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Presidential Green Chemistry Challenge Awards Program:

Summary of 2013 Award Entries and Recipients

An electronic version of this document is available at:
http://www2.epa.gov/green-chemistry

Presidential Green Chemistry Challenge Awards Program: Summary of 2013 Award Entries and Recipients

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Introduction

Each year chemists, engineers, and other scientists from across the United States nominate their technologies for a Presidential Green Chemistry Challenge Award. This prestigious award highlights and honors innovative green chemistry technologies, including cleaner processes; safer raw materials; and safer, better products. These awards recognize and promote the environmental and economic benefits of developing and using novel green chemistry.

The U.S. Environmental Protection Agency (EPA) celebrates this year's innovative, award-winning technologies selected from among scores of high-quality nominations. Each nomination must represent one or more recently developed chemistry technologies that prevent pollution through source reduction. Nominated technologies are also meant to succeed in the marketplace: each is expected to illustrate the technical feasibility, marketability, and profitability of green chemistry.

Throughout the 18 years of the awards program, EPA has received 1,545 nominations and presented awards to 93 winners. By recognizing groundbreaking scientific solutions to real-world environmental problems, the Presidential Green Chemistry Challenge has significantly reduced the hazards associated with designing, manufacturing, and using chemicals.

Each year our 93 winning technologies are together responsible for:

- Reducing the use or generation of 826 million pounds of hazardous chemicals
- Saving 21 billion gallons of water
- Eliminating 7.8 billion pounds of carbon dioxide releases to air

And adding the benefits from the nominated technologies would greatly increase the program's total benefits.

This booklet summarizes entries submitted for the 2013 awards that fell within the scope of the program. An independent panel of technical experts convened by the American Chemical Society Green Chemistry Institute® judged the entries for the 2013 awards. Judging criteria included health and environmental benefits, scientific innovation, and industrial applicability. Five of the nominated technologies were selected as winners and were nationally recognized on December 11, 2013, at an awards ceremony in Washington, D.C.

Further information about the Presidential Green Chemistry Challenge Awards and EPA's Green Chemistry Program is available at www2.epa.gov/green-chemistry.

Note: The summaries provided in this document were obtained from the entries received for the 2013 Presidential Green Chemistry Challenge Awards. EPA edited the descriptions for space, stylistic consistency, and clarity, but they were not written or officially endorsed by the Agency. The summaries are intended only to highlight a fraction of the information contained in the nominations. These summaries were not used in the judging process; judging was based on all information contained in the entries received. Claims made in these summaries have not been verified by EPA.

Academic Award

Sustainable Polymers and Composites: Optimal Design

Professor Richard P. Wool, University of Delaware

Innovation and Benefits

Professor Richard Wool has created several high-performance materials using biobased feedstocks, including vegetable oils, chicken feathers, and flax. These materials can be manufactured using less water and energy, and producing less hazardous waste compared to petroleum-based processes. Professor Wool's products can be used as adhesives, composites, foams, and even circuit boards and as a leather substitute.

Many advanced composite materials use hazardous chemicals in the adhesive resin and use inorganic fibers for strength. A typical composite like fiberglass might use a styrene-polyester co-polymer, a polyurethane, or an epoxy resin. While the cured resin is unreactive, the uncured form may be quite toxic, posing risk during manufacturing. Furthermore, the resources used to make traditional composites are non-renewable: petroleum, natural gas, and minerals.

Professor Wool has developed several new biobased materials that can be used as substitutes for toxic substances used to make high-performance materials, like adhesives, composites, and foams. The processes to create these biobased materials yield less waste, require less water and energy, and are well-suited to mass production. His materials start with vegetable oils triglycerides and vegetable oil free fatty acids, cellulose and lignin from wood or plant stalks, and fibrous materials such as flax and chicken feathers.

To design these new biobased materials, Professor Wool evaluates the mechanical and thermal properties of the resins, integrates molecular design, and selects products with minimal toxicity. He developed the Twinkling Fractal Theory (TFT) to help predict the functional properties of a material based on its molecular properties, enabling a more focused design approach. He then evaluates the potential toxicity of the materials using the U.S. EPA's EPI Suite™ software. Using these design and predictive methods, Professor Wool has synthesized a number of lignin-based replacements for styrene and identified three of these as being less toxic. Other products that Professor Wool has designed include biobased composite resins used in pressure sensitive adhesives, composite resins, and thermoplastic polyurethane foam. The latter was developed in collaboration with Professor Epps, also of the University of Delaware. In addition to its reduced toxicity, this foam is also compatible with living cells and supports the growth of human tissue. One of Professor Wool more recent inventions is a breathable, biobased "Eco-Leather", which avoids the traditional leather tanning process and can be entirely vegan.

Since 1992, Professor Wool has been awarded five patents for his safer materials and has applied for three additional patents. As of 2012, Dixie Chemical began producing Professor Wool's biobased composite resins for a worldwide market. His discoveries led to the development of soy-based composites used to make boats, tractor panels, and wind turbine parts. He developed the biobased foam replacement for polyurethane in collaboration with Crey Bioresins Inc. This biobased foam is now being considered as a replacement component by several packaging and automotive suppliers. Professor Wool's start-up company, Eco-Leather Corp., has entered into collaborations with Nike and Puma to use his leather substitute in their products.

Small Business Award

Faraday Technology, Inc.

Functional Chrome Coatings Electrodeposited from a Trivalent Chromium Plating Electrolyte

Innovation and Benefits

Chrome plating in many high-performance uses, such as some aircraft parts, still requires hexavalent chromium, a carcinogen, to achieve the necessary performance. Various chrome-free replacements have limitations that preclude widespread adoption. Faraday has developed a plating process that allows high-performance chrome coatings to be made from the less toxic, trivalent chromium. This nearly drop-in replacement can reduce millions of pounds hexavalent chromium without comprising performance.

High-performance, functional chrome coatings plated from a hexavalent chromium [Cr(VI)] plating bath are widely used in industrial applications for military and commercial markets. These coatings provide resistance to abrasives and sliding wear in heavy-duty machinery, especially pneumatic tubing. However, Cr(VI) is the most toxic form of chromium due to its carcinogenic properties. Reducing or eliminating the use of Cr(VI) has been a priority for governments and industry for years. A number of alternative, non-chrome plating technologies have been developed, but do not provide the performance required for the full range of industrial or military applications.

The FARADAYIC® TriChrome Plating process uses trivalent chromium [Cr(III)] a much less toxic and non-carcinogenic form of chromium, in place of Cr(VI) in the plating baths. This approach maintains the advantages of a functional chrome coating but vastly reduces the hazards associated with the plating process. In the past, Cr(III) had been used for decorative coating when only a thin layer of plating was needed, such as on a car bumper, but such coatings are not suitable for heavy-duty applications where hardness and wear resistance are required.

The conventional Cr(VI) electrodeposition process uses a constant direct current during the entire process. Faraday designed a new electrodeposition process that alternates between a forward (cathodic) pulse followed by a reverse (anodic) pulse and an off period (relaxation). Not only does this process allow for thicker coatings from Cr(III), but it can also be adjusted to affect the structure and properties of the coating. This new process results in a product that exhibits equivalent or improved wear and fatigue performance compared to chrome coatings plated from a Cr(VI) bath. In addition, this new Cr(III) plating process is more efficient that the Cr(VI) plating process and does not produce any Cr(VI) as a byproduct. Yet another advantage to this technology over non-chrome alternatives is that it is a true drop-in replacement technology for Cr(VI) coatings. Only new plating bath electrodes are required. Unlike many non-chrome technologies, Faraday's process can plate both the inner and outer surfaces of a tube.

Development of the FARADAYIC® TriChrome Plating process has been supported by EPA, through its Small Business Innovation Research program, the National Center for Manufacturing Sciences, The Boeing Co., and other potential commercial clients. Commercialization of the FARADAYIC® TriChrome Plating process will occur via the existing metal finishing supply chain via partnerships with chemical formulators and chemical vendors. Use of Faraday's technology could eliminate about 13 million pounds of hexavalent chromium waste each year in the Unites States and as much as 300 million pounds worldwide.

Greener Synthetic Pathways Award

Safe, Sustainable Chemistries for the Manufacturing of PCR Reagents

Life Technologies Corporation

Innovation and Benefits

Polymerase Chain Reaction (PCR) is the process used to perform genetic testing. Manufacturing the key chemicals required for PCR tests is quite wasteful, often producing thousands of times more waste than product. Life Technologies has developed a three-step, one-pot synthesis which is much more efficient. The new process prevents about 1.5 million pounds of hazardous waste a year.

Polymerase chain reaction (PCR), the process of amplifying genetic material, is used in basic research, genetic engineering, forensics, infectious disease identification, food safety, and, most recently, personalized medicine. The expanding role of PCR in science and medicine highlights the need to create safe and sustainable chemistries for the manufacture of reagents for these applications. Deoxyribonucleotide triphosphates (dNTPs) are the individual building blocks for the DNA that is made during PCR. Conventional syntheses of dNTPs are inefficient, involve multiple steps that require isolation and purification of intermediates, and use excessive volumes of toxic or hazardous solvents and reagents.

Researchers at Life Technologies have devised synthetic routes for the manufacture of dNTPs that are only three steps in a single pot, eliminating the need to transfer reaction material. These synthetic routes also eliminate the need for a variety of hazardous reagents and solvents, including zinc chloride, triphenyl phosphine, aldrithiol, dimethyl formamide (DMF), and dichloromethane. By using these new dNTP routes, worker exposure to hazardous materials is minimized and the process E-factor (the ratio of amount of waste to amount of product) is improved by about a factor of 10.

In 2011, Life Technologies implemented these greener synthetic routes for the full-scale production of dNTPs and their analogues at their Austin, Texas manufacturing site. Organic solvent consumption has been reduced by up to 95 percent and other hazardous waste up to 65 percent compared to conventional protocols. By improving the yields and specificity of reaction, process E-factor (the ratio of the mass of waste to the mass of product) has been reduced from approximately 3200 to 400, almost a full order of magnitude, leading to a savings of 1.5 million pounds of hazardous waste.

Greener Reaction Conditions Award

The Dow Chemical Company

EVOQUE™ Pre-Composite Polymer Technology

Innovation and Benefits

Titanium dioxide (TiO_2) is added to paint as the base white pigment that hides color on the painted surface. TiO_2 is energy intensive to make, so increasing the amount added increases the cost of paint as well as the emissions from TiO_2 production. Dow has developed a coating that, when applied to TiO_2, improves its dispersion, thus decreasing how much TiO_2 is needed.

