Quantifying the Benefits of Green Chemistry

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I. Making the Business Case

1. Introduction: What is Green Chemistry and what does it offer Business?

Green Chemistry[1] enables companies to design new products and processes around sustainability criteria; helps capture top and bottom line profits throughout the value chain, and allows companies to differentiate and gain competitive advantage. As shall be discussed in this paper, many specific Green Chemistry applications are emerging in companies in a wide range of industries, including chemical giants such as Dow, DuPont, and Rohm and Haas; as well as in consumer product producers S.C. Johnson, Shaw carpets and a host of leading pharmaceuticals companies. Small businesses, like AgraQuest and Metabolix, also play a leading innovative role. Green Chemistry design and innovation is being applied to a range of industrial applications including:

- Adhesives
- cleaning products
- fine chemicals
- fuels and renewable energy technologies
- nanotechnologies
- paints and coatings
- pesticides
- pharmaceuticals
- plastics
- pulp and paper
- textile manufacturing
- water purification

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[1] *Green Chemistry: Theory and Practice* by Paul Anastas and John Warner.

What does Green Chemistry offer in terms of benefits and how can these benefits be measured? A foundational Green Chemistry design tool is the concept of the “atom economy,” which would have manufacturers make the most efficient use possible of each molecule of input. If you consider that on average 94% of the resources that goes into making a product is discarded as waste, this principle has profound ramifications not only for companies in terms of waste and cost savings, but broader societal benefits as well.

The pharmaceutical industry, an early adopter of Green Chemistry principles in industrial processing, uses a metric called *E-factor* to measure the ratio of inputs to outputs in any given product. In essence, an E-factor measurement tells you how many units of weight of output one gets per unit of weight of input. This figure gives companies a sense of process efficiency and inherent costs associated with waste, energy and other rates of resource use. By applying Green Chemistry principles to pharmaceutical production processes companies have been able to dramatically lower their E-factor – and significantly raise profits.

Merck and Co, for example, “discovered a highly innovative and efficient catalytic synthesis for sitagliptin, which is the active ingredient in the company’s new treatment for type 2 diabetes, Januvia™. This revolutionary synthesis creates 220 pounds less waste for each pound of sitagliptin manufactured and increases the overall product yield by nearly 50 percent. Over the lifetime of Januvia™, Merck expects to eliminate the formation of at least 330 million pounds of waste, including nearly 110 million pounds of aqueous waste."[i] The bottom line benefits to both Merck and the environment of this Green Chemistry process innovation are clear.

In this paper we will examine a suite of company examples and note how they have measured a variety of benefits derived from Green Chemistry innovations in industrial processes or products. Green Chemistry places both company profitability and ecological health at the heart of innovative product design and manufacturing. It uses the creativity of nature's biological processes to create molecules, materials and processes that are safe and high-performing. Moreover, because it calls for an increased reliance on renewable inputs, at a macro level Green Chemistry provides the means of shifting away to a bio-based economy. This has profound consequences for a wide range of issues, from environmental health, to worker safety, to national security, and the farm economy. While no one science supplies all the answers, Green Chemistry plays a foundational role in enabling companies to see concrete benefits from greener design.

2. The Market for Green Materials

> *"I foresee the time when industry shall no longer denude the forests which require generations to mature, nor use up the mines which were ages in the making, but shall draw its materials largely from the annual produce of the fields."*
> \- *Henry Ford, 1940*

> *Ratio of plastic to zooplankton found by researchers studying North Pole marine debris: 6:1*

In 1941 Henry Ford unveiled a plastic car. Although using plastic in auto bodies is not uncommon today, this particular car was extraordinary from a sustainable design perspective even by current standards. The body was made of plastic which was seventy percent derived from wheat straw, the other thirty percent was from soy. “The timing gears, horn buttons, gearshift knobs, door handles and accelerator pedals were derived from soybeans. The tires were made from goldenrod bred by Ford’s close friend Thomas Edison. The gas tank contained a blend: about 85 percent gasoline, and about 15 percent corn-derived ethanol.”

Ford came up with the idea for the “field-grown” car in the 1930s, when the Depression, drought and debt were driving American farmers from their land. With the onset of World War II and heightened uncertainty of access to foreign resources, the idea of plant-based plastics made even more sense. But the end of the war brought with it unfettered access to foreign oil supplies and the subsequent dawning of the petrochemical age. This era brought with it increasing reliance on industrial chemical inputs which have had serious long term environmental consequences we are only now coming to appreciate.

The concept of clean materials design opens up vistas for product innovation and market shifts. There are fundamental and visible manifestations of change in emerging product and materials which are revolutionizing our industrial relationship to chemicals. In response to concern for the impact of chemicals on biological systems many companies are now investing in efforts to design new products and services that significantly reduce, if not eliminate, questionable materials. Design teams are actively seeking opportunities to substitute benign materials in both products and manufacturing processes. The rationale for this trend is clear: if a company’s ultimate goal is sustainable prosperity (either its own or society's), then production systems require new thinking, new formulae, and new inputs – that and sometimes the reexamination of old knowledge put aside.

