

## Challenges and Opportunities in Process Innovation

Larry R. Genskow

*Associate Director – Process and Emerging Technologies  
The Procter and Gamble Company  
8256 Union Centre Blvd.  
West Chester, Ohio 45069 USA*

### Abstract

This addresses key challenges and opportunities in process innovation. Important capability trends are identified and discussed. Key challenges and opportunities to be addressed include:

- 1) The challenge of learning at the smallest scale to increase innovation speed and decrease cost – and lessons from biotech.
- 2) The importance of identifying emerging technologies and disruptive innovations – innovations that can ultimately obsolete incumbent businesses with new to the world technologies.
- 3) The need for diversity to fuel diversity of thought – to nourish and enable creativity and invention.
- 4) The challenge and the promise of micro-technologies.
- 5) The role of modeling and simulation in process innovation.

**Keywords:** process, innovation, disruptive, modeling, emerging technologies

### 1. Introduction

#### *1.1 Overview*

The pace of innovation continues to increase not only in the developed world, but in developing markets. This is being driven by the consumer and enabled by increased technical capabilities. Consumers are demanding increased levels of personalization in their products. One of the most obvious examples of this is in the automotive industry. The number of automobile models has increased from 250 in 1999 to a projected 330 by 2008, according to Global Insight Inc., a Waltham, Mass., researcher. And the speed of innovation has increased. A decade ago the time from design concept to “on the showroom floor” was about 5 years. Today, best in class is well under 2 years. This reduction of innovation cycle times is largely a result of moving from a world of physical testing and prototype development to a virtual world enabled by modeling and simulation capabilities.

We have not seen the same scale of progress in the chemical industries. The time from discovery to commercialization of a “new to the world” product is still measured in years. At the risk of over simplification, this is in large part due to the added complexity of chemical systems compared to mechanical systems. Certainly at P&G, we are still measuring innovation cycle times in years, even for some “new and improved” products. We have also seen added complexity as the variety of products (SKU’s) that we offer the consumer has increased at about 10% annually over recent years.

As a result, **better, faster, cheaper** innovation is a top priority for us and for almost any company that hopes to remain in business. This paper addresses some of the key issues today, especially from the perspective of a consumer products company – but I believe these same issues are prevalent across the chemical industries.

### 1.2 What is Innovation?

Let's be clear on what innovation is before addressing challenges and opportunities. Innovation is:

- The practical translation of ideas and inventions into new and improved products, services, processes, or social interactions. As such it spans the earliest discovery work through commercialization.
- Innovation is creating something that others want and has commercial value.
- *"Innovation is our lifeblood – new ideas and new products that make consumer lives better."* - AG Lafley, CEO, The Procter and Gamble Company
- *"People implementing new ideas to create value."* – Joyce Wycoff, founding Director of Innovation Network

It's important to distinguish innovation from invention. Invention is also the creation of something new but some inventions are never commercialized to create value.

## 2. The Challenge of Learning at the Smallest Scale

### 2.1 Overview

*"Make your learnings at a small scale and your profits on a large scale."*<sup>1</sup> Learning at a small scale used to mean learning at the pilot plant scale or at the bench scale. Today we talk about learning at the micro scale, the nano scale or the virtual scale. Generally, the smaller the scale of learning, the faster and cheaper it is. The reality is that we can't afford to learn at a large scale today. Importantly, we can get more creative and take greater risk at this "smaller scale" because of the faster, cheaper learning. We can be more innovative. Another key driver to the challenges of learning, certainly in the consumer products sector, has been the increase in product complexity. As we add greater and greater product functionality from new ingredients, products become increasingly more complex. There are almost always, synergistic or harmful interactions between ingredients and these impact both product efficacy and stability. So much of our focus is new tools which enable faster and cheaper understanding of both efficacy and stability. It's important to contrast this with the challenges of commodity chemicals where the focus is primarily cost.