Titanium dioxide (TiO_2) is added to most paint as the base white pigment that hides the color of the painted surface. It also helps prevent tannin stains (from the underlying wood) and rust stains (from underlying nails or screws) from bleeding through. TiO_2 is employed due to its high refractive index and light scattering power. However, the high levels of TiO_2 commonly found in paint formulations come at a cost to the paint formulator and the environment. TiO_2 is often the most costly and energy-consuming component in a can of paint, and has the largest impact on the eco-profile of the finished paint formulation.

Dow Chemical has developed a polymer "shell", called EVOQUE™, that wraps around the TiO_2 particles and improves their dispersion in the paint, allowing better hiding at lower pigment loading. The polymers bind to the pigment, improve the pigment interaction with the rest of the paint formulation, and result in a more even, contiguous dry paint layer. Once dry, paints formulated with EVOQUE™ polymers provide better hiding, reducing the appearance of stains or colors on the painted surface and improved durability as a result of less pigment clumping.

EVOQUE™ polymers are compatible with a wide range of paint formulations, including zero-VOC waterborne paints, reduce the need for rheology additives, and allow up to 20 percent lower TiO_2 loading. A third-party validated Life Cycle Assessment (LCA) showed that TiO_2 reductions allowed by EVOQUE™ polymers in exterior house paint reduces the paint's carbon footprint by over 22 percent, water consumption by 30 percent, NO_x and SO_x emissions by 24 percent, and the potential impact on water eutrophication (algae bloom) by 27 percent. Other benefits found in the LCA include a 30 percent reduction in potential chemical oxygen demand (COD) and a 35 percent reduction in non-methanic volatile compounds, two factors that impede water quality and air quality. These benefits are in addition to the improved performance of the paint.

Designing Greener Chemicals Award

Vegetable Oil Dielectric Insulating Fluid for High Voltage Transformers

Cargill, Inc.

Innovation and Benefits

High-voltage electric transformers require an insulating fluid to prevent short circuiting and provide cooling. Polychlorinated biphenyls (PCBs) were used as transformer fluids until they were banned in the 1970s, and mineral oil became the primary replacement. Unfortunately, mineral oil is flammable and may be toxic to fish. Cargill has developed a vegetable-oil-based transformer fluid that is much less flammable, provides superior performance, is less toxic, and has a substantially lower carbon footprint.

High-voltage electric transformers must be filled with an insulating fluid that absorbs heat and prevents short-circuiting. For many years, most transformers were filled with polychlorinated biphenyls (PCBs) or, especially after they were banned, petroleum-based mineral oil. While the mineral oil is significantly less hazardous than PCBs, it is quite flammable and may be toxic to aquatic species. Furthermore, mineral oil is very hydrophobic, so any water in the system is taken up the solid insulating material inside the transformer, usually cellulose (wood, paper, or cardboard). Cellulose degrades when exposed to water and the operating temperatures of a typical transformer. The service interval for transformers is largely dependent on the operational life of the solid, cellulose insulators, so preventing the degradation of those insulators can significantly extend the service life of the transformer.

Cargill has developed Envirotemp FR3 transformer oils based on soybean oil instead of petroleum. These biobased oils can be used as drop-in replacements for mineral oil. If used in newly designed transformers, the transformers can be made smaller owing to better thermal performance of Cargill's oils. The Envirotemp oils are significantly less flammable than mineral oil, greatly reducing the risk of fire or explosion. Cargill's oils also increase the service life of the cellulose insulators by about a factor of 10, so transformers run about ten times longer than those using mineral oil.

According to a lifecycle assessment using BEES® 4.0, a transformer using Envirotemp FR3 fluid has a lower carbon footprint across the entire life cycle of a transformer, with the largest reductions occurring in the raw materials, manufacturing, and transportation phases. The total carbon foot print of an electric transformer is about 55-times lower when using Envirotemp fluids compared to mineral oil. This is all in addition to the low toxicity, high biodegradability, and the fact that they're based on a renewable resource. Furthermore, there have been no known explosions or fires in the hundreds of thousands of transformers filled with Envirotemp FR3 fluid since the product launched.

Envirotemp FR3 fluid has achieved numerous industry validations including EPA Environmental Technology Verification, the lowest environmental impact performance score in a BEES lifecycle assessment, USDA Bio-based Product certification, and certification as a less flammable fluid by both Underwriters Laboratory (UL) and Factory Mutual Research Corporation.

Entries from Academia

Highly Efficient and Practical Monohydrolysis of Symmetric Diesters

Professor Satomi Niwayama, Department of Cell Physiology and Molecular Biophysics, Texas Tech University Health Sciences Center

Desymmetrization of symmetric compounds is one of the most atom-economical and cost-effective reactions among synthetic conversions because the starting compounds are often easily obtained from commercial sources, on a large scale, from inexpensive sources. Water-mediated desymmetrization of symmetric organic compounds is, therefore, of tremendous synthetic value. However, organic compounds generally have limited solubility in water, limiting successful organic reactions in aqueous media. Furthermore, reported reactions in aqueous media do not necessarily show improvement of the reactivity and/or selectivity compared to those in organic solvents. Existing reactions also require many steps before the reactions are conducted in aqueous media.

Half-esters, which are produced by such monohydrolysis of symmetric diesters, are versatile building blocks in organic synthesis. They are applied to synthesis of polymers and dendrimers which have applications to industrial products of commercial value. However, since the two ester groups in symmetric diesters are equivalent, the statistically expected maximum yield of half-esters is only 50 percent. Classical saponification usually affords complex mixtures of dicarboxylic acids, half-esters, and the starting diesters. These are difficult to separate and yield a large amount of waste. Another option, ring-opening reactions of cyclic acid anhydrides, requires hazardous organic solvents.

Dr. Niwayama pioneered water-mediated desymmetrization and has developed monohydrolysis of symmetric diesters with remarkable success. This includes the discovery of a highly efficient and practical ester monohydrolysis of symmetric diesters. In this reaction, an aqueous base such as sodium hydroxide or potassium hydroxide is added to a symmetric diester that is suspended in water (sometimes containing a small amount of a cosolvent) at 0°C. With this reaction, pure half-esters are obtained in high to near-quantitative yields without production of waste and without use of hazardous organic solvents. This reaction has been licensed by three companies and several half-esters produced by this reaction have been commercialized.

A Greener Hydroformylation Technology

Professor Bala Subramaniam Department of Chemical and Petroleum Engineering, University of Kansas

Hydroformylation for producing chemical intermediates such as aldehydes and alcohols from olefinic substrates is a 15 billion pound per year industry. It also can be a route for producing longer chain olefins. Hydroformylation technologies with tunable selectivity are of particular interest. During conventional hydroformylation with 1:1 syngas (molar H_2/CO =1), the H_2/CO ratio in the liquid phase is ~0.6, which is not only sub-optimal for rate/selectivity but also non-tunable without adding extra H_2 in the feed.

Dr. Subramaniam demonstrated continuous hydroformylation of olefins in carbon dioxide-expanded liquids (CXLs) at unprecedented rates and selectivities. This was accomplished in a stirred reactor equipped with a nanofiltration membrane that effectively retains a dissolved rhodium complex in the reactor, allowing only lighter components to pass through. This technology uses benign solvents, intensifies the process at mild conditions, and eliminates toxic reagents. Additionally, comparative economic analyses demonstrate practical viability. Environmental analysis shows that the CXL process produces 50 percent less waste and is 33 percent less toxic than the conventional cobalt-based process. The technology has been successfully extended to several olefinic substrates demonstrating its versatility.

Remarkably, when the conventional solvent is partly replaced by dense CO_2 to create a CXL phase, the H_2/CO ratio in the CXL phase is significantly increased at mild syngas pressures (~6 bar) and neither syngas starvation nor CO inhibition is observed. The increased free volume in CXLs apparently enhances H_2 solubility beyond what is possible by Henry's law. Consequently, 1-olefin hydroformylation in a CXL phase with a simple rhodium catalyst complex [$Rh[(CO)_2$(acac) and triphenylphosphine (TPP)], results in impressive turnover frequency (~340 h-1) and regioselectivity (linear/branched aldehydes ~ 8) at mild pressure (~38 bar) and temperatures (30-60°C). A nearly quantitative rhodium recovery is accomplished by using the bulky JanaPhos ligand (molecular weight: 12,000 g/mol) which is effectively retained in solution by nanofiltration. This technology has been extended successfully to produce 1,4-butanediol via the hydroformylation of allyl alcohol. Based on lab-scale demonstration data, a major U.S. company has licensed the issued patent and the patent application for defined fields of use and industry partners are also evaluating the technology for licensing.

Drs. Shelby F. Thames and James W. Rawlins, School of Polymers and High Performance Materials, University of Southern Mississippi

Formaldehyde-Free Commercial-Grade Particleboards Based Solely on Soybean Protein Adhesive

Decreasing forest cover and an increase in consumption of wood-based materials have generated strong demand for particleboard and other engineered wood composites made from wood wastes. Commercial particleboards use urea-formaldehyde (UF) resin as an adhesive and are known to emit formaldehyde during manufacture use. Formaldehyde causes adverse health reactions in humans, even at low concentrations, and the International Agency for Research on Cancer has classified formaldehyde as a human carcinogen.

The occupational exposure of formaldehyde during particleboard production and the slow liberation of formaldehyde during the service life of particleboards pose serious health concerns. Alternative particleboards have been derived from wheat straw blended with methylene diphenyl diisocyanate, corn stalk pith, and sodium hydroxide-modified soy protein isolate. However, isocyanates present toxicity issues of their own with respect to handling and processing. There are no existing commercially viable technologies that totally replace the UF resin without adversely affecting particleboard properties, increasing production costs, and/or using another toxic chemical.

Drs. Thames and Rawlins have developed particleboards that are free of synthetic formaldehyde precursors by employing a soybean protein adhesive (SPA) as the sole binder. The SPA particleboards match, and in some instances, exceed the performance properties of commercial particleboards. Their research generated two U.S. patents and recent discoveries have been included in another patent application. Trials at a particleboard manufacturing plant in Texas have validated the scalability and feasibility of commercializing the SPA.

The adhesive synthesis involving mechanical blending of commercial grade soybean protein with water and raw materials to open the protein chains thereby making them amenable to flow and wetting. The process is energy efficient and does not involve toxic chemicals. The adhesive blends easily with wood furnish at wood to resin ratios similar to those employed for commercial particleboard manufacture. Particleboards manufactured with SPA technology meet the American National Standards Institute (ANSI) performance specifications for M-1, M-2, M-3, and M-S grade particleboards and completely avoid synthetic formaldehyde precursors. A full plant trial adoption of SPA at just one plant would lower the consumption of UF resin by ~35,000 metric tons and toxic formaldehyde by ~17,500 metric tons.