Gaining a broader systemic perspective on a product/service can bring up uncomfortable conclusions: Ford's plant-based plastic car was a significant sustainable business innovation, but the long-term systemic impact of the car was not as consciously considered. Nor indeed, is it addressed by current cleaner engine designs – a freeway choked with cars, even if they are cleaner, is still an impediment to economic activity. As we shall discuss in a subsequent chapter, perhaps the service in demand –mobility – is still unmet by current product designs. However, Henry Ford's successor, William Clay Ford, Jr, in seeking a broader systemic perspective recently directed Ford to redesign and rebuild its Rouge River headquarters (production site of the original Model T) using very innovative and sustainable industrial and architectural criteria. There are always gains to be made, if one but looks.

The spectrum of company activities in the sustainability arena is wide: while some are early entrants into this arena and are fundamentally reconfiguring product systems, others take more incremental steps toward adopting cleaner, innovative materials and processes. As noted in the previous chapter on perspectives, incremental change can be revolutionary, so long as one constantly looks over the hill toward self obsolescence.

Many companies, within the chemical industry and outside, now understand that cost reductions and product/process improvements are available through environmental efficiency policies. Documented cost reductions in materials input, waste streams, and energy use are readily available. In recognition of the efficiency gains to be realized, as well as risk reduction and regulatory advantages, most firms acknowledge the benefits that result from taking the environmental management agenda seriously. In addition, companies know they can help avoid the adverse effects of ignoring theses issues, such as boycotts and stockholders resolutions that generate negative publicity.

But the efficiency improvements and risk reduction sides of environmental concerns and sustainability are just the leading edge of the opportunities possible. Innovation goes beyond incremental improvement to the existing systems to the creation of innovative alternatives. This future oriented perspective on sustainability thinking – geared toward new processes, products, technologies, and markets – offers profound prospects for competitive advantage over rival firms. At a deeper level, this mode of strategic thinking holds the potential to transform the way we think about the management of economic activity over the next few decades.

The chemical industry has the opportunity to benefit a broader set of stakeholders while better serving the financial interests of stockholders. For many these claims may sound hollow. Everyone knows that global expansion of the chemical industry, even with good faith effort to comply with safety and pollution requirements, naturally carries with it adverse and unintended effects from chemical production and use. Such is the price of economic growth, correct? Wrong. In fact, our passive acceptance of this paradigmatic view of the chemical industry may pose the most formidable obstacle to change. If so, the challenge may be more in our minds – in our inability to perceive opportunities – than our any shortcoming in our capabilities.

The reality is that innovative individuals and companies have already challenged these assumptions with alternatives to conventional chemical design and application, working from the feedstock molecules up, and from the final product down to its material components. For these innovators, new scientific information, future-oriented conceptual maps, new design parameters, and the commitment to benign alternatives all combine to create breakthroughs. The opportunity offered to the chemical industry can be understood if one looks for possibilities for new products and markets.

While commitments to existing asset investments may prevent wholesale switching over to new operating and product design approaches, strategically savvy companies are gaining expertise and market presence. Sony is using corn-based plastics in components and packaging. First available in Japan, the casing for the Walkman stereo, wrapping film, and blister packaging are vegetable-based. Such products are designed using environmental technology to encourage recycling activities, energy conservation and reduction in the use of hazardous materials. This replacement plastic uses only 45% of the oil-derived resources of conventional plastic, with commensurate reductions in carbon dioxide emissions.

In a modern rendition of Henry Ford’s field-grown car, Ford has introduced a concept SUV with a hydrogen engine and using biomass-derived materials including Cargill Dow’s PLA (polylactide) biopolymer derived from corn. Bio-based materials contribute to the roof, carpet mats, tires, seating foam, and lubricants. Collaboratively with Toyota, Toray Industries has developed PLA material for use in an extensive range of automotive components. Toray Industries expects to reach revenues of $86 million in 2005. Currently PLA raw materials are sourced through an alliance with Cargill Dow but Toyota is developing its own bio-plastics production facilities – expecting that Asian and European demand for bio-plastics will open a large market.

From the European Union, “eco-technology” that includes innovative processes and products is expected to be one of the fastest growing market arenas in the 21st century. The export market to developing countries for environmental technologies was reported to have grown by 10-17% between 1998 and 1999, with a lower growth rate for activity in developed markets. The sector was reported to have created more than 500 jobs between 1997 and 2002.

Reducing manufacturing costs is a big incentive for many. Materials maker DuPont used to make 10,000 tons of a polymer called Sorona each year using a petrochemical process in which oil was the raw material. Sorona was used in swimsuits, slacks, and jackets, since fibers made from it were soft and recovered their shape after being stretched. Such fibers aren't biodegradable, however, and they are expensive to make because their manufacture requires high-temperature, high-pressure reactors.