### 2.2 Example from genomics/biotech

The revolution in biotech and genomics should provide those of us in chemical related industries with some true inspiration in terms of what's possible with small scale learning. It's remarkable that the human genome was mapped just 6 years ago and even more remarkable that we're using offshoots of this technology to understand and treat disease. The Human Genome Project itself is comparable to the invention of the first commercialized plastic, Bakelite, by Leo Hendrik Baekeland in 1906 or the discovery and invention of the transistor by John Bardeen, Walter Brattain, and William Shockley of Bell Labs in 1946. Bakelite led to the plastics revolution and the transistor led to the communications revolution. The Human Genome Project is enabling a genomics/biotech revolution.

Technology projections are that we will all have our own personal genome chips in as little as 10 -15 years, i.e., they will be affordable in that timeframe. This will enable the assay of everyone for disease susceptibility and drug response; and enable selective prescription of pharmaceuticals to avoid ineffective treatment or adverse side effects, problematic with the prescription of drugs today.



HUMAN GENOME ON A CHIP



DISPLAY OF GENES EXPRESSING

**Figure 1 (a)** Affymetrix GeneChip<sup>®</sup>

**Figure 1 (b)** Gene expression display

An example of this revolutionary GeneChip<sup>®2</sup> is shown in Figure 1 (a). The GeneChip<sup>®</sup> contains all the genes in the human body – over 30,000. And they are all contained in a chip the size of a piece of Belgium chocolate. The possibilities enabled by the GeneChip<sup>®</sup> are profound. This chip enables us to screen new actives for treatment of disease – to determine which genes express, Figure 1 (b), when subjected to a specific chemistry. It enables companies like P&G and L’Oreal, to screen new actives to give us healthy and vibrant skin and hair. Recent patent applications<sup>3</sup> by L’Oreal claim genes associated with hair graying. It enables us to screen new actives to improve our oral health and hygiene. And the cost of this chip is less than \$500. The traditional alternatives for screening new actives have orders of magnitude higher cost. Clearly, this is a very powerful capability that has gone well beyond its initial applications in the pharmaceutical industry. It enables better, faster, cheaper innovation.

You could say we have yet to develop the genome chip capabilities in chemical processing. While we could draw some analogies with the developing capabilities of microfluidic devices to facilitate learning, they clearly have not been developed or commercialized to the extent of the GeneChip<sup>®</sup>. This is in large part the result of the huge investment in genomics and biotech today. Genomics/biotech are the fourth broad scale technology revolution. (The first was the Industrial Revolution, the second the Chemical Revolution, and the third the Transistor/Microchip Revolution.) Certainly many parts of the chemical industry appear to have reached the plateau of the technology ‘S’ curve where margins are slim for the most part and many products have reached commodity pricing status. We have to question whether the Chemical Revolution itself has reached the plateau. Perhaps this is why many of the large, prestigious chemical companies are diversifying into biotech, agro-chemicals, and life science.

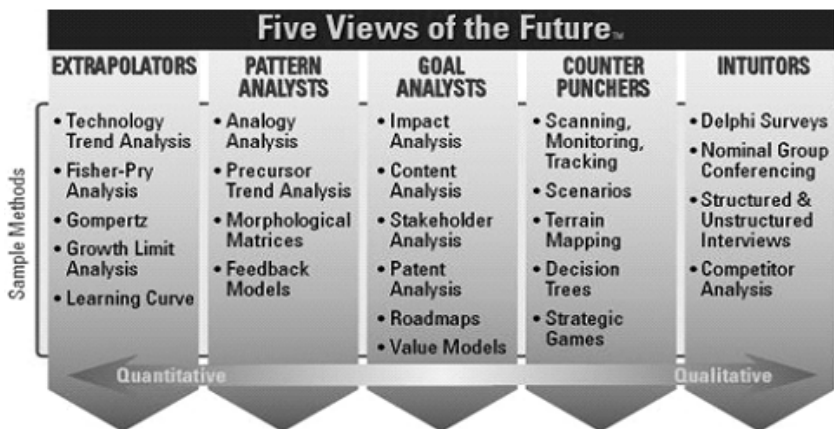
### 3. Identify Emerging and Potentially Disruptive Technologies

#### 3.1 Overview

Identifying emerging technologies, particularly those that can significantly disrupt current business models, is critical to long term successful innovation and the life of a company. And to do it well, an organization must **dedicate resources to breakthrough innovation**, i.e. create an organization whose objective is breakthrough innovation. Too frequently, rather than dedicating resources to breakthrough innovation, an organization will ask each employee to “allocate 10% of their time to innovation.” This very seldom works. The business problems of the day usually force this to 0%.