Entries from Small Businesses

Changing the Nature of Surfactants: Protein-Surfactant Synergists with Enhanced Cleaning Power and Bioremediation Abilities

Advanced Biocatalytics Corporation (ABC)

Research on the interaction between proteins and surfactants has focused on the ways surfactants change the properties and behavior of proteins including folding/unfolding, solubilization, and effects on enzymatic activity. While the effects of surfactants on proteins have been studied, some small proteins, acting as hydrotropes, can also affect the behavior and performance of surfactants.

Yeast responds to stress conditions, such as elevated, but non-lethal, temperatures by releasing small non-enzymatic stress exo-proteins. Advanced BioCatalytics Corporation (ABC) discovered that these proteins form tight protein-surfactant complexes (PSCs) and enhance the surface activity of a broad range of surfactants as manifested by reduced interfacial tension (IFT) and critical micelle concentration (CMC). These PSCs were also found to improve wetting, spreading, and uptake of actives by various surfaces.

In addition, PSCs activate the biooxidation of organic contaminants by naturally present microflora, such as in wastewater treatment, by uncoupling this process from biosynthesis and hence from bacterial proliferation, thus reducing accumulation of solid sludge by 30-50 percent. PSCs also assist natural microflora in converting hydrophobic contaminants, such as fat, oil, and grease, into soap-like surfactants, thereby rendering the process of degreasing autocatalytic in its nature, and thus converting sewer lines into wastewater preprocessing reactors. PSCs enhance the activity of interfacial enzymes, such as lipase, and improve the uptake of actives (as herbicides, micronutrients, etc.) by green leaves of plants and fertilizers by plant roots. ABC incorporated PSCs into cost-effective, water-based, nearly neutral products that do not contain any harsh chemicals, ozone-depleting, volatile organic compounds, active enzymes, or living cells. The key benefits include decreasing the use of surfactants, organic solvents, and/or petroleum-based chemicals, needed for various industrial applications. ABC is creating a new paradigm of performance enhancement and cost reduction agents with many actual and potential end uses including enhanced oil recovery, degreasing, cleaning, wastewater processing, odor and biofilm control, as adjuvants in agricultural chemicals, and elsewhere.

New Chemicals Derived from Novel Marine Microbes Impede Biofilm Formation and the Adhesion of Foulers

Aequor, Inc.

Biofilm is a matrix of extracellular polymeric substances formed by microorganisms as they colonize on inert and biological surfaces. Biofilm cause "microfouling" such as corrosion, slimes, and contamination and "macrofouling" that includes the adhesion of algae, mussels, and barnacles. The Centers for Disease Control and Prevention associates biofilms with 80 percent of all bacterial infections. The global costs of procuring and applying biocides to kill bacteria and foulers are estimated to exceed $600 billion annually across multiple sectors. Aequor has developed a portfolio of chemicals isolated from novel marine microbes to reduce the formation of bacterial biofilm and the adhesion of foulers on inert and biological surfaces. Aequor is positioning to scale-up of a synthesized version of the naturally-occurring lead compound.

Aequor's lead compound consistently impedes the formation of *Staphylococcus aureus* biofilms, penetrates and removes pre-formed *S. aureus* biofilms, and impedes the adhesion of macrofoulers. It can replace overused and ineffective germicides and antibiotics to dramatically reduce biofilm-related water- and air-borne diseases, as well as hospital-acquired infections. Third-party testing indicates that Aequor's lead compound is suitable for incorporation in sprays, washes, creams, and paints for use by industry, healthcare, and consumers.

Aequor's compound can also replace many of the toxic biocides currently used as antibiofilm/antifouling inputs. Current biocides accumulate in marine sediments, ground waters, and soils and harm human health. In the marine transportation sector alone, the lead compound can replace 36 million metric tons of heavy metals used in hull paints, while reducing drag, fuel consumption and corresponding CO_2 emissions by 50 percent. Proof-of-concept agreements already executed with six potential licensees will accelerate chemical production, prototype development, and product launch.

AnCatt Inc.

Conductive Polymer Nanodispersion (CPND) and the Environmentally Friendly Heavy-Duty Anti-Corrosion Coating Platform Technology

Every year direct corrosion cost is estimated at trillions of dollars worldwide and nearly every industry sector is affected. Current coating technologies utilize anti-corrosion pigments in the primer to protect metals from corrosion. Hexavalent chromium has been the strongest anti-corrosion pigment on the market but it is facing regulation due to its high toxicity and carcinogenicity. Zinc pigments are environmentally preferable chromium alternatives, however, they are increasing in price and zinc cannot protect aluminum (a major material for the aerospace industries) or galvanized steel. Zinc is also less effective than chromium in severe corrosive environments.

AnCatt Inc. has discovered a high-performance anti-corrosion coating platform technology utilizing novel conductive polymer nanodispersion (CPND) as the anti-corrosion pigment instead of traditional toxic heavy-metal pigments. CPND-based coatings show superior performance to the current zinc alternatives, and CPND can also outperform traditional hexavalent chromate. In independent tests with 13,740 hours of salt fog test (ASTM B 117), a CPND-based coating outperformed chromate, zinc, and other commercial anti-corrosion coatings. The test results indicate that AnCatt's next generation anti-corrosion coating platform may be used in a wide range of anti-corrosion applications to protect all sorts of metals with improved performance without using toxic heavy metal anti-corrosion pigments.

Accelerated corrosion test results indicate that CPND technology can also extend the performance life of anti-corrosion coating systems and therefore the performance life of the metal structures they protect. CPND coatings may therefore result in reduction of waste metal; repaint and coating maintenance costs; as well as corrosion related accidents, injuries, fires, and delays. CPND technology can also prevent toxic heavy-metals contamination and sidestep the zinc reserve depletion issue.

The CPND pigments and coating formulation have been filed for patent protections and are readily manufactured in scalable processes. They are cost competitive with other alternativesanti-corrosion systems and AnCatt is working with paint manufacturers, government, and private companies for licensing negotiation.

Bioformix

Breakthrough High Performance, Energy Efficient, Sustainable and Green Polymer Platform to Transform Industrial Manufacturing

Epoxy markets have long dealt with problems associated with mixing, short pot lives, and long and/or heated cures. Methylene malonates are disubstituted vinyl monomers that polymerize by any form of addition polymerization, such as free radical and anionic polymerization with near zero energy input at high speed. Bioformix's green polymer platform, based on methylene malonates, provides energy efficiency savings via a solventless, high-speed, virtually zero-heat input cure. This may result in multi Quad Btu's savings in adhesive, sealant, coating, and

composite curing at lower cost with improved product performance and less environmentally impact.

Bioformix's breakthroughs dramatically increase yields, allow for derivitization of numerous resins, and eliminate impurities that affect cure, thereby overcoming hurdles that have plagued this platform since its discovery in 1877. Near zero-heat cures enable far less expensive thermoplastic fibers versus carbon fibers at much lower weights than glass fibers. While petroleum, carbon dioxide, and methane can be used as feedstocks, Bioformix is also developing renewable malonic acid from biobased 3-hydroxypropionic acid (3-HP) to further enhance environmental benefits and reduce greenhouse gas emissions compared with current resins.

Initial materials display very high solvent and thermal resistance, outstanding optical properties, and strong, durable bond strengths on most metals, woods, and plastics. Initial offerings encompass high performance adhesives, sealants, inks, and coatings with improved cost and performance that significantly reduce source pollution and embedded energy consumption. These materials can also eliminate chemicals of concern such as formaldehyde, styrene, and bisphenol A and provide environmentally benign end of life options. Bioformix's products deliver increased performance to cyanoacrylates including temperature, water, and solvent resistance, which may open new markets and enable the reduction of vehicle weights.

Initially pursuing high margin (70+ percent) reactive products with an efficient, drop-in, capital light deployment, Bioformix has secured funding (including from confidential U.S. automotive leader), and sold initial commercial product.

FRX POLYMERS® Inc.

Polymeric, Non-Halogenated Flame Retardants with Broad Applicability in Multiple Industries

Halogenated, small-molecule flame retardant (FR) additives readily migrate out of their host plastic, exposing humans to toxic chemicals and diminishing the application's flame retardant function. Electronic device manufacturers have instituted voluntary bans on plastic formulations with halogen-containing FR additives. Other industries are also moving away from halogenated FR additives. Consequently, the plastics industry is searching for cost-effective, non-migrating, non-halogenated alternatives.

FRX POLYMERS® Inc. (FRXP) developed halogen-free polymers based on phosphorus for use as non-migrating FR additives. These unique polymers have been commercialized under the brand name NOFIA® and have the highest limited oxygen index measured for any thermoplastic material, highlighting their FR functionality. The polymers can be used as standalone, inherently FR materials. They can also deliver FR performance and additional properties when blended with polycarbonate, polyesters, (thermoplastic) polyurethane, unsaturated polyesters, and epoxies.

Sustainable developments led to processes to make these new innovative monomer and polymers that are based on Green Chemistry principles. No solvents are used and the atom economy of the reactions is 100 percent. A minimum amount of waste is produced from FRXP's polymer production. NOFIA® products can readily be converted into useful products via normally difficult melt processes like melt spinning or blown film processing, giving NOFIA® a distinct advantage verses other types of FR additives.

NOFIA® is commercial in applications including electronic housings, industrial textiles, printed circuit boards, transparent laminates and structural panels in high speed trains, and synthetic leather. Multiple toxicology studies have shown a low risk profile and FRXP's monomers and polymers are now globally registered. FRXP is currently constructing a several thousands of metric tons commercial plant. In September 2012, FRXP broke ground on the facility and the first-of-its-kind plant is on track to start up by mid-October 2013.

H-O-H Water Technology, Inc.

Cooling Tower Water Conservation and Chemical Treatment Elimination

Properly engineered electrolytic extraction of calcium carbonate from recirculating cooling water has successfully controlled deposit formation on heat exchange and other surfaces in practical systems such as industrial and HVAC cooling tower systems. Electrolysis of ionic-rich water produces exploitable *in-situ* chemistry requiring no external chemical reagent other than electricity. A Green Machine consists of a series of steel tubes that make the cathodic element of an electrolytic cell where water is reduced to form molecular hydrogen and hydroxide ion, and calcium carbonate is subsequently made to accumulate. Centered in each tube typically is a titanium rod coated with a mixture of ruthenium and iridium oxides, and makes the anode of the electrolytic cell. The common name for an anode of this type is "dimensionally stable anode," or DSA. It is the coating of the anode that is critical in driving the oxidation of water to produce molecular oxygen, hydrogen ion, and higher oxygen species such as hydroxyl free radical and ozone. DSA technology allows for the efficient splitting of water at a low practical voltage potential above that theoretically required, the difference being termed overpotential. DSAs have been responsible for past Green Machine success. Supplementing DSAs with anodes coated with boron-doped, ultrananocrystalline diamond (BD-UNCD) now allows control over troublesome calcium carbonate deposition, as well as more efficient *in-situ* chlorine formation and degradation of organic contaminants. Microbiological control in cooling water is significantly more efficient.