DuPont engineers cloned genes from a bacteria, inserted them into a fermentation process -- and created a microorganism that did not exist in nature. A bioengineered organism, the new creature turned glucose -- a form of sugar -- into Sorona in a single step. This new process debuts commercially in 2004. As a result DuPont will not need either its oil-based raw material or the expensive reactors. Not only will production will be much cheaper, says DuPont research manager Scott Nichols, but Sorona will be biodegradable, and the process for making it will be more environmentally friendly.

GE Plastics, a subsidiary of General Electric (GE), has developed a technology that by 2006 could make it unnecessary for carmakers to paint vehicles. It costs around $300 million to build paint lines and they take up about half of a car plant's floor space. GE's Lexan SLX product promises to eliminate the expense and the space requirements. Thus far the technology has been used only to paint the bumpers of a two-wheel personal transportation system called Segway. A thin film, when heated it can be molded into shapes that correspond to parts of a car. While the film currently is more expensive than paint, the process eliminates the need for paint lines and uses a plant's existing molding equipment. GE Plastics expects to announce its first contract with a carmaker in 2004. What does this litany signify? What are the drivers behind such innovative activity and what some would consider such risky investments? What follows is a discussion of the drivers behind these and the innovations discussed in the following case studies. One of the central drivers for these new ways of perceiving opportunity is that science is revealing new interactions between common chemicals and the New Commons, our bodies. Following the discussion of drivers will be a brief mention of some of the research and development partnerships available now aiding companies in their quest to design environmentally safer products.

3. Making the Business Case for Green Chemistry

People unfamiliar with sustainability often ask, “But what is the *business case* for sustainability?”[2] With a skeptical tone, they inquire, “What is the business case for incorporation of Green Chemistry principles into corporate strategy?” These are appropriate questions. How can companies translate the pressures they are experiencing into practical implementation steps, metrics, and improved financial performance? This paper is an attempt to clarify the financial and strategic motivations –an essential step to making the business case – by illustrating the links between sustainable business practices, competitive advantage, and the measurement of value creation applied to adoption of Green Chemistry and Green Engineering practices. The goal is to provide a framework that enables managers and executives to make objective decisions based on financially and strategically thoughtful logic.

Green Chemistry practices improve the company’s value proposition in many of the same ways any action does that lowers costs, grows revenues, or results in brand enhancement. Green chemistry and engineering principles also hold significant potential for avoided liability and risk, no small consideration in our litigious environment.

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[2] See forthcoming article, Geoff Archer, Andrea Larson, Jeff York, **SUSTAINABILITY: GREEN CHEMISTRY AND ENGINEERING LINKS TO FINANCIAL ANALYSIS AND CORPORATE STRATEGY**

As the reader is well aware, making the business case is not about creating a stock price jump. Nor can any specific decision – related to sustainability topics or not - ever definitively cause a rise in stock price. But over the long run however, one hopes that creative and worthy efforts by and on behalf of those with a stake in the venture will drive up the value of the firm. We assume this outcome because ideally the value proposition offered by the firm is being continually improved, and this ultimately will be reflected in the stock price to the extent that stock prices reflect "good management". We hold that commitment to good management yet overlooking sustainability logic (implemented through specific green chemistry and engineering applications) means senior management is not serving its stockholders or stakeholders as fully as the competition may be, putting the firm at a competitive disadvantage and failing to deliver on fiduciary responsibility to stockholders.

4. Green Chemistry is Financial *and* Strategic

The choice to pursue sustainability is a strategic issue. As such it is not a simple matter of what tactics to employ, but a question of how the firm will develop and maintain competitive advantage.[3] For this conversation we will simplify competitive advantage to be derived from two sources. Competitive advantage can be gained from either differentiated cost savings, in other words, the ability to produce the same goods at a reduced cost relative to the competition, or from increased revenue attained by access to new, or preferential treatment by current, customers.

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[3] Level Three Leadership: Getting Below the Surface by James G. Clawson, Pearson Education, 2003.

Making the business case for investments, particularly ones that alter conventional strategy, such as in new Green Chemistry, always combines financial arguments with strategic rationales. Few companies can allow short-term financial drivers to consistently trump strategic thinking. Positioning a company for future growth requires adapting financial models. In other words, once models are built, the company's strategy staff works with the finance managers to adapt them to desired future strategic outcomes. Ideally these leverage corporate capabilities with outside trends. Importantly, you don't want the finance tail to wag the strategy dog. Imaginative strategic thinking about creating future market dominance, with a clear understanding of risks and financial downsides, leads to market differentiation and new market creation.

5. Green Chemistry and Engineering in Corporate Financial Terms

Depending on the specific decision to be made, how can a company include Green Chemistry in strategic conversations without having to overhaul the current decision making process? How can we talk about gaining competitive advantage in everyday business language? Depending on the scope of a decision, as well as company norms, the language of strategic decisions will vary. In this paper, we demonstrate the advantages to be derived from sustainable business thinking whether the corporate language is Economic Value Added (EVA), Net Present Value (NPV) or strategic externalities. Although obviously not comprehensive, we believe this gives any manager or executive a good starting point.

