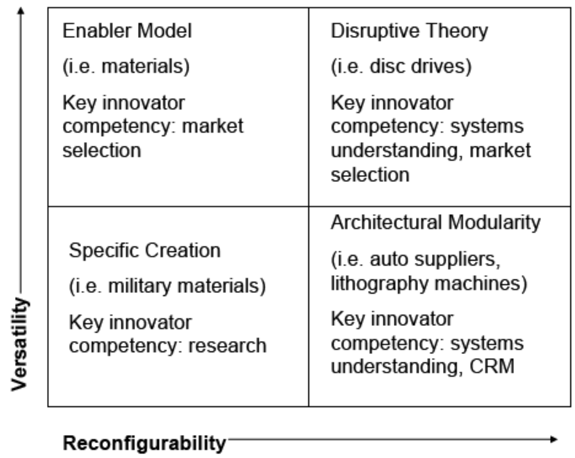


Figure 9.1: Versatility vs. reconfigurability