Infinite Energy/ Infinite Enzymes

Infinite Enzymes: Low-Cost, Plant-Based Enzymes for Converting Cellulosic Biomass into Biofuels and Other Biobased Products

Infinite Enzymes (IE), established in 2006, is a plant biotechnology company with a novel genetic technology for producing low-cost, industrial, and reagent enzymes.

The company's plant genetic technology enables the production of cellulase enzymes in the germ of the corn kernel. Using genetically-engineered corn as a "plant factory" for producing cellulase enzymes, Infinite Enzymes can deliver high-quality, cost-competitive cellulase enzymes on a commercial scale without the capital intensive requirements and environmental costs associated with existing enzyme production through microbial/fungal fermentation processes.

The enzymes produced by IE are used in industries from textile production to renewable fuels. IE's first products are cellulases. Cellulases are a group of enzymes that degrade plant stems and leaves and thus are able to convert plant bodies into sugars. These sugars can be used for fermentation into biobased products such as fuels, plastics, and chemicals.

Biobased products are referred to as the "third wave of biotechnology". Industrial biotechnology employs developed and new technologies to transform agricultural and forestry materials into consumer products. The advantages of plants include being biodegradable, endlessly renewable, and environmentally friendly.

IE aims to produce enzymes for the biofuel industry. Two hundred 35 million dry tonnes of biomass would be needed to produce 20 billion gallons of biofuel, the Renewable Fuel Standard goal. The amount of enzyme needed to convert this volume of feedstock has been estimated to be approximately 0.6 million tonnes.

The agricultural bio-production system offers the potential for a viable and scalable alternative to lower the cost of enzymes for biomass deconstruction. IE's technology offers a cleaner and more environmentally friendly alternative to current production methods.

Temporary Assembly Lubricants for Rubber and Plastic Articles Using Renewable Oil-in-Water Emulsion Technology

International Products Corporation

Rubber, plastic, and articles thereof intrinsically manifest significant friction during their manipulation and assembly to other materials. The assembly of a hose onto a manifold requires strenuous exertion, particularly when the mated components are designed with tight tolerances for a permanent union.

Historically, the assembly friction is mitigated by using chemicals conveniently found throughout the manufacturing facility; these include transmission oil, motor oil, coolants, gasoline, and metalworking fluids. In the domestic automotive industry alone, International Products Corporation (IPC) estimates the misapplication of these chemicals generates over ten thousand gallons of hazardous waste annually from spills, drips, and overuse. Other detrimental consequences include fugitive emissions, unnecessary exposure, and housekeeping hazards. This problem spans into many other industries, including aerospace, appliance, recreational equipment, marine, pump, and after-market maintenance and repair needs.

IPC is providing an innovative product line to overcome these problems. By using emulsion technology, superior lubrication is achieved with no adverse environmental or health hazards. Unlike petroleum products, P-80 lubricants provide a thin lubricating film on the elastomer. After assembly, the water evaporates, the negligible synthetic esters absorb into the porous elastomers, and the lubrication ceases.

In the last 10 years, non-porous elastomers with longer lives and a burgeoning use of plastics penetrated manufacturing industries. IPC responded with Grip-It and RediLube. Grip-It offers both adequate lubrication and a tacky residue that promotes adhesion of the mated components. In 2009, the low-solids RediLube emulsion was launched with enhanced lubrication and no interfering residue. Like the rest of the product line, RediLube is solvent-free, water-based and non-hazardous. Plus, P-80 Emulsion, THIX, RediLube, and the incidental food contact lubricants are biodegradable. All products are non-irritating to eyes and skin and non-toxic, based on an independent laboratory's evaluation.

The P-80 lubricants have a global presence in many industries that use or manipulate rubber or plastic.

Expanding the Renewable Polymers "Tool Kit" with Bio-Succinic Acid

Myriant Corporation

In the second quarter of 2013, Myriant Corporation will be the first in the U.S. to commercially produce bio-succinic acid at its flagship facility in Lake Providence, Louisiana. Bio-succinic acid is an organic acid with the potential to be used as a raw material for the production of numerous industrial and consumer applications. Myriant's high purity bio-succinic acid is made from renewable feedstocks and is chemically equivalent to petroleum-based succinic acid while significantly reducing harmful greenhouse gas emissions. Polyester polyols are mainly produced using adipic acid, a petroleum-based chemical that can be replaced with Myriant's bio-succinic acid without compromising the final product quality or performance. Myriant, Piedmont Chemical Industries, and Dupont Tate & Lyle have partnered to produce 100 percent renewable polyester polyols formulations for the production of polyurethanes.

Myriant Corporation

Biobased Chemicals from Low-Cost Lignocellulosic Sugars

Myriant successfully developed its proprietary process for the production of drop-in chemicals and replacement chemicals, including succinic acid and lactic acid, from low-cost, non-food, lignocellulosic feedstocks. Myriant currently has several *E. coli* platforms capable of generating high titers of organic acids from clean sugars and most importantly from lignocellulosic hydrolysate sugars. Life cycle studies performed on Myriant's bio-succinic acid technology as compared to petroleum-derived succinic acid showed a potential of 94 percent reduction in greenhouse gases. Myriant's bio-succinic acid, a four-carbon molecule, and biobased lactic acid, a three-carbon molecule, will be used as drop-in and replacement chemicals in their current petroleum-based markets. In the second quarter of 2013, Myriant's flagship commercial facility that utilizes a multi-feedstock technology platform will produce annually 30 million pounds of bio-succinic acid.

New Sky Energy, LLC

Sustainable Soda Ash for the Glass Industry

New Sky Energy is a clean chemistry company dedicated to source reduction of carbon dioxide pollution in the air as well as salt brine pollution in fresh water. New Sky's technology offers a novel approach to making high-purity, commodity chemicals (acids, bases, carbonates, and bicarbonates) that are key inputs for many industrial processes and building materials. Instead of mining, processing, and transporting virgin materials, New Sky's technology uses the carbon dioxide and salt brine waste products from industrial processes as low-cost, renewable feed-stocks for generating high-value, clean chemicals. Using New Sky's technology, carbonates and bicarbonates for glass, cement, paper, plastics, and food processing can be produced on-site, minimizing transportation costs and emissions while using reaction conditions that are entirely compatible with renewable energy and a smart grid.

The environmental benefits of New Sky's technology are numerous and include power plant emission controls, wastewater from biofuels and oil and gas, and recycling of acid or salt wastes from semiconductor manufacturing, mining, and other industrial activities. There are also lifecycle benefits of using the process to make sodium carbonate (soda ash) for the glass industry.

New Sky is currently working with one of the world's largest glass companies toward the goal of deploying the New Sky process on an industrial scale within three years. Based on estimates by New Sky's glass industry partners, use of the New Sky process to replace traditional sources of soda ash (i.e., trona mining and synthetic (Solvay Process) soda ash) would reduce the industry's direct CO_2 emissions by 15-20 percent. Furthermore, when powered by zero-carbon energy, New Sky's process could eliminate almost all of the glass industry's upstream emissions from soda ash production, resulting in total CO_2 reductions of up to 35 percent.

Renmatix

Affordable Building Blocks for Plantrochemicals: Products of the Plantrose™ Process

Manufacturers are increasingly seeking affordable, biobased sugar intermediates as an alternative to volatile petroleum feedstocks for use in a range of applications including chemicals, consumer products, and fuels. These sugars are derived from plant material available all around the world. Initially, industry tapped sugars derived from corn and sugarcane, but in order to satisfy the global demand for renewable materials – a $150 billion and fast growing market – new ways to economically convert available non-food plant material into industrial sugars must be found.

Traditional methods of breaking down biomass require expensive enzymes or harsh chemicals, and can take up to three days to yield sugars and require exotic alloys or complex recovery systems. Renmatix takes a fundamentally different approach to producing the lowest-cost cellulosic sugars. Using supercritical water – water at elevated temperatures and pressures – Renmatix's Plantrose™ process is able to deconstruct non-food plant material in seconds using no significant chemicals or consumables. The continuous process has remarkably fast reaction cycles, produces much of its own process energy, and is biomass agnostic – capable of hydrolyzing many varieties of globally sourced biomass.

Renmatix is now processing biomass at two locations – its King of Prussia, Pennsylvania headquarters and its primary operations facility in Kennesaw, Georgia. These locations support developmental research and customer-driven sampling programs in addition to demonstrating the technology at scale. Renmatix is in conversations with a number of strategic industry partners to license its technology for large-scale implementation and replication in global markets. Proliferation of the Plantrose™ process creates access to highly sought building blocks upon which the bioindustrial economy can thrive. By delivering cellulosic sugars at prices competitive with first generation, food-based sugars, Renmatix provides the bridge between upstream biomass and downstream products. This is a crucial link, which translates to expanded economic opportunities up and down the new bio-value chains.

Easy (1-Reagent) Nitrate Method: A Green Alternative to Traditional USEPA Approved Nitrate Methods

Systea Scientific, LLC

Several methods exist for determining nitrate in aqueous solutions. However, the traditional USEPA approved methods 353.1 (Nitrate Hydrazine Reduction) and 353.2 (Nitrate Cadmium Reduction) are problematic, frequently unreliable, and utilize carcinogenic and highly toxic chemicals. Thousands of laboratories in the U.S. and worldwide use these methods, or variations of them. The alternative methods performed by ion chromatography and ion selective electrode are slow and unreliable when performing analysis on samples with high ionic strength, such as wastewater, ground water, and soil extracts. The new Easy (1–Reagent) Nitrate Method was developed by Systea Scientific, LLC to eliminate the problems associated with these traditional methods and improve performance.

The Easy (1-Reagent) Nitrate Method utilizes a reaction in which nitrate is reduced to nitrite by a proprietary reagent "R1"—a non-hazardous, non-enzymatic reducing agent. The method protects laboratory personnel from hydrazine and cadmium exposure and eliminates hazardous waste, significantly reducing potential liability associated with waste handling and disposal.