Economic Value Added (EVA) is a commonly used method to report on value created during a given time period (quarterly, annually, etc.) and is typically used as a "top down" measure of the entire company's performance.[4] Let's look now to the EVA as a tool. The equation is EVA = (ROIC-WACC) * invested capital. ROIC stands for return on invested capital and WACC refers to weighted average cost of capital. Three levers in this formula can be used to analyze investment in Green Chemistry technologies:

1) Increased ROIC - Driven up by increased revenues from sales or reduced costs from improvements to your operations.
2) Decreased WACC - Driven down by decreased risk in the eyes of lenders.
3) Increased Capital Availability – Expanded sources of capital availability through a widened pool of funding availability

Second, consider **Net Present Value (NPV**). NPV is the most common method used to assess specific project viability by discounting all future cash flows from the project to the present value using a set hurdle rate for investments. All positive NPV projects are considered attractive, as they create shareholder value. NPV discounts the future, which naturally is going to be a hard fit with sustainability. The two concepts are almost necessarily in conflict, because sustainability asks us to value the future like the present, not discount it with compound interest. NPV is a tool for specific project decisions, and as such, you must ensure that your assumptions include sustainability issues to capture the true value created.

Lastly, **Strategic Externalities** (new science on chemicals and health, changes in regulations, growing consumer demand for "cleaner" products, etc) are factors that

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[4] Harris, R. S. 1997. Value Creation, Net Present Value and Economic Profit. Charlottesville, VA: The University of Virginia, Darden School Foundation.

clearly will emerge as we make business choices on Green Chemistry, and they will potentially have a positive strategic impact. In other words, they may create competitive advantage, but it would be difficult to demonstrate the case using current financial measures of value creation. However they *should* be considered in the process of robust, long-term strategic planning.

6. The Bottom Line: Green Chemistry Reduces Costs

As companies take Green Chemistry into financial account, they must measure potential cost savings and enhanced revenue streams: i.e. the bottom and top line profits Green Chemistry offers. At the bottom line, Green Chemistry offers **Differentiated Cost Savings**: i.e. the ability to produce the same product as your competition at a lower cost. Bob Willard has provided a useful framework for considering the cost/benefit of sustainability[5] including, but not limited to:

a. Reduced Operating & Manufacturing Expenses – Derived from reuse, waste reduction, and reduced resource consumption (water, electricity, packaging, etc.). Let us look at how EVA and NPV lenses might yield insights.
b. Risk Reduction – Includes legal, regulatory and social risks

c. Decreased Employee Expense – Increased productivity and retention, reduced recruiting expenses

All of these cost savings criteria are valid for Green Chemistry. What follows is a matrix of Bottom Line cost savings companies have realized in applying Green Chemistry innovations:

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[5] Willard, B. 2002. The Sustainability Advantage: Seven Business Case Benefits for a Triple Bottom Line. Gabriola Island, British Columbia: New Society Publishers.

Metrics: Bottom Line Results: Cost Savings & Improved Profitability
• Improved manufacturing capacity utilization (more throughput per unit of time)
• Improved ‘E Factor’ / Increased product yield
• Lower energy and water consumption
• Waste reduction; hazardous waste elimination
• Waste (esp. toxic) disposal fee avoidance/reduction
• Lower material procurement costs (reduced feedstock volumes and processing materials)
• Lower inventory costs (few materials required on site)
• EH&S overhead reduction (less handling risks, safety equipment; monitoring, data gathering and reporting overhead)
• Liability risks lowered (contingency set asides avoided)

Examples of Company Bottom Line Savings[6]:

Ion Edge Corporation
Zero-waste dry plating of cadmium
Ion Edge Corporation employs five people, and is not a multi-national corporation. Annual production of their green dry plating is 100,000 parts, and thus replaces 100,000 parts made by the conventional method. In comparison to a medium size electroplating facility, their zero-waste dry plating of cadmium, annually saves

- 2,500,000 gallons of water
- $50,000 from reduced water use
- 1900 kwh of energy
- $2,000 from reduced energy use
- 1,500,000 lb of raw material solids
- 2,500,000 gallons of raw material liquids
- $252,000 from reduced raw materials use

ULVAC Technologies, Inc.
Eliminating solvents from silicon wafer manufacturing
ULVAC Technologies, Inc. employs 3,000 people as a multi-national corporation. This process reduces 744,857 gallons of hazardous or toxic waste from the waste stream annually. Emissions of GHG were reduced by eliminating need for destruction of haxmays, but there is no quantitative data available. Annually, ULVAC’s customer manufactures 520,000 8 nch wafers using this process and saves

- 391,134 gallons of water
- $39,112 from reduced water use
- 2,488 kWh of energy
- $204 from reduced energy use
- 41,614 gallons of raw material liquids

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[6] Quantitative Indicators Supplied by the University of Scranton.