#### 3.2 Capabilities to identify trends and key technologies

It's important to identify future technology and consumer trends as part of our innovation work. There are many approaches and certainly the capabilities that a diverse external focus provides are critical. Technology Futures nicely summarizes many of the important capabilities to view the future in “Five Views of the Future”<sup>4</sup> as shown Figure 2 below. Most multi-national companies use some of the capabilities shown in this chart. And the capabilities may show up in various parts of the business. Some capabilities could be within a Strategic Planning organization and others within the technology organizations (Engineering, R&D, or even a Modeling and Simulation organization). And of course, they are also appropriate tools within Financial organizations.



**Figure 2** Various approaches to “view” the future from Technology Futures, Inc.

#### 3.3 TRIZ as a P&G example to identify trends

We have found that an approach called Theory of Inventive Problem Solving (TIPS or TRIZ for the Russian acronym) to be very helpful. TIPS addresses the invention part of innovation in a very structured way. It was developed by Genrich Altshuller<sup>5</sup> in Russia during the 1940's and is taught rather extensively in Russia today – and now in Europe and North America. Altshuller was a patent examiner (like many other inventors) and noted some common “invention principles” and “technology trends” as

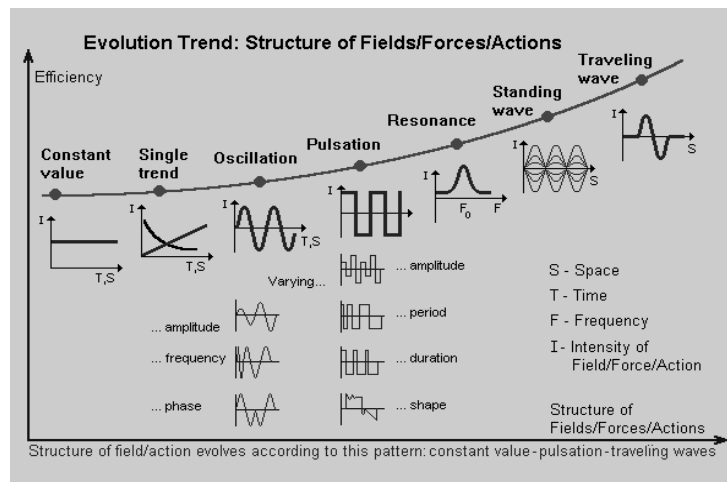
he reviewed patent material. He eventually identified 40 *inventive principles* and 12 *evolutionary trends*.

The evolutionary trend curves all exhibit the familiar ‘S’ shape for market adoption of technically superior new technologies – a pattern frequently characterized by mathematicians as a “logistic curve” or a Fisher-Pry model. The model has been recently popularized by Malcolm Gladwell in a book titled Tipping Point<sup>6</sup> – the “tipping point” being the first inflection of the ‘S’ curve when growth accelerates rapidly. While most of us as engineers feel a great technology can and should sell itself, this is in fact rarely the case. Gladwell explores the social and psychological aspects which can facilitate and even push a technology, concept or product past its tipping point.

One of Altschuler’s “evolutionary trends”, the Structure of Fields and Forces<sup>7</sup> is shown in Figure 3 below. It illustrates, as observed from Altschuler’s analysis of fields and forces patents that this trend moves from a constant field or force input ultimately to a standing wave.

We might think of this input as a process variable, for example, the air flow in a dryer. This is in fact an area of research today and beneficial results have been found by a variety of researchers. These were some of the conclusions.