The Easy (1-Reagent) Nitrate Method eliminates analytical problems associated with nitrate analysis, such as poor reproducibility, recovery, and matrix interferences. With the Easy (1-Reagent) Nitrate Method, the nitrate to nitrite reduction is consistently between 95 and 105 percent, which is a dramatic improvement over traditional nitrate methods. In the cadmium reduction method and hydrazine methods, efficiency of the reduction depends on the matrix. After extensive testing on various matrices, no matrix interference problems have been observed when using the Easy (1–Reagent) Nitrate Method. Furthermore, the reagent costs dramatically less than other non-hazardous methods for nitrate, such as enzymatic tests. Depending on how the method is performed, the reagent costs approximately four cents or less per test. Laboratories also save time on analytical runs, since the overall performance of the new method is better and matrix interference problems are not present. The Easy (1-Reagent) was EPA approved in 2009 for analysis of both drinking water and wastewater. It was listed in the Federal Register as an approved method for nitrate, nitrite, and combined nitrate/nitrite analysis under 40 CFR Part 136.3 on May 18, 2012.

Terramera Inc.

CIRKIL Biopesticide

The common bed bug (*Cimex lectularius*) has re-emerged in recent years and has become a serious problem. The U.S. Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention (CDC) and the U.S. Department of Agriculture (USDA) consider bed bugs to be a pest of significant public health importance. To combat this problem, Terramera developed the CIRKIL product line using naturally-occurring biochemicals that interrupt insect systems, delivered and stabilized using green chemistry principles. CIRKIL Products are minimally toxic, yet highly effective against bed bugs at all stages of their life cycle, both as a direct and residual treatment. They are the first products known to kill bed bug eggs as a residual treatment, not requiring direct contact. An independent study showed that eggs introduced to surfaces treated with CIRKIL 24 hours earlier resulted in 0 percent eclosion. CIRKIL works against pesticide-resistant strains of bed bugs, and is labeled for use against many other insects including cellar spiders, certain species of cockroaches, ants, firebrats, silverfish, flies, and aphids. As a result, Terramera's products are an ideal alternative to widely used conventional pesticides.

The active ingredient in CIRKIL is cold-pressed neem oil, which is pressed from the seeds of the neem tree (*Azadirachta indica*). Terramera's technology was found to be "in the public interest" by the USDA's IR4 Project. Terramera's regulatory applications were expedited by the U.S. EPA and the California EPA's Department of Pesticide Regulation (DPR).

CIRKIL products are being introduced to the market in phases, first to the commercial market through Pest Management Professionals ("PMPs"). Initial professional-use pilots began in California in 2012. Terramera has signed four major professional pest control distributors across the U.S., representing a potential reach to over 60 percent of the U.S. professional market. Initial consumer products will be available in late 2013.

Virent, Inc.

Converting Plant Sugars into Paraxylene for 100 Percent Renewable, 100 Percent Recyclable Packaging and Fibers

Volatile costs of fossil fuels, concerns for the environment, and focus on sustainability and domestic energy security have sparked worldwide interest in developing alternatives to petroleum-based chemicals and fuels. Virent has discovered an innovative technology that catalytically transforms 100 percent renewable sources into paraxylene. Traditionally sourced from petroleum, paraxylene is a chemical highly useful in the production of packaging and fibers.

Compared to other biomass conversion systems, Virent's technology broadens the range of viable renewable feedstocks as a variety of cellulosic and conventional sugars can be utilized. Virent's bio-based paraxylene, BioFormPX, is molecularly identical to petroleum-based paraxylene and is compatible in today's chemical supply chains. PET made with BioFormPX paraxylene can also seamlessly enter into already established recycling streams and infrastructure. This retains the majority of the energy used to manufacture the material in contrast to biodegradable molecules.

Across its supply chain, from sustainable feedstock through manufacturing to final highly useful products, bio-based paraxylene is more environmentally friendly and less threatening to human health compared to petroleum as a feedstock. Not only are biobased feedstocks safer than petroleum to handle, Virent's production of paraxylene incorporates CO_2 from the atmosphere into materials, thereby reducing greenhouses gases by up to 55 percent with conventional sugars.

Virent currently produces biobased hydrocarbons – including the basis for its BioFormPX product – at its 30,000 kg/year demonstration plant. In 2011, Virent and The Coca-Cola Company formed a strategic partnership to accelerate commercial production of Virent's BioFormPX paraxylene. Coca-Cola's PlantBottle is currently made with up to 30 percent biobased material. Virent's BioFormPX is the missing ingredient needed to make 100 percent biobased PET.

This will enable The Coca-Cola Company to launch commercial scale 100 percent biobased PET bottles, providing its customers with 100 percent renewable and recyclable PET beverage packaging made from biobased materials.

Entries from Industry and Government

Hybrid Polymers

AkzoNobel Surface Chemistry

AkzoNobel has developed a new, biodegradable biopolymer technology for the fabric and cleaning marketplace. Based upon the combination of selected polysaccharides and synthetic monomers, the 2nd generation Hybrid Polymer technology (Alcoguard® H 5941 and Alcoguard® H 5958) readily biodegrades in the environment, offers a preferable carbon footprint, and is effective in replacing synthetic polymers in formulations such as automatic dishwash (ADW) and laundry detergents. This 2nd generation technology provides a sustainable and cost-effective alternative to existing synthetic options. Compared to synthetic (acrylic acid) polymers, the Hybrid Polymers provide: 40 percent lower CO_2 evolution; 44 percent lower energy use; 10% percent lower acidification; 43 percent lower resource depletion; and 40 percent lower ground level ozone depletion.

Upcycling Process that Converts Unsorted Plastic Waste into Functional Carbon Materials

Argonne National Laboratory

Environmentally harmful plastic waste is a major concern throughout the world. Argonne's novel autogenic process completely destroys unsorted plastic waste in a technologically beneficial, environmentally responsible manner before the plastic enters the waste stream. The one-step, low-energy, solventless process is called "upcycling" because it produces products having greater value than the original plastics, particularly hard carbon microspheres that have important tribological and battery technology applications and carbon nanotubes that may prove preferable to the carbon microspheres for some tribological uses.

Current automotive engine lubricants contain anti-friction and anti-wear additives that poison catalysts in catalytic converters, thus increasing harmful emissions from such vehicles. To meet the increasingly stringent emission targets of the EPA and other regulators, lubricant manufacturers have sought, yet unsuccessfully, to replace these damaging additives. Dispersing small amounts of Argonne's carbon microspheres or nanotubes in engine oils yields great reductions in both friction and wear, thus potentially permitting discontinuation or reduced use of the harmful additives, thereby boosting catalytic converter effectiveness in reducing emissions.

Graphite is universally used in the negative electrodes (anodes) of commercial lithium-ion batteries, even though graphite anodes can cause the batteries to rapidly overheat and catch fire, as perhaps recently occurred aboard the Boeing Dreamliner aircraft. Anodes made with Argonne's hard carbon microspheres cycle lithium much more safely than flake-like graphite anodes. Also, upon being briefly heat-treated to 2400–2800°C and sonochemically coated with a lithium-alloying element, the microspheres can deliver an electrode energy capacity (>400 mAh/g) that exceeds the capacity of every commercial graphite anode in use today. Both capabilities are crucial to the increased use of lithium-ion batteries in transportation applications. Numerous other applications exist for the carbon microspheres and nanotubes as well, ensuring that the technology can potentially prevent large amounts of unwanted plastic from ever entering the waste stream.

Breakthrough Coating for Ceiling Tiles

Armstrong World Industries, Inc.

Armstrong World Industries has developed a formaldehyde-free coating which can be applied to the surface of any fibrous panel such as a ceiling tile to prevent product sagging. This invention is the result of an extensive research effort to develop a new coating technology with the following four performance parameters: (1) capable of hydroscopic expansion at high humidity to resist sag; (2) can maintain a high modulus even at high humidity; (3) is compatible with other coatings and/or fillers; and (4) a waterborne coating system. Currently, three out of four of Armstrong's U.S. plants fully utilize the coating technology. Approximately 2.7 million pounds of formaldehyde resin and approximately 36,000 pounds of triethylamine were eliminated from U.S. plants in

2012. The U.S. plants will complete the conversion to the new coating system in early 2014. When this partially renewable biobased coating is implemented worldwide, Armstrong globally will eliminate the use of approximately 8,300,000 pounds of formaldehyde resins, approximately 416,000 pounds of formaldehyde emissions to the air, and approximately 134,000 pounds of triethylamine emissions annually.

Formaldehyde is a classified as a "known" carcinogen by International Agency for Research on Cancer and as "reasonably anticipated to be a human carcinogen" by the National Toxicology Program. Formaldehyde is a key ingredient in a wide variety of building products including pressed-wood products, such as particleboard, plywood, and fiberboard; glues and adhesives; permanent-press fabrics; paper product coatings; and certain insulation materials. Historically, Armstrong and other ceiling tile manufacturers have applied a formaldehyde-resin-based back coat to prevent ceiling tiles from sagging, because of formaldehyde resin's unique hydroscopic properties.

Armstrong has been using this newly invented coating technology to replace all formaldehyde resin ceiling tile applications as the new coating provides for hydroscopic expansion at high humidity while maintaining a high modulus to prevent sag. The new coating is compatible with other coatings and/or fillers and is a water-borne coating. The benefits of eliminating the use of formaldehyde resin include the:

1. Avoidance of employee formaldehyde and triethylamine exposure risk at four Armstrong manufacturing facilities in the U.S. and five international facilities;

2. Elimination of formaldehyde and triethylamine stack emissions associated with the ceiling tile back coat that resulted from the melamine formaldehyde cross linking process;

3. Removal of potential formaldehyde emissions from finished products after they are installed;

4. Reduction in life cycle assessment impacts associated with upstream production of formaldehyde and triethylamine.

AstraZeneca and Forest Laboratories

An Order of Magnitude Improvement in Sustainability Through Core Application of Green Chemistry Principles: The Process Development of Avibactam.

Avibactam is a novel Beta-lactamase inhibitor which seeks to reinvigorate a co-administered antibiotic by sacrificially binding to β-lactamase enzymes produced by drug resistant bacteria. A combination of out-sourcing the synthesis and a fast track clinical program led to many challenges in meeting the clinical and manufacturing demands for a new product launch, not least the inheritance of a synthetic route with many inefficiencies in yields and reagent/solvent use, but also lack of environmental consideration in selection.

Within Forest and AstraZeneca laboratories, a focus was placed on improving the synthesis of Avibactam. The current process has been redefined with considerable sustainability benefits compared to previous through selection of greener solvents and reagents, and process optimization resulting in a subtle but effective route change.