- $2,080,728 from reduced raw materials use
- $17,153 from decreased production of liquid waste (solvent, IPA, water)

Eastman Kodak Company
Minimizing environmental emissions by using different solvents in manufacturing processing.
Eastman Kodak Company employs 80,000 people and is a multinational corporation. They report less energy use for the new process due to the removal of several process steps, and a reduction in energy required for waste treatment. The cost of handling 400,000 lb/y of hazardous waste has been eliminated. Additional cost and hazard reduction was achieved by eliminating methanol purchases. Annually, Eastman Kodak

- Saves 60,000 gallons of raw material liquids
- Decreases solid waste production by 40,000 lbs
- Decreases liquid waste production by 60,000 gallons
- Decreases hazardous air emissions by 1,500 lbs

7. Top Line Benefits of Green Chemistry

Companies are discovering that they can increase revenue through sustainable business practices such as Green Chemistry and Engineering. The mechanisms here are:

Increased Revenue and Market Share: Obtained through differentiation and preferred access to markets inaccessible to competitors. These may include, but are not limited to:

a. Access to Markets – Access to previously, or soon to be, inaccessible markets can be improved

b. Preferential Purchasing – Current customers may be retained through passing the cost savings generated in production through the supply chain

c. Increased Innovation – Green Chemistry can serve as an impetus for innovation; the company that figures out how to comply, and even be in advance of, regulation better, faster, and cheaper will have a competitive advantage[7]

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[7] R. Edward Freeman, J. P., Richard H. Dodd. 1999. Environmentalism and the New Logic of Business. New York, New York: Oxford University Press.

What follows is a matrix of top line benefits companies are increasingly experiencing through Green Chemistry:

<u>Metrics: Top Line Improvements & Growth Opportunities</u>
• New & improved products
• New markets
• Competitive differentiation/advantage
• Increased Sales/Revenues (enhanced ability to meet demand through expanded production capacity and lower costs)

8. Other Benefits

Last, but not least, there are new measures of success emerging that companies employing Green Chemistry innovations are experiencing; benefits which require us to think up new categories than “top” or “bottom” lines. These are often the result of changes in a company’s “soft assets”, such as brand recognition, company reputation, consumer trust, etc. Green Chemistry offers distinct benefits in these areas as well:

<u>Metrics: Other Benefits</u>
• Process patents
• Brand enhancement/protection
• Enhanced community reputation
• Corporate Sustainability Report indices – attract investors
• Preferred supplier status

II. Case Study Examples:

What follows is a collection of company examples which are illustrative of the strategic decision making process a company goes through and the benefits companies can realize by engaging in Green Chemistry innovation.

1. NatureWorks

In 2002 NatureWorks LLC (formerly named Cargill Dow after the corporate joint venture, renamed in January 2005), US agricultural giant Cargill Inc.'s small subsidiary, received the prestigious Presidential Green Chemistry Challenge Award from the American Chemical Society's Green Chemistry Institute for its development of the first synthetic polymer class to be produced from renewable resources, specifically from corn grown in the American midwest. The product delivered on the promise of biomass materials and specifically the replacement of petroleum based polymers with renewable feedstock.

Polylactic acid (PLA) innovation has the potential to revolutionize the plastics and agricultural industries by offering benign bio-based biopolymers to substitute for conventional petroleum-based plastics. NatureWorks bio-based plastic resins are named and trademarked NatureWorks PLA for the polylactic acid that comprises the base plant sugars. In addition to replacing petroleum as the material feedstock, PLA resins have the added benefit of being compostable (safely biodegraded) or even infinitely recyclable, which mean they can be reprocessed into the same product again and again. This provides a distinct environmental advantage, since recycling, or "downcycling", post-consumer or post-industrial materials into lower quality products only slows material flow to landfills by one or two product life cycles. Additional life cycle environmental and health benefits have been identified by a thorough LCA (life cycle analysis) from corn to pellets. PLA resins, virgin or post-consumer, can then be processed into a variety of end-uses.

NatureWorks' process for creating a proprietary polylactide, trade named NatureWorks PLA (for plastics) and Ingeo (for fibers), is based on the fermentation, distillation and polymerization of a simple plant sugar, corn dextrose. The process harvests the carbon stored in plant sugar and make a polylactic acid polymer with characteristics similar to those of traditional thermoplastics.

The manufacturing sequence reduces consumption of fossil fuel by 30 to 50% compared to oil-based conventional plastic resins. PLA plastic waste safely composts in about 45 days if kept moist and warm (above 140 degrees Fahrenheit) or, once used, can be burned like paper, producing few byproducts. PLA offers a renewable resource replacement material for PET and polyester, both used widely in common products like packaging and clothing.