- A decrease of air consumption can be achieved in a fluid bed dryer with a pulsed fluidization technique without affecting drying time.<sup>8</sup>
- An increase of range of velocities in a fluidized bed within the fluidized state can be achieved and there is a possibility of achieving the fluidized state at lower velocities.<sup>9</sup>
- Optimized and more frequent airflow reversals in a kiln dryer can improve final moisture distribution, reducing in-process and residual lumber stresses.<sup>10</sup>



**Figure 3** TRIZ Evolutionary Trend Curve for Structure of Fields/Forces/Actions

There is the opportunity to apply this evolutionary trend very broadly if we undertake a research program (academic or industrial) to explore this effect in key process unit operations. This is an example of how TIPS can provide a structured approach to innovation and how it can be used to leverage a well documented trend prediction.

Generally, a company must have a program for sustaining “new and improved” innovation and a program that addresses breakthrough innovation and the possibility that a new disruptive technology could obsolete their products. Clayton Christiansen has popularized the concept of disruptive technologies in his best seller books<sup>11,12</sup> on innovation. The basic premise is that the more successful your firm is in addressing the needs of your customers, the better your market research, the better your product is in meeting your best customers’ high end needs, the more likely your firm is to fail.

You will have focused too much on incremental innovation and insufficiently on breakthrough innovation and the next technology ‘S’ curve. Someone, likely a new player in the industry, will jump frog your best products. So we need the appropriate balance between “new and improved” innovation and breakthrough innovation. The innovation focus on “new and improved” products or processes keeps the firm financially healthy over the short term. The innovation focus on breakthrough enables the firm to remain financially healthy over the long term.

## **4. Diversity Fuels Innovation**

### *4.1 The power of a diverse organization to fuel innovation*

A diverse organization fuels diversity of thought. Diversity of thought nourishes and enables creativity and invention. One of America’s strengths has certainly been innovation, facilitated by the American “melting pot”. Diversity of race, religion, ethnic background, gender and education is a powerful enabler. If we all come out of the same mold (more or less), then we all think similarly. But if we come out of very different molds, then we have significant diversity of thought and are likely to be more innovative as an organization.

### *4.2 Xerox example*

Xerox’s Palo Alto Research Center (PARC) has long been noted for their creativity and invention. As the birthplace of technologies such as laser printing, Ethernet, the graphical user interface, and ubiquitous computing, PARC has an established track record for transforming industries and creating commercial value. It was not unusual for Xerox to staff a project with engineers, scientists, artists, and psychologists. While Xerox was noted for creativity and invention, they struggled with their ability to commercialize their inventions. And as pointed out earlier in this paper, innovation spans commercialization and this piece of the innovation cycle, in contrast to the discovery process, requires significant structure coupled with strong execution skills.

So the challenge is to staff an organization, which is charged to create, invent and commercialize, with a diversity of thought and capability. Those charged with discovery need to be comfortable with uncertainty and change. Those charged with project execution need to be comfortable with tight schedules and cost control. Usually, these are very different people.

#### 4.3 P&G examples

Personally, I have strived to staff my Engineering organization with diversity of disciplines not often found in a consumer products engineering organization. This organization includes expertise in ceramic engineering, radio engineering, plasma physics, ultrasound, biochemistry, polymer chemistry, rheology, and various disciplines within chemical engineering (mixing, heat transfer, powders processing, drying, etc.). It also includes diversity from numerous regions of the world (North America, Latin America, Western Europe, Eastern Europe, and Asia). And of course it includes gender diversity. It is a melting pot.