This improved synthesis of Avibactam introduces several sustainability elements. The efficiency of the synthesis has been improved 92 percent compared to the traditional technology as evidenced by the reduction of the process' PMI (Process Mass Intensity) from 6480 to 526. Organic solvents have been reduced from 3229 kg per kg of API to160 kg per kg (20 to 1 reduction in volumes). Water consumption has also been reduced from 2290 kg per kg of API to 61 kg. The improved synthesis reduces annual waste reduction by 89,310 tonnes (based on predicted peak sales). The technology avoids hazardous chemicals by switching from dimethylformamide (DMF) and dichloromethane (DCM) to less impacting alternatives, and eliminating the use of a sulphur-trioxide DMF complex and triphosgene. The improved synthesis of Avibactam introduces considerable energy savings by avoiding distillation of 11 ml/g DMF and 120 ml/g Xylene. It also avoids environmental and hazard issues by eliminating need for distillation of

DCM, reducing catalyst loadings by 90 percent and using a safer "wet" catalyst, and telescoping stages to avoid isolation and associated energy intensive processing.

INFUSE™ Olefin Block Copolymers

Dow Chemical Company

INFUSE™ Olefin Block Copolymers (OBCs) are produced via a novel catalytic shuttling process, creating a unique block architecture which enables customers to expand into a wide range of innovative market applications currently served by styrene- or vinyl chloride-containing polymers. OBCs have highly differentiated material properties that break the traditional relationship of flexibility and heat resistance while providing significantly improved compression set and elastic recovery properties. Importantly, OBCs also maintain the ease of formulation and low energy to process that is expected from a polyolefin.

Sustainable chemistry benefits include: atom efficiency; reduced toxicity/risk; source reduction; reduced energy requirements; and improved eco-profiles. INFUSE™ OBCs are created with more efficient chemistry with less by-products, fewer extractables, and less volatiles. The formulation of other OBCs requires significant resources to strip initiator residues after polymerization. The unique block architecture of INFUSE™ OBCs allows high performance from a polyolefin and reduces toxicity/risk by enabling customers to substitute for materials like PVC and styrene-butadiene-based polymers with regulatory or de-selection issues. Greenpeace lists polyolefins as among the most Earth-friendly polymers, and the materials OBCs are replacing as among the least. INFUSE™ OBCs introduce source reduction through complete elimination of emissions of styrene, butadiene, aromatic solvents, or vinyl chloride compared to incumbent competitive styrene-ethylene/butylene-styrene (SEBS) or f-PVC technology. Their manufacture also has reduced energy requirements compared to incumbent polymer technology because OBCs are produced in existing polyethylene plants with an energy-efficient process, as processing steps like catalyst and volatiles stripping are eliminated. The molecular weight distribution of OBCs affords lower processing temperatures for the plastic fabricator, and reduced energy usage during fabrication versus competitive resins. Overall, INFUSE™ OBCs have superior eco-profiles compared to competitive styrenic-based block copolymers. The production of OBCs has significant environmental advantages in total energy use, global warming potential, acidification potential, photochemical ozone creation potential, eutrophication potential, and water consumption. The cumulative energy demand and GWP100a ("carbon footprint") for producing OBCs are 23-38 percent less than for SEBS or SEBS compounds.

Sugar to Diesel (Biodiesel from Microbial Oil) – A Sustainable, Scalable, and Affordable Option to Petroleum Diesel

DSM's Biobased Products & Services B.V. and BP Biofuels UK Limited

According to the BP Energy Outlook 2030 (published January 2013), the demand for liquid transport fuels is expected to continue to rise. Approximately an extra 16 million barrels a day will be required by 2030. Replacing fossil-derived diesel is a worldwide priority. Producing a low-cost fuel for heavy goods transportation via biological means while also reducing carbon emissions is a viable response to this need.

Biobased/renewable diesel options do exist, but most are produced from vegetable oils such as palm, soy bean, and rapeseed oil. These routes face major concerns about sustainability, availability, and, in the case of photosynthetic algae, fundamental technical and engineering challenges.

DSM and BP have just completed the third year of a pioneering research program to demonstrate that heterotrophic-derived microbial oil can be developed as a sustainable, scalable and cost-effective alternative to fossil-based diesel. The technology uses microorganisms that convert sugars into lipids through fermentation (heterotrophic conversion), which does not require sunlight or a source of carbon dioxide (CO_2).

Heterotrophic-derived diesel offers the potential to deliver significant lifecycle greenhouse gas emission reductions (estimated at >60 percent) when compared to traditional fossil fuels and therefore is less harmful to the environment. This pathway allows access to a wide variety of "greener" biomass feedstocks such as sugarcane, sugarcane waste, and woodchips, which can be produced at scale and with high yields, offering a "greener" synthetic pathway for diesel fuel.

The program seeks to utilize novel, low-cost, solvent-free, extraction processes that have the potential to deliver lower cost oil via greener reaction conditions. Further, this platform has the potential to enable the conformity of fuel providers worldwide with biofuel blending mandates. To summarize, the technology being developed by BP and /DSM offers an alternative to the current biodiesel and other renewable diesel options and is a viable, practical route to low-cost, sustainable bio-diesel.

DuPont

Development and Commercialization of an Integrated Cellulosic Ethanol Production Platform

DuPont has integration chemistry, biology and process engineering to develop a commercially viable, scalable technology platform for the production of cellulosic sugar and its conversion to ethanol. The work required the integration of a novel pretreatment process, the development of improved enzymes for hydrolysis, and the genetic engineering of a novel, highly efficient fermentation host. The resultant DuPont integrated process is a novel, integrated production platform, with three major technology components, for the production of ethanol at sufficiently high yields and titers to achieve commercially viable economics. To optimize the process, it was necessary to consider and innovate all three conversion steps holistically. First, a novel dilute ammonia biomass pretreatment process decouples the carbohydrate polymers from the lignin matrix with minimal formation of compounds that inhibit subsequent fermentation, thus eliminating the need for costly "detoxification" steps common in other cellulosic ethanol technologies. Next, an enzymatic hydrolysis step uses a novel suite of high performance enzymes specifically engineered by DuPont to depolymerize and hydrolyze both cellulose and hemicellulose to high titers of fermentable sugars in a single sugar stream. Thirdly, the metabolic pathways of a recombinant bacterium, *Zymomonas mobilis*, were integrated and optimized to simultaneously metabolize both 6-carbon (glucose) and 5-carbon (xylose) sugars to efficiently produce ethanol at high yields and titers from the hydrolysate. This unique integration of three technology components enables a very efficient, "clean" flowsheet with minimal steps, a reduced environmental footprint, and reduced cost and capital versus other known cellulosic ethanol processes. Commercially viable ethanol yields have been consistently achieved in DuPont's 250,000 gallon per year demonstration facility in Vonore, Tennessee; yields of >70 gallons/U.S. ton of biomass and ethanol titers in excess of 70 g/L have been demonstrated. Comprehensive "Well-to-Wheel" Life Cycle Analyses show that the combined process has the potential to achieve more than a 100 percent reduction in greenhouse gas (GHG) emissions compared to gasoline, which is substantially better than current grain-based ethanol GHG performance. The DuPont technology has been demonstrated successfully and the first commercial plant for conversion of corn stover to ethanol is under construction in Nevada, Iowa.

DuPont and Goodyear

An Innovative Cell Factory and Bioprocess for Production of BioIsoprene™ Monomer

DuPont and Goodyear are involved in a highly collaborative effort to develop an integrated process to make isoprene (BioIsoprene™ monomer) from renewable raw materials. Currently, the two companies are in a joint research stage of the platform's development. The technology is an innovative production system for isoprene based on microbial fermentation of renewable sugars. The production system includes an engineered *E. coli* cell factory, a fermentation-based bioprocess, and continuous recovery and purification from the fermentation

of gas that results in 99.95 percent product purity even from cellulosic residue sugar streams. BioIsoprene™ monomer yields approaching commercial targets have been demonstrated and rate and titer metrics are at or greater than those needed for commercialization. A further significant step towards commercialization has been demonstrated by the integration of unit operations at research and development scale, producing over 20 kilograms of purified BioIsoprene™ monomer, some of which has been chemically polymerized to *cis*-polyisoprene, a rubber component of passenger car tires. Concept tires produced from the BioIsoprene™ monomer validate completing the supply line from renewable feedstock to consumer product. The technology will help mitigate a number of problems associated with the incumbent supply chains of natural and synthetic rubbers. An investment in a dedicated pilot plant for the production of renewably sourced BioIsoprene™ product will address the growing demand for isoprene, which is utilized for a wide range of industrial applications, including synthetic rubber, specialty elastomers, and in adhesive applications.

Envirocid Plus: No Phosphorous and Low Nitrate CIP Acid Cleaner

Ecolab

Product quality and food safety are of utmost importance in today's highly automated food and beverage processing industry. Clean In Place (CIP) technology enables food plants to meet these vital objectives in a cost-effective manner. CIP is a multi-step process to circulate solutions of alkaline cleaners, acid cleaners, and sanitizers to remove organic and inorganic soils, without the need for disassembling equipment and manual intervention.

Conventional acid cleaners for CIP operations are nitric-phosphoric blends, which contribute high loads of phosphate and nitrate to the process wastewater. Food plant effluent with high concentrations of these nutrients can have a detrimental impact on aquatic life and human health, primarily through the eutrophication of aquatic and terrestrial ecosystems.

In order to help reduce these nutrient constituents in plant effluent, Ecolab developed Envirocid Plus, an acid cleaner option that is phosphorus-free and contains 70 percent less nitrogen in comparison to other available acid cleaners. In addition to the reduced environmental impact, Envirocid Plus has performance benefits for CIP operations, including low foam wetting agents for improved soil removal, excellent mineral removal properties, and improved gasket compatibility.

Since its launch in 2010, Ecolab has sold 1.81 million gallons to more than 350 customer plants in 40 U.S. states. Users that have converted from a conventional acid cleaner to Envirocid Plus have reduced the discharge of nutrients in wastewater by 4.3 million pounds of nitrogen and 79,000 pounds of phosphorus from 2010 through 2013.

GeoSpray™ Geopolymer Mortar System for Structural Rehabilitation of Sewer and Storm Water Infrastructure

GeoTree Technologies, Inc.

Asset owners throughout the U.S. and the world are in search of cost-effective and environmentally-friendly solutions to severe infrastructure degradation problems such as aging pipes. GeoSpray™ is a revolutionary geopolymer mortar system that is an environmentally-preferred solution for trenchless storm and sewer water pipe repair. GeoSpray™ allows a contractor to perform an on-site reconstruction of new structural storm or sewer pipe using a patented spray technology resulting in improved strength and flow characteristics within the old pipe. GeoSpray™ is a styrene-free, easy-to-install pipe within a pipe. It fits within the old pipe regardless of the original pipe condition. The GeoSpray™ system offers a cost advantaged solution to both contractors and asset owners.