Field corn is the most abundant and cheapest source of fermentable sugar in the world, the standard variety used by NatureWorks (yellow dent #2) is also commonly used to feed livestock . The corn is sent to a mill, where it is ground and processed to isolate the sugar molecules (dextrose). Dextrose is purchased from Cargill and fermented using a process similar to that used in beer and wine production. This fermentation yields lactic acid. The lactic acid is then processed, purified, melted then cooled, and chopped into pellets. It is then ready for sale and to be made by processing companies along the supply chain into cups, plates, take-home containers, polyester-like fabrics, or laptop computer covers. Once the product is used, it can either be composted (meaning it would biodegrade) or melted down and recycled into equal quality products. Though NatureWorks has the technical capacity to include post-consumer PLA products in with virgin corn feedstock to make new product, large-scale collection requires a reverse logistics system. The hope is to develop this capacity in the future which will allow NatureWorks to close the loop of their industrial process and practice "cradle to cradle" manufacturing, a replacement model gaining credence as a substitute for the linear, cradle to grave industrial process that had characterized western industrial economies.

A key design breakthrough resulted in a dramatic cost reduction to manufacture the lactic acid for making PLA polymers. A new fermentation and distillation process was used that enabled cheaper purification, better optical composition control, and significant yield increases over existing practice. This compared with two-thirds of the material inputs in conventional PLA processing lost to waste streams. NatureWorks holds patents on the process. Their proprietary process also enables inexpensive production of different PLA grades for multiple markets in a flexible manufacturing system within a single plant, while adhering to environmentally sound practices throughout.

2. Shaw Carpets

In 2003 Shaw's EcoWorx product won the US Green Chemistry Institute's Green Chemistry Award for Designing Safer Products. The company combined application of green chemistry principles with a cradle-to-cradle design approach to create new environmentally benign carpet tile. The product met the rising demand for sustainable products, helping create a new market space that opened up in the late 1990s and 2000s as buyers became more cognizant of health hazards associated with building construction materials and furnishings. EcoWorx also educated the marketplace on the desirability of sustainable products as qualitatively, economically, and environmentally superior substitutes, in this case for a product system that had been in place for 30 years.

Shaw's introduced EcoWorx in 1999. A polyolefin backed carpet tile, EcoWorx offers an alternative to the industry standard PVC backing at comparable cost, 40% less weight, and equal or improved performance across all performance categories. EcoWorx earned the 1999 Best of Neocon Gold Award at the largest annual interior furnishings and systems show in the U.S. In 2002 the company's EcoWorx tile called "Dressed to Kill" won the carpet tile design Neocon Gold Award, effectively mainstreaming the new material. Customers preferred the new product, consequently by 2004 80% of carpet tile sold by Shaw—faster than anticipated—was made with EcoWorx.

In 2005 Shaw Industries of Dalton, Georgia was the world's largest carpet manufacturer selling in Canada, Mexico, and the US, and exporting worldwide. Its carpet brand names included Cabin Crafts, Queen, Designweave, Philadelphia, and ShawMark. The company sold residential products to distributors and retailers and offered commercial products directly to customers through Shaw Contract Flooring. The company also sold laminate, ceramic tile, and hardwood flooring.

Given the developing niche in the market for “green” products, Shaw Industries was poised for more innovation and leadership. In 2003 Shaw recorded $4.7 billion in sales. Shaw Industries was publicly traded on the New York Stock exchange until 2001, when it was purchased by Warren Buffet’s Berkshire Hathaway Inc. The company’s primary market was in woven and tufted broadloom carpet. In 2004 the global market for carpeting was about $26 billion, expected to grow to $73 billion in 2007. Carpeting and rugs sectors expected a combined growth rate of 17%.

Carpet tile as a product category bridged most commercial market segments (offices, hospitals, universities). On the market for over 30 years, it was introduced originally as a carpet innovation enabling low cost replacement of stained or damaged tiles, rotation of tiles in zones of high wear, and to provide easy access to utility wiring beneath floors. Carpet tile’s higher cost, high mass and embodied energy, more stringent backing adhesion performance specifications compared with broadloom, and rapid market growth made it a logical focus for exploring alternative system designs.

Tile is comprised of two main elements, the face and the backing. The face is made from yarn made of either Nylon 6 or Nylon 6.6 fiber, the only viable nylon in commercial carpet. Historically U.S. carpet tile has been made with PVC plastisol backing systems. The backing provides the tile’s mechanical properties and its adhesive stability. PVC was under suspicion however, due to the potential of the plasticizer to migrate from the material causing health problems and product failure.

EcoWorx, the replacement system for the PVC-nylon incumbent system, drove double-digit growth for carpet tile after its introduction in 1999. The system made it possible to recycle both the nylon face and the backing components into next generation face and backing materials for future EcoWorx carpet tile. Shaw used its own EcoSolution Q nylon 6 branded fiber that would be recycled as a technical nutrient through a recovery agreement with Honeywell's Arnprior depolymerization facility in Canada. The nylon experienced no loss of performance or quality reduction and cost the same or less.