All that said, the other side of internal diversity is external diversity. AG Lafley, Procter and Gamble CEO, has noted “*we will acquire 50% of our technologies and products from outside P&G*”<sup>13</sup>. The approach we use is one of “connect and develop”, or C&D, to identify these “acquisitions” at any stage in the innovation cycle – discovery through commercialized and in the market (e.g. Gillette, which P&G recently acquired). The C&D concept has evolved as a best practice at P&G<sup>14</sup> and has also become popularized as “Open Innovation” by Henry Chesbrough.<sup>15</sup> The challenge is really to bring an external focus to innovation. At a minimum we need to know what is available externally that can solve our problem or meet a consumer need. We can agree there is a wealth of external ideas, inventions, and problem solutions and the challenge is to first decide to seek, and then to find these solutions. The good news is there are many companies today that specialize in finding and linking the needs of one client with the solutions of another client. Companies like NineSigma (which P&G helped create), and Innocentive (which was founded by Eli Lilly), specialize in connecting clients like Procter and Gamble, who are seeking problem solutions, with companies and individuals (inventors, academics, etc.) who may already have solutions to these problems. And NineSigma promotes open innovation as a way of making internal R&D more important, not simply an outsourcing of R&D.

And there are other ways that P&G leverages diverse external capabilities. P&G joined several other *Fortune 100* companies about six years ago to invest in Yet2.com, an on-line marketplace for intellectual property. Yet2.com connects globally across industries, universities, and national labs. A client such as P&G works closely with Yet2.com to write a “brief” describing the need or problem to be solved. This brief is then distributed to this global network. If there is a connection, then the client negotiates directly with the provider.

Realizing the richness of retired technologist, P&G partnered with Eli Lilly, Boeing and other companies in 2003 to form *YourEncore*, a business that connects retiree mastery with short term company needs. It’s a simple, but powerful way to bring the diversity of thinking from another industry to bear on a particular problem or project.

Lastly, P&G has developed a specific role to facilitate our C&D work. We have roughly 70 *Technology Entrepreneurs* around the world whose job responsibility is to identify external connections with real business value. A Technology Entrepreneur, exploring the Japanese market, identified a technology which enabled a new product, P&G’s Mr. Clean Eraser®.

## 5. The Challenge and Opportunities with Micro-Technologies

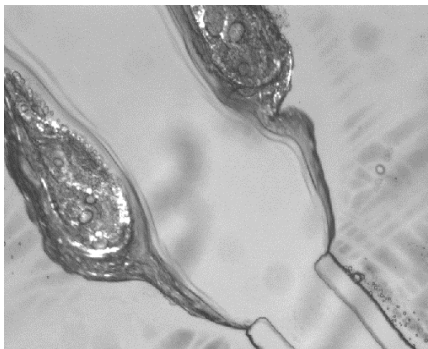
### 5.1 Overview

The promise of micro-technologies or more specifically, microfluidics for process engineers, continues to be an area of significant research effort. Much of the early work focused on parallel processing to enable smaller more efficient mixing, heat transfer and reaction processes. This also enables a simpler “number scale-up” instead of size scale-up. There have been some successes in this area, but we appear to still be in the low slope part of the ‘S’ curve. We haven’t reached the tipping point. The other area which seems to be getting more attention now is the capability of micro-technologies to enable us to “make our learnings on the smallest scale” – the concept of the lab-on-a-chip. An excellent review of this work was done by Stone<sup>16</sup>, et al.

These devices enable us to develop a mechanistic understanding of various process phenomena (e.g., emulsification, crystallization, precipitation). And these fundamental understandings enable more effective discovery work, analysis and scale-up for these systems. They are innovation enablers.

### 5.2 Micro-technology example

For example, Figure 4 shows a 200 micron jet in a microfluidic system. A surfactant dissolved in a solvent flows in the center tube and an aqueous polymer solution flows in the outer channel. Upon contact, lamellar liquid crystalline vesicles form and the interfacial viscosity rises significantly. As a result, chaotic flow occurs as the system forms recirculation zones. This type of system then, gives us some valuable insight as to the transformations occurring at this scale.



**Figure 4** 200 micron microfluidic jet

Micro-rheology is another interesting micro-scale capability. It enables us to study micro-scale phenomena that bulk rheological measurements may miss. This is done by following the Brownian motion (or externally induced motion) of tracer particles. It is also a fast growing area which can give some remarkable insights into product transformations during processing, stability, and product performance.