The environmental benefits of the GeoSpray™ system include: (1) use of industrial waste materials that would otherwise be landfilled; (2) substantial reduction in environmental disruption from the use of a trenchless technology; (3) significantly reduced CO_2 emissions when compared to standard cement materials; and (4) replacement of styrene-based resin alternative solutions of cure-in-place-pipe (CIPP). The mix of a proprietary geopolymer formulation containing at least 80 percent post-industrial waste streams and biobased components has significant environmental advantages as compared to dig and replace, CIPP, and Portland cement. These advantages include preservation of current sensitive environments, greater than 80 percent postindustrial recycled content, and reduced carbon dioxide emissions. For example, CO_2 emissions are reduced up to 90 percent compared to dig and replace solutions with an additional 90 percent reduction over standard Portland cement – all with a styrene-free chemistry.

To date, more than 10,000 linear feet and 5 million pounds of GeoSpray™ have been installed in 10 states. This constitutes over 150 individual structures. In addition, on-going and scheduled projects in 2013 amount to more than $8 million in material sales. GeoSpray™ is the environmentally friendly trenchless solution to sewer and storm water infrastructure decay.

Honeywell International

Hydrofluoro-Olefins as Low Global Warming Substitutes

With the EU F-Gas Regulation enacted in 2008, the long-felt need for acceptable, more environmentally-friendly replacement molecules to serve market applications, such as foam blowing, refrigeration and solvent cleaning applications, further intensified. Honeywell has identified and developed a series of more environmentally-friendly replacement molecules based on hydrofluoro-olefins that meet the market need. Through an extensive and lengthy research and development process, Honeywell has demonstrated that the C_3-hydrofluoro-olefins, specifically trans-1-chloro-3,3,3-trifluoropropene (trans HCFO-1233zd); trans-1,3,3,3-tetrafluoropropene (trans HFO-1234ze); and 2,3,3,3-tetrafluoropropene (HFO-1234yf) are environmentally acceptable alternatives to currently used materials. The 100 year global warming potential (GWP) values for these molecules are 7, 6 and 4, respectively, which are much lower than the GWP values of currently used substances, such as HFC-134a which has a value of ~1400. These new Honeywell alternatives also have an ozone depletion potential of zero, as well as low and acceptable toxicity and flammability. They also exhibit excellent thermal and chemical stability with the materials and components in the intended applications and have thermodynamic and performance properties that lead to increased energy efficiency. These molecules have been commercialized by Honeywell under its SOLSTICE™ trade mark.

Lonza, Inc.

Dantogard® 2000 Preservative: An Antimicrobial Technology with Reduced Environmental Impact for Hydraulic Fracturing of Shale Gas Plays

The development of shale gas plays within the U.S. is growing. In order to effectively produce the gas, hydraulic fracturing techniques are required. Such techniques have been under significant scrutiny, particularly with regard to the potential for contamination of drinking water aquifers. Specific concern has focused on the use of biocides in hydraulic fracturing fluids. Commercially launched at the World Shale Gas Conference® in November 2011, Dantogard® 2000 Preservative provides antimicrobial protection while reducing worker and operational risks associated with handling biocides since it ships as a non-hazardous product, is readily biodegradable, and exhibits up to 300 times lower environmental toxicity than alternate biocide technologies currently being used on the market for this application. Further, its extended antimicrobial protection and improved interaction with fluid additives provides the ability to reduce the amount of biocide utilized by 50 percent and the potential to eliminate carbon dioxide emissions by over 16,000 MT per year.

Vistive® Gold Soybeans and Biosynthetic Technologies Enable Biodegradable, Non-Toxic, Renewable and Economical Industrial Bio-Lubricants

Monsanto and Biosynthetic Technologies

Lubricant manufacturers have tried for years to use vegetable oil as a base stock to meet the growing demand for biodegradable, non-toxic, and renewable products, thereby reducing the world's reliance on limited petroleum-based oils. However, vegetable oils' poor oxidative stabilites and insufficient cold temperatures properties limit their usefulness in the lubricant market.

Monsanto scientists combined cutting edge RNAi biotechnology and molecular breeding to create Vistive Gold® soybeans, setting a new performance standard for vegetable oil. These soybeans produce 60 percent less saturated and polyunsaturated fats and three times more monounsaturates than commodity soybeans. The reduced saturates improve cold temperature properties, while increased monounsaturates (high oleic) and reduced polyunsaturates improve oxidative stability, making the oil better suited for industrial and automotive use.

Vistive Gold® soybean oil can be a feedstock for a new class of bio-based synthetic oils that meet or exceed the performance characteristics of the highest quality petroleum-based oils currently used in the automotive and industrial lubricant sectors. In 2011, U.S. consumption of lubricants was estimated at 2.4 billion gallons.

Biosynthetic Technologies developed this new class of biosynthetic oils in collaboration with the U.S. Department of Agriculture (USDA). The most significant benefit is that these lubricants are biodegradable. Since one gallon of used engine oil can contaminate over one million gallons of fresh water, 40 percent of freshwater pollution comes from used motor oil, and over 500 million gallons of petroleum oil is released into the ocean annually, the global impact of these technologies is yet to be realized.

Biosynthetic Technologies is in the final stages of fleet testing LubriGreen® biosynthetic motor oils and several major oil companies are formulating their first-ever biosynthetic motor oils from these bio-based oils. Pilot plant production will begin in 2013.

The Use of Nitrate and Selected Live Strains of Nitrate Reducing Bacteria to Replace the Use of Biocide in Hydraulic Fracturing Operations

Multi-Chem, A Halliburton Service

Hydraulic fracturing in shale formations to enhance extraction of hydrocarbons is a relatively new technique in the oil and gas industry. Concerns have arisen regarding the potential environmental impact of fracturing due in part to the use of large volumes of chemicals used for each well. Biocides are used during fracturing to prevent biogenic production of toxic and corrosive H_2S. The technology was developed to completely eliminate the use of biocides during fracturing and replace them with a technology that employs relatively benign components. This technology relies on the use of live strains of nitrate reducing bacteria (NRB) that have been selected to grow in reservoir conditions of the given oil or gas field. The NRB, in addition to a nutrient (sodium nitrate), are injected into the formation during the fracturing operation. NRB are able to consume the nutrients that deleterious bacteria, such as sulfate reducing bacteria, would otherwise use, thus preventing corrosion and production of H_2S. This technology has been fully tested in both the laboratory and the field. To date, 20 wells have been successfully treated. Treatment results from each of the test wells have been equal or superior to conventional biocide treatments (bacteria concentrations, sulfide concentration, and water clarity). Multi-Chem expects to fully commercialize manufacturing and application by the 3rd quarter of 2013. Multi-Chem estimated that this technology will be suitable to treat 15,146 wells per year based on 2013 estimates of wells to be completed in formations with temperature less than 180°F

(upper temperature limit of NRB strains). Biocide types and volumes used in fracturing vary somewhat, but based on typical use patterns it is estimated that 15,903,300 gallons of 50 percent glutaradehyde/quat biocide (or other equivalent biocide) may be eliminated annually due to this technology.

Nalco Champion, An Ecolab Company

eVerified ASP560: An Environmentally Friendly Corrosion Inhibitor

The discovery of shale plays across the U.S. has caused an unprecedented growth of oil and gas production. Hydraulic fracturing has become widely used to access these unconventional oil and gas reservoirs. However, public debates over the safety of hydraulic fracturing and state-government regulations have increased the demand for the use of environmentally friendly hydraulic fracturing fluids.

To meet this challenge, Nalco has developed environmentally friendly hydraulic fracturing fluids additives--called eVerified products--to replace more hazardous conventional technologies. Specifically, Nalco focused on acid corrosion inhibitors (ACIs). ACIs are an integral part of the acidizing segment in a hydraulic fracturing and acid fracturing application and considered to be one of the most hazardous components in these applications. Conventional ACI chemistries often contain Clean Water Act and Clean Air Act contaminants; may be toxic, persistent, bioaccumulative (PBT); and may be carcinogens, mutagens, or reproductive toxicants (CMR). The goals of eVerified are: to improve the overall hazard profile, meet key performance attributes, and be cost-competitive.

The eVerified ACI ASP® 560 is based on a patent-pending chemistry that used EPA predictive modeling for the design of the active component. The formulation was developed using a hazard profile screening tool, called eVerified, to make environmental, ecological, and human health improvements. Specifically, ASP® 560 removed priority pollutants; removed CMRs, Drinking Water, and Clean Air Act contaminants; enhanced biodegradability; reduced aquatic and mammalian toxicity; and reduced the flammability/combustibility when compared with current technologies. Assuming that the hazard profiles of Nalco ACIs for this market segment are typical, replacing all ACIs currently being used from all suppliers with ASP® 560 could remove an estimated 18 million pounds per year of hazardous substances.

Novozymes

Enzymes for the Production of Economical Sugars: A Linchpin of the Carbohydrate Economy

With the introduction of CTec3, Novozymes has catalyzed the commercial plans of major biofuel and renewable chemical producers globally. Plant cell walls are a complex matrix of cellulose, hemicellulose, and lignin. Efficiently hydrolyzing this recalcitrant lignocellulosic material is a critical step towards providing high-quality sugar streams as a feedstock for the production of fuels and chemicals via fermentative or chemical pathways. Novozymes' technology employs biological catalysts (enzymes) to achieve high sugar yields from a variety of feedstocks (e.g., corn stover, wheat straw, perennial grasses). A key breakthrough in Novozymes' development was the discovery of a previously uncharacterized family of proteins (GH61), which utilize a redox mechanism to synergize with classical hydrolases in lowering the enzyme dose needed to hydrolyze lignocellulose. Novozymes pioneered this novel technology, and holds several patents covering the use of these important cellulolytic enhancers. A highly active GH61 protein has been incorporated into the CTec3 enzyme cocktail. CTec3 allows a significant improvement in biomass conversion efficiency over previous enzymatic cocktails, enabling the production of cellulosic biofuels whose utilization reduce greenhouse gases by 90-115 percent in comparison with gasoline. Novozymes is supporting its key partners in commercializing proven technologies

for producing these biofuels, including the world's first commercial cellulosic ethanol production facility (13 million gallons per year) currently being commissioned by the Mossi & Ghisolfi Group (M&G) in Crescentino, Italy. A subsidiary of M&G (Chemtex) announced that it has received a $99 million loan guarantee from USDA for the engineering and construction of a biofuels plant in North Carolina utilizing dedicated energy crops as the biomass feedstock. Other major companies (POET, Abengoa, DuPont) are also proceeding with biorefinery construction plans.