Backing provides functions that are subject to engineering specifications, such as compatibility with floor adhesives, dimensional stability, and securing the face fibers in place. Selecting backing material and getting the chemistry right for the system's performance took time. Inadequate backing compound, lamination (attachment) was a liability that shortened product service life, reduced tile flexibility for ease of installation, and reduced wear resistance. Dow Chemical provided new matallocene polyolefin polymers to achieve Shaw's performance specifications, to which Shaw added a proprietary compounding process to complete the material design. Seeking every way possible to reduce materials use, remove hazardous inputs yet maintain or improve product performance Shaw made the following changes:

- Replacement of PVC and phthalate plasticizer with inert and nonhazardous mix of polymers ensuring material safety (PVC contaminated nylon facing cannot be used for noncarpet applications of recycled materials) throughout the system
- Elimination of antimony trioxide flame retardant associated with harm to acquatic organisms
- Dramatic reduction of waste during the processing phases by immediate recovery and use of the technical nutrients (the production waste goal is zero)
- A life cycle inventory and mass flow analysis that captures systems impacts and material efficiencies compared with PVC backing
- Efficiencies (energy and material reductions) in production, packaging and distribution – 40% lighter weight of EcoWorx tiles over PVC-backed tiles yields transport and handling (installation and removal/demolition cost savings
- Use of a minimum number of raw materials none of which lose value, as all can be continuously disassembled and remanufactured
- Use of closed-loop, integrated plant-wide cooling water system providing chilled water for the extrusion process as well as the heating & cooling system (HVAC)
- Provision of a toll free number on every EcoWorx tile for the buyer to contact Shaw for removal of the material for recycling

Models assessing comparative costs of the conventional versus the new system indicate the recycled components are less costly to process than virgin materials. Essentially EcoWorx tile remains a raw material indefinitely. Unique in the carpet industry, Shaw’s tile products will make the full C2C cycle back to manufacturing and new product. The benefits: a 40% weight reduction of the backing compared to the PVC plastisol-backed tile lead to savings in all phases of the product life cycle.

3. Pfizer

In 2002 Pfizer won the US Presidential Green Chemistry Award for Alternative Synthetic Pathways for its innovation of the manufacturing process for sertraline hydrochloride. Sertraline (“sir-tra-leen”) HCl was the active ingredient in the pharmaceutical, Zoloft®. Zoloft®, the most prescribed agent of its kind, was used to treat an illness (depression) that each year struck 20 million adults in the U.S. and that cost society $43.7 billion (1990 dollars). 2003 global sales grew to $3.4 billion (+11%) with over 115 million prescriptions written.

Applying the principles of green chemistry to the Zoloft production line, Pfizer dramatically improved the commercial manufacturing process of sertraline. Each chemical step was analyzed for opportunities to improve the yield and reduce the cost. As a result, Pfizer significantly improved both worker and environmental safety. The new commercial process (referred to as the "combined" process) offered dramatic pollution prevention benefits including improved safety and material handling, reduced energy and water use, while doubling overall product yield.

E-Factor, an efficiency assessment tool for the pharmaceutical industry, is defined as the ratio of total kilograms of all materials (raw materials, solvents and processing chemicals) used per kilogram of active product ingredient (API) produced. By 2005 E-factors were being used in the industry to evaluate all major products. Firms were identifying drivers of high E-Factor values and taking actions to improve efficiency. A pivotal 1994 study indicated that for every kilogram of API produced, between 25 and 100 kilograms or more of waste was generated as standard practice in the pharmaceutical industry, a ratio still typical in the industry in the early 2000s. Multiplying the E-Factor by the estimate of kilograms of API produced by the industry overall suggested that for the year 2003 as much as 500 million to 2.5 billion kilograms of waste could be the byproduct of pharmaceutical industry API manufacture. This waste represented a double penalty: the costs associated with purchasing chemicals that are ultimately diverted from API yield and costs associated with disposing of this waste (ranging from $1 to $5 per kilogram depending on hazard). Very little information was released by competitors in this industry, but a published 2004 GlaxoSmithKline lifecycle assessment of their API manufacturing processes revealed approximately 75-80% of the waste produced was solvent (liquid) and 20-25% solids, of which a considerable proportion was likely hazardous under state and federal laws.

After implementing the GCI award-winning process as standard in sertraline manufacture, Pfizer's experience suggested the results of green chemistry-guided process changes brought E-Factor ratios down to 10 -20 kilograms. The potential to dramatically reduce E-Factors through "benign by design" can, in fact, be significant. Lilly, Roche, and Bristol Meyers Squibb—all winners of a Presidential Green Chemistry Award between 1999 and 2004—reported improvements of this magnitude after green chemistry principles had been applied. Not surprisingly, and not to be discounted, green chemistry also fits with 6-sigma whose principles considered waste a process defect. "Right the first time" was an industry quality initiative backed strongly by the FDA.