Much of this work has been enabled by developments in genomics, biotech, and microchips. The fabrication techniques and the applications are quite diverse and our challenge in the process field is to understand what’s possible in terms of application of these capabilities to address process issues. Again, how can these capabilities enable better, faster, cheaper innovation.

## 6. The Role of Modeling and Simulation in Process Innovation

As noted earlier, we could say that modeling and simulation can enable learning at the smallest possible scale – the virtual scale. And as we think about the entire innovation process, we need to apply modeling tools during each of the phases. Models can facilitate a broader range of options studied since they significantly reduce the risk of

failure. We like to say “**explore digitally and verify physically**” with regard to reducing innovation cycle times.

It’s also important to start with simple “pilot” models that provide quick learnings with an immediate payback. As more is learned, the models can get more detailed and complex. We can draw an analogy with the innovation cycle for physical prototyping.

As noted earlier, much of the modeling and simulation capability today is with mechanical systems. This work was fueled in large part by the application of Computer Aided Engineering (CAE) in the automobile and aerospace industries.

### 6.2 Modeling challenges

The technical challenges are even greater in the chemical processing industries – and if we break this down further we can say that solids processing challenges are greater than fluids processing challenges. For example, the modeling and prediction of solids (granular) flows is certainly in its infancy and well behind those capabilities for fluids. Modeling of unit operations such as agglomeration and spray drying is very difficult. The challenge of modeling a unit operation such as spray drying is modeling of the various transformations (e.g., droplet formation and agglomeration) in addition to powder and air flows and heat and mass transfer.

Certainly computational modeling is a growth area in P&G as noted by our Chief Technology Officer, Gil Cloyd, in a recent issue of Industry Week –

*“Computational modeling once existed primarily in a computer-aided-engineering context to facilitate our manufacturing processes. Now we’re using it to help with actual product design.”....It will enable us to be more creative and design better products”<sup>17</sup>*

And he predicts that as much as 90% of P&G’s R&D will be done in a virtual world with the remainder being physical validation. The reality is we are using modeling and simulation very broadly today. For example, we’re realizing significant cost and time savings in consumer testing. Internet Product Panels enable 24 hour engagement with consumers. We’re adopting a multiscale modeling approach that spans discovery through commercialization. The challenges are many – consumer modeling, connecting models across scale, modeling of product performance and stability, modeling of the transformations that occur during processing, and effective management of the data that goes into the models - to note just a few.

In many situations it is difficult to measure key variables necessary to validate a model. For example, it is a real challenge to measure powder and air velocity profiles in a spray dryer operating at high temperature and high humidity. And although we’ve been using CFD to model our spray dryers for years, the model is still incomplete in terms of modeling the agglomeration transformation that occurs in the dryer and which is a key morphological attribute of the dried powder.

There is also frequently a misunderstanding of what can and can not be modeled with today’s capabilities. It is all too frequently assumed that we can model anything. The fact is that in many cases we do not have the physical systems and prototypes to enable us to get the data needed to begin even elementary empirical models – much less the

first principles models that we prefer to enable getting outside the box of current product and process designs, i.e., getting to the truly innovative designs. And frequently the challenge is our ability to get good data – not the modeling associated with that data.

This is again a situation where small scale capabilities are very valuable. For example, while we can get data on a plant scale system, it is usually cost prohibitive to go outside the boundaries of normal operation – so the model has limited capability. Having the capability to get this data at pilot scale certainly lowers the cost and increases the range of operation that can be modeled. This can still be very expensive though. However, if the data can be obtained at a bench or micro-scale, then this cost may not be a critical issue in the overall data generation/model development picture. We can better fuel innovation.

## 7. Summary and Conclusions

Innovation is a broad topic that is in the spotlight of most corporations today. There are many thoughts on innovation. There are many books on innovation. There is not one approach which works for all organizations or all situations in an organization. In the end we need to approach innovation as we do other technical issues or problems. Survey trends and what is available. Gather data and information. Test a specific method that looks appropriate for your situation on a pilot basis. Learn and move forward.

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