Owens Corning

Sustainability and Owens Corning's EcoTouch™ Insulation Conversion

Sustainability is a core business strategy at Owens Corning (OC). OC is committed to driving sustainability by delivering solutions, transforming markets and enhancing lives. From a 2002 baseline, OC set aggressive 10-year footprint reduction goals across seven key areas of resource consumption, waste, and air emissions. Six of the seven goals were achieved by the end of 2012. OC's 2020 goals target significant reductions in energy, greenhouse gas, water, toxic air emissions, particulate matter, and waste-to-landfill. In addition to footprint reduction goals, OC has expanded its 2020 goals to drive and track the sustainability of its products and their applications, and to accelerate its supplier sustainability initiatives.

OC's insulation product is comprised of 95 percent glass fibers and 5 percent binder. The binder is a chemical adhesive that is required to hold the glass fibers together. EcoTouch™ insulation is a new fiberglass wool insulation product that is 99 percent natural and certified to have a minimum of 58 percent recycled content. OC has used a formaldehyde-based binder for over 70 years and its customers were increasingly requesting a product made with more sustainable materials. In addition to satisfying the customers, the substitution of the starch-based binder for the phenolic/formaldehyde binder eliminated or significantly reduced the hazardous air pollution (phenol, formaldehyde and methanol) along with ammonia emissions associated with the old resin formula. Reducing the environmental footprint of OC's manufacturing plants is consistent with the sustainability strategy initiated by the company while delivering the product performance attributes that the customers expect.

EcoTouch™ is the first fiberglass insulation to be certified by the U.S. Department of Agriculture (USDA), as a biobased product. In addition to the USDA renewable plant material certification, EcoTouch™ was recently certified by Scientific Certifications Systems for new recycled content figures, total recycled content rose from 50 percent to 58 percent for faced batts and rolls, to 65 percent for unfaced batts, rolls, MBI and loosefill. EcoTouch™ insulation has achieved GREENGUARD Children & Schools Certification, is verified to be formaldehyde-free ,and carries the UL Environment Ecologo CCD016 preferable product designation.

The Procter & Gamble Company and DuPont Company

Cold-Water Protease: Reducing the Environmental Footprint of Residential Laundry through Low Temperature Cleaning

Proctor & Gamble (P&G) and its strategic partner Genencor, now part of DuPont, entered into an agreement in 2008 with the specific objective to develop the next generation superior protease enzyme technology suitable for cold water washes in P&G's global laundry detergents. To this end DuPont applied a suite of innovative protein engineering methods to invent an optimal protease that at 60°F matches the cleaning performance of the previous generation product at 90°F, thus closing the temperature wash performance gap on proteinaceous soils without loss of protease stability in detergents. A production process was developed for this protease and has been carried out in large-scale fermenters (95,000 liters) at DuPont's manufacturing plant in Cedar

Rapids, Iowa. The synergistic enzyme-detergent system developed will reduce the environmental impact of clothes cleaning worldwide through energy savings and reduced greenhouse gas emissions. Three scenarios were evaluated to estimate a range of improvement potential of broad adoption of a reduced wash temperature in the U.S. Relative to the average load of laundry, potential reductions in annual energy use range from roughly 10.9-45.7 billion kWh, or the equivalent of 2.8-11.7 days of U.S. residential energy use. Similar reductions in greenhouse gases are estimated, ranging from 7.6-32.2 million metric tonnes of CO_2e, or the equivalent of removing 1.5-6.3 million passenger vehicles from the road (based on average annual emissions).

Sanofi and Amyris Inc

Semi-Synthetic Artemisinin: Path to Industrial Sustainable Production. Malaria Drug Production from Dream to Reality.

Global demand for artemisinin, the key ingredient of artemisinin-based combination therapies (ACTs), has increased since the World Health Organization identified ACTs as the most effective malaria treatment available. Because the existing botanical supply of artemisinin – derived from the sweet wormwood plant – is inconsistent, having multiple sources of high-quality artemisinin will strengthen the artemisinin supply chain, contribute to a more stable price, and ultimately ensure greater availability of treatment to people suffering from malaria. The development of a new commercial-scale alternative manufacturing process to produce a complementary source of artemisinin started nine years ago. The project built upon pioneering synthetic biology work by Dr. Jay Keasling, and involved a team of public and private partners, including Sanofi and the synthetic biology innovator, Amyris, Inc., to take the project from laboratory research to commercialization.

Sanofi is committed to producing semisynthetic artemisinin using a no-profit, no-loss production model, helping to maintain a low price for developing countries. This is a pivotal milestone in the fight against malaria, which affects about 300 million people every year and was responsible for more than 650,000 deaths in 2010.

This innovative industrial process to produce semisynthetic artemisinin consists in the production of artemisinic acid through fermentation - which is performed by Huvepharma, in Bulgaria – followed by a synthetic transformation of the artemisinic acid into artemisinin via photochemistry, which will be performed at the Sanofi's Garessio site. Sanofi plans to produce 35 tons of artemisinin in 2013 and, on average, 50 to 60 tons per year by 2014, which corresponds to between 80 and 150 million ACT treatments.

Stepan Company

Enabling Performance, Environmental, and Human Health Benefits in Hard Surface Cleaners and Industrial Solvents

Increasingly strict health and environmental regulations drive manufacturers and users to seek cost-effective solutions with superior performance and reduced exposure concerns. These regulations include restrictions on chemicals designated as Hazardous Air Pollutants, Volatile Organic Compounds, and worker safety standards regulating product attributes including flammability (flash points) and health-risk exposure (toxicity).

Leveraging the unsaturated chemistry of Elevance starting materials, Stepan's novel alkenyl amide demonstrates superior degreasing performance versus its saturated analog, alkanyl amide, and common industrial solvents such as benzyl alcohol. At 50 percent of the competitive product use levels, the alkenyl amide shows equivalent performance, thereby creating source reduction and cost competitiveness with lower cost solvents. It has a boiling point above 260°C which is classified, according to the EPA standards adapted from WHO, as a semi-volatile organic compound. It has a reduced likelihood of emission from a formulation or surface into the air,

reducing the potential human health impact of photochemical smog and ozone depletion. It provides an alternative to solvents currently utilized in the industrial market that contain 100 percent petroleum-derived carbon and contribute to climate change and greenhouse gas emissions. The alkenyl amide contains greater than 80 percent of biorenewable-based carbon.

Most heavy-duty consumer hard surface cleaners are used at high pH ranges which often necessitate a danger/warning label. The alkenyl amide can be formulated at neutral pH and deliver enhanced cleaning, potentially negating the need for danger/corrosive labels and mitigating skin/eye exposure concerns. The industrial solvent market currently utilizes a range of hazardous materials that are toxic to carcinogenic, resulting in harmful worker exposure. While the alkenyl amide has yet to receive a hazard classification, its saturated TSCA listed analog contains only an irritant warning on the MSDS and no evidence of toxicity, carcinogenicity, or mutagenicity.

A Novel High Efficiency Process for the Manufacture of Highly Reactive Polyisobutylene (PIB) Using a Fixed Bed Solid State Catalyst Reactor System

Synthetic Oils and Lubricants of Texas, Inc. (Soltex)

Polyisobutylene (PIB) is an isobutylene polymer containing one double bond per polymer molecule. In high-reactive PIB, the double bond is at or near the end of the polymer chain making product more reactive. When the double bond is located at internal positions, PIB is less reactive, creating low-reactive PIB.

Traditional processes to make high-reactive PIB use a liquid polymerization catalyst. The catalyst is continually fed to the reactor and mixed with isobutylene monomer. The liquid catalyst is toxic, hazardous, and requires special handling systems and procedures to avoid exposure and vapor release. As the reaction mixture leaves the reactor, the catalyst must be immediately neutralized and separated. The separation process involves washing the neutralized catalyst complex from the reaction mixture with copious amounts of water to remove all catalyst residues. Trace amounts are corrosive to subsequent processing steps and detrimental to product quality and stability. Neutralized catalyst cannot be recycled. This process substantially increases plant capital investment, increases operating costs, and generates approximately as much wastewater as product.

Soltex's new process is based on a novel solid catalyst composition using a fixed bed reactor system. A solid catalyst, in the form of a bead or other convenient geometrical shapes and sizes, is packed into a tubular reactor to form a stationary, completely contained bed. Isobutylene monomer is fed to the reactor at a controlled rate and passes over the solid catalyst allowing polymerization reaction to occur. The polymer mixture exits the reactor at the same controlled rate. This reactor effluent contains no catalyst residues, therefore no subsequent catalyst separation or water wash is required.

The Soltex process, using this solid catalyst composition, produces high yields of high purity product, is a simplified, highly efficient operation with substantially reduced capital investment, low operating and catalyst costs, and no waste generation.

Pure Solutions Chemical Line for Laundries

Washing Systems LLC

Since 2005, Washing Systems has made the commitment to develop washing chemistry for industrial laundries across the U.S. that would enable customers to improve their environmental profile and financial well-being. After two years of developmental work and field testing, the Pure Solutions Chemical Line for detergents was developed which is entirely nonylphenol ethoxylate free. As of April 2013, 100 percent of Washing Systems' customers have converted to these green DfE (USEPA Design for the Environment) detergents. From the projects inception, the Pure Solutions Chemical Line has reduced over 21.6 million pounds (an average of 3.6 million pounds per year) of NPE discharged into the environment from wastewater discharge, which is toxic and an endocrine disruptor.

Washing Systems also introduced a new builder (Structure) which is based on natural, sustainable, and biodegradable chelating agents for lowering water hardness within the washer. This builder eliminates the use of phosphates and ethylenediaminetetraacetic acid which is a persistent organic chemical with hazardous degradation products. This product was developed in 2010, and distributed in 2011. Currently, 100 percent of Washing Systems' customers have converted to this more environmentally friendly chemistry which has reduced the level of tetrapotassium pyrophosphate by 1.5 million pounds and 104,000 pounds of tetrasodium ethylendiamine tetraacetate within one year.

Another 2011 Washing Systems project initiative was to eliminate the petroleum solvents from its solvent/detergent formulas. Washing Systems has also replaced two of its core products that contained aromatic hydrocarbons and aliphatic hydrocarbons, which easily bioaccumulate, with a nonhazardous, biodegradable, biobased product. In just a few months of distribution, this product has reduced over 100,000 pounds of petroleum solvents into the environment; and as of 2013, its use has reduced petroleum solvents close to 400,000 pounds per year, 50 percent of our customers.

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Award winners are indicated with asterisks.

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