Zoloft :

Zoloft was released in 1992 and was approved for six mood and anxiety disorders, including depression, panic disorder, obsessive-compulsive disorder (OCD) in adults and children, post-traumatic stress disorder (PTSD), pre-menstrual dysphoric disorder (PMDD), and social anxiety disorder (SAD). Zoloft was the most prescribed depression medication, with more than 115 million Zoloft prescriptions written in the US in its first seven years on the market. Zoloft brought in $3.4 billion in worldwide revenue, with $2.5 billion from the US market. These revenues showed an increase of 16% worldwide, 14% in the US and 23% internationally during the fourth quarter of 2003 compared to the same period of the previous year. Combining US and worldwide prices gave Zoloft an average selling price of $1.70/dose with a median dose of 50mg. Waste disposal cost savings could be considerable, but these dollar savings were only a piece of the financial upside. Zoloft sales comprised approximately 9% of Pfizer's total US sales in 2003, second only in sales percentage to Lipitor. Worldwide sales of Norvasc outpaced Zoloft's $4.5 billion (+ 7%), and worldwide sales of Lipitor were $10.3 billion (+14%). [8]

Zoloft, a pure output of sertraline must be isolated from a reaction which occurs in solvent (or in a combination of solvents). The "combined" process of isolating sertraline was the third re-design of the commercial chemical process since its invention in 1985. Each of these re-designed reactions decreased the number of solvents used, thus simplifying both the process (through reduced materials and energy required, and fewer worker-safety precautions) and the resulting waste disposal. The traditional process used titanium tetrachloride, a liquid compound that was toxic, corrosive, and air-sensitive (it formed hydrochloric acid when it came in contact with air). It was used in one phase of the process to eliminate water, which reversed the desired reaction if it remained in the mix. In the process of "dehydrating" this step of the reaction, the titanium tetrachloride reacted to produce heat, hydrochloric acid, titanium oxychloride, and titanium dioxide. These bi-products were carefully recovered and disposed, which required an additional process (energy), inputs (washes and neutralizers), and costs (waste disposal).

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[8] IMS World report 2004

The new process blended the two starting materials in the benign (and renewable) solvent ethanol, and relied on the regular solubility properties of the product to control the reaction. By completely eliminating the use of titanium tetrachloride, the “combined” process removed the hazards to workers and the environment associated with transport, handling, and disposal of titanium wastes. Using ethanol as the solvent also significantly reduced the usage of one of the starting materials, MMA, and allowed for this material to be recycled back into the process, increasing efficiency.

Another accomplishment with the new process was discovering a more selective catalyst. The original catalyst caused a reaction that created unwanted bi-products. Removing these impurities required a large volume of solvent as well as substantial energy. Also, portions of the desired end-product were lost during the purification process, decreasing overall yield. The new, more selective catalyst produced lower levels of impurities, which in turn had the effect of requiring less of the reactant (mandelic acid) for the next and final reaction in the process. Finally, the new catalyst was recovered and recycled, providing additional efficiency.

By re-designing the chemical process to be more efficient and produce fewer harmful or expensive waste products, the “combined” process of producing sertraline provided both economic and environmental/health benefits. Typically 20% of the wholesale price is manufacturing costs, of which approximately 20% is the cost of the tablet or capsule with the remaining percentage representing all other materials, energy, water, and processing costs.   With generics on the horizon, achieving materials and processing cost reductions could prove a decisive capability differentiator.

Subsequent to receipt of the green chemistry award Pfizer realized an even more efficient process driven off the earlier successes. The starting material for sertraline, called tetralone, contained an equal mixture of two components. One produced sertaline, the other a byproduct which had to be removed, resulting in a process that was only half as productive. Using a cutting-edge separation technology called multiple column chromatography (MCC) Pfizer scientists were able to fractionate the starting material into the pure component that results in sertaline. The other component was recycled back to the original 1:1 mixture which could be mixed with virgin starting material and resubjected to MCC separation. This new process was reviewed and approved for use by the FDA. The net result is twice as much sertraline produced from a unit of starting material. Moreover, only half the manufacturing plant capacity is required per unit of sertraline produced.

Case Studies:

Cleaning products
- 7th Generation
- Biosolutions
- Coastwide (industrial cleaning products)
- CoolClean (SCO2 Dry Cleaners)
- DuPont (Canada)
- Ecolab
- Ecover
- JohnsonDiversey (formulator, cleaning products)
- SC Johnson (Green List, cleaning products)
- Method

Pesticides
- AgraQuest (biopesticides)
- Bugs R done
- Fungiperfecti
- Picaridin
- Sentricon
- Seanine

Paints/Coatings
- Archer Daniels Midland
- Benjamin Moore
- Caliwel
- Milkpaint
- Tried and True Wood finish

Polymers/Plastics
- Metabolix (biopolymers)
- Natureworks (biopolymers)

Pharmaceuticals
- Bristol Myers Squibb (Taxol)
- Merck (2005)
- Pfizer

Building Products
- Columbia Forest Products (non formaldehyde wood)
- Shaw (carpets, polymers)
- Tandus (Collins and Aikman)
- Insulation

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[i] http://www.epa.gov/greenchemistry/pubs/pgcc/winners/gspa